Diversity and the Energy Trilemma.

The Case of India (1990-2014)

PhD THESIS

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Abstract

Securing a reliable and high-quality energy supply, ensuring universal affordable access to energy services, and mitigating the emission of greenhouse gases are the three main energy issues that all countries must promptly address, both individually and cooperatively. Therefore, developing an energy system capable of balancing these three demands, i.e. the energy trilemma, remains a significant challenge.

This task faces several difficulties, including the insufficient progress made within the international energy cooperation framework. Despite their apparent interest, different countries have divergent priorities, which result in drawn-out and complex negotiations. Moreover, they have the exclusive authority to determine how demands are to be met in accordance with their unique characteristics, including the selection of energy sources and strategies. This challenge is further compounded by conflicting interests in each area, the traditional approach of seeking solutions to each problem individually, and the lack of a wide-ranging consensus on the meaning and implications of each issue.

Despite these obstacles, there is a growing body of literature that advocates an inclusive approach, especially from the perspective of sustainable development. It encourages the use of renewable energy sources alongside carbon capture and storage technology as well as the implementation of efficiency measures.

Consequently, it is of analytical interest to determine whether the diversity of the energy mix can be used as a main indicator in the analysis of the energy trilemma following an econometric model. The research proves the aforementioned constraints, the insufficient impact of some of the measures adopted, and the importance of diversity as an energy strategy. It also reveals the value of using an inclusive approach and the newly developed model. The results of the individual and joint analyses for the selected country and the observed period show thought-provoking changes in both the importance and sign of this indicator.

Resumen

Asegurar un suministro de energía fiable, continuo y de alta calidad, garantizar el acceso universal y asequible a los servicios energéticos y mitigar las emisiones de los gases de efecto invernadero son las tres principales cuestiones energéticas que todos los países deben abordar con prontitud, tanto individual como colectivamente. El desarrollo de un sistema energético capaz de equilibrar estas tres demandas, es decir, el trilema energético, constituye, por lo tanto, uno de los mayores desafíos actuales.

Esta tarea se enfrenta a una serie de dificultades, entre las cuales se encuentra el insuficiente progreso en el marco de la cooperación energética internacional. A pesar del interés mostrado, los Estados tienen prioridades divergentes que conducen a largas y complejas negociaciones. También poseen la competencia exclusiva para determinar la forma de satisfacer la demanda en función de sus características particulares, incluyendo la selección de las fuentes y estrategias energéticas. A ello se suman los intereses opuestos de cada área, el enfoque tradicional de buscar soluciones a cada problema individualmente así como la falta de un amplio consenso sobre el significado y las implicaciones de cada uno de ellos.

A pesar de estos obstáculos, cada vez es más numerosa la literatura que aboga por un enfoque inclusivo, sobre todo desde la perspectiva del desarrollo sostenible. En ella se fomenta principalmente el uso de las fuentes de energía renovables acompañadas por la tecnología de captura y almacenamiento de carbono así como la aplicación de medidas de eficiencia.

Por consiguiente, se ha considerado de interés analítico determinar si la diversidad de la matriz energética puede utilizarse como indicador en el análisis del trilema energético utilizando un modelo econométrico. La investigación demuestra las limitaciones mencionadas, el impacto insuficiente de algunas de las medidas adoptadas y la importancia de la diversidad como estrategia energética. También revela el valor de un enfoque inclusivo y la pertinencia del nuevo modelo desarrollado. Los resultados de los análisis individuales y conjuntos, para el país seleccionado y el período observado,

muestran cambios interesantes tanto en la importancia como en el signo de este indicador.

Résumé

Assurer un approvisionnement énergétique fiable et de qualité, garantir un accès universel et abordable aux services énergétiques et mitiger les émissions de gaz à effet de serre sont les trois principaux problèmes énergétiques que tous les pays doivent résoudre sans délai, tant individuellement qu'en coopération. Par conséquent, la mise en place d'un système énergétique capable d'équilibrer ces trois exigences, c'est-à-dire le trilemme énergétique, reste un défi crucial.

Cette tâche comporte plusieurs difficultés, notamment les progrès insuffisants réalisés dans le cadre de la coopération énergétique internationale en matière d'énergie. Malgré leur intérêt apparent, les différents pays ont des priorités divergentes, ce qui entraîne des négociations longues et complexes. En outre, ils ont le pouvoir exclusif de déterminer comment répondre aux demandes en fonction de leurs caractéristiques uniques, y compris la sélection des sources d'énergie et des stratégies. Ce défi est encore aggravé par les conflits d'intérêts dans chaque domaine, l'approche traditionnelle consistant à chercher des solutions à chaque problème individuellement et l'absence d'un large consensus sur la signification et les implications de chaque question.

Malgré ces obstacles, il existe un nombre croissant d'ouvrages qui préconisent une approche inclusive, en particulier du point de vue du développement durable. Elle encourage l'utilisation de sources d'énergie renouvelables parallèlement à la technologie de capture et de stockage du carbone ainsi que la mise en œuvre de mesures d'efficacité.

Par conséquent, il est intéressant, d'un point de vue analytique, de déterminer si la diversité de la matrice énergétique peut être utilisée comme indicateur dans l'analyse du trilemme énergétique en utilisant un nouveau économétrique. La recherche prouve les contraintes susmentionnées, l'impact insuffisant de certaines des mesures adoptées et l'importance de la diversité en tant que stratégie énergétique. Elle révèle également la nécessité d'une approche inclusive ainsi que la pertinence du nouveau modèle développé. Les résultats des analyses individuelle et

conjointe, pour le pays sélectionné et la période observée, montrent des changements intéressants tant en termes d’importance que de signe de cet indicateur.

Laburpena

Energia hornidura fidagarria eta kalitate handikoa ziurtatzea, zerbitzu energetikoetarako sarbide unibertsala eta eskuragarria bermatzea, eta, azkenik, berotegi efektuko gasen isuriak arintzea dira herrialde guztiek, bakarka zein taldeka, energiaren alorrean berehala jorratu behar dituzten hiru gai nagusiak. Beraz, egungo desafio handienetako bat da hiru eskaera horiek —trilema energetikoa— orekatzeko gai izango den energia sistema sortzea.

Zeregin horrek hainbat zailtasun ditu: besteak beste, urrats sendorik egin ez izana nazioarteko energia lankidetzan. Interesa erakutsi arren, estatuek lehentasun dibergenteak dituzte, negoziazio luze eta konplexuak eragiten dituztenak. Gainera, eskumen esklusiboa dute eskariari nola erantzun erabakitzeko, aintzat harturik haren ezaugarri bereziak, energia iturriak eta estrategia energetikoak hautatzea barne. Horri gehitu behar zaizkio arlo bakoitzeko aurkako interesak, arazo bakoitzari irtenbideak banan-banan bilatzeko ikuspegi tradizionala, eta adostasun zabal baten falta arazo horietako bakoitzaren esanahiari eta inplikazioari buruz.

Oztopoak oztopo, gero eta ugariagoa da ikuspegi inklusibo baten aldeko literatura, batez ere garapen jasangarriaren ikuspegitik. Ikuspegi horrek bultzada eman nahi die energia iturri berriztagarriei, karbonoa atzitzeko eta biltegiratzeko teknologiarekin batera, eta efizientzia neurrien aplikazioari.

Horrenbestez, interes analitikokotzat jo da honako hau zehaztea: hots, erabil ote daitekeen matrize energetikoaren dibertsitatea trilema energetikoaren analisiaren adierazle gisa, eredu ekonometriko bat erabilita. Ikerketak agerian utzi ditu aipatutako mugak, hartu diren neurri batzuen inpaktu eskasa eta dibertsitateak estrategia energetiko gisa duen garrantzia. Agerian utzi ditu ere ikuspegi inklusiboaren balioa eta eredu berriaren egokitasuna. Banakako eta baterako analisien emaitzek, aukeratutako herrialderako eta aintzat hartutako aldirako, aldaketa interesgarriak erakusten dituzte adierazle honen garrantziari nahiz zeinuari dagokienez.

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Acronyms & Abbreviations

AAUs Assigned Amount Units

AHWR Advanced Heavy Water Pressure Reactors

APERC Asia Pacific Energy Research Centre

APM Administered Prices Mechanism

ARTC Assam Railway and Trading Company

CASE Commission for Additional Sources of Energy

CDM Clean Development Mechanism

CERC Central Electricity Regulatory Commission

CERs Certified Emission Reductions

CI Composite Indicators or Composite Indices

CIAB Coal Industry Advisory Board

CIL Coal Indian Limited

$CO_{2\text{-eq}}$ Carbon Dioxide Equivalent

CO_2 Carbon Dioxide

COP Conference Of the Parties

DDUGJY Deen Dayal Upadhyaya Gram Jyoti Yojana Gram

DI Diversity Index

DNES Department for Non-Conventional Energy Sources

ECBC Energy Conservation Building Code

ECT Energy Charter Treaty

EDI Energy Development Index

EE Energy Efficiency

EI Emissions Index

EII Emission Intensity Indicator

EMM Emissions Mitigation Mechanism

ERUs Emission Reduction Units

ESI Energy Security Index

ET Emissions Trading

ETCR Energy, Transport Communications Regulation

EU European Union

FBRs Feedback Fast Reactors

FIP Feed-in Premium

FIT Feed-in Tariff

G-20 Group of Twenty

G-77 Group of 77

G-8 Group of Eight

GDP Gross Domestic Product

GDPpc Gross Domestic Product per capita

GECF Gas Exporting Countries Forum

GEF Global Environment Facility

GEG Global Energy Governance

GHG Greenhouse Gases

GWP Global Warming Potential

IAs Implementation Agreements

IEA International Energy Agency

IEF International Energy Forum

IEM Internal Energy Market

IEP Integrated Energy Policy

IER Independent Energy Regulators

IET International Emissions Trading

IGO Intergovernmental Organization

IMF International Monetary Fund

IMWG Inter-Ministerial Working Group on Energy Conservation

INDC Intended Nationally Determined Contributions

IPCC Intergovernmental Panel on Climate Change

IPP Independent Power Producers

IPR Industrial Policy Resolution

IRENA International Renewable Energy Agency

ISPR Indian Strategic Petroleum Reserves

ISPRL Indian Strategic Petroleum Reserves Limited

ITMOs Internationally Transferred Mitigation Outcomes

JI Joint Implementation

JNNSM Jawaharlal Nehru National Solar Mission

LMDC Like Minded-Group of Developing Countries

LPG Liquefied Petroleum Gas

LULUCF Land Use, Land-Use Change and Forestry

MDGs Millennium Development Goals

MNES Ministry of Non-Conventional Energy Sources

MNRE Ministry of New and Renewable Energy Sources

MoPNG Ministry of Petroleum and Natural Gas

MSDM Mitigation and Sustainable Development Mechanism

NAFCC National Adaptation Fund for Climate Change

NAPCC National Action Plan on Climate Change

NCDP New Coal Distribution Policy

NCEF National Clean Environment Fund

NEA Nuclear Energy Agency

NELP New Exploration Licensing Policy

NGO Non-Guvernmental Organization

NLC Neyveli Lignite Corporation Limited

NMEEE National Mission for Enhanced Energy Efficiency

OECD Organization for Economic Co-operation and Development

OIDB Oil Industry Development Board

OLADE Organización Latinoamericana de Energía (Latin American Energy Organization)

OPEC Organization of Petroleum Exporting Countries

PAT Perform, Achieve and Trade

PES Primary Energy Source

Ph Household Prices

PHWRs Pressurized Heavy Water Reactors

Pi Industrial Prices

PPP Purchasing Power Parities

REC Rural Electrification Corporation

REDD+ Reducing Emissions from Deforestation and Forest Degradation

RGGVY Rajiv Gandhi Grameen Vidyutikaran Yojana

RUs Removal Units

SCBA Social Cost Benefit Analysis

SCO Shanghai Cooperation organization

TGC Tradable Green Certificates

TPA Third-Party Access

TPES Total Primary Energy Supply

TSOs Transmission System Operators

UMPP Ultra Mega Power Projects

UN United Nations

UNCED United Nations Conference on Environmental and Development

UNCHE United Nations Conference on the Human Environment

UNDP United Nations Development Programme

UNEP United Nations Environment Programme

UNFCCC United Nations Framework Convention on Climate Change

WB World Bank

WCED World Commission on Environment and Development

WEC World Energy Council

WHO World Health Organization

WMO World Meteorological Organization

WRI World Resources Institute

WTO World Trade Organization

WWF World Wildlife Fund

Chapter 1

Introduction

"Four decades ago no one managed energy. No one sold energy, or bought it. No one had heard of energy companies. No one made energy policy. Yet energy is now the world's largest business. [...] Despite all the dramatic technological and economic advances we have seen, some two billion people, one-third of humanity, are still without electric light. Those of us who have it worry about 'energy security', that we may soon have trouble keeping the lights on. Meanwhile the best available scientific evidence suggests more and more urgently that we are now upsetting climatic systems, with consequences that could be catastrophic worldwide. Something is seriously wrong with the way we manage energy. Can we not do better? And if so, how?".

(Patterson, 2008, pg. 2)

1.1 The problem

Energy is a major global concern. The former Secretary-General of the United Nations (UN), Ban Ki-moon (2012), defined energy as the golden thread that connects economic growth, social equity and environmental sustainability.

Rubio Varas and Muñoz Delgado state that (2019, pg. 158) "[a]lterations in the composition of the energy mix in the long run define the concept of energy transition(s)". Energy transitions linked to technological progress have enabled rapid economic and social development —it is clear that household services and benefits, public services, transport and the production of goods are now very different from how they were two hundred years ago— but have also led to a 27-fold increase in energy consumption in less than 200 years. Furthermore, the first major energy transitions promoted the use of fossil fuels, mainly coal and oil, which are geographically concentrated, limited —they are formed over centuries in the interior of the earth from organic matter and are therefore depletable— and polluting, as they are composed mainly of coal and hydrogen. Their excessive and irresponsible use, perhaps due to ignorance, has created situations of energy insecurity, energy inequalities such as poverty and environmental risks such as climate change. These must be controlled and prevented from worsening, assuming that they cannot be reversed. Furthermore, these three energy challenges, known as the energy trilemma (WEC, 2012), are characterised by being strongly interconnected while having conflicting interests. Moreover, they have a domestic basis but an international impact, i.e. it goes beyond national borders. Hence, the fragmentation that has characterised energy laws and policies in the past, all of which focused on a single problem or a single energy source, must be overcome.

The interaction between international, national and local levels is crucial. The need to address these challenges urgently and simultaneously is also often expressed by scholars. Cherp et al. (2011) advocate the need for a long-term global commitment to a high-level integration of energy policies at all scales of energy governance as well as in energy systems and technologies. However, the current model seems to be, according to Sovacool and Florini (2012, pg. 252), "full of sound and fury, but means very little substance". Different internal political situations and energy mixes result in significant differences in the priority accorded to each dimension (House of Lords European Union Committee, 2015).

A transition into a new energy system is necessary given the unsustainability of current energy systems (Grubler, 2012). The measures taken so far have proved insufficient and many are calling for an energy system based on renewables (e.g. Villavicencio Calzadilla and Mauger (2018); Gielen et al. (2019)). However, neither of these are without flaws (e.g. Moriarty and Honnery (2016); Villavicencio Calzadilla and Mauger (2018)), nor is the transition likely to be achieved in the near future (York and Bell, 2019). Heffron and Talus (2016b) claim that the focus should be on the sustainable management of each energy source in order to provide a fair and equitable balance between the three dimensions of the energy trilemma.

Many papers discuss the links between these issues, analyse a country's performance and/or strategy, and suggest ways forward (e.g. Gunningham (2013); Strambo et al. (2015); Cherp et al. (2016)). These indicators are described as prerequisites for the establishment of energy targets, as well as the evaluation of future scenarios. They can contribute to policymaking by condensing large amounts of complex data into recognisable patterns, which can then enable policymakers and analysts to find the best energy solutions from a range of available options (Sovacool and Mukherjee, 2011). In energy policy, diversity, i.e. the composition of the energy mix, is regarded as essential to a system's long-term survival (Ranjan and Hughes, 2014), and is used, alone or with other indicators, to analyse the vulnerability, sustainability, and resilience (Stirling, 1994) of energy systems. It is also used to analyse the energy planning and, in certain cases, the decrease in relative fossil fuel dependence (Ghanadan and Koomey, 2005) as well as to analyse renewable energy in the UK (Cooke et al., 2013), energy security (Chalvatzis and Ioannidis, 2017), energy intensity and carbon intensity (Rubio-Varas and Muñoz-Delgado, 2019; Ioannidis et al., 2019).

1.2 The aims and scope

The main objective of this research is to design a quantitative model measuring the impact of the diversity of sources on the three main pillars of the energy trilemma simultaneously.

The application of this model to past data will help identify the impacts of decisions already taken, which can act as a basis for estimating future consequences, i.e. to learn from mistakes. As Grubler (2012, pg. 8) claims, "[a]n old adage states that those who are not prepared to learn from history are bound to repeat past mistakes. History does not preordain the future, but it is the only observational space available from which to draw lessons from and to inform policy models and makers of what it takes to initiate and to sustain a much-needed next energy transition towards sustainability".

The application of this model to other scenarios will help both analysts and decision makers evaluate the potential effects of future initiatives or policies before their implementation, i.e. it will serve as an a priori control instrument instead of an a posteriori analytical instrument.

To reach this point, it is first important to clarify why the diversity of the energy mix has been identified as a key element. This hypothesis is based on the social evolution that is accompanied or promoted by energy transitions, which are characterised by the predominance of one source and are the origin of the energy trilemma, whose repercussions extend beyond national borders. In other words, there is a need to address the issues of global governance, the energy system, energy security, climate change and energy poverty. Therefore, this study can also participate in and contribute to discussions on all these aspects at different levels of analysis (such as through a general analysis that is conceptual or a more specific analysis that is the result of an applied policy).

The energy trilemma is also assessed at the national level. Each state has sovereignty over the natural resources, including energy resources, in its territory and is therefore free to determine its energy mix. Hence, the model must also be applied at this level. In this paper, India has been chosen as a case study, so it is feasible to envisage contributions to the discussions on India's energy issues.

Finally, diversity indices are commonly used in the context of energy security. This paper goes beyond this dimension by considering the three pillars of the trilemma simultaneously.

1.3 Research methodology

The research methodology is based on a multidisciplinary approach and uses descriptive and explanatory analyses. The former helps characterise key concepts and variables by examining specialised academic literature. The latter helps establish cause-effect relationships. For this purpose, data from different databases such as IEA, WB, and EUROSTAT have been collected, to which different estimation models are applied.

1.3.1 Data and indicators

A major issue faced in conducting quantitative studies in the field of energy is the unavailability of data. Another challenge is the selection of the indicators to be used.

As stated by Ciegis et al. (2009), indicators are a useful tool for developing a feedback mechanism that highlights areas where appropriate action is being taken and where further attention is needed. Perfect indicators are rare, so they generally imply a methodological commitment. OECD and JRC (EC) (2008) provides a complete guide on how to build a composite indicators (CI); yet, the variety of indices provided in the literature are sources of disagreement among experts on issues such as the selection of indicators, prioritisation, weighting procedure, scoring, the use of quantitative versus qualitative methods, scale, comprehensiveness, time and context, and quality and availability of the data (Valdés, 2018). However, Ang et al. (2015) find that indices are useful for certain purposes, such as country self-assessment, progress monitoring, scenario analysis and cross-country comparisons. The model applied in this case study uses indices as variables.

1.3.2 India as the case study

India has been selected as the case study because of its growing importance in the international arena and its particular characteristics. India's substantial and continuous economic growth is placing enormous demands on its energy resources, worsening the demand and supply imbalance. India's energy system is characterised by the high consumption of fossil fuels and a considerable level of energy dependency. Although India has considerable coal reserves, its average coal quality is quite poor, so high-quality coal must be imported to meet the needs of the steel plants. Also, more than 70% of their requirements are covered by imported oil. Energy self-sufficiency or independence is a recurrent topic in India's energy policy dialogue. To achieve it, the government has adopted different strategies based on diversification of sources by increasing the use of domestic sources, mainly hydropower, nuclear and renewable energy.

Its rapid economic growth has also boosted emissions from 652.5 Mtons of CO_2 in 1990 to nearly 2,342 Mtons of CO_2 in 2014 (data from EDGAR (2015) database). Even with the decline in carbon intensity, the forecasts suggest that India's absolute emissions will increase. At the same time, several hundred million people subsist on marginal lands (one-fifth of the population lives in conditions of absolute poverty), and hundreds of millions of people depend on Himalayan melt-waters during the dry season. All these make India extremely vulnerable to climate change, yet with limited adaptive capacity. India must ensure affordable energy that meets its growing demand while reducing greenhouse gas emissions. In terms of energy policy, this translates into an effort to maintain or expand the extraction of fossil fuels, mainly coal (one of the major challenges facing India is the reduction of emissions from coal-fired power plants), while expanding renewable energies (Goodman, 2016).

Moreover, although the Indian electricity sector has been one of the fastest growing sectors in recent years, approximately 240 million Indians still lack access to electricity. India's energy policy seeks to address the three problems of the energy trilemma; however, economic and social development are its priorities.

There is also no doubt regarding the importance and impact of India's energy policy in the increasingly integrated and interdependent global energy market. The country has exhibited notable growth in energy-related international activity. In March 2017, India joined the International Energy Agency (IEA) as an association country. It seeks a more proactive role in global governance to develop a cohesive strategy in its interactions with other nations on a range of energy issues.

The period studied, 1990-2014, has been set by the availability of data in the year this study began. The period also coincides with the first 25 years of the economic liberalisation in India.

1.4 Thesis structure

This thesis is presented as a compendium of two book chapters and two articles, complemented by three original chapters to address the key aspects of the research.

The two book chapters have been published in Spanish, but English translations are included. The publisher is indexed in the Scholarly Publishers Indicators. Of the two articles, one has been published and the other is under review in two international journals referenced in the Journal Citation Reports (JCR). JCR is the best known relative quality indicator and is highly valued by both research evaluation bodies and the scientific community, with a Q2 in the categories of Environmental Studies-SSCI and Environmental Sciences-SCIE and a Q1 in the categories of Environmental Sciences; Engineering, Environmental; and Green & Sustainable Science & Technology.

- Chapter 1 presents the conceptual and methodological framework and establishes the necessary background for the topics discussed in the following chapters. The background and analytical interests pertaining to the research topic are established. The objectives and methodology used are also outlined.

Part I presents the theoretical framework. Due to the scope of the concepts within this framework, Part I is further divided into two independent chapters. The objective of these two chapters is to demonstrate the relevance of developing a model that analyses the impact of the diversity of the energy mix in each area of the energy trilemma simultaneously.

- Chapter 2 explains the relevance of different energy sources in the evolution of societies and the reason for which international energy cooperation, i.e. global energy governance is necessary. It also highlights the fragmentation and complexity of the system.
- Chapter 3 provides an overview of the underlying areas of conflict, i.e. energy security, climate change and energy poverty, as well as their synergies and trade-offs based on the use of different energy sources. It also questions the intended transition into an energy system free of fossil-fuels.

Part II provides three examples of the different measures and strategies adopted under the energy governance framework to address the problems of the energy trilemma and which affect the composition of the energy mix. It includes two publications —a book chapter and an article— and another original chapter.

- Chapter 4 presents the first publication, titled "*La seguridad energética a través de la diversificación en los países de la OCDE*" (Energy security through diversification in OECD countries). The chapter shows how one of the main actors in global energy governance, the IEA, promotes the diversification of sources without exclusion as a key instrument in its long-term energy security strategy.

- Chapter 5 presents the main agent of global energy governance in the fight against climate change. It summarises the importance and urgency of addressing this problem and explains the main measures and mechanisms adopted, to reduce emissions from fossil fuels as well as promote renewable sources and efficiency.

- Chapter 6 presents the second publication, titled "*Industrial electricity prices in the European Union following restructuring: A comparative panel-data analysis*". This paper analyses the impact of regulatory reform on industrial electricity prices and the differential between industrial to household prices for the period of 2003-2013 in 15 European Union countries.

Part III contains the case study. It comprises two publications: a book chapter and an article.

- Chapter 7 presents the third publication, titled "*El escenario energético de India*" (The Indian energy outlook). The objective of this chapter is to present a picture of India's energy system, as it is the country chosen for the case study.

- Chapter 8 presents the fourth publication, titled "*Assessing the energy trilemma through the diversity of the energy mix: The case of India*". The paper proposes a new procedure to analyse the problem of the energy trilemma by quantitatively examining the effects of diversity, i.e. the energy mix (DI), on each issue both individually and simultaneously.

Part IV contains the concluding chapter.

- Chapter 9 presents the most relevant conclusions and advances some lines of research for the future.

The Appendix section contains the original version of the two book chapters in Spanish as well as a list of publications related to this thesis which have not been included in it.

Part I

Chapter 2

Global Energy Governance

2.1 Introduction

Energy plays a key role in security, social and economic development as well as global sustainability by creating strong linkages across different fields and levels (national, regional and local). Hence, any energy policy must not only consider its specific objective, but also its potential impacts, both direct and indirect, on other areas and actors (Goldthau, 2011). At the same time, the global energy context is not static and has been altered by factors such as shale gas and tight oil production (increasing the market uncertainty), the loss of a certain degree of control by the main international organisations (the members of the organization for Economic Co-operation and Development (OECD) are no longer the biggest consumers) and the structural and economic changes needed to cope with sustainable development, (i.e. all energy actions must address not only energy security but also climate change and energy poverty).

The concept of global governance emerged from the necessity of explaining the international changes that occurred as a result of the end of the Cold War and expansion of globalisation (the high-water mark of economic liberalism). The end of the Cold War marked the end of the bipolar system dominated by the United States and the Soviet Union, the revision of realism as the dominant theory, the incorporation of new agents, and the expectation that the United Nations system would acquire a more active and efficient role in global governance. The debate on globalisation is mainly economic (Brand, 2005), meaning the expansion of markets. In addition to military power, other powers linked to global finance and the development of information technology are recognised which require a renewal of the international frameworks for multilateral cooperation (Hewson and Sinclair, 1999). However, the problems do not derive from globalisation itself, but from deficiencies in its governance (Weiss and Thakur, 2010).

The new international context caused changes in both the international actors (altering their role, number and composition) and the international agenda (incorporating topics such as energy). In this context, and with an explicit normative interest, the objective of those studies was to identify possible new approaches to future global challenges involving state and non-state agents with no formal-legal global authority and policies formulated in both vertical and horizontal directions (Hofferberth, 2016; Hewson and Sinclair, 1999; Weiss and Thakur, 2010; Stripple and Stephan, 2013). The concept of global governance emerged as a new way of assessing global issues as well as a new approach to global policy-making, as conventional procedures were considered weak (Hofferberth, 2016). The increased intensity and global scale of interactions caused new and diverse challenges that needed to be addressed through cooperation and dialogue beyond the limitations of the traditional state-centred international system (Brand, 2005).

The international character of the energy system and the inability of the market alone to deliver satisfactory results to the externalities associated with it justify the need for some form of energy governance (Van de Graaf and Colgan, 2016). A new field of study emerged, the Global Energy Governance (GEG), in the spirit of addressing energy from a broader perspective than the traditionally-dominant issues of geopolitics and security. Experts began to critically review the treatment that energy had received in the literature of International Relations and Foreign Policy as well as of globalisation. They questioned the excessive attention paid to the aspects mentioned, mainly related to the problem of access to resources based on the theory of the zero-sum game. Scholars asked why there was a lack of effective international cooperation or management in a field that is directly related to other political fields such as trade, sustainability, the environment and climate (Goldthau and Witte, 2009; Lesage et al., 2010; Van de Graaf and Colgan, 2016).

This chapter is dedicated to the notion of global energy governance and the terms that compound it, i.e. global governance and energy. The rest of the text is structured as follows: Section 2.2 explains what global governance is, and when and where was proposed. Section 2.3 describes the main components of the energy system and Section 2.4 deals with the implications of switching from one predominant energy source to another on the economy, development and policy areas. Section 2.5 reviews the issues of "who governs or should govern energy" and the performance of the actual GEG. Finally, Section 2.6 summarises India's participation in global energy governance.

2.2 Global governance: origin and roots of the concept

The term governance is used in many disciplines, thereby impeding the articulation of a single definition. Despite some common characteristics, each area provides particular and relevant aspects (Van de Graaf and Colgan, 2016; Stripple and Stephan, 2013; Björk and Johansson, 1999; Kobayashi, 2005). Thus, corporate governance lies at the very origin of the term. Owing to the phenomenon of globalisation, companies were impelled to work in the context of a global market and in adherence to international standards. Good governance (promoted in the 1980s by the World Bank with the state as the main objective) evinced the participation and empowerment of the people, along with the principles of responsibility, political stability, rule of law and efficiency of governments and institutions. Governance is understood as a normative concept (Weiss and Thakur, 2010), as a political instrument to transform societies that refers to what "should be" and not to what "is" (Hufty, 2008, pg. 3). By focusing on the actions of governments and not on the objectives, it falls more on the realm of public administration than policy (Fukuyama, 2013). Economic approaches encouraged the use of the term "global governance" instead of "international governance". This has resulted in the inclusion of non-governmental actors and the dissemination of interactions between different levels, pointed to the absence of a global government and assumed the assumption of a results-focused methodology. Yet the element of global recognition, came from the Commission on Global Governance, a body linked to the UN. According to the definition given in a report titled *Our Global Neighbourhood* (1994), global governance must respond to a collective will and a common responsibility. It was understood as a complex, multi-level system, committed to the principles of equality and democracy, in which the States would share the management of public affairs with other public and private actors.

While the number of definitions has multiplied since then, as Pattberg (2005, pg. 177) noted, "[it] is generally believed to encompass different systems of rule on different levels of human activity as an organising principle beyond hierarchical steering and the sovereign authority of states". Global governance has been defined as the formal and informal processes and institutions that guide and limit a group's collective activities (Keohane and Nye, 2000) and as "the sum of laws, norms, policies and institutions that define, constitute, and mediate relations among citizens, society, markets, and the state in the international arena—the wielders and objects of international public power" (Weiss and Thakur, 2010, pg. 5). Quite significantly, it implies progress in the complex relations established between the different actors interested in participating effectively in the resolution of problems, through cooperation and dialogue. In doing so, global governance includes non-state actors, different political levels, new levels of production and maintenance of public goods, as well as new levels of authority (Lexian, 2012). However, as underscored by Hufty (2016) global governance is a semantically vague and imprecise concept, somewhere between politics (power relations) and management (technocratic regulation), which allows establish practical consensus between agents with different interests through the use of neutralised language.

Under the scope of global governance, the energy field would include any process or political structure that goes beyond the purview of national borders. As is often the case in this field of study, the concept of global energy governance (GEG) is still under construction. However, it can be defined as the architecture of processes and political institutions —formal and informal, public and private— that contribute to the definition of collective norms and regulations, as well as structure global energy relations (Kérébel, 2009). It also represents the international collective efforts undertaken to manage and distribute energy resources along with the provision of energy services (Florini and Sovacool, 2009).

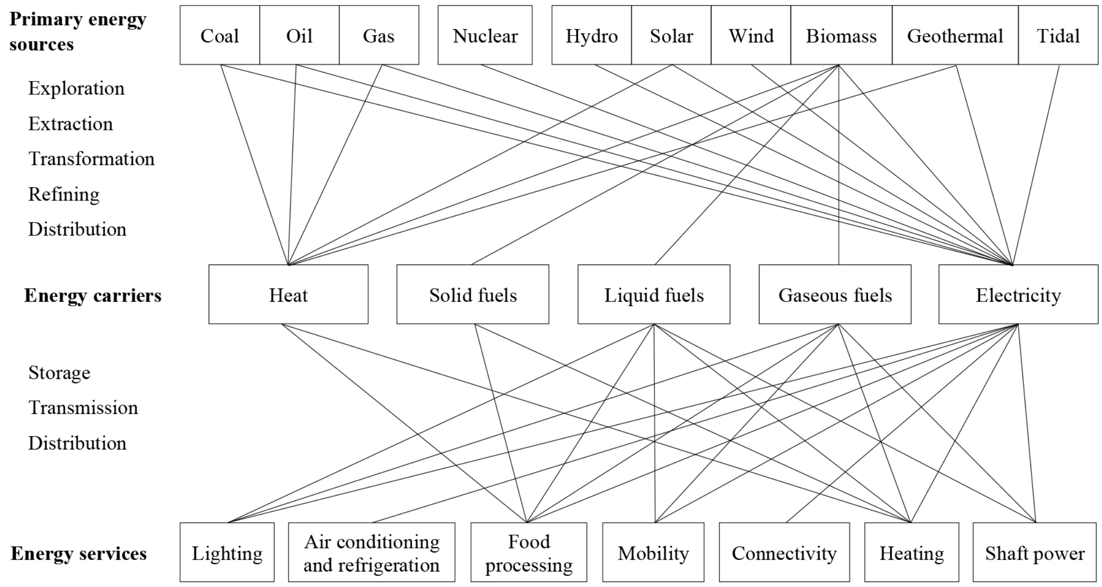
The genesis of GEG can be found in a double need. On the one hand, the existing energy system needed to be changed to a more sustainable model, a model of socio-economic development which would not compromise the availability of resources for future generations (Gatto, 1995). On the other hand, although closely linked to the first, there was a recognition of the need to improve the regulation of energy trade. All this requires a commitment on the part of international actors and the formation of global energy policies.

2.3 The energy system

The prevailing meaning of the term "energy" arose in the mid-19th century (1840-1850) during the discovery of the principle of conservation. In physics, energy is usually defined as the capacity to carry out work and follows the conservation principle. This means that energy linked to an isolated system remains constant over time. That is, energy is neither created nor destroyed; it is only transformed. Other fields of study use this term to allude to the natural resources and their associated technology to extract, transform and give them an end use.

As Figure 2.1 illustrates, the three different stages of an energy system's conversion process are energy primary sources (PES), energy carriers and energy services. Energy converters are necessary to move from one stage to the next. The main technological and economic challenge is to optimize the conversion processes so as to avoid as much energy loss as possible (RACEFN, 1986).

Figure 2.1 – Basics components of the energy system



Source: Bailis (2011)

PES (see Section 2.3.1) are obtained directly from nature. They include nuclear, fossil fuels (finite, geographically concentrated, storable and easily transported) and renewables (with variations among them, they are generally less geographically concentrated, intermittent, more difficult to store and transport and with a lower degree of energy density). Meanwhile, *energy carriers* (Section 2.3.2) are derived from the transformation of PES and represent an intermediate step that facilitates the storage and transport prior the final use. They vary in quality, efficiency and ease with which they can be converted into useful services, i.e. heat can be used for food processing and heating, while electricity is used in all energy services. *Energy services* are representative of all energy end uses. The relationship between energy carriers and energy services is used to establish indicators that measure the extend of energy poverty. Finally, *energy converters* (Section 2.3.3) are the different techniques and technologies that transform PES into secondary sources and into energy services. New energy converters not only improve the quantity and quality of the services offered, but also saves both time and fuel. For this reason, their significance in the energy system is beyond doubt.

In simpler energy systems, only a few energy sources are involved, which are transformed using one or two inefficient types of conversion. In addition, only basic energy services are provided. Modern energy systems obtain energy from many natural sources which are converted through numerous (and increasingly efficient) processes. They also offer a greater number of services to meet the needs of complex societies with high energy demand (Smil, 2010).

2.3.1 Primary Energy Source (PES)

Obtained directly from nature, PES can be classified as fossil fuels, nuclear (both types known as "stock" energy sources due to their exhaustive nature) and renewables (or "flux" energy sources) (Smil, 2010; Martínez-Val Peñalosa, 2004; Furfari et al., 2010).

2.3.1.1 Fossil fuels

Fossil Fuels —coal, oil and gas (solids, liquids and gases)— are a consequence of the transformation of deposits of organic material subjected to heat and pressure conditions for millions of years. While coal is fundamentally comprised of carbon molecules, oil and gas are essentially made up of carbon and hydrogen. Hence, they are called hydrocarbons. They are depleting resources and even though the exact residue amount remains unknown (due to the discovery of new deposits and the improvement of extraction technology that makes it possible to recover resources at profitable costs), this quality has marked energy policies to a large extent, especially in the case of oil.

Industrialisation was the driving force behind the massive use of coal. The invention of the steam engine, which entailed the use of coal as a fuel, contributed to an unprecedented economic expansion and a major modification of the military power, first in Western Europe and later in the United States. This triggered an actual revolution in the transport and industrial sectors and made it possible to meet growing national needs. In fact, coal remained the main PES until the beginning of the 20th century.

The invention of the explosion and diesel engines in 1860 and 1897 respectively marked the beginning of the "oil age", although the biggest impetus came from Winston Churchill's decision in 1911 to replace coal with oil as fuel for the British naval force to preserve maritime hegemony. Other factors that drove demand for oil included Europe's recovery after World War II, a booming U.S. economy, an increase in the number of car owners and the surge in air travel. All these factors favoured the creation of large pipeline and tank networks that allowed the exportation of oil and its derivatives at reasonable prices. Additionally, its great versatility turned it into the raw material for many industries, including petrochemicals and textiles.

During the first half of the 20th century, gas consumption remained limited due to concerns about the exploitation of fields, their transport and the safety of consumption. The technological improvement in these three areas, coupled with the 1973 oil crisis, made it an alternative source to oil, given that it lowered the risks linked to dependency. Its use as a competitive energy source in the production of electricity and heating, its low CO_2 emissions levels, as well as the development of liquefied gas and techniques such as fracking, are the reasons why some experts have foreseen a bright future.

2.3.1.2 Nuclear energy

Nuclear energy can be produced through fission or fusion processes. Nuclear fission is based on the characteristics of the uranium atom (U235), whose nucleus undergoes a slow natural excision and is then transformed into atoms of other chemical elements. The reactor induces and accelerates the process of splitting the uranium-235 isotope, producing a significant amount of energy in a continuous process called a chain reaction. Nuclear energy is considered to be clean energy in terms of CO_2 emissions, which explains why it is ahead of fossil fuels in the fight against climate change. However, three issues stymie its acceptance and development. On the one hand, radioactive waste (Iodine, Caesium and Strontium) also gets formed during the excision of the uranium atom and must be stored in what is known as a “radioactive cemetery”. On the other hand, there are concerns about the safety of nuclear power plants due to the sheer severity and longevity of the consequences. Finally, the issue of armament development also cannot be undermined.

Unlike nuclear fission, nuclear fusion requires joining of nuclei of hydrogen atoms, which, in turn, produces a heavier element and a substantial quantity of energy. Despite the apparent advantages over the fission, the time required for the commercial use of this process remains nebulous.

2.3.1.3 Renewables

Renewable energy sources are in essence inexhaustible and associated with natural elements and processes involving the sun, water (evaporation, jumps, waves, sea currents and temperature difference in ocean layers), wind, biomass as well as the Earth’s internal heat. The energy produced can be used to generate electricity and, in some cases (solar, geothermal and biomass) also heat.

The evolution pattern in renewable energy consumption is different from those in fossil and nuclear sources. At the beginning of the 19th century, renewable sources accounted for 95% of the global consumption of PES (Fouquet, 2009). Two hundred years later, this figure reduced to merely 13%[1]. However, the trend seems to be changing. Renewable energies are gaining weight in electricity generation, in thermal applications (in both the industrial and domestic sectors), as transport fuels and in the supply of off-grid energy services across rural areas of developing countries. They are of great interest because they are clean energies, which makes them indispensable in the fight against climate change. Furthermore, their potential to reduce energy dependence and energy poverty in off-grid areas has been recognised (EUCO, 2009).

2.3.2 Energy carriers

Energy carriers (also referred to as secondary sources) result from the transformation of PES. Sometimes, this transformation merely implies a change in their physical properties, but it often requires a chemical transformation.

Just as what happened with PES, the utilisation of the energy carriers has evolved with time. According to Smil (2010) the main energy carrier was charcoal before the industrial revolution. This solid fuel, often obtained by slow pyrolysis (chemical decomposition caused by heating of wood or other substances to high temperatures in the absence of oxygen), is practically pure carbon and produces very little smoke (although it emits CO_2). However, the production process remained extremely inefficient. In mass terms, up to 15 units of wood were needed for a unit of charcoal and about 60% of energy content was lost in the transformation. From the mid-18th century onwards, and after having considerably reduced its price, coke (also obtained by pyrolysis and first used in England during the 1640s), began to replace charcoal, emerging as the preferred fuel for iron production.

During the next century, the use of gaseous fuels was normalised. While technological challenges did curtail the use of natural gas to local industrial use, city gas (gas made from coal) became the fuel used for urban lighting and cooking. However, the development of natural gas, other gases such as propane and butane (derived from oil and with cleaner combustion (McMullan et al., 1981)), and electricity will eventually replace it.

Currently, liquid fuels and electricity are the main secondary sources. Crude oil is refined to obtain different fuels such as petrol, kerosene, diesel and fuel oil. All of them are used in the transport sector, although the last two fuels are also used to generate electricity with stationary motors.

With regard to electricity, there are many reasons why it has emerged as the preferred energy carrier since its commercialisation in the 1880s. From an economic viewpoint, its high final conversion efficiency, productivity and flexibility stand out.

[1]Own calculation. Data from the IEA (2016b) database.

Also noteworthy are delivery, cleanliness, odourless, easy-of-use and safety. The commercialisation of electricity was not ascribed to a gradual accumulation of various events, but the result of the deliberate creation of an entirely new energy system by Thomas Alva Edison. As evidenced in Figure 2.1, electricity can be generated from each PES, what is a clear advantage. However, due to the very heritage of its development, the majority of the world's electricity continues to be generated from fossil fuels. In the current context of the fight against climate change, maintaining this situation means developing a whole new carbon capture and storage industry that is similar to the size of the global oil industry. On the other hand, a substantial increase in generation from renewable sources would affect key elements of the electricity's infrastructure, and any move towards a system based on nuclear generation would need to overcome many socio-economic and technical obstacles (Smil, 2010).

2.3.3 Energy converters

If technological development has been important for PES, it is central in the development of energy converters, which, in turn, are key to the so-called energy transitions (a long-term alteration in the composition of the energy mix and a long-term structural change in the energy system). In this context, two energy transitions are considered critical for the development of societies: 1) the substitution of traditional biomass by fossil fuels; and 2) the substitution of animal power by inanimate power (technology). The energy converters which contributed to the second are grouped by Smil (2005) into three main categories: a) pre-1900s, especially those developed during the last twenty years of the nineteenth century; b) technological advances related to extraction, conversion and transport activities; and c) innovations that have contributed to the efficiency, accuracy and security of telecommunication and the digital age at large.

The first group includes internal combustion engines, electric motors and steam turbo-generators. Combustion engines were a breakthrough for the automotive industry, augmenting the power of automobiles. Only the rise in oil prices, and therefore the price of petrol, arising from the 1973 crisis, temporarily slowed down their development. Yet, other aspects such as sustainability or fuel consumption did not receive sufficient attention. These energy converters, although improved, continue to be the most widely used today.

The second category covers technological advances such as gas and rocket (or jet) engines or the technology that has enabled nuclear fission or photovoltaic energy. Both gas engines and rocket (jet) engines thrived at the end of World War II. Initiallly, gas engines were used on military aircraft, which would subsequently serve as models for passenger planes. These engines are also used in gas pipelines pumping stations, the chemical and metallurgical industry, and electricity generators. Rocket (jet) engines signified a major breakthrough in the telecommunications and arms (missiles) fields.

The last group of energy converters encloses less visible but no less important technological advances. Related to the development of informatics and telecommunications, they have revolutionised the accuracy of measurement, exploitation, design and efficiency in all the links of the energy system.

2.4 Implications of a change in the energy system

Energy transitions require a long period to be completed, are local (they do not occur simultaneously all over the world) and irregular (not homogeneous where it occurs). Thus, the transition from biomass to fossil fuels and from animated to inanimate force took place a few centuries ago in Europe. However, in the case of China or India, this transition occurred only a few decades ago. Throughout their history, societies have generated different energy systems conditioned by their energy sources and their use. Technical innovation, new energy markets and the ever-increasing demand of more efficient, economic and flexible energy services are driving these changes. The first-hand tools helped accelerate the development of mechanical instruments. The development of agriculture and livestock farming boosted population density, leading to social stratification, occupational specialization, incipient urbanisation and trade. Fossil fuels, electricity and internal combustion engines changed the world in a few generations. They increased food supply and variety, mechanised mass production, improved the quality of goods, introduced new materials (such as metal and plastic) and boosted trade, transport and telecommunications. In terms of the social sphere, life expectancy increased, literacy was normalised and a greater number of people had access to higher education. Development of democracies and social rights took laced, although it was accompanied by he emerge of wars and weapons. Barriers were overcome allowing humans to fly into space. However, they also brought an almost absolute dependency on electricity and a means of understanding the energy-development relationship that could best be described as a vicious-circle (Smil, 1994, 2010).

2.4.1 Economy, technological innovation and energy sources

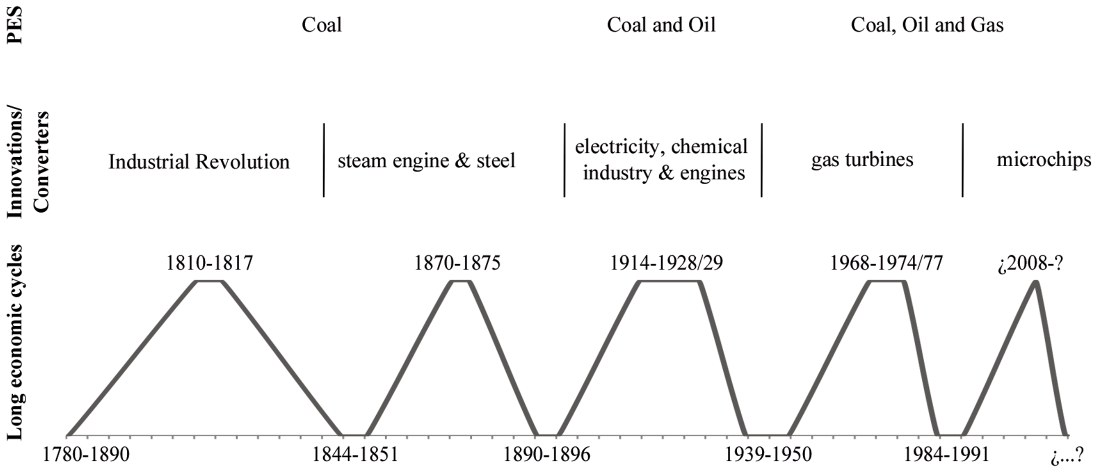
The relationship between technological innovation, energy transitions and economic development (under the framework of capitalism) has been widely studied and, despite the fact that there is no unanimous agreement (Korotayev et al., 2011), many authors defend the existence and correlation between long economic cycles and cycles of technological innovation.

The long economic cycles, also known as Kondratieff-waves (or K-wave for the Soviet economist), are cyclical fluctuations with sinusoidal form and an average length of 50 years (although the duration can vary). A period of high growth (prosperity) and a period of relatively slow growth (crisis and depressions) alternate during those years. In their work, Kondratieff and Stolper (1935) identified three long cycles. The first commenced during in the late 1780s or early 1790s and concluded between 1844 and 1851. The second one lasted from that point until 1890-1896. Due to the end date of the study (1914-1920), for the third cycle he could only indicate when the descent phase would begin. The end of that third cycle is currently dated between 1939-1950. For each cycle, it was noted that "during the recession of the long waves, an especially large number of important discoveries and inventions in the technique of production and communication are made, which, however, are usually applied on a large scale only at the beginning of the net long upswing" (Kondratieff and Stolper, 1935, pg. 1281). Schumpeter (1939) went one step further and identified a direct correlation between economic cycles and technological innovations. Thus, Kondratieff's first cycle corresponds to the industrial revolution that, according to Schumpeter, occurred between the late 1780s and 1842. The second cycle saw the expansion of the steam engine and the steel (1842-1897). Kondratieff's last cycle coincides with the emergence of electricity, the chemical industry and different engines (1898-[1942]). Since then, another complete cycle (from the 40s to the end of the 80s) has been added, which would technologically coincide with gas turbines. We are currently in a fifth cycle linked to computer chips, the age of information and communication (Korotayev et al., 2011).

In Section 2.3.3, that the direct relationship between technological development and energy converters has been established. Thus, another element can be included in the linkage between economic and innovation cycles: PES. Smil (1994) associated the two first cycles with coal, the third cycle with coal and oil and the last completed cycle with the predominance of the three fossil fuels (coal, oil and natural gas). Although the author did not mention it, these sources also correspond to the current cycle.

One of the characteristics of modern society is its high energy consumption, mainly consisting of fossil fuels. The question is which technological change will be associated with the next economic cycle and whether it will be possible to achieve the transition to a secure, reliable and sustainable energy system. It is also necessary for the transition to reflect a high degree of justice, fairness and equity (Girijesh, 2017). After studying past energy transitions, Fouquet (2010) concluded that the complete

Figure 2.2 – Long economic cycles–Technological innovations–PES



Source: Own elaboration

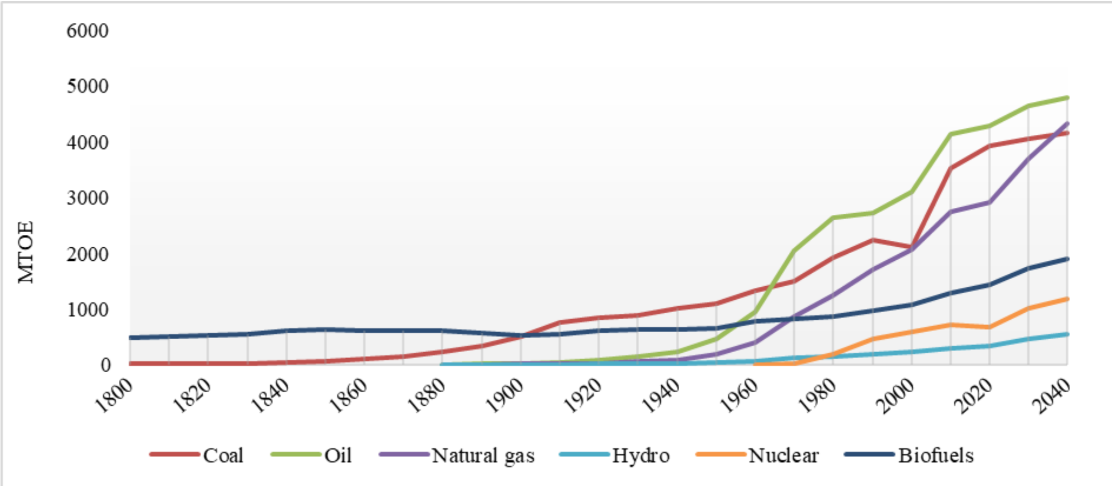
transition to a low-carbon economy is expected to be very slow-paced and will not reduce fossil fuel consumption for a very long period. Energy transitions resulted in cheaper or better energy services. To ensure the transition to a system based on low-carbon energy sources and technology, the services will have to be sufficiently cheap to compensate for any unfavourable characteristics (such as intermittence and low power density). Furthermore, while the low price is indeed consolidating, it would also need supportive instruments (such as carbon taxes or tradable permit schemes) to enhance its competitiveness as this would encourage fossil fuel companies to improve theirs.

2.4.2 Development and energy consumption

All energy transitions have led to an increase in total and per capita energy consumption. Throughout the 20th century, there was a significant increase in the relatively low consumption per capita maintained by pre-industrial societies.

Inevitably, the adoption and diffusion of new energy sources and new energy converters have both economic and social consequences. The most developed societies are characterised by significantly higher per capita consumption than their lesser-developed counterparts. In 1990, the average per capita consumption of OECD countries (developed countries) was 4.23 tonnes of oil equivalent (toe/capita) while the average per capita consumption was less than one tonne of oil equivalent for the non-OECD countries. For example, a comparison between USA and India reveals that the difference in per capita consumption is greater, with values of 7.65 and 0.35,

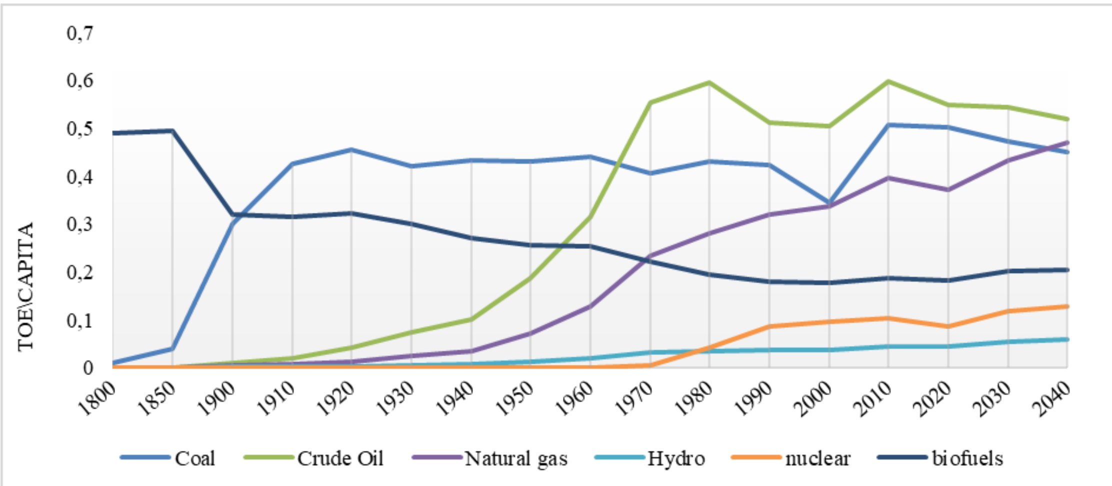
Figure 2.3 – Evolution of World energy consumption (1800-2040)



Source: Own elaboration. Data from Smil (2010) and IEA (2016e)

respectively. In 2015, the picture is similar (OECD = 4.12; non-OECD = 1.32; USA = 6.8; India = 0.65) although there is a downward trend in developed countries and an upward trend in developing countries.

Figure 2.4 – Evolution of World energy consumption per capita (1800-2040)



Source: Own elaboration. Data from Smil (2010); IEA (2016e); UN (2017); WB (2016)

An interesting approach in the study of energy transitions is to observe the change in the use of individual fuels as well as the consumption patterns of different sectors (Smil, 2010). When assessing the wealth or the level of development of a country, the evolution of energy consumption in the transport and residential sectors is an important indicator, although they need some form of clarification regarding the type of consumption.

Table 2.1 – Weight of different sectors in total final consumption

	Industry		**Transport**		**Household**	
	1990	**2015**	**1990**	**2015**	**1990**	**2015**
	Total final consumption (all PES)					
OECD	27.07%	21.77%	30.18%	33.89%	19.39%	18.83%
Non-OECD	32.70%	35.79%	14.63%	20.29%	31.47%	25.46%
USA	21.94%	17.21%	37.69%	41.38%	16.23%	17.18%
India	27.45%	33.80%	8.56%	14.89%	49.24%	33.00%
	Total final consumption (electricity)					
OECD	40.26%	31.58%	1.41%	1.14%	30.75%	31.13%
Non-OECD	56.38%	51.18%	4.73%	2.87%	16.76%	23.51%
USA	32.90%	21.32%	0.16%	0.23%	35.09%	37.07%
India	49.10%	43.96%	1.91%	1.64%	15.39%	24.05%

Source: Own elaboration. Data from IEA (2016b) database. The sectors not included in the table are: commercial and public services; agriculture and forestry; fishing; non-specified; and non-energy use

Table 2.1 shows how different it is to measure the weight of these sectors in the total final consumption if we include all energy carries (from all PES) or electricity only. For example, the transport sector is highly relevant in advanced societies. However, the use of electric vehicles is still anecdotal; thus, the weight of this sector in energy consumption is found to vary enormously if we consider all energy carriers or only electricity. In the residential sector, the difference is marked by the consumption of traditional biomass and other non-modern energy sources or services. If they are included in the analysis, i.e. if the weight of household consumption in total final consumption is measured, the percentage obtained is higher in less advanced societies. However, we obtain the opposite result if the study is restricted to the consumption of electricity. This aspect is central to the analysis of energy poverty.

The energy transitions experienced in western countries caused a great inequality, both in term of economic development and in levels of energy consumption, with respect to other countries. They are also at the origin of environmental risks. The new energy system, which is the international objective of the GEG, must ensure a synergy between economic/social development and environmental protection and dismantle the detrimental linkage between development and energy consumption. However, this also means questioning the model of production and consumption followed by developed countries and preventing developing countries from applying it.

This is something that can be considered unfair by the latter.

2.4.3 Politics of energy sources

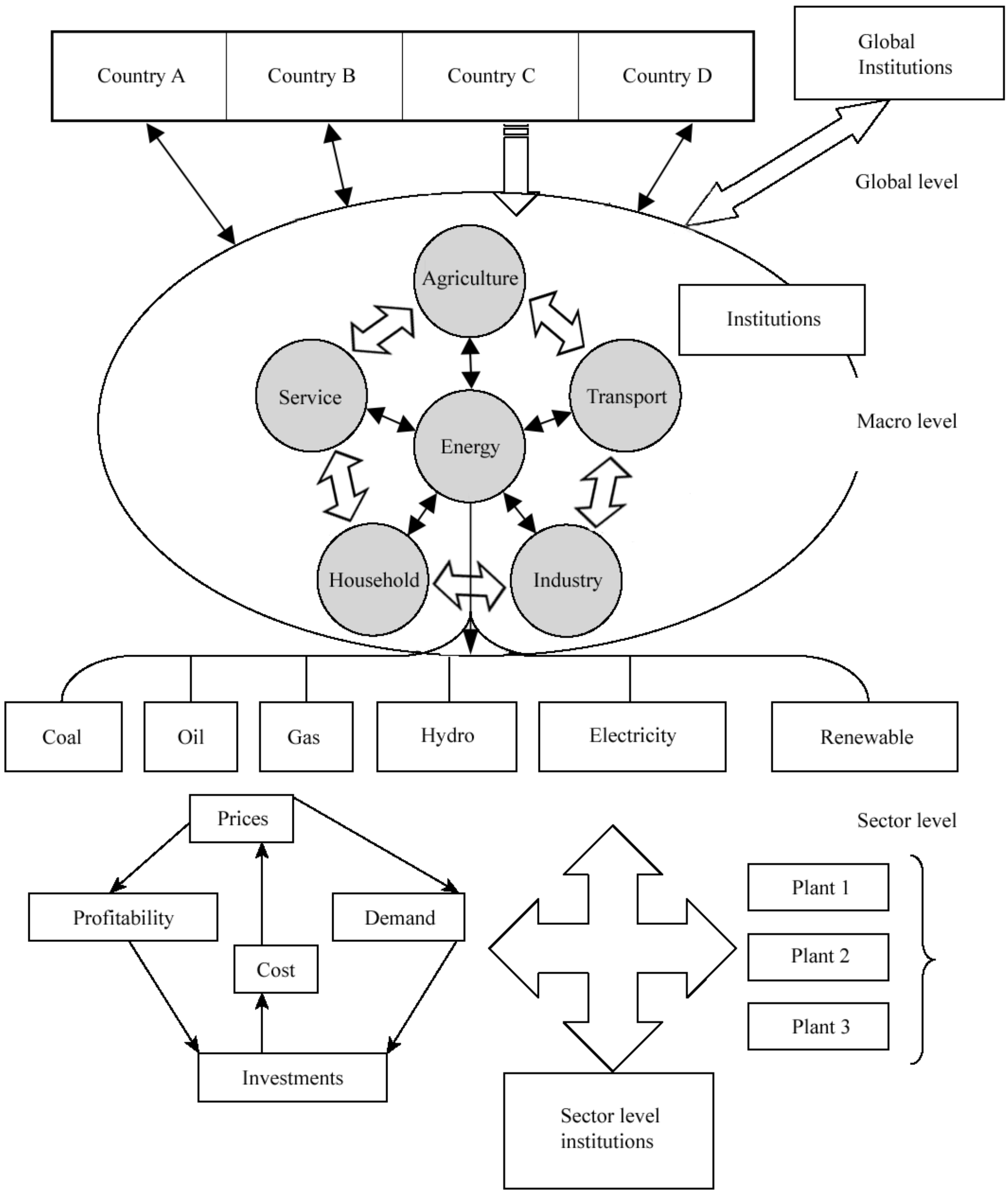
"Energy politics tends to be inherently complex for several reasons: there is no single government policy tool (akin to tariffs) that functions as a focal point for interest groups; energy is an important input into most economic activity in modern societies; and energy often has important environmental and security externalities" (Hughes and Lipscy, 2013, pg. 452). In adopting energy policy decisions, governments are invariably required to straddle national and international priorities. It is collective outcome that will determine the pace and limits of global warming, the stability of energy markets and the harmonious evolution of international energy relations (Hirst and Froggatt, 2012).

Figure 2.5 illustrates the complexity and multidimensional nature of the energy-related interactions according to Bhattacharyya (2007).

Globally, three sources of influences (neither exclusive nor static) can be easily identified: 1) the energy trade; 2) the international institutions; and 3) other interaction between countries. The first one is linked to the transactions pertaining to energy commodities (due to the heterogeneous geographical dispersion of natural resources), technologies, human resources, financial and other resources, as well as pollutants generated from energy and other materials. It is possible for international institutions (i.e. legal frameworks, treaties and conventions, international organisations such as the UN, the World Bank (WB) and the International Monetary Fund (IMF), the judicial system and similar) to be involved in the relationship between countries and transactions. Finally, governments and/or entities (such as companies) from different countries interact with each other in terms of cooperation, competition and conflicts.

At the macro (or national) level, a vicious circle exists between economic activities (largely energy-dependent) and the energy sector (development of which is predicated on economic growth). This affects the supply and demand for energy, goods and services, the potential for substitution of energy sources or other resources, decisions related to investment and a country's macroeconomic variables. Here again, national-level institutions influence and are influenced by these interactions. Consequently, influences at this level arise from a variety of sources including the level of economic activities, the interactions of energy and other economic activities (and among them), the structure of each activity, the technical composition and characteristics of the economic activities, the institutional arrangement and the macro-management of the economy and its interaction with the institutional arrangement. Their evolution over time is also another factor.

Figure 2.5 – Multidimensional relations in the energy sector



Source: Bhattacharyya (2007)

Finally, the energy sector comprises diverse industrial sub-sectors, each with different technical and economic (and to some extent also interdependent) characteristics. Each industry seeks to achieve a balanced operation by taking into consideration supply and demand, investment, price and the institutional environment. Thus, the sector must make decisions about short-term, medium and long-term issues. Due to specific characteristics of the energy sector, the decisions should be taken well in advance and therefore, involve a high level of uncertainty.

The traditional approach to energy has been dominated by the expectation that global demand for oil will continue to grow and the geopolitical ramifications of the struggle for access to scarce oil and gas reserves. Access to oil reserves has been regularly used for wider political objectives and influence. Nevertheless, things have changed due to actors such as efficiency, fuel-switching and changes in the regulation as a consequence of climate change (Hirst and Froggatt, 2012; Van de Graaf, 2017; Konoplyanik, 2018).

The origin of the actual process of "energy resource diversification" was the oil price increases in the 1970s, which affects both the production and demand side. At the production side, the first reaction to oil price increase in 1973 was not so much the diversification of resources as of suppliers. Rising prices encouraged the development of North Sea oil and/or unconventional liquid fuels beyond the Organization of Petroleum Exporting Countries (OPEC). However, these measures were unable to lower the price of oil, but fostered the development of international oil infrastructure and trade besides partially reducing dependence on oil from OPEC. Oil substitution by other fossil fuels (first) and renewables (later) also began a few years later (Konoplyanik, 2018). Recently, the development of the fracking technology has made feasible, both physically and economically, the extraction of large deposits. This has increased the reserves, especially of gas, which facilitates migration from one fuel to another, thus reducing the time from the investment decision to actual production and accelerating the eastward migration of the global oil market. Such is the significance of this technology that in 2011, the IEA spoke of a possible "golden age of gas". However, although global gas resources are widely dispersed, there are also risks of dependence and/or interdependence (as with oil). This was evident in 2009 when Russia cut off supplies to Ukraine due to a payment dispute (Hirst and Froggatt, 2012; Van de Graaf, 2017; IEA, 2011c).

On the demand side, the main response was to reduce consumption through efficiency and energy savings, although such measures were time and cost-extensive, and were therefore adopted following the implementation of other instruments aimed at changing consumer behaviour (Konoplyanik, 2018). On their part, the Paris Accord and other climate policies, the decoupling of energy consumption (oil) from economic development, the lowering of the cost of renewable energy and electricity storage, as well as the increased use of electric vehicles entail a new energy mix dominated by renewables. The deployment of carbon capture and storage (CCS) could reduce the rate of fossil fuel consumption, but its effect could be modest given the time required for this technology to spread globally and also because it is less cost-effective than renewable or nuclear energy, thus underpinning the need for an international economic framework for investment and cooperation. Moreover, it is not entirely carbon-free (Hirst and Froggatt, 2012; Van de Graaf, 2017).

For Konoplyanik (2018), future energy policies should respond to an energy system of centralised cross-border energy industries (non-renewable energy) and more decentralised energy industries that is mostly based on domestic renewable energy development. It must also include issues of access to capital, technology and innovation. The main drivers will continue to be climate change, import dependence and security of supply. Moreover, the fight against energy poverty trigger the debate on the most appropriate types of energy development for a non-industrialised and decentralised energy system.

2.5 Governance, government and global energy governors

A substantial part of the literature is concerned with mapping the global energy architecture or, as Florini and Sovacool (2009) asked, “Who governs energy?” given that there is no international energy organisation compared to other domains, such as health (World Health Organization (WHO)), financing for development (WB) or finance (IMF). These studies address issues such as the level of international cooperation, desirability and necessity of a single organisation, couple with the analysis of the activities undertaken by the main institutions.

2.5.1 Governance and government

Many governance debates centred on the evolution of the number and type of actors and places of decision-making, the replacement of hierarchical rationality of the state by horizontal relationships, as well as the self-regulation of interactions. Governments tend to look at other actors to engage in a wider governance landscape wherein cooperation exist (Hufty, 2008; Sullivan and Gouldson, 2017). Indubitably, the involvement of non-state actors in public policy issues has gained significance, this has not translated into a commensurate withdrawal of the state as a major actor. As a matter of fact, a major contentious matter of discussion among academicians is whether or not there is similarity between the terms “governance” and “government”. While both terms refer to a system of rules, a behaviour that is in pursuit of specific objectives, they differ in several aspects, which inevitably results in a disagreement among experts.

Governance, for those who advocate the identification of both terms, would be equate with “global governance”, i.e. formal institutions that are looking to coordinate and control interdependent social relations whilst being empowered to force decisions. In this context, a genuine global government must be capable of the following: controlling or suppressing threats, increasing profits, establishing expenditures, redistributing wealth and establishing/safeguarding the rights and duties of citizens. Although the UN system stands as the best bid among the advocates of this thesis, the objective appears to be elusive from political acceptance (Weiss and Thakur, 2010).

Contrastingly, the majority of experts consider both terms as distinct. They opine that the government is the formal and institutional state-level processes for maintaining law and order as well as for facilitating collective action, whereas governance signifies a change in the mode of government. Specifically, it aims at the creation of a structure stemming from the interaction between the various actors that does not necessitate a formal authority. Hence, some authors plead for the existence and value of governance without government per se (Rosenau and Czempiel, 1992; Stoker, 1998; Bevir and Rhodes, 2003; Jordan et al., 2005; Börzel and Risse, 2010).

In its most extreme sense, the identification of governance and government would correspond to the international system that Rittberger and Zangl (2006) refer to "World-state". The process of civilisation did not end with the emergence of sovereign states. Instead, it will end with the creation of a world state capable of establishing and implementing binding global norms. Located at a higher hierarchical level than the rest of the states, this World-state will monopolise the legal use of the force. International organisations, and especially the UN with the powers of the Security Council, would be its precursors. However, its actualisation seems rather unlikely for several reasons. It is difficult to envision the collective willingness of all the present states to renounce their sovereignty in favour of a higher institution, especially when power, the non-negotiable aspect of a government, is organised at the national level (Weiss and Thakur, 2010). Furthermore, this option would pose the problem of what to do or how to "persuade" states that are unwilling to participate. It would also be necessary for all the states to reach a consensus on the kind of political and organisational system that would be established and the guarantees of their permanence over time. Equally, it must be remembered that a World-state is not synonymous with a global society. If its creation is the culmination of the process of civilization, it must have a global society, given that it is the relationships between the social actors the basis of this process.

According to Claude (2002), the idea of identifying government and governance relates more to the concept of "state of law" than to politics. The lack of central authority or global government can be understood as a source of inefficiency. However, neither national problems can be extrapolated to the international arena, nor can international problems be resolved by a government based solely on the basis of law. Besides, limiting governance to the existence of a single authority tantamount to ignoring the complex reality in which diverse agents promote a rich web of relationships. It needs to be recognised that the demands of society are far too complex to be solved by governments alone. Commission on Global Governance (1994) posited that order at the highest and most extensive level of relations was necessary, although it should not be similar to the traditional concept of a global government. This is because the idea is, in addition to being utopian, undesirable. The concept of governance is broader than that of government, coalescing public and private governance mechanisms, public and private agents and the very objects of governance (Kobayashi, 2005).

One of the questions derived from this approach is the extent to which governance has replaced government. Some authors attempt to identify an answer through comparative analysis although they recognise that the majority of definitions are not clear enough to be able to precisely differentiate between "traditional forms" and "new ways" of government. There seem to be, however, a consensus on several basic points. On the one hand, governance is associated with the reduced ability of central governments to manage society. On the other hand, multi-level government structures, such as the European Union (EU), are emphasised as an example of the new modes of governance. Additionally, both terms are presented as the two contrasting poles on a continuum of different governing types. Government is associated with the concept of "strong state" with the use of a binding regulation (hard law), while governance is a coordinated, self-regulated network of societal actors through non-binding mechanisms that work through moral persuasion or economic incentives (soft law). For this reason, it does not rest on the government's authority. This differentiation allows the establishment of at least four possible forms of interaction, classified as: co-existence (they complement one another), fusion (they merge), competition (they compete and conflict) and replacement (one eclipses or replaces another) (Stripple and Stephan, 2013; Jordan et al., 2005; Salamon, 2000; Steurer, 2013).

2.5.2 The global energy governors

The many efforts made to identify the number of "global energy governors" results as diverse as six or fifty (Van de Graaf and Colgan, 2016). Confronted with this diversity, some authors prefer to avoid nominal and exhaustive lists and offer classifications in accordance with various criteria such as the types of international institutions (Florini and Sovacool, 2009), the institutional interactions (e.g. the classifications used by Young, Oberthür and Stokke or Scott found in Isailovic et al. (2013)) and the three issues falling under the purview of energy trilemma (Cherp et al., 2011; Meyer, 2012).

Table 2.2 – Global energy [trilemma] governors

Issue	Origin	Actors	Objectives	Governance mode
Energy security	Oil crisis (1970s)	Trade and investment institutions & major exporters and importers of energy (nation states) and their alliances (e.g. WTO, ECT, IEA, OPEC, IEF, OLADE, SCO, GECF)	Stable and secure global energy supply	Commitment and efficiency. Binding agreements regulating access to resources and infrastructure as well as stocks and flows of fuels
Energy poverty (energy access)	International development agenda (1980s)	Economic energy institutions, International development organisations and NGOs & multilateral partnerships (e.g. World Bank, UNDP, IRENA)	Access to modern forms of energy	Decentralisation. Loosely structured mechanisms regulating flows of financial and technical assistance. Capacity building and information exchange.
Climate change	Environmental sustainability (1990-2000)	Environmental-specific institutions, Nation states, IGOs, NGOs (e.g. UNFCCC, IPCC, UNEP, UNDP, Global Environment Facility (GEF), WWF)	Mitigation of greenhouse gas (GHG), forests, appropriate land use, adaptation to climate change	Diverse ranging from binding agreement to finance, technical assistance, production and dissemination of knowledge and facilitation of networks

Own elaboration from Cherp et al. (2011) and Meyer (2012).

The vast number of agreements and international organisations related to different aspects of energy in the international arena operate at different scales, with different norms, actors and discursive formations (Sovacool and Florini, 2012; Isailovic et al., 2013). However, the rudimentary characteristic of the GEG architecture is fragmentation mainly originated by energy dependency. The establishment of international organisations such as OPEC, IEA or IRENA responded to a historical context so that their mandates and powers were established to solve specific governance problems at particular times, rather that to develop proper energy governance (Meyer, 2012). This, in turn, imbues some clarity on their limitations. Moreover, the creation of international institutions endowed with elaborate norms or binding agreements at the global level is an onerous and difficult process. On the contrary, quasi-formal institutions or discussion forums such as the Group of Eight (G-8), the Group of Twenty (G-20), the International Energy Forum (IEF) or the Gas Exporting Countries Forum (GECF) are much easier to establish, which is why they are increasingly becoming the preferred option. However, their informal and non-binding nature also leads to contradictory opinions. For example, while the informality and “acting in good faith" are, for some authors, the main reason why states participate in the G-8 openly and sincerely, others opine that the Group failed to lead the global policy and to provide an effective GEG owing to the presence of opposing interest within it, the lack of control and mechanisms to ensure compliance of agreements and the inability to consider the needs and opinions of non-member countries (Lesage et al., 2009; De Jong, 2011; Florini and Sovacool, 2011; Hirst and Froggatt, 2012). In any case, intergovernmental organisations (whether formal or quasi-formal) are key actors in the process of GEG.

A great number of studies have looked at individual institutions and their role in the GEG. Given the scope of this research, only three will be mentioned here: the IEA, the UNFCCC and the EU. One of the institutions to have elicited the most attention is the IEA, an intergovernmental organisation established in 1974 within the framework of the OECD to help its members respond to major oil supply disruptions. Van de Graaf and Colgan (2016, pg. 5) described it as "the world's foremost multilateral energy organization" and "the closest we have to a World Energy Organization". Although energy security represents a major area of the Agency (as it will be seen in Chapter 4), it also addresses aspects related to the promotion of energy efficiency, international collaborations, data and statistics, training, technology collaboration, global engagement and industry engagement.

According to Meyer (2012), the UNFCCC is a particularly notable energy institution. While the UNFCCC aims to address a broad array of climate-related issues, the UNFCCC's mitigation efforts are largely focused on incentivising an economy-wide shift from a high greenhouse to low greenhouse energy sources (see Chapter 5). Unlike other (traditionally) single-source organisations such as OPEC, IEA, GEF, IRENA or IAEA, the UNFCCC deals with energy sources in their entirety.

The EU, "the world's most advanced example of international cooperation" (McCormick, 2017, pg. xii) is a regional institution. This explains its frequent exclusion from the lists of international agreements and organisations dealing with international energy (Meyer, 2012). However, its genesis is linked to energy. Built on two treaties – the European Coal and Steel Community Treaty and the Euratom Treaty– the EU was created with the initial aim of preventing the possibility of future outbreaks of war through a common plan for managing energy resources and assets (Heffron, 2015; Heffron and Talus, 2016a). Within that context, the 2015 Energy Union strategy (COM/2015/080) (EC, 2015b) aims at building an energy union that delivers secure, sustainable, competitive and affordable energy to all EU consumers, both encompassing households as well as businesses (Chapter 6 will analyse the impact of one of the measures adopted to achieve this). The strategy is premised on genuine solidarity and trust between the Member States, and on having a single European voice on global energy issues. It intends to create an integrated energy system for the entire continent wherein energy flows freely across borders, based on competition and the best possible use of resources, also accompanied by effective regulation of energy markets at the EU level, where necessary.

2.5.3 Performance and deficiencies

According to Hughes and Lipscy (2013), academic research has been very inconsistent in leaving out important questions. For Van de Graaf and Colgan (2016), the question of effectiveness, or in the authors' words "how well or poor is energy governed", has not received adequate attention. The following paragraphs cover this issue and, in terms of effectiveness, the findings of various analyses are not particularly laudatory.

Howlett and Ramesh (2014) identified two types of governance failures. The first one relates to discrepancies between the mode of governance[2] in place (legal/hierarchical, market, network or corporatist) and the nature of the problem. Identifying the problem's characteristics and adopting the best mode of governance to deal with it (e.g. a problem linked to incorrect incentives should be managed by a market governance mode) would address this problem. The second type is linked to government capacity issues, i.e. the problem has been properly identified and the chosen mode of government is correct, but the governments (which continue to be a major actor in the majority of existing public governance arrangements) do lack the requisite resources and skills to compel the governance mode to make sound policy choices and implement them efficaciously.

Table 2.3 – Key gaps and cleavages for goals

Objective	Key gap in governance	Key cleavages
Energy security	Dispute resolution, especially for energy transit issues	Exporting, importing and transit states
Economic development	Energy poverty in developing countries	Developed and developing states
International security	Conflicts and arms purchases from petrodollars	Varies
Environment	Developing meaningful responses to climate change	Developed and developing states
Good governance	No real buy-in for EITI-like principles of transparency, human rights	Oil corporations, producer states and international civil society

Source: Own elaboration from tables in Van de Graaf and Colgan (2016)

[2] A governance mode describes the type of relationship between governmental and non-governmental actors.

Table 2.3 summarizes the gaps and cleavages in GEG according to Van de Graaf and Colgan (2016). The authors make two assessments based on the degree of legitimacy of each institution and the institutional interest in each of the five objectives identified. The conclusion in terms of the effectiveness-legitimacy relationship is clear: an institution is potentially more effective if it enjoys a high degree of legitimacy (i.e., it is deemed appropriate and one to be obeyed). According to the second analysis, there is an unequal interest in certain objectives, such as energy security, as opposed to others, such as international security or good governance. Additionally, the specific concerns of each institution concerning the same objective are known to differ, thus curtailing international cooperation.

Weiss and Thakur (2010) and Stripple and Stephan (2013) analysed the deficiencies of five areas of action: 1) information, 2) norms, 3) standards, 4) capacity and 5) implementation. Effective policymaking entails sharing meaningful knowledge and information to understand the problem and reach consensus on its nature, causes, severity and magnitude. However, this is also unusual since several debates are characterised by strong polarised views. In order to surmount this deficiency, one must distinguish between factual information and theoretical information.

The norms either define ethical principles (the behaviour to be adhered to in accordance with the values of the system), or specify the most common behaviour, but they do not always coincide or complement one another. Nor is there sufficient information to determine who is legitimised to articulate "global" norms or how they arise, are disseminated, consolidated and internalised. Furthermore, the mere existence of a norm does not imply that it is immediately and completely applicable. In fact, the "life cycle" of a norm involves three distinct phases: (a) the emergence and adherence of some followers, (b) the adoption by a significant number of actors who legitimise and promote it, and (c) the internalisation (it no longer needs further justification). Notably, not all norms are able to complete the "life cycle" (Finnemore and Sikkink, 1998).

The third deficiency, labelled as "policy gaps", pertains to the standard-setting practice of global governance. A policy entails two elements —the agency and the purposive action— generating a dual challenge. The first one questions the main "international" policymakers. The second refers to the disconnection between these and the different actors affected by the policies adopted. While the latter are varied and belong to all civil, political and economic fields, the former are limited both in number and in nature, primarily focusing on those who represent the authority in international institutions. Additionally, representatives of national governments tend to adopt decisions framed by their foreign policy, even if it is a global issue.

Directly related to the debate on the GEG architecture, the last two gaps concern capacity-building as well as the implementation, monitoring and enforcement of adopted standards and policies. As seen above, the participation of multiple actors in global governance has the advantage of a transnational network of resources and expertise that are often organised in flexible cooperation mechanisms. This, in turn, facilitate learning-by-doing and addresses specific aspects of a complex issue in isolation. However, both nature and performance have not been impervious to critical analysis, identifying aspects such as global legitimacy, participation, transparency, accountability and effectiveness. The lack of a global authority can create the possibility of ignoring or omitting various international aspects in resolutions (who possesses the authority to control who applies the measures and acts against those who do not?) and leaves it up to individual states to provide the necessary resources.

A more critical and pessimistic view, on the very existence of global governance, and not to effectiveness, is offered by Gilpin (2001), who is of the view that governance at any level should be premised on shared beliefs, cultural values and, above all, in a common identity. The concept of a global civil society located between the economy and the state, oriented to a worldwide scale of activity and organisation is another main aspect of global governance that has developed a line of thinking inquiring into its normative and democratic potential. As a matter of fact, the term global governance was first used when exploring the increasing skills, capacities and orientations of not only individuals, but also small groups (Hewson and Sinclair, 1999). Gilpin denies the existence of a global civic culture and affirms that identities and loyalties remain national, local, ethnic or racial. The fact remains that modern states remain egocentric and rarely care about others. Under these conditions, even the debate about a global governance turns out to be futile.

2.6 India and global energy governance

India is building up a position among world powers. Its international activity, both in multilateral and bilateral channels, has witnessed notable growth. The economic development of the last two decades (between 1991 and 2014, the Gross Domestic Product (GDP) per capita in constant terms tripled) has led to a more ambitious foreign policy.

Economic growth and energy are two directly related terms. India's energy model is characterised by a high consumption of fossil fuels and a considerable level of energy dependency and insecurity. Despite the fact than the Indian electricity sector has been one of the fastest-growing in recent years, around 240 million people are still without access to electricity. Furthermore, environmental considerations constitute a source of international pressure on India to initiate more concrete measures in the fight against climate change. However, the use of energy justice by India to justify increased emissions is noteworthy: the tenet of inclusive growth is linked to universal access and energy security and thus to increased emissions (Goodman, 2016).

As seen above, global governance is an essentially collaborative (not flawless) process between interconnected international institutions, forums of experts, non-governmental groups and private sector entities that deal with overlapping issues by setting norms, rules and standards. Since independence, India has participated in this process. Membership in international organisations provided the newly independent state with not only greater legitimacy and recognition, but also with a viable opportunity to influence the agenda by underscoring the concerns and differences of developing countries (Narlikar, 2017).

India has changed its approach towards participation in international organisations due to changes in its interests and demands resulting from economic growth and increased power. Members of the Working Group on India and Global Governance (WGIGG) (Ghosh et al., 2011) point out that this evolution involves a change in four aspects related to more active participation, not only with regard to the process of rule-making within existing institutions, but also in the design/engagement in the new complex and multidirectional structure of the global system. Robust and well-functioning institutions enable efficient decision-making, pragmatic pricing and regulatory reforms (NITI Aayog, 2017). For example, the attitude of India in international debates concerning climate change has varied over the years from very critical to proactive. Traditionally, India has invoked the principle of differentiated responsibilities so that environmental issues would not pose limits to its economic development. This refusal to take on more responsibility was motivated by concerns about the global governance agenda. According to India, it only served the interests and objectives of the great world powers. Also, as long as the country per capita income remained low, India would privilege national concerns over international ones. Nonetheless, there was a change at the 2015 United Nations Climate Change Conference (COP-21) in Paris. While maintaining its earlier advocacy of the principle of "common and differentiated responsibility", its Nationally Determined Contribution (NDC) reconciled economic development and environmental protection. Furthermore, India requested international financial assistance only after demonstrating genuine efforts in mitigation and adaptation. Besides, India played an important role as a pioneer in the development of a new scheme on renewable energy sources, launching, together with France, the International Solar Alliance[3] (Narlikar, 2017).

[3] More information at http://isolaralliance.org/

India is a country of contradictions. Its rapid economic growth contrasts with the high rate of poverty (both relative and absolute) alongside other social deprivations, belonging to the group of both emerging economies and developing countries. India's engagement varies from one issue to another, depending on its varied interests and resources. Through more active participation in the development of rules, the country can find ways of balancing the needs of both imperatives. However, India must also determine its role in international agenda-setting, regulation, implementation, monitoring and enforcement, as well as the formal institutions (which have greater legitimacy) or informal networks (which offer greater efficiency)in which it wants to participate, thereby circumventing the loss of freedom of manoeuvre (Ghosh et al., 2011; Pant, 2017).

India's participation in the different forms of collaboration constituting GEG varies. In addition to the fact that the country is not a member of the most regional organisations, the scope of multilateral institutions is also limited. Moreover, bilateral relations with certain oil-producing states have created a situation of dependence, which is in itself both a risk and a matter of concern. Not surprisingly, India seeks a more proactive role in global governance to develop a more cogent strategy in its interactions with other nations on a plethora of energy issues. In March 2017, India activated the partnership status with the IEA. For India, this implies the right to participate in the meetings of the IEA's standing groups, committees and working groups without prior invitation and to collaborate with the IEA on energy security issues, energy data and statistics and energy policy analysis. This partnership is also aimed at strengthening capacity building in the areas of energy efficiency, technology, renewables, electricity security and grid integration. For the IEA, India's participation means a move to better represent major players in today's global energy markets, thereby augmenting its efficacy in setting the right agenda today to help address some of the biggest challenges of tomorrow (Nakano et al., 2017).

From the work of the WGIGG (Ghosh et al., 2011) it can be surmised that India's demands from GEG are not very different from those of developing countries. In addition to having access to predictable, affordable and reliable supplies of energy resources, the country is seeking freedom in choosing the options of its energy mix in order to prevent its potential economic development from being constrained. For India, environmental concerns must be addressed equitably (following the principle of "common and differentiated responsibility"), while mounting costs stemming from changes in energy-related technologies must be supported by access to financial support.

However, in order to favourably respond to these demands, India must successfully participate in climate policy, finance and technology negotiations. According to WGIGG, India is required to expand its participation in different multilateral forums to preserve recognition of its development and poverty reduction priorities, as well as to resolve disputes over access to energy resources or sudden restrictions on energy flows from major suppliers. Furthermore, the country must also actively participate in designing a decentralised mechanism (with elements of the UNFCCC and regional institutions) to fund the important fight against climate change. In terms of the decision on whether or not to maintain bilateral relations, these should respond to security (ensuring access to energy) and financing issues (access to climate-related technologies). Finally, India needs to recognise and take advantage of the importance of civil society and non-governmental organisations (NGOs). Energy and climate change standards developed outside the intergovernmental processes could be included in international treaties, and India must participate in those processes.

Chapter 3

The scope of GEG: The Energy Trilemma

3.1 Introduction

From the definition of GEG (Chapter 2, Section 2.2), Van de Graaf and Colgan (2016, pg. 3) inferred that "(t)he *potential scope* of GEG is any social, political or economic issue that (1) crosses international borders and (2) is tightly connected to the production, distribution or consumption of energy". Yet, the paper also noted that "(t)he *actual scope* is the set of issues to which attention is actively being paid by a set of relevant actors, including states and/or existing international organizations". Thus, the statements present a gap between potential and actual scope, indicating the prospective avenues for effective change.

Several authors have tried to identify the goals of the GEG. For example, Florini and Sovacool (2011) analysed the links between the provision of energy services and the deployment of technologies with the geopolitical, environmental, and economic dimensions, to suggest five dimensions: 1) geopolitics and security, 2) transboundary externalities, 3) political economy of energy, 4) development and energy, and 5) emerging issues in global governance and energy policy.

Cherp et al. (2011) observed, as seen in Chapter 2 Table 2.2, the historical context and the political agenda to establish a three-dimensional framework constituting 1) energy security, 2) access to energy (energy poverty), and 3) climate change.

Dubash and Florini (2011) scrutinised the global political pronouncements emanating from meetings, mandates and policy statements of international institutions, and initiatives of non-state actors and multi-stakeholder networks and segregated these objectives as: 1) energy supply security, 2) energy poverty, 3) environmental sustainability, and 4) domestic good governance and corruption.

Correspondingly, Goldthau (2013) also identified four key dimensions: 1) markets, 2) security, 3) sustainability, and 4) development.

Van de Graaf and Colgan (2016) synthesized the GEG goals as 1) security of energy supply and demand, 2) economic development, 3) international security, 4) environmental sustainability, and 5) national good governance.

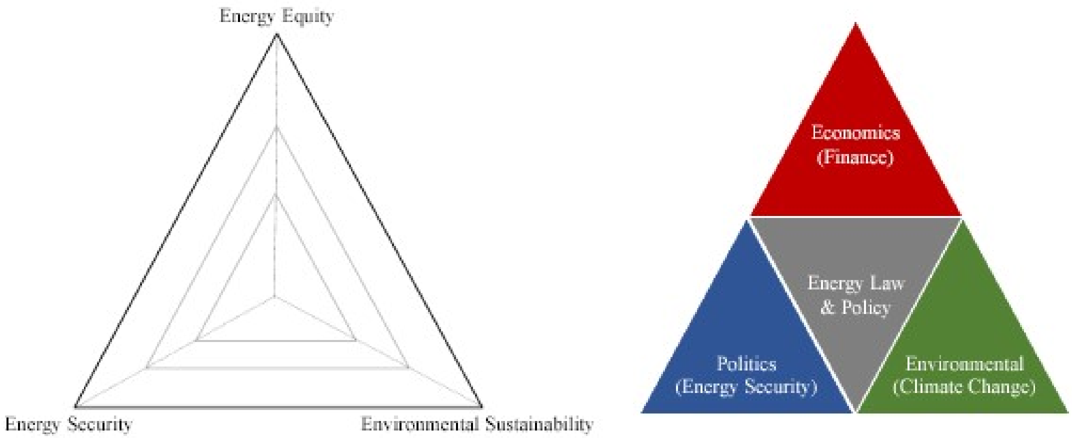
All these objectives have demonstrate essential characteristics of global public goods and thus exceed the national level of action (e.g. climate change); cause international concern, despite if the issue mainly affects the inhabitants of a state (e.g. energy security and energy poverty); and concern the international institutions used by different actors to seek non-coercive ways of introducing changes in their national governance (e.g. climate change) (Lesage et al., 2010; Van de Graaf and Colgan, 2016; Florini and Sovacool, 2009). The achievement of all these objectives requires complex links between international organisations, state and non-state actors.

The energy trilemma is a term used to describe the political challenge of simultaneously addressing the potentially competing goals of energy security, energy equity (affordability and accessibility), and climate change. The energy trilemma is consistent with other policy discourses such as the three pillars of sustainability — economic, social and environmental— from the Brundtland report (1987), i.e. meeting the needs and aspirations of the present generation without compromising the ability of future generations to meet theirs. This explains, according to Rinkinen and Shove (2019) why it has become a powerful rhetorical device through policy and research. Since 2011, the World Energy Council (WEC) has been publishing annual reports on the 'World Energy Trilemma', that is, the performance on the three dimensions.

Sometimes the energy trilemma is identified with the energy triangle, where energy law and policy are at the centre of the triangle and the economics (finance), politics (energy security) and the environment (climate change) constitute the three vertices (see Figure 3.1). There is, however, a distinction between these regarding the economic aspects. While the energy trilemma focuses only on energy equity, the energy triangle broadly emphasises financial issues. Also, energy law and politics aim to either increase energy security and/or economic benefits and/or environmental objectives while the energy trilemma depicts the (un)balance between the results of the measures taken to address them. The concepts, however, present a similarity, wherein, each of the issues attempt to pull energy law and policies towards it (Heffron, 2015).

This chapter focuses on the energy trilemma. Wherein, Section 3.2 provides a review of the concept of energy security, the evolution undergone (Section 3.2.1) and the related dimensions (Section 3.2.2). Section 3.3 presents the concept of climate change, its background (Section 3.3.1) and its main consequences and future risks (Section 3.3.2). Section 3.4 explains the different approaches to the concept of

Figure 3.1 – Energy trilemma and Energy triangle



Source: Own elaboration

energy poverty and its impacts on different areas of development (Section 3.4.3). Finally, Section 3.5 shows the interconnection of the three dimensions and raises the question of developing a model that analyses the impact of diversity of the energy mix in all three dimensions simultaneously.

3.2 Energy security

There is no universally agreed-upon definition of "energy security" (e.g. Sovacool (2011b), Winzer (2012) and Gasser (2020)) due to the diverse perceptions of the stakeholders or the selection of possible threats by the authors in their analysis (Winzer, 2012; Azzuni and Breyer, 2018). In other words, the meaning of energy security depends on the situations and people (Luft et al., 2010; Ciută, 2010). For Cherp and Jewell (2014), however, the concept is the same and changes in its expression, based on the conditions.

Several differences are found in the literature from the perspective of the challenges that resource-rich (exporting) countries and resource-poor (developed and developing importing) countries may face (Bhattacharyya, 2011). Most authors mention aspects such as vulnerability, reliability of supply, resource management, and price volatility that require action at the global, national, and local levels. Thus, importing countries would understand energy security as energy availability at affordable prices (developed) and would be concerned about the consequences of unstable prices over their balance of payments (developing) while producing countries would focus on keeping the external demand of oil as a significant part of their income comes from exporting (Yergin, 2006). Also, affordable price illustrates a different meaning to each agent (public, private and civil society) that belongs to each group of countries (consumers, producers and developing). A more precise example of these differences can be found in Sovacool (2016). The author, in his study, analyses how energy-users perceive the importance (rated from extremely unimportant (1) to extremely important (5)) of 16 energy security dimensions: 1) securing a supply of traditional fuels (fossil fuels and uranium); 2) bolstering trade in energy fuels, commodities, and technologies; 3) maximizing production and minimizing depletion of domestically available fuels; 4) providing predictable and clear price signals; 5) enabling affordably priced energy services; 6) providing equitable access to those energy services; 7) diversifying and decentralizing energy infrastructure; 8) promoting energy efficiency and lowering energy intensity; 9) researching and developing new energy technologies; 10) ensuring transparency and participation in project siting and decision-making; 11) offering energy education and information; 12) preserving land and forests; 13) enhancing the availability and quality of water, a key input into energy supply chains; 14) minimizing air pollution; 15) building resilience and adaptive capacity to climate change (called "adaptation"); and 16) reducing greenhouse gas emissions (called "mitigation"). In total, 2495 surveys were (partially or fully) completed across 11 countries that represented a mix of urban and rural populations, developed and developing economies, import- and export-dependent energy trading flows, post-communist and capitalist societies, liberalised and state-owned energy markets, and different geographic sizes. Table 3.1 shows the mean value of each dimension for each country (i.e., the number of surveys is indicated under each country). The maximum and minimum values are highlighted in bold and in grey, respectively.

According to the author, the results show how the social, economic, political and geographical context of the actor influences its interpretation of energy security. For example, the security of supply is the most important issue for China but the least for Germany. Yet, as highlighted by the author, there are also some common points. Despite the differences between countries, all dimensions are highly considered with the majority of mean values above 4 (important to extremely important), with the availability and quality of water for energy supply chains and R&D of new technologies being the two dimensions most often mentioned as the most worrying. At the other end are the diversification and decentralisation of energy infrastructures (mostly rated below 4) and maximizing production and minimizing depletion of domestically available fuels.

Another conclusion is that the results not always support well-established hypotheses in the academic literature, e.g. energy efficiency is equally important for both the less developed and more developed countries; nor is there a great disparity between countries in their preference for green energy.

Table 3.1 – Energy security perceptions by country

Dimension	Mean for each country										
	Brazil (115)	**China (312)**	**Denmark (328)**	**Germany (114)**	**India (172)**	**Japan (346)**	**Kazakhstan (138)**	**Papua New Guinea (48)**	**Saudi Arabia (298)**	**Singapore (93)**	**USA (427)**
Security of supply	4.70	**4.82**	3.81	3.75	4.86	4.42	4.68	4.66	4.79	4.34	4.14
Trade	4.70	3.99	4.09	4.23	4.57	4.14	4.47	4.53	4.49	4.16	4.19
Depletion	4.68	4.57	3.99	4.07	4.61	4.37	4.54	4.40	4.40	3.54	4.08
Prices	4.75	4.27	4.16	4.15	4.47	4.27	4.49	4.67	4.55	4.24	4.34
Affordably	4.82	4.21	4.31	4.15	4.67	4.34	4.51	4.79	4.61	4.28	4.10
Accessibility	4.79	4.36	4.20	4.24	4.49	4.11	4.39	4.79	4.72	4.33	4.53
Decentralisation	4.47	3.62	3.41	4.34	4.17	3.99	3.76	4.50	4.47	3.53	3.97
Energy intensity	4.59	4.44	4.40	4.57	4.52	4.36	4.14	4.45	4.41	4.16	4.49
R&D	**4.98**	4.68	**4.67**	**4.89**	4.83	4.50	4.66	4.60	4.78	4.37	**4.83**
Transparency	4.65	4.21	3.96	4.15	4.58	4.00	4.36	4.77	4.46	4.01	4.47
Information	4.82	4.04	3.89	4.41	4.74	4.11	4.37	4.77	4.72	4.23	4.56
Forests	4.90	4.79	4.36	4.52	4.82	4.48	4.71	4.81	4.64	4.18	4.73
Water	4.88	4.75	4.66	4.47	**4.89**	4.35	**4.79**	**4.84**	**4.91**	**4.66**	**4.83**
Air pollution	4.86	4.76	4.56	4.46	4.80	**4.57**	4.71	4.60	4.84	4.53	4.75
Adaptation	4.84	4.54	4.36	4.22	4.59	4.23	4.29	4.69	4.55	4.33	4.56
Mitigation	4.88	4.62	4.43	4.74	4.76	4.36	4.51	4.66	4.62	4.33	4.65

Source: Sovacool (2016)

Besides these points, it can be observed that the dimensions related to the affordability and accessibility (i.e., key issues to energy poverty) are ranked halfway down in almost all countries, the exception being Papua New Guinea, where both dimensions are part of the fourth most relevant ranking. Notably, the provision of equitable access to energy services is the third least important dimension for India, at least in terms of energy security. Better placed, mostly from the middle up and always in this order except for Papua New Guinea, are the issues of mitigation and adaptation, which constitute key dimensions in the fight against climate change.

3.2.1 Evolution of the concept of energy security

Energy security is a multifaceted, contextual and dynamic concept that evolves as circumstances change over time. Due to the growth of electricity consumption generated by alternative sources to oil, and the concern for the environment, the concept of energy security has become more complex and diffused. It has been referred to as an "abstract, elusive, vague, inherently difficult and blurred" concept (Chester, 2010, pg. 887). The reason for being "polysemic", "slippery" and "dynamic" arise from several issues that need to be considered (i.e. management risks, energy mix, some form of strategic intent, differences between energy markets and stakeholder's interest) and because the perception may change depending on the time frame analysed. The term has evolved alongside the transformation of the energy regime marked by "the growing dominance of fossil fuels, the liberalisation of energy markets, the development of nuclear energy, the escalating energy demands of developing nations, and the impacts of political instability and large-scale nature events" (Chester, 2010, pg. 889).

The 1970s marked a turning point in the history of energy security. Until then, each source (and its respective industry) represented its own independent economic area, even if they were sometimes interconnected. The concern, therefore, was centred on the "security of supply". From that time on, the political dimension of the concept of "energy" developed, which denotes the combination of the different industries and supply chains of the various sources (coal, oil, gas and, although not a source as such, electricity) (Patterson, 2008). The concern thus develops beyond the supply to become "energy security".

Churchill's decision to use oil instead of coal led to a debate that fits neatly into a modern understanding of energy security. Faced with growing doubts about the availability and reliability of oil supplies from sources other than Persia (now Iran), price volatility and market manipulation by a few companies, the answer of Churchill was frame under the motto of diversity: "On no one quality, on no one process, on no one country, on no one route and on no one field must we be dependent. Safety and certainty in oil lie in variety and variety alone" (Yergin, 1991, pg. 144). It is important to keep in mind Churchill's political and military role, which shows how the question of energy security (still focused on the security of supply) was considered as a military and national security issue. This approach remained dominant until the oil crisis of 1973, which highlighted the dependence of industrialised countries and the importance that energy had acquired in economic and social life (Cherp and Jewell, 2011). In response, the IEA was created in 1974, support was given to the development of new non-OPEC controlled oil and gas fields and to new technologies, and the use of alternative sources was promoted.

As for the concept at hand, the security of supply was expanded to include price fluctuations and their effects on the overall economy, as well as to accommodate the use of other energy sources. Thus, the security of supply became "energy security", defined as "the loss of economic welfare that may occur as a result of a change in the price or availability of energy" (Bohi and Toman, 1996, pg. 1). This definition responded to the vulnerability arising from not only dependency on imported energy but also from the privatisation and liberalisation of national energy markets. Energy security relied on well-functioning markets with their self-correcting nature as the main corresponding argument. But markets do not always function well and, in addition to their ability to reconcile supply and demand, they can be a source of insecurity due to its deregulation.

The question of the price can also be interpreted from individual consumption, i.e. energy poverty. Thus, Sovacool and Brown (2010) when describing the affordability dimension of energy security, referred to the price that the households must pay to access energy services, which must be of quality. If this price is too high, households with less economic resources will be limited in their capacity to access them or to invest in other areas that may allow them to improve their situation. In addition to this, Azzuni and Breyer (2018) introduced a political dimension to the price of energy: the use of subsidies. According to the author, subsidies for certain energy sources (such as fossil fuels) affect the choices and the options for energy sources since their price does not reflect the real cost. The absence of choice is a key aspect of the definition of energy poverty (see Section 3.4).

The environmental issue can be traced back to the 1960s and 1970s, but while resource scarcity was a key concern in the early discourses on the environment (*ecological security*) and the implications of that scarcity for state security (*environmental security*) over the next two decades, from the late 1990s onwards, climate change and Anthropocene became the focus of discussions (*climate security*). "The relationship between energy and the environment that prevails today is almost the inverse of that which dominated previous work" (Mulligan, 2010, pg. 80). The two-way relationship (with positive and negative effects) between the environment and energy security is clear. Energy consumption has an effect on the environment (i.e. emissions or impacts on biodiversity) as well as extreme weather effects can impact the supply (i.e. power cuts or restricting the use of water for extraction and/or production) (Kester, 2016). Renewable sources are seen as a clear alternative for reducing emissions and preventing waste emissions however their intermittent nature raises issues such as storage or the need for conventional reserves (Moriarty and Honnery, 2016). Yet, this property "can be predicted, managed, and mitigated" (Sovacool, 2009). In terms of its effect on dependency, it can be reduced (if clean energy is produced in the country itself) or increased (if clean energy is imported) (Holley and Lecavalier, 2017). Climate change has been seen as a threat multiplier (Mazo, 2009; Luft et al., 2010), so it would seem obvious that it is included in the field of energy security, but not all authors share this view. Including climate change in the list of elements concerning energy security (i.e. diversification of sources, risks of interruption, energy import, physical security of infrastructures, spare capacity and emergency stocks, improvement of efficiency and conservation measures) could mean overlapping political objectives and delayed decision-making (Winzer, 2012; Luft et al., 2010). Also, the characteristics of climate change are more specific to public goods, requiring international action, while energy security is closer to the scope of private goods more specific to the national level (Luft et al., 2010).

Finally, the term energy security can refer to the whole energy system in its entirety. Energy security understood in this way would be characterised by the totality of energy (security of everything, everywhere and against everything) and its reflexivity (we are all potential sources of insecurity as energy actors) (Ciută, 2010). The aim is to protect the entire system infrastructure, but since this is impossible, the goal is to build a resilient system that can handle adverse disruptions with minimal impact. In addition, as the system does not function in isolation, threats or disruptions can come from any other element external to the energy system itself, but necessary for its functioning (e.g. transport or telecommunications) so it is imperative to ensure this as well (Kester, 2016).

This broadening of the range of issues encompassed by the concept of energy security represents the so-called re-securitisation process. Wherein, the focus has shifted from sustainability to energy security and the notion of which is used as a rationale for a variety of policies. These policies range from military action to massive intervention in energy markets to speed up or slow down the deployment of renewable energy or the reduction of CO_2 emissions (Valdés, 2018).

3.2.2 Evolution of the dimensions of energy security

An easier way to appreciate the evolution of the concept of energy security is to look at the different dimensions that have appeared in the literature over time. In this sense, the work by Chester (2010) provides a segregation of the different authors in three categories: 1) those focused on economic issues (the behaviour of markets); 2) those attempting to quantify (through different indicators) the risks of energy disruptions caused during the transit, storage and delivery of the sources; and 3) those who, in addition to the previous issues would introduce social aspects and environmental risks. The priority aspect of energy security varies and increases from one category to another, broadening the definition of the term in the process. From focusing on availability (category 1), the authors add adequacy of capacity (category 2), as well as affordability and sustainability (category 3).

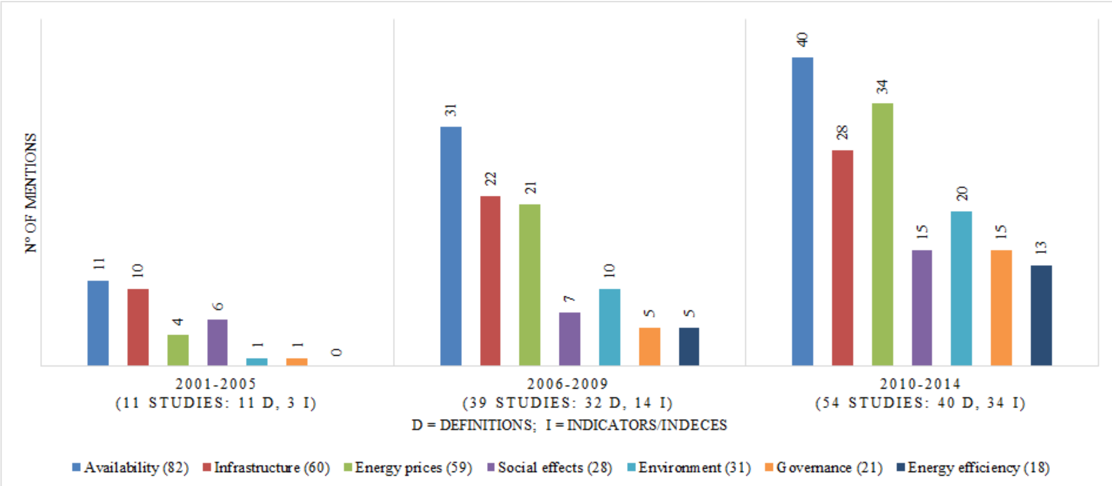
As such, based on research interviews, survey results, a specialist workshop and an extensive review of the literature, Sovacool and Mukherjee (2011) proposed that energy security should comprise five dimensions, which are divided into 20 parameters: 1) availability (security of supply and production, dependency, diversification); 2) affordability (price stability, access and equity, decentralization, affordability); 3) technology development and efficiency (innovation and research, safety and reliability, resilience and adaptive capacity, efficiency and energy intensity, investment and employment); 4) environmental and social sustainability (land use, water, climate change, pollution); and 5) regulation and governance (governance, trade and regional interconnectivity, competition and markets, knowledge and access to information).

Ang et al. (2015) analysed 104 studies on energy security conducted by different agencies from 2001 to June 2014. The majority (71%) were journal papers. The rest were reports from national agencies, international organisations, and professional associations. 83 studies provided specific definitions and 51 covered indicators and/or indices. Every study that provided a definition of energy security mentioned at least one dimension. Of the remaining studies, only one did it. They distinguished seven recurrent dimensions which relate to different aspects: 1) availability (diversity (of supply, spatial, of fuels, technology, transport route and supply pipelines) and geopolitics (wars, destabilised regimes, regional tensions)); 2) infrastructure (energy transformation, distribution and transmission facilities, investments, cyber-security risks and the availability of energy products on the market); 3) energy prices (affordability (absolute price level, price volatility, the degree of competition in energy markets)); 4) societal effects (energy poverty, acceptability); 5) sustainability and environment (carbon and other gas emissions, risks such as inundation of forests or oil leaks and spills); 6) governance (short and long-term policies, taxes and subsidies, energy diplomacy, information collection); and 7) energy efficiency (energy efficiency and energy intensity). An analysis of how many studies included a particular dimension illustrated the different relevance of each one. Not surprisingly, the most frequent were availability (82), infrastructure (60) and prices (59), as they are part of the traditional concept of energy security. In the rest, the environment was mentioned in 31 studies, societal effects in 28, governance in 21 and energy efficiency in 18. The authors also divided the time into three periods of four/five years each. As Figure 3.2 shows, this brought forth three important nuances: the relationship between dimensions and time; the increasing interest in energy security, revealed by the number of studies in each period; and the growing interest in quantitative studies through the use of indicators/indices.

More recently, Azzuni and Breyer (2018) studied 101[1] literature sources (i.e., peer-reviewed papers, scientific journals, and books) from 1970 to 2016. The definition of energy security should, according to the authors, refer to the three parts of the energy system —supply (the production of energy sources), demand (the consumption of energy services) and transfer from the production to consumption— and take

[1]The authors state 104 sources, however when reviewing the data given the number of unique sources is 101. The difference is due to two of the sources being linked to more than one definition.

Figure 3.2 – Dimensions of energy security by period (2001-2014)

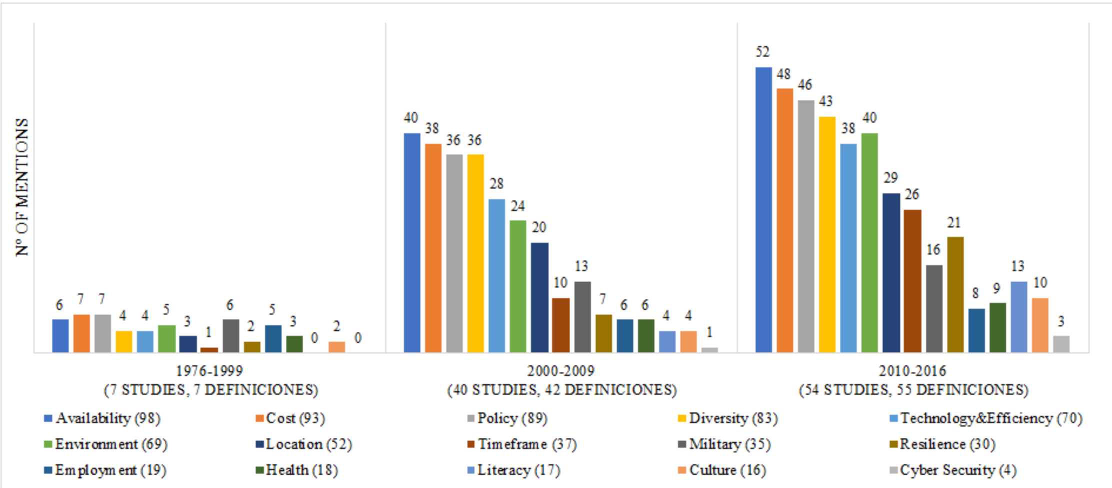


Source: Own elaboration

into consideration the concept of sustainability and the degree to which the system is unable to cope with events (i.e., threat, risk, vulnerability). Thus, the researchers excluded from study all literature that failed to provide an explicit definition, as well as definitions that were considered too restrictive or partial. The paper found 66 definitions, making obvious that some demonstrated a wider acceptance than others.

For the analysis, the authors observed the mention of the following 15 dimensions which comprises 50 parameters: 1) availability (i.e., existence of resources, existence of consumers, existence of means of transport (access)); 2) diversity (i.e., diversity of sources [suppliers], diversity of fuel (energy carriers), diversity of means (technologies, transportation), diversity of consumers); 3) cost (energy price (i.e., consumers, producers, pricing system/subsidies, energy poverty, peak oil, and stability/volatility), cost of disruption, cost of securing the system); 4) technology and efficiency (i.e., new technology advancement, energy system efficiency, energy intensity, energy conservation); 5) location (i.e., energy systems boundaries, location of energy source, density factor (centralised/decentralised), land use, globalization, population settlement and distribution, geography, industrial intensity); 6) time frame (i.e., timeline, length of the event, length of the effect); 7) resilience (i.e., adaptive capacity); 8) environment (i.e., exploration rate and resources' location, extraction and transportation methods, outcomes from energy use, impact resulting from environmental change, relationship to water); 9) health (i.e., impact of people's health on the energy system, impact of the energy system on health of (energy sector workers, consumers, and international society)); 10) culture (i.e., cultural effect on the energy system [production, connection, consumption, cultural acceptance (NIMBY, Not In My Back Yard)], energy conditions shaping cultural aspects); 11) literacy (i.e., information availability (quality, market information, public awareness, and structured educational program), information presentation and provision, usage of energy information); 12) employment (i.e., effect of energy security on unemployment rate, effect of employment rate on energy security); 13) policy (i.e., political system, democracy/dictatorship (nature, stability, citizen's will, and internal and external relationship), regulations (liberalised and controlled market, rules, and subsidies), governance (flowing the rules (transparency), following the rules selectively, not following the rules, corruption)); 14) military (i.e., energy use for military purposes, militarization, energy weapon, destabilization factor (resources curse, environmental deterioration, economies of violence)); and 15) cyber-security (i.e., cyberattacks, software use, IT skills).

Figure 3.3 – Dimensions of energy security by different periods (1970-2016)



Source: Own elaboration

Figure 3.3 illustrates the extent to which each appears in the studies divided into three periods: before the 21st century, 2000-2009, and 2010-2016; sorted by their total number of appearances. The three dimensions present in most of the literature, include availability (98), cost (93), and policy (89). Diversity (83) follows policy closely, sharing the number of appearances during the first decade of this century and proving its relevance to energy security. At the other end of the list are cybersecurity (4), culture (16), and literacy (17).

As Ang et al. (2015) before them, the authors note an increase in the number of researchers over time providing a definition, but also a change in the approach to the concept. From being simple and general, new parameters were specifically included and therefore necessitated a longer duration to finally return to a certain simplification through the use of more comprehensive terms but which refer to all specific parameters.

3.3 Climate change

According to the IPCC (2014), climate change refers to “a change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer”. This definition does not make a distinction between natural or anthropogenic causes unlike the one given by the Framework Convention on Climate Change (UNFCCC) (1992, art. 1): “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods”.

Climate change is the result of the excessive accumulation of greenhouse gases into the atmosphere. The importance of keeping adequate levels of these gases (see the main ones in Table 3.2) can be attributes to the atmosphere’s ability to capture and store part of the solar rays (ultraviolet rays) that the earth bounces into space as heat (infrared rays). This way, the temperature of the earth does not drop drastically (to freezing levels) during night hours and maintains an average temperature throughout the day which is needed for the optimum development of life, as we know it. A change in greenhouse gases’ concentration, either by excess (too much heat retained) or by default (not enough heat retained), would, therefore, have a direct consequence on the temperature of the planet and its habitability.

The carbon dioxide (CO_2) is the most abundant among the greenhouse gases. As explained by Martínez de Alegría et al. (2017c) this is the reason why greenhouse gas emissions are commonly referred to in terms of “carbon dioxide equivalent ($CO_{2\text{-eq}}$)”, which is the quantity of CO_2 that would have the same global warming potential (GWP) as the given mixture of well-mixed greenhouse gases. The GWP measures how much energy the emissions of one ton of one greenhouse gas will absorb over a given period (generally 100 years), relative to the emissions of 1-ton CO_2. Table 3.2 shows the different GWPs for the main greenhouse gases.

While variations in the climate have occurred before (e.g. glaciations) they never did at the current speed. “Human activities are estimated to have caused approximately 1.0 °C of global warming above pre-industrial levels, with a likely range of 0.8 °C to 1.2 °C. Global warming is *likely* to reach 1.5 °C between 2030 and 2052 if it continues to increase at the current rate. (*high confidence*)” (IPCC, 2019). And it is this speed that is putting the biosphere’s ability to adapt in check, having a direct

Table 3.2 – Global warming potential of key greenhouse gases

Type of greenhouse gas	GWP		
	20 years	**100 years**	**500 years**
Carbon dioxide (CO_2)	1	1	1
Methane (CH_4)	56	21	6.5
Nitrous oxide (N_2O)	280	310	170
Hydrofluorocarbons (HFCs)	460 to 9100	140 to 11700	42 to 9800
Perfluorocarbons (PFCs)	4400 to 6200	6500 to 9200	10000 to 14000
Sulfur Hexafluoride (SF_6)	16300	23900	34900

Source: UNFCCC (2016)

impact on vegetation, animal species and humans. Besides these, many argue that the political consequences can also include a rise in civil unrest and even war over access to natural resources as well as an increase of the disparity gap between the northern and southern regions of the world (Royer, 2016).

3.3.1 Climate change concept and interest

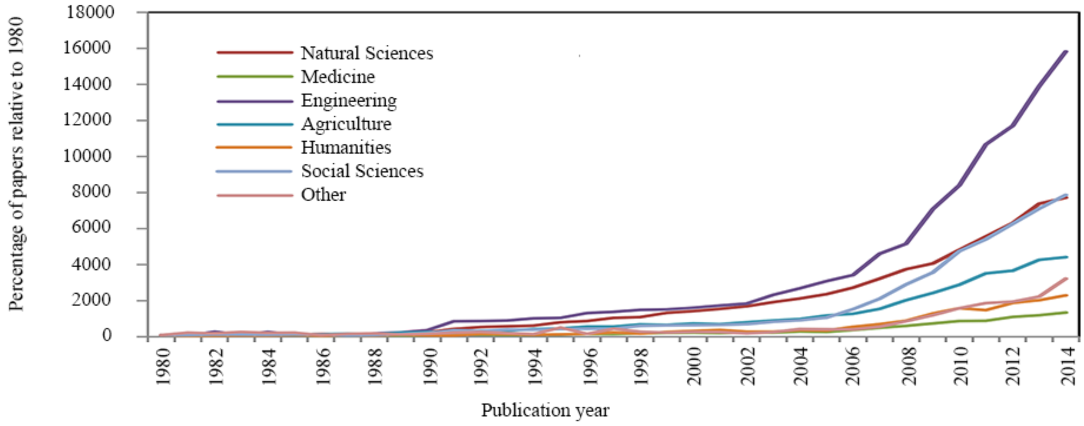
The scientific studies on climate change began in the late eighteenth century, when Professor Horace Bénédict de Saussure built his hot box, a kind of mini-greenhouse, hoping to find out why the Earth did not freeze in the night hours. This work led him to the conclusion that the atmosphere acted as a kind of "cover" preventing the exit of the heat and this was the origin of the concept of the "greenhouse effect". Furthermore, the French mathematician Joseph Fourier provided mathematical support to this surmise in 1820. Nearly two decades later, in 1837, the Swiss scientist Louis Agassiz, as a result of his studies about glaciers, established a truly revolutionary theory: the existence of an era, in terms of temperature, before the present. This constituted the origin of the concept of climate. The work of these scientists served as a basis for John Tyndal to establish the relationship between the two concepts, i.e. how the greenhouse effect could cause a change in the climate. After his death in 1894, the Swedish chemist Svante Arrhenius demonstrated that a decrease in CO_2 concentration by half would mean a decrease in temperature between 4 and 5 °C. Likewise, if the amount of this gas was doubled, the temperature could increase between 5 °C and 6 °C, which was considered beneficial to mankind, as a more benign climate in certain areas would improve agricultural production and facilitate conducive living conditions (Yergin, 2012).

During the following decades, industrialisation flourished and CO_2 emissions rose without anyone paying attention to its effect on the climate. Or almost nobody. Only an amateur but meticulous meteorologist, Guy Stewart Callendar, continued with the studies that showed “the positive” climate change. In fact, it was not until the middle of the 20th century that the implications of increasing greenhouse gas in the atmosphere took on a negative meaning thanks to the work of the International Geophysical Year (IGY) on weather, and that of Charles David Keeling (father of the curve that took its name) on measuring and predicting the concentration of CO_2 in the atmosphere. Keeling showed how in just half a century, the atmosphere had gone from having 315 parts per million of CO_2 to 394 parts per million. At that point, climate change garnered attention not only from the scientific and academic world but also from the political world.

Since then the interest in the issue of climate change has not stopped growing, as shown by the studies conducted by Haunschild et al. (2016) and Minx et al. (2017). Both studies tracked the number of publications on climate change as recorded on the Web of Science (WoS), a database that provides a wide range of peer-reviewed articles, books and conference proceedings across disciplines. Despite the likely differences in methodology (i.e. the terms used in the different search fields) as well as the time of analysis, both studies concluded that the literature on climate change has increased exponentially. Haunschild et al. (2016) studied articles and reviews only published between 1980 and 2014 and found that a total number of papers of 222,060 with a doubling every 5–6 years. The work of Minx et al. (2017) covered the period 1986 to 2016. At the beginning of the study, there were less than 1000 annual publications while in 2016 that number increased to more than 33,000, i.e. a total of about 273,000 publications over the whole period.

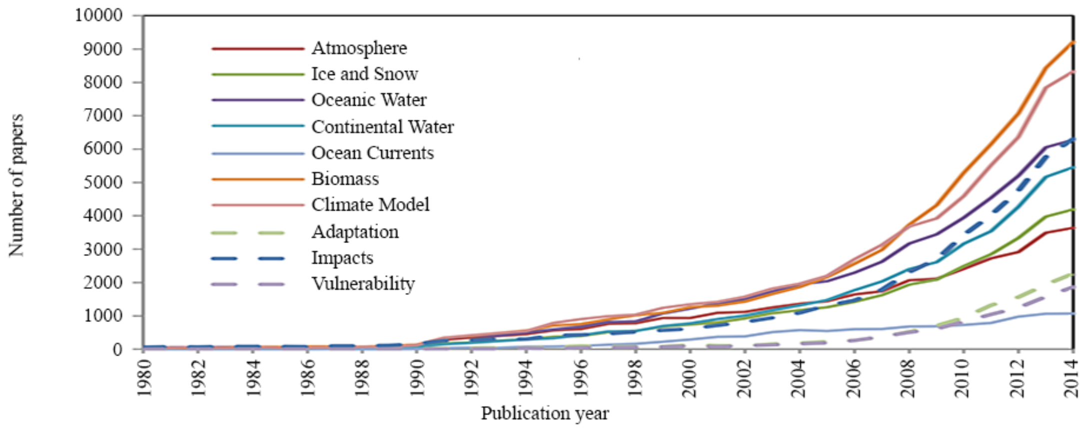
Both works also show the changes in different study disciplines, coinciding in the predominance of natural sciences and the “small” or recent interest of other areas such as social sciences. For example, the results of Minx et al. (2017) demonstrated that 66% of the publications corresponded to the area of natural sciences, 17% to engineering and technology, 11% to agricultural sciences, 7% to social sciences, 2% to medical and health sciences and 0.3% to humanities. However, Haunschild et al. (2016) noted that since around 2009 the relative increase of the natural sciences and the social sciences is almost identical (Figure 3.4). These authors went one step further and evidenced the evolution of the major topics of climate change research (Figure 3.5).

Figure 3.4 – Field-specific relative increase in climate change related papers published since 1980, based on the main OECD categories (the number of papers published in 1980 equals 100%)



Source: Haunschild et al. (2016)

Figure 3.5 – Time evolution of the papers of the major subfields within climate change research



Source: Haunschild et al. (2016)

3.3.2 Observed changes and future risks

Climate change is responsible for global warming, rising sea levels, intensifying tropical storms, reducing snow and ice, more intense and frequent extreme weather events, increasing and decreasing precipitation in high latitudes and the subtropics,respectively, as well as the appearance of changing microclimates that affect food production (Brown and Sovacool, 2011). According to IPCC (2014), between 1750 and 2011, cumulative anthropogenic CO_2 emissions to the atmosphere were 2040 +/- 310 $GtCO_2$ and about half of them have occurred in the last 40 years. Between 1880 and 2012, the globally averaged combined land and ocean surface temperature data show a warming around 0.85 °C. As for ocean warming, accounting for more than 90% of the energy accumulated in the climate system. For the period 1971-2010, the upper 75 m of the oceans warmed an average of 0.11 °C per decade, with a 26% increase in its acidification since the beginning of the industrial era. Also, averaged precipitation has increased since 1901; over the last three decades, the extent of Arctic sea ice decreased in the range of 3.5 to 4.1% per decade; and since the beginning of last century and until 2010, global mean sea-level rose by 0.19 m and it is very likely that, by the end of the 21st century, about 70% of the coastlines worldwide will have a sea level change within +/- 20% of the global mean. Moreover, the IPCC (2014) also warns about the effect of continued emission of greenhouse gases. Further warming and long-lasting changes in the climate system will occur as the future climate will depend on the past, as well as future anthropogenic emissions and natural climate variability. The most optimistic projections on the global mean surface for the period 2016-2035 relative to 1850-1900 point to an increase of 1.5 °C while the less optimistic show an increase higher than 2 °C. The warming will be faster in the Arctic region which will melt the sea ice and raise the global mean sea-level. Although the rise would not be even across regions, about 70% of the coastlines worldwide are expected to undergo a sea level change within +/- 20% of the global mean. Also, the frequency and the duration of heatwaves will increase while occasional cold winter extremes and changes in precipitation will continue to occur.

The changes and risks not only affect the climate system but also have a direct effect on human and natural systems. The risks associated with rising temperature include loss of ecosystems, biodiversity and ecosystem goods, functions and services; food and water insecurity due to the redistribution of marine species and marine biodiversity, the negative impact on the production of some grains and the reduction of water resources; and the exacerbation of health problems. Pollution and extreme weather issues will affect urban as well as rural areas; the economic growth will slow down making poverty reduction more difficult, increasing migration and amplifying the drivers of violent conflicts (IPCC, 2014).

But not every region will experience the same future. Climate-related hazards exacerbate other stressors derived from non-climatic factors and multidimensional inequalities generating negative outcomes, especially for people living in poverty. That is why, as highlighted by the IPCC (2014), climate policies must address sustainable development, equity and limitation of the effects of climate change in conjunction, and require collective action on a global scale. The atmosphere and greenhouse gases do not understand frontiers and the emissions by any agent affect the others. Correspondingly, actions to mitigate emissions must be coordinated at a high level irrespective of the congruent local benefits. For adaptation, although it focuses on local to national levels, can also benefit from international cooperation.

In the context of COP-21, the Parties to the Paris Agreement invited the IPCC to assess the effects of global warming of 1.5 °C above pre-industrial levels rather than using the 2 °C boundary and the related emissions pathways. As expected, the special report (IPCC, 2019) concluded that in this new scenario, the effects were found to be less severe than on the previous one. In terms of how to accomplish this, the first step is to reduce global anthropogenic net CO_2 emissions by about 45% from 2010 levels by 2030, reaching net-zero by about 2050. This implies 20% fewer emissions in 2030 and about 20 years less to reach the net-zero than in the 2 °C scenario. This requires rapid and far-reaching transitions in energy, land, urban and infrastructure systems (including transport and buildings) and industrial systems, entailing deep emission reductions in all sectors, a broad portfolio of mitigation options, and a significant increase in investments. All pathways project the use of carbon dioxide removal (CDR) but the report raised an alert that to achieve this new goal, global CO_2 emissions must begin to decline well before 2030.

This new scenario also represents a clear improvement in terms of the impact on sustainable development, poverty eradication and the reduction of inequalities. Although some trade-offs will have to be assumed, the IPCC envisages that these will be outweighed by the results of adaptation and mitigation measures, yet the net effect will depend on the pace and magnitude of change, the composition of the package and the management of the transition. Further investment in adaptation and mitigation measures, policy instruments, acceleration of technological innovation, and behavioural change is needed. There is also a need to strengthen the capacities of national and subnational authorities, civil society, the private sector, indigenous peoples and local communities to support climate action. International cooperation can provide an enabling environment as is a crucial catalyst for developing countries and vulnerable regions.

3.3.3 Emissions and economic growth

The fight against climate change while maintaining economic and social development requires a major shift in the production and use of energy (Moomaw et al., 2011). However, according to the data given by the IEA (2016e), in 2014, fossil fuels, whose combustion is the main source of all anthropogenic GHG emissions, provided 81% of the total primary energy. Most academics agree that economic growth (GDP) is the main factor leading to increasing CO_2 emissions and that energy intensity (energy consumption per unit of GDP) is the critical factor in reducing them (Chen et al., 2018).

The dynamic relationship between environment, energy, and economy has been expansively explored in research. Pao and Chen (2019) classified the studies into three strands: energy-output nexus, emissions-output nexus and the three elements nexus. Energy consumption represents different types of energy sources. The first nexus presents four hypotheses, namely neutrality (energy consumption is not correlated with GDP), conservation (energy conservation policies such as energy efficiency or mitigation has little or no adverse effect on economic growth), growth (energy consumption plays an important role in economic growth), and feedback (energy consumption and economic growth are interdependent with a clear impact on each other) (Payne, 2008; Ozturk, 2010). The second strand investigates if growth can be decoupled from GHG emissions as countries become more energy-efficient and technologically advanced using the Environmental Kuznets Curve (EKC) hypothesis. The third nexus examines the previous two nexuses under an integrated framework.

Knowing whether or not emissions can be decoupled from growth is a critical issue for climate change because a negative answer implies that reducing emissions would limit growth —a scenario not welcomed either by developed or emerging countries. On the contrary, decoupling implies that deep emission reductions are possible with little or no effect on growth (Deutch, 2017). It can be relative (*weak*, i.e., the economic growth rate is higher than the growth rate of energy consumption/environmental impacts) or absolute (*strong*, i.e., the relevant environmental pressure is stable or declining and the economic driving force increase strong). Correspondingly, research shows that the relative depletion means an improvement in efficiency but not a break of the link (Pao and Chen, 2019).

Cohen et al. (2018) used a simple trend/cycle decomposition to analyse decoupling in the 20 largest emitters in the world. Their results suggested that only the richest nations, particularly European countries, have made progress in decoupling. Also, countries with underlying policy frameworks that are more favourable to renewable energy and climate change mitigation activities tend to show greater decoupling.

Recently, Parrique et al. (2019) published a report reviewing the empirical and theoretical literature to evaluate the validity of the hypothesis that the decoupling of environmental pressures from the gross domestic product (GDP) could enable future economic growth without end. The results are clear. According to the authors, not only there is no empirical evidence to support the existence of such decoupling on a scale close to that required, but also, such decoupling seems unlikely to occur in the future. This means that decoupling on its own has not been and will not be enough, and as such, sufficient decoupling cannot be achieved only through increased efficiency without limiting economic production and consumption.

The starting premise of the study is that decoupling of economic growth from all critical environmental pressures (all the consequences an economy has on nature) must be absolute (emissions and growth evolve in opposite directions), permanent (for as long as the economy grows), global (since greenhouse gases are trans-boundary pollutants and climate change is a global phenomenon), just (shared but with differentiated responsibility the number of affluent countries must be large), and sufficiently fast (must be reached before irreversible damage thresholds are exceeded). Subsequently, the authors used these parameters to assess the empirical research using two sets of environmental variables: 1) resources (materials, energy, and water) and 2) impacts (greenhouse gases, land, water pollutants, and biodiversity loss). The work revealed a lack of solid evidence to support the theory of decoupling. The examples found were mostly of relative decoupling. In cases where decoupling was absolute, it demonstrated a temporary and/or local nature. They also identified several reasons to be sceptical about decoupling related to rising energy expenditures (costs of extraction for both energy sources and materials), rebound effects, problem shifting (efforts to solve one environmental problem can create new ones and/or exacerbate others), the underestimated impact of services, the limited potential of recycling in a growing economy, insufficient and inappropriate technological change, and cost-shifting (decoupling in one country cannot be achieved by increasing the environmental pressures in another one).

Despite these results, the authors still consider that the decoupling hypothesis is theoretically possible if resource productivity grows sufficiently fast to keep pace with GDP on a permanent and comprehensive basis. This could be achieved through measures such as increasing the geographical coverage of emission trading systems in combination with the phasing out of fossil fuel subsidies and directing investments towards sustainable infrastructure.

3.4 Energy poverty

Developing and undeveloped countries must fight energy poverty (WEC, 2010). As seen in Section 2.3, energy is essential for the development of multiple aspects of modern life. Beyond catering to the basic needs of "cooking" and "heating", energy is used in the sectors of education, health, social life (community), water purification, industry, transport. As such, inequality in energy supply and quality causes many social injustices.

Traditionally linked to impacts on health and quality of life, opportunities or sustainable development in developing countries and under the prism of affordability in developed ones, energy poverty is the issue of the energy trilemma most neglected

(González-Eguino, 2015). Or was so, at least until the launch of the Sustainable Energy for All initiative in 2012 aimed at focusing political attention and implementation capacity on this challenge (Bazilian et al., 2014). Gradually, it has become a widely recognised social challenge among the major academic, professional and policymaking circles (Bouzarovski et al., 2014).

As is the usual feature in the study of energy governance, in this case there is also no single definition of the concept of energy poverty. In addition to being a multifaceted concept (Moore, 2012; Bouzarovski and Petrova, 2015; Meyer et al., 2018), the issue of energy poverty has been studied from two different perspectives following the traditional North-South distinction, that is, developed and developing countries, providing two streams of definitions and terms (*fuel poverty* and *energy poverty*) depending on whether the stress is on price (affordability) or access (accessibility). Table 3.3 summarises the main elements of these two perspectives according to Bouzarovski and Petrova (2015).

Table 3.3 – Principal elements of 'energy poverty' and 'fuel poverty' frameworks in traditional understandings of the two concepts

Element	Fuel poverty	Energy poverty
Recognition	First mentions date back to the late 1970s and 1980s, principally referring to rising energy costs and 'the right to fuel' in countries like the UK. Later research allowed for a wider understanding of the problem.	Explicitly acknowledged in isolated documents during the early 1970s. Subsequent debates mainly focused on technological expansion. More recent research addresses participation and governance challenges.
Driving forces	High or rising energy prices vs. low household incomes. Inefficient housing, heating systems and appliance stocks.	Primarily low levels of electrification and other forms of networked energy provision due to economic underdevelopment and non-functional institutions.
Expression	Mainly inadequate heating in the home; importance of other services (particularly space cooling, lighting, appliances, IT) is increasingly recognised in recent years.	Lack of access to adequate facilities for cooking, lighting and electric appliances, but also other services such as space cooling and heating.
Consequences	Long and short-term mental and physical health, inadequate participation in society.	Detrimental impacts on health, gender inequality, education and economic development more generally.
Principal policies	Combination of income support, provision of energy at lower costs, and energy efficiency investment.	Support for transitions to 'modern' energy fuels, investment in power grid expansion or micro-scale renewables; income support.

Source: Bouzarovski and Petrova (2015)

Some authors, as noted by Li et al. (2014), have used the terms indistinctly, ignoring the possible conceptual differences derived from this north-south division even though their studies fall within it, while others prefer to find broad definitions that can integrate all the affected parties, overcoming this spatial difference, for example, considering energy poverty in terms of justice. Indeed, both also present some similarities (they focus on energy consumption in the residential sector and low income is the main feature) and tend to exacerbate poverty, damage health, undermine equity and hinder the proper development of society (Li et al., 2014).

3.4.1 Energy poverty as a matter of affordability

The energy poverty framework has been used to encapsulate the problems of the developed world at the nexus of energy efficiency and affordability (Bouzarovski et al., 2014). The problem of not being able to afford adequate warmth in the home was already a political issue in the UK in the early 80s, but the work of Boardman in 1991 establishing 10% of income as a baseline for assessing whether a household was in "fuel poverty" or not opened the door to scientific debate. Here the focus is on the difficulties of individuals and households to pay for energy (either because of low income or very high costs), thereby, impacting their access to certain energy services (mainly heating) and technologies to satisfy their basic energy needs (Huybrechs et al., 2011).

The definitions broaden as they consider more or fewer energy services, (e.g. heating, lighting, hot water, refrigeration, cooking, among others (Bouzarovski and Petrova, 2015; Castaño-Rosa et al., 2019)), whether technological appliances are included for their use and whether it considers only electricity and gas or includes other fuels. As well as, if the problem is seen as more or less dynamic in time (related to the concept of energy vulnerability (Bouzarovski and Petrova, 2015)) and/or multifaceted, i.e. that affects different people differently (Butler and Sherriff, 2017). The majority of the parameters used to define fuel poverty can be easily operationalised and measured using the indicators of expenditure, consumption, tariffs and income although there is much debate on how to compute this or identifying the most appropriate method. Furthermore, Papada and Kaliampakos (2018) highlighted two major weaknesses. Firstly, the vast majority of calculations are based on actual household energy consumption rather than on the necessitated data, leading to deceptive results. Second, while the parameters affecting fuel poverty are widely known, the relative impact of each of them on the overall problem has not yet been quantitatively determined.

Both energy needs and satisfaction are defined by a particular society, located in a territory, in a temporal context, and specific socio-cultural conditions. This leads to different approaches, with each country focusing on specific drivers, impacts and dynamics in accordance with national priorities (Meyer et al., 2018). The process of how the relevant actors establish the price of energy or support particular groups through measures such as indirect subsidies included in energy tariffs, fiscal or pricing measures targeting certain types of fuel or regulation or deregulation of the electricity markets, plays a powerful role in determining whether a household is likely to live in conditions of domestic energy deprivation. For example, Chester and Morris (2011) claimed that reform, i.e. liberalisation or deregulation, of the electricity sectors has resulted in higher prices, causing an increasing number of low-income and vulnerable households to spend a greater proportion of their disposable income on energy bills and to suffer deprivation and social exclusion as a result, and they refer to the EU as an example. The 2015 Energy Union strategy (COM/2015/080) (EC, 2015b) aims at building an energy union that delivers secure, sustainable, competitive, and affordable energy to all EU consumers (households and businesses). The strategy is based on genuine solidarity and trust between the Member States, and on having a single European voice on global energy issues. It intends to create an integrated energy system for the whole continent in which energy flows freely across borders, based on competition and the best possible use of resources, accompanied by effective regulation of energy markets at the EU level where necessary. In order to accomplish this strategy, the EU countries have carried out (as well as many other countries over the world) a restructuring of their electricity sectors. Chapter 6 shows the impact of this reform on industrial electricity prices, and the differential between industrial to household prices, in 15 European Union countries for the period 2003 to 2013.

3.4.2 Energy poverty as a matter of accessibility

The concept of energy poverty often refers to the problems of inadequate access to energy in developing countries, involving a range of economic, infrastructural, social equity, education and health concerns (Bouzarovski et al., 2014).

Although there is no single definition, access to modern energy is often understood as access to a minimum level of electricity and safer and more sustainable fuels and stoves for cooking and heating at the household level, as well as access to modern energy to enable productive economic activity and the provision of public services at the community level (IEA, 2020a) or as "the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe and environmentally benign energy services to support economic and human development" Reddy et al. (2000).

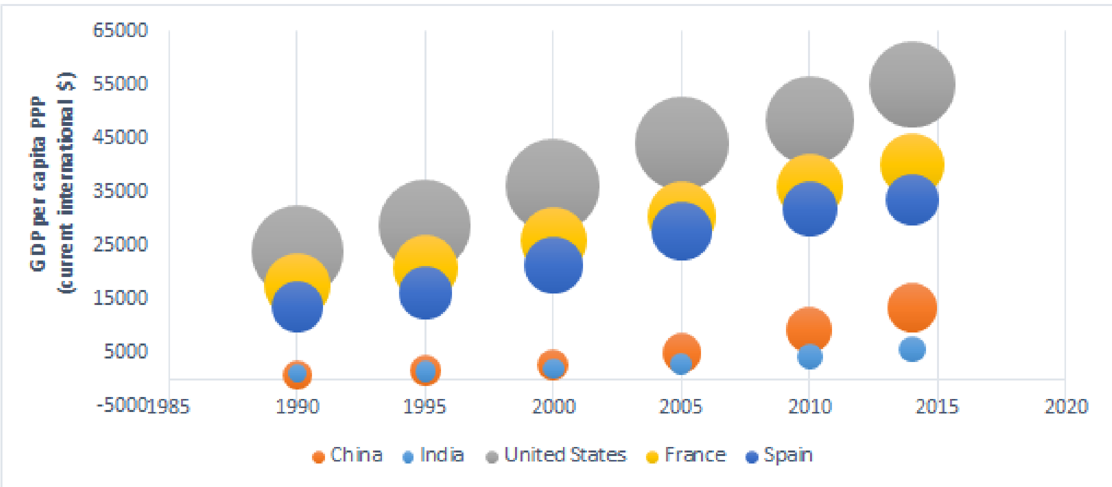
As evident in any field of research, definitions rarely convince everyone. Sankhyayan and Dasgupta (2019) drew attention to the definition of "access to" and the indiscriminate use of availability and accessibility even if the two terms do not convey the same meaning. While the former refers to the physical availability of energy carriers, accessibility refers to the final connection of the users to those energy carriers. And not always the former is accompanied by the latter. In India, for example, an area is considered to have electricity ("availability") if it has basic supply infrastructure, if at least 10% of households have "access" to electricity and if electricity is supplied to certain public places. Clearly, there is a distinct difference between the two terms and availability is not enough. Nor are there universally agreed definitions of "modern" or "sustainable" (Villavicencio Calzadilla and Mauger, 2018). Another weakness in this context is that the definitions seem imply that the expansion of the electricity network is a sufficient condition for providing certain energy services or minimum consumption to cover basic needs. Furthermore, there is no agreement of what these minimum needs are, being established arbitrarily and knowing that after having access, energy uses increase. This phenomenon is known as the "ambition gap", i.e. the difference between the amount of energy considered to be the minimum for the first connection and that actually required for uses involving an increase in productivity or human well-being, taking into account aspects such as availability, reliability, and quality. A further criticism is that it is difficult to measure energy poverty since an excess of one energy service cannot replace the defect of another, i.e., they cannot be converted into fungible units and simply added up (Culver, 2017).

Nevertheless, the complexity of Reddy's definition is also strongly supported. First, Reddy mentions *the absence of sufficient choice*. Access to energy services is essential for a decent quality of life; the lack of access leads to the severe exclusion or impoverishment issues. Development is more about not being excluded, and pertains to having choices that provide well-being than about the level of well-being itself (González-Eguino, 2015; Sovacool, 2015; Meyer et al., 2018). Second, the definition refers to *energy services*, i.e. what matters it is not the energy itself or its consumption but the end use (e.g. mobility, lighting, heating, cooking, cooling, etcetera). It implies, therefore, the use of fuels (PES) and the technologies that transform them (energy converters) (see Chapter 2, Section 2.3) (Bouzarovski et al., 2014). It could be said that it does not matter which source is used if it were not qualified by the following point. Third, the definition includes several desirable features of the technologies that provide these services. The technologies must be *adequate* (and accepted) in terms of geographical area, knowledge, and culture; *reliable* and *affordable* compared to alternatives; *safe*, i.e. that they do not pose a health risk; and*environmentally benign*, i.e. that they do not compromise the future of future generations. In this regard, the UN Secretary-General's Advisory Group on Energy and Climate emphasizes, in its discussion of how to eliminate energy poverty, that where feasible, priority should be given to the use of energy sources with low greenhouse gas emissions (United Nations Industrial Development Programme, 2010).

3.4.3 Focusing on energy services

Chapter 2, Section 2.4, has shown how the evolution of the energy system has been a leading companion in social and economic development. Most economic activity to date cannot be done without energy. Trade, manufacturing, distribution and transport of materials and products require reliable energy. In order to assess the economic and development situation of a country, macroeconomic indicators are often used, including energy and electricity consumption, as well as the number of cars and, more recently, CO_2 emissions per capita (González-Eguino, 2015). Figure 3.6 shows the per capita relationship between energy consumption (the size of the bubbles) and GDP between 1990 and 2014 for China, India, USA, France and Spain. In countries with the highest GDP, energy consumption is higher. Correspondingly, a rising trend in consumption as to GDP increases is also seen, yet a nuance can be made here. While this trend is shared by all countries until 2005, from that year onwards the trend continues in developing countries (China and India), whereas in developed countries (USA, France, and Spain) consumption appears to be stagnant or even slightly reduced, probably as a result of the economic crisis and the policies adopted to fight climate change.

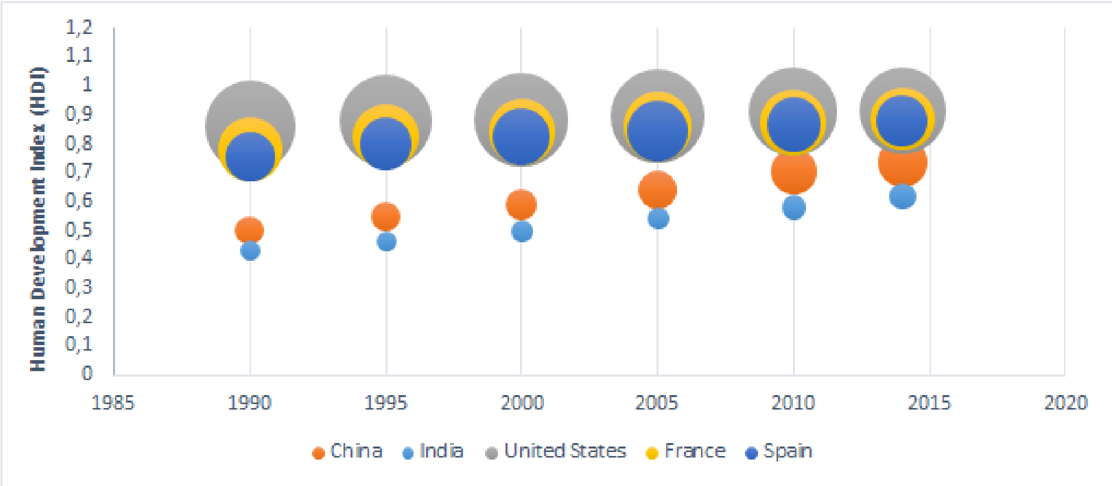
Figure 3.6 – Link between energy consumption and national income (per capita)



Source: Own elaboration with data from WB. The bubble size is set by the commercial energy use (Kilograms of Oil Equivalent)

Economic disparities lead to different levels of energy consumption. Not a single country in modern times has substantially reduced poverty without a massive increase in energy use (UNDP, 2005). A clear conclusion is, therefore, that energy plays a highly influential role in poverty alleviation through household income, health, ed-

Figure 3.7 – Link between energy consumption per capita and human development



Source: Own elaboration with data from WB. The bubble size is set by the commercial energy use (Kilograms of Oil Equivalent)

ucation, gender, environment and other economic and productive activities. Hence, energy is central to practically all aspects of sustainable development. However, its international coverage has proved to be very limited. Moreover, the topic of energy access has always been a sensitive one, as it is at the heart of all traction between sustainable and economic development, particularly in developing countries. It questions the possibility of economic and social growth with environmental sustainability, i.e. it raises the issue of decoupling. For some, as noted by Dubash and Florini (2011) the absence of a specific target among the Millennium Development Goals (MDGs) or an indicator to measure progress on the energy poverty-related MDGs was considered a clear manifestation of these tensions. In fact, the problem has been addressed as a national supply issue, mainly of electricity, to be solved by large engineering projects. For example, of the 54 national development strategies to achieve the MDGs presented at the World Summit in 2005, 93% opted to expand/develop the power grid while only 20% proposed modern fuels for cooking and heating or mechanical power for productive applications (Takada and Charles, 2007). Yet many authors have agreed on the need to overcome this approach claiming that the main asset is not energy itself but the access to energy services, which are vital for life and human development, both economic and human (Bhattacharyya, 2012; Pachauri and Cherp, 2011; Florini, 2010; Takada and Charles, 2007; Reddy et al., 2000).

"If there is one common thread that connects both developed and developing world countries with respect to the underconsumption of energy in the home, it is the pivotal role of 'energy services'" (Bouzarovski et al., 2014, pg. 5). As seen in

Chapter 2, Section 2.3, the energy services are produced by the different energy carriers, i.e. heat, fuels and electricity. The importance of electricity versus fuels varies according to disparate needs and the economic and social circumstances that enable their use (UNDP, 2005). Pachauri and Cherp (2011) highlighted that most households in developing countries barely use electricity for cooking, even when they have access to it, and as such, improving access to clean fuels is a big challenge, if not bigger.

Often there is a perverse link between the lack of access to modern and affordable energy services and poverty. Despite employing a considerable proportion of their income to obtain energy services, the poorest members of the population have access only to poor and inadequate energy services and this has a direct impact in areas such as welfare, health, gender and the environment (e.g. Table 3.4 lists their effects on the MDGs). Moreover, this disparity could also threaten modern notions of equity, justice and fairness (Sovacool, 2015; Meyer et al., 2018).

Table 3.4 – Effects of access to modern energy services on the MDGs

MDGs	Energy effects
Goal 1: Eradicate extreme poverty and hunger by reducing the proportion of people whose income is less than $1 a day	Household income increase through economic development and reduction of time-consuming domestic workload.
Goal 2 and 3: Achieve universal primary education and promote gender equality and empowerment of women	Free time to study and increase study hours; access to information and development of productive activities.
Goals 4, 5 and 6: Reduce child and maternal mortality and reduce diseases	Provision of clean water and reduction of malnutrition and emissions. In hospitals and clinics, refrigeration of vaccines, sterilization of operating rooms and medical supplies, and lighting at nightfall. Improvement of general living conditions.
Goal 7: Ensure environmental sustainability	Enhanced energy efficiency, introduction of modern technologies for energy production and use, replacement of polluting fuels with less polluting fuels and introduction of renewable energy.

Source: Own elaboration from UN-Energy (2005)

The inefficient combustion of energy sources in poor households leads to indoor air pollution which generates serious and widespread health impacts (Sagar, 2005; Florini, 2010; Meyer et al., 2018), such as respiratory and cardiovascular diseases and cases of lung cancer (González-Eguino, 2015), with women and children facing particular risk (Sagar, 2005). In cold climates, living in poorly equipped houses for a long-term i.e., with an unsatisfactory indoor temperature standard could increase rates of mortality (Li et al., 2014). Furthermore, the lack of electricity impacts several other areas. It prevents most industrial activities that improve social welfare since people demonstrate better affordability of health and other social services when they have better-paying jobs (Li et al., 2014). Interior lighting allows doctors to treat patients outside daylight hours, have advanced medical facilities to operate and the possibility to access various multimedia channels for information exchange. It also makes it easier for students to study outside daylight hours and reduces the risk of visual impairment as well as freeing them from time-consuming manual tasks which deprive them of study time. Furthermore, a high level of education could promote economic growth (Li et al., 2014; González-Eguino, 2015). Finally, it also affects the environment due, for example, to land use and deforestation resulting from increased land use for farmland for crops and livestock and illegal logging (González-Eguino, 2015).

In short, as Bazilian et al. (2014) stated, energy poverty poses at least three requirements to the actors and processes of energy governance: access, affordability, and quality. First, access imperatively needs to be understood as availability (physical sense) and connectivity to the energy services, which can require different technologies or fuels to be delivered. Second, access to energy means little if people cannot afford it. Third, the quality of services must be acceptable, including adequacy, reliability, and security. It must also take into account environmental sustainability.

3.5 Synergies, trade-offs and the diversity of resources

The fact that experts concerned with energy security have incorporated parameters specific to climate change and energy poverty into the definition is one of the best examples of the linkages between these three areas of concern. As it is also the deficit of single-issue, non-inclusive proposals. However, this approach of using energy security as a holistic framework cannot be deemed appropriate given the expansive and multimodal impacts of energy poverty and climate change issues. More specifically, the energy security would be prioritised over the other two, as it would entail the ultimate objective of the policies to be adopted, with the issues of energy poverty and climate change being subordinated and attenuated by the other security parameters. However, the interactions between the three areas can in fact be positive, i.e. improvements in one lead to improvements in another or the other two, though not necessarily. Notably, the areas can have opposite interests, and as such, it is not advisable to assume that one should predominate the others.

While synergies can lead to progress, trade-offs between energy objectives complicate governance. IEA (2007) reviewed the interactions between energy security and climate change mitigation policies in five OECD European countries (Czech Republic, France, Italy, Netherlands and UK). The results show the invalidity of the policies considered acceptable for reducing CO_2 emissions or improving energy security when viewed through the prism of the integrated energy policy framework. In most of the five countries, the trend for both CO_2 emissions and energy security have been worsening, although differences in fuel mixes and the organisation of the gas sector are leading to significant variations in the five countries. Indeed, this development highlights that policies aimed at addressing resource concentration concerns may have the most important consequences for climate change mitigation and vice versa: both policies are likely to affect fuel and associated technological options.

Dubash and Florini (2011) warned of the possible incompatibility between the security of energy supply and environmental sustainability in the short and medium-term, especially in situations demonstrating a dependence on fossil fuels as a primary source of energy. Likewise, pressures to limit greenhouse gas emissions may threaten the balance between development objectives and environmental sustainability, leading to an impasse on "burden-sharing" in the climate negotiations. However, the research also noted that these compensations are not immutable but the consequence of a dysfunctional system linked to the technological conditions of the moment, and therefore the situation would be different in a low-cost clean energy future. The research recommended trade-offs amendments, through, for example, rapid technological or institutional change or improved prioritising of objectives as possible solutions. Both require more robust international cooperation.

Gunningham (2013) used fossil fuel subsidies as an example of these stresses. Fossil fuel subsidies can help mitigate energy poverty and improve security by promoting the production of domestic resources. Yet, these subsidies often increase insecurity by consuming a high percentage of government expenditure and preventing infrastructure investment. Furthermore, the associated increased in fossil fuel consumption, not only can aggravate dependency but also result in harmful effects on the environment. In the author's words, subsidies "deliver only one of the three wider objectives of energy policy (an outcome that in terms of the trilemma, is 'win-lose-lose')" [pg. 188]. The author concluded that achieving complementarity between the three vertices of the energy trilemma requires a transformation of the energy sector towards a low-carbon economy, with renewable energy as the main source of electricity generation supported by energy efficiency initiatives and possibly by nuclear power, structured in a way that also alleviates energy poverty and ensures energy security. However, this can only be achieved through effective energy governance.

Ang et al. (2015) focused on energy security in order to identify certain common elements between this and the other two priorities of energy policy, that is, economic competitiveness and environmental sustainability. These include energy prices and infrastructure costs, as well as energy conservation, energy efficiency, and clean and low-carbon energy sources. While there are some potential synergies, these are definitely surrounded by certain conflicts. For example, the desire to use a polluting source, such as coal if the country has cheap deposits,and/or a renewable source that requires a large infrastructure because of its capital costs and possible environmental degradation. The research also referred to the potential problems generated by dependence on renewables as an alternative to traditional energy sources such as intermittency, high operating costs, or threats to water and food from biofuels. Finally, although the research considered that sustainability should be the general principle when evaluating objectives and energy policies, these should need to fulfil the prerequisite condition of having energy security.

Strambo et al. (2015) summarised some synergies and trade-offs concerning energy security and climate change in the EU framework. For example, as a positive interaction, reduced use of fossil fuels and overall energy demand through energy efficiency can lessen the import dependence while mitigating the global economic crisis effects. However, achieving energy security through bilateral gas imports can adversely affect the EU's climate, market integration and foreign policies. Also, some low-carbon strategies create new risks for energy security, such as the lack of stable base-load capacity due to the high penetration of variable wind and solar energy. Thus, the authors concluded that while there may be synergies between climate mitigation and energy security policies, there may also be political trade-offs and conflicting objectives. Similarly, after analysing the association between these two issues, Luft et al. (2010, pg. 43) stated that "[i]t is (…) incorrect to contend that we may be able to achieve both reductions in greenhouse gas emissions and improvement in energy security with one strike. In fact, too much emphasis on one could compromise the other".

Pachauri and Cherp (2011) argued how inadequate access forces the governments to build additional infrastructure and purchase fuels, an outcome that can be perceived as an additional burden on energy security. At the same time, the disruption of access to affordable energy can affect political and economic stability. Hence, both issues involve interrelated financial, economic, and regulatory arrangements and recall the conclusion of the World Energy Assessment that it is more cost-effective to address the issues of climate change, energy security and energy access simultaneously and in an integrated manner.

Ürge Vorsatz and Tirado Herrero (2012) explored the synergies and trade-offs between climate change and fuel poverty (although the authors referred to energy poverty), and as such, the main research conclusions related to developed and transition economies. In this context, the authors identified efficiency in equipment, buildings, and infrastructure as the best way to reduce both issues. On the flip side, carbon pricing would negatively affect climate change, as well as fuel poverty if the internalisation of the external costs of carbon emissions is not offset by efficiency gains. Other measures, such as energy price subsidies or social subsidies would have a positive effect on alleviating fuel poverty (although temporarily) but could increase emissions as these might encourage consumption and discourage efficiency. The research also suggested that only policies that address both objectives, perhaps with the inclusion of others, such as energy security, are likely to tilt the cost-benefit balance and provide sufficient political motivation to mobilize resources and commitments on a large scale.

For Heffron and McCauley (2017), the focus on low cost and efficient solutions (affordability) meant the continued use and development of fossil fuels as these remain cheap energy sources because the fuels do not pay for externalities, such as the long-term storage of the wastes of GHG or the damage already incurred because of the emissions. Also, these fuels receive some of the highest subsidies worldwide, which has rather acted as a deterrent to the development of a low carbon energy infrastructure or economy. On the other hand, Rinkinen and Shove (2019) stated that the decisions to pass the costs of ensuring more secure, lower-carbon supplies on to the consumer arguably represent a choice in favour of energy security and climate change at the expense of energy poverty.

All of the above arguments show the need for an integrated policy approach. Gielen et al. (2019) subscribe to the idea that it is technically possible to achieve better access to energy and energy security simultaneously while avoiding climate change. However, the research cites the urgency of including these global concerns in local and national policy priorities to generate integrated policies that identify cost-effective and win-win-win solutions across all objectives.

Renewable energy sources are avowed as the most efficient and effective way to deal with the energy trilemma sustainably (e.g. Villavicencio Calzadilla and Mauger (2018); Gielen et al. (2019)). Their critical role was acknowledged at the 2015 Conference of the Parties held in Paris (COP-21) and underpins Goal 7 of the 2030 Agenda for Sustainable Development (Samarakoon, 2019), which aspires to ensure access to affordable, reliable, sustainable and modern energy for all, by increasing substantially the share of renewable energy in the global energy mix (UNGA, 2015), although it does not specify what “substantially” means or how it should happen or what aspects should be considered when countries adopt renewable energy policies (Villavicencio Calzadilla and Mauger, 2018).

Villavicencio Calzadilla and Mauger (2018) offered a good summary of the benefits of the use of renewable energy in the three areas of the trilemma. The research inferred that renewable energy improves energy security by diversifying energy supply and reducing energy imports. It contributes to fighting climate change by promoting the efficient use of natural resources, protecting the environment through its low environmental impact, and counteracting the rapid growth of greenhouse gas emissions. Finally, it provides broader access to sustainable energy (including isolated off-grid areas) to meet basic human needs, which improves health conditions and living standards, creates employment opportunities, drives economic growth and helps meet the world's growing demand for energy (at a lower cost than fossil fuels). In addition, the research also reported some resultant problems from communities, indigenous people and the environment due to the development of large-scale infrastructures of renewable energy. For example, large-scale solar power plants can affect health as they generate waste and pollution from toxic materials (mainly in the manufacturing and end-of-life phases), as well as may cause the removal of vegetation for plant placement or road construction, and disruption of local hydrology, and pose a supply risk due to high water consumption, especially for concentrated solar power cooling systems. Furthermore, solar and wind technologies' impacts also pose threat to wildlife (especially birds and bats), noise (during construction, operation and demolition phases), and aesthetic issues. The research also identified other possible social concerns such as the effect of the transition to renewable energy on workers whose livelihoods depend on fossil fuel sectors and the impact of wind projects on the cultural heritage of local populations and indigenous people.

The authors framed their analysis under the concept of *energy justice* which has been defined as "the application of rights (both social and environmental) at each component part of the energy system" (McCauley, 2018, pg. 2) or as the fifth stage in the evolution of energy law, dealing with the issue of energy waste management and ensuring that the individual and the harmful effects from the energy sector are accounted for in all stages of the energy life-cycle. The four previous stages related to safe (focused around coal and the conditions endured by coal miners), energy security (the management of energy resources), economics (competition and market liberalisation) and energy infrastructure development (at all levels of the energy life-cycle) (Heffron and Talus, 2016b). Energy justice has several central tenets, namely distribution (fairness in the distribution of sources, both benefits and detriments, but also the responsibilities), procedural (all groups should be able to participate in decision-making in a non-discriminatory way) and recognition justice (individuals must be fairly represented, free from physical threats and with complete and equal political rights) (Heffron et al., 2015), to which have been added cosmopolitan (principles must apply universally to all human beings in all nations) and restorative justice (non-Western understandings of justice) (McCauley et al., 2019). It is also said to have eight core principles —availability, affordability, due process, transparency and accountability, sustainability, intra-generational equity, inter-generational equity, and responsibility— (Sovacool et al., 2016). Among the different authors who approached the energy trilemma from the perspective of energy justice (e.g. Heffron et al. (2015); Healy and Barry (2017); Heffron et al. (2018a); McCauley and Heffron (2018)), McCauley (2018) recommended the three key concepts of justice (i.e., distributional, recognition, and procedural) to the three areas of the energy trilemma. The paper concluded that energy security is inadequate as a conceptual framework for understanding energy in a low-carbon context due to the opportunities for "self-sufficiency" that modern renewable energy offers communities and which challenge the traditional logic of the concept, based on suppliers and consumers and the objective of securing a country's natural resources. In the area of energy poverty, the author recommended focusing on rights-based rhetoric rather than on liberal terms, i.e. to consider residents as end consumers. Under this logic, all individuals would have the right to "access" energy at every stage of the energy system, so affordability would become a secondary concern. About climate change, the research warned against thinking only in terms of renewable energy, despite the opportunities it offers and reminded that modern energy is not explicitly defined within UN terms as renewable. A shift in the energy mix towards low-carbon solutions must take place, but additional considerations such as waste management, infrastructural delivery, community displacement and health concerns must also be taken into account. The author advocated for a more decentralised and socially sensitive energy system, in line with the differentiated responsibilities, i.e. developed nations should adopt a radical aggressive policy towards reducing carbon-intensive activities and new emerging economies should commit to such reductions in the future as a trade-off for carbon emissions today, what implies that both high and low carbon energy systems will exist in tandem for quite some time as the transition may take some time.

If the transition ever happens. York and Bell (2019) suggested that a transition implies the creation of the necessary infrastructure and the expansion in the production of a new source of energy which at the end replaces the established sources (or significantly reduces their use). Neither in the previous cases (the so-called energy transitions) nor at present, this second aspect has occurred, so the authors preferred to use the term "energy addition". A review of the world energy consumption (Figure 2.3) from that perspective would prove them right. There was no replacement of established energy sources, but rather new energy sources were added on top of those already established. In fact, as the authors highlighted, the consumption of established sources continued to increase after the introduction of the new one. For all these reasons, the authors concluded that the historical pattern suggests that the simple promotion of renewable sources will not lead to a complete transition/suppression of fossil fuels.

Two clear conclusions can be drawn from all the above. The first reiterates that all three issues need to be addressed in an integrated manner.

The second is that the composition of the energy mix, i.e. its diversity, is key to all the strategies. The energy mix is crucial to determine aspects such as energy efficiency, energy intensity, energy security, and carbon intensity (Rubio-Varas and Muñoz-Delgado, 2019). Diversity extends the choice of energy sources (supply side) and energy use (demand side) and increases competition. In energy policy, it is often used as a key indicator for assessing energy security, financial risk, the efficiency of energy use, accessibility, the environment and how to catalyse innovation (Ranjan and Hughes, 2014; Lo, 2011; Cooke et al., 2013; Ghanadan and Koomey, 2005; Jansen et al., 2004; Kruyt et al., 2009; Stirling, 1994).

Therefore, the question that arises is why not use the diversity of the energy mix as a tool to measure the impact of substantial modification in its composition on the balance of the three dimensions of the trilemma? That is, not only to assess the impact on each of the dimensions considered in isolation but also the impact on each of them when the other two are taken into consideration. This implies a second question: how can this be done? Chapter 8 answers these questions with a case study applied to India between the years 1990-2014.

Part II

This section includes an English version of a book chapter (the original version is included as an Appendix) and an article published in:

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Article quoted 1 time in Google Scholar, and 1 time in Scopus and Mendeley.

Chapter 4

Energy security through diversification in OECD countries

4.1 Introduction

The International Energy Agency has served as a forum for the coordination of the energy policy of its Member States for over four decades, becoming one of the major actors in global energy governance. It was established in November 1974 within the context of the first oil crisis with a two-fold aim: to promote energy security among its Member States and to produce reliable information on how to provide secure, affordable and clean energy for both Member and non-Member States.

The Agreement on the International Energy Programme (IEP) not only highlighted the necessity to design an emergency system for immediate action in the event of a supply disruption but also to place the projects of the Member States in a broader time horizon with the aim of reducing oil dependence. Two documents —the Long-Term Co-operation Programme and the Group Objectives and the Principles for Energy Policy adopted in 1976 and 1977— further develop the content of this new field. Energy efficiency and energy savings, research and development, and diversification of sources have become increasingly important as the perception of short-term supply crises, like those of the 1970s, has receded.

The Agency does not lay out an identical pattern for all states. The specific circumstances of each state recommend adopting the energy mix that each one considers most appropriate (IEA, 2001). However, most of the efforts of the Agency focus on promoting alternatives to fossil fuels (mainly to oil) and on the development and use of carbon capture and storage technology to ensure a "fast" and smooth transition to a low-emission economy and a more secure, sustainable and cleaner energy future (IEA, 2009). Chapter III of the Long-term Cooperative Programme discloses the Member States' commitment to this strategy (IEA, 1976). They agreed to spur national programmes and cooperation measures.

This chapter is devoted to the IEA's strategy to promote diversification of sources and reduce dependence on oil imports, which is a common feature of most of its members[1]. We will argue how, in the early days, coal was considered as one of the most affordable alternatives to oil, although its popularity has faded as the environmental agenda evolved. Gas also gained weight in the energy structure of the Member States, due to lower emissions. But it was undoubtedly nuclear energy that contributed most to reducing the predominance of oil. Ultimately, although renewable energies were part of the diversification plans from the beginning, we will see how it would have to take more than a decade for them to gain weight among the energy options.

4.2 The alternative fossil fuels

The Principles for Energy Policy (IEA, 1977) identified the progressive replacement of oil in electricity generation as the general aim of energy diversification. This goal should be achieved through promoting the use and trade of coal, the development and promotion of natural gas (including the necessary infrastructure for its transportation) and by expanding nuclear generation capacity. Given the state of technological development, the IEA focused on energy R&D through several Implementation Agreements (IAs) on technologies for energy diversification. It also adopted collaborative projects and established a favourable climate for energy investments that would allow the flow of public and private capital to the sector.

4.2.1 Coal

When the IEA was founded, the coal sector represented the main alternative to oil due to tradition and experience. The Agency did not yet consider environmental issues, so coal outperformed other sources in terms of availability (it was present in consuming countries), ease of transport, and extensive experience in its usage. Thus, the Agency began to promote coal as the main fuel, both in power generation and in the industrial sector; to coordinate the development of production, export and consumption policies in its Member States; and to develop plans of action to anticipate the expected infrastructure bottlenecks.

[1]The IEA understands by alternative source all sources other than oil, including all other fossil sources (coal and natural gas will play a primary role) and nuclear energy. In the political debate on climate change, alternative sources often are identified with renewables and nuclear energy, i.e. alternative sources to all fossil fuels.

Meanwhile, the message that in the absence of adequate measures, oil availability at a reasonable price —as well as of other energy sources— would soon be insufficient had gained momentum. In May 1979, the Governing Board agreed on the Principles for IEA Action on Coal. Building on the Steam Coal Prospects to 2000 study and with a long-term perspective in mind, the Board urged governments to adopt the necessary policies to boost investment in this fuel. These should satisfy the individual needs of each state while ensuring the supply of others. They should also manage the environmental impact to acceptable levels of extraction, use and transport as well as reduce uncertainties for investors and markets. Owing to the diverse needs of individual states, the Agency stressed that action should be taken in a context of international cooperation and proposed itself as the best option (IEA, 1979a). That summer, the Coal Industry Advisory Board (CIAB) was created, which represents a varying number of companies of the coal sector with different characteristics from both Member and non-Member States (representatives are appointed for three years), and which functions as a consultation forum. In 1982, the Board set up the coal information system, which, since 1983, has evolved into the annual publication *Coal Information*, a worldwide benchmark publication.

However, environmental concerns, especially regarding CO_2 emissions into the atmosphere, question the convenience of using coal. At the 6th United Nations Framework Conference on Climate Change (COP-6) held in The Hague in November 2000, the CIAB shared its main concerns. its main concerns. It believed that governments lacked an understanding of the potential of coal to meet the world's energy needs. The CIAB also concerned about the exclusion of projects for the development of clean coal technology from the flexibility mechanisms of the Kyoto Protocol. It argued that not including them would have a negative impact on the progress of such projects and on greenhouse gas emissions. The CIAB urged both the Agency and the rest of the participants to consider coal not as the source of the problem, but as an integral part of the solution. Under these assumptions, it pointed out that as per Articles 6, 12 and 17 of the Protocol, no energy source should be excluded and recommended the adoption of different measures to control emissions effectively (CIAB, 2000). Years later, the rationale for the argument remains the same: the relevance of coal and the development of clean coal technology (CIAB, 2013). Converting coal into a clean energy source is also part of the objectives of the IAs.

Still, in 2013, almost half of the world's CO_2 emissions (46%) were due to carbon consumption (IEA, 2015a). The CIAB denounces the scarce and slow development of measures linked to the clean use of coal and disapproves the position of the governments who continue to deny the urgency of acting against CO_2 emissions and focus their policies on promoting a shift towards natural gas and renewables.

Nor does it share the public opposition to coal. It believes that this is the result of a misperception whereby the world's growing energy demand and climate change mitigation goals can be met while reducing its consumption. This social opposition prompts governments to implement measures that further delay the development of coal plants (CIAB, 2012). The Agency still supports the development of coal as an alternative source but coupled with measures to fight the effects of high levels of concentration of greenhouse gases and to ensure more efficient consumption (IEA, 2015e). The slow development and deployment of carbon capture and storage technology only highlight the need to intensify efforts in its implementation, especially if the challenge of limiting the increase in global temperature by 1.5°C set at the Paris summit is to be met (IEA, 2016e).

4.2.2 Natural gas

Using gas in electricity generation is of interest for several reasons. First, it is a very flexible energy source based on a safe and economically viable technology. Second, the time taken to build a natural gas plant is less than the time taken to build a nuclear plant, for example. Moreover, the plant's production is easily adaptable to current demand, which also makes gas an ideal companion to renewable energies. This status is strengthened by the fact that it releases fewer greenhouse gases than other fossil fuels, which increases its acceptability in the context of climate change mitigation.

Just like coal and nuclear energy, the IEA declares natural gas as an alternative energy source to oil in terms of usage, especially in electricity generation. In a few decades, natural gas has become an essential primary source. Both the IEP Agreement (IEA, 1974, art. 42) and the Long-term Co-operation Programme (LCP) (IEA, 1976) outline this process.

During its early years, the Agency showed modest interest in natural gas. The turning point came in 1979. That year, the Governing Board agreed on "the need to encourage both indigenous production and international trade in natural gas" as the most readily available alternative fuel (IEA, 1979b). However, the Agency knew that increasing its consumption meant expanding imports. There was a risk of shifting dependency from oil to natural gas. At the peak of the Cold War, there was concern about the dominant role of the former Soviet Union as a supplier of this primary energy source. Subsequent events will justify this concern. In 1990 and 1992, Moscow cut off supplies to the Baltic republics to influence the independence movement, and in retaliation for having to withdraw its troops from the region. In 1993 and 1994, Russia reduced its gas supply to Ukraine in order to obtain from the latter a greater control over the Black Sea fleet.

Supplier diversity was identified as a critical measure in the strategy to adopt in this state of need and concern. The Agency asked both governments and companies to include the security factor when assessing the total cost of supply and choosing a supplier. The security of gas was understood in market terms by the Agency (IEA, 2004). Also, there was a need to adopt protocols to deal with possible disruptions to ensure the supply of individual countries and to avoid reverting to the use of oil (IEA, 1985d) and returning to the starting point. In 2008, strategic emergency gas stocks were identified by the Agency as an inefficient and expensive instrument (Jakubowski et al., 2011). By 2011 they had become a valuable tool (IEA, 2011b). The only effective mechanism available as a group would be, according to some analysts, to adjust the oil emergency response (opening the reserves) to mitigate the adverse effects on a country's economy caused by a disruption in gas supply (Jakubowski et al., 2011). The Agency took on the role of supervisor and coordinator in case of need (IEA, 2011b).

As for the future of natural gas, the extent to which its consumption will increase depends on its accessibility and competitiveness against other sectors. In recent years its demand has increased in the regions with the greatest need for adjustment to reduce their high levels of CO_2 emissions but has fallen in other areas such as the European Union. Many factors raise doubts about the future of natural gas. First, a primary reason for the slowdown in global gas demand growth lies in electricity generation systems (IEA, 2016e). Prices are competitive but efficiency policies, competition with renewables (and in some places also with coal) and lack of investment limit their expansion. Second, while demand was slowing down, supply was increasing, which has undeniably affected the price, which impacts future investment (IEA, 2015e). Third, transport costs are also a constraint in countries without abundant reserves. If new LNG projects are to be promoted to avoid price volatility (as overcapacity seems to end in the next decade), the industry must reduce costs significantly.

Furthermore, although carbon intensity of gas is lower than that of other fossil fuels, which gives it some advantage in the transition to a decarbonised energy system, it is not small enough to take a leading role in meeting the 2 °C target. Not to mention the uncertainties associated with potential leaks of methane throughout the supply chain (IEA, 2016e). Nevertheless, although the commitments signed at the Paris Agreement will exceed this target, the role of gas has been strengthened — unlike coal and oil, whose relative weight has fallen sharply— becoming a major asset in the transition to more demanding climate scenarios. If the stated commitment levels persist over time, gas will be the principal source of energy in OECD countries by 2035.

Perhaps the greatest uncertainty about the future role of gas in the global energy mix comes from the development of unconventional gas. The sharp increase in exports —particularly shale gas— in the United States prompted the possibility of a "golden age". However, the opposition of some governments and part of the civil society to the exploitation of these resources due to the environmental and social risks that the extractive technology entails hinders the process. To solve this, the Agency developed in 2012 its so-called "Golden Rules", grouped into seven sections that cover aspects such as transparency, responsibility, technology or environmental commitment (IEA, 2013a). The adoption of these measures would entail an increase in investment costs, but would also have a direct impact on demand, as well as altering the commercial and geopolitical order of gas (IEA, 2013b). At present, unconventional gas accounts for around 60% of the growth of global gas supply, but its development outside North America remains unchecked.

In summary, the Agency's action in the gas area focuses on the collection and systematisation of data on gas markets, just as it does on oil markets. As for technological cooperation, this is mainly focused on reducing environmental impact. This is reflected in the Implementation Agreements on fossil fuels, which promote, among other measures, carbon capture and storage.

4.3 Nuclear energy

While most of the history of nuclear energy is focused on nuclear fission energy, research into nuclear fusion energy, more powerful and cleaner but very costly and currently at a primary stage of development, has been ongoing for several years.

4.3.1 Nuclear fission

When the International Energy Agency was founded, nuclear fission energy was considered, along with coal, one of the most promising alternatives to imported oil. By 1974, nuclear energy was already based on mature technology, excluding the issue of waste, and was well established in many of the OECD countries. Unlike gas, concern about supply was almost non-existent because of the abundant uranium reserves in member countries. There were, however, significant concerns about plant safety, nuclear waste storage and non-proliferation of nuclear weapons. Key aspects that have shaped this energy's development over the years.

As with other elements of the IEA's long-term energy policy, nuclear energy is first recognised and supported in the IEP Agreement, which incorporates all the above-mentioned concerns as well as the need both for the use of nuclear energy and for enhanced technological cooperation on uranium enrichment (IEA, 1974). One difference with other energy sources is the distribution of competences, as the IEA is not the only organisation responsible for nuclear energy linked to the OECD. While the IEA has focused on policy issues since the adoption of the Long-term Co-operation Programme in 1976, the Nuclear Energy Agency (NEA) manages the technical and technological aspects. The NEA was created in 1958 and all OECD countries are members, excluding New Zealand and Poland.

Regardless of the national differences on the use of nuclear energy (which persist), explicitly stated in the Conclusions of the 1977 Ministerial meeting (IEA, 1977), the Agency's Programme of Work in Nuclear Energy was launched in 1978 to assess the capacity of nuclear energy as a substitute for oil and to fulfil the general objectives of the IEA (IEA, 1978). Yet the two nuclear accidents at Three Mile Island (USA) in 1979 and Chernobyl (USSR) in 1986 were serious setbacks. Its potential, the negative consequences of not using it and the commitment to improve safety (Scott, 2004) did not stop doubts about safety, waste management and environmental pollution slowing down its development. Even so, the Agency did not cease its efforts. In the early 1990s, it re-emphasised the "substantial contribution" —real and potential— of nuclear energy to the overall energy supply of the Member States (IEA, 1985b), both in strengthening energy security and in reducing greenhouse gas emissions[2].

In response to a forecast of a continuing decline in nuclear generation, the Agency proposes in the "Medium-Term Strategy: 1997-2000" two objectives: one, to maintain its competence in nuclear energy matters but without interfering with or duplicating the responsibilities of the Nuclear Energy Agency or the International Atomic Energy Agency, and two, to assess the opportunities and consequences of the gradual phasing out of unwanted nuclear plants (Bamberger, 2004).

In December 1997, the OECD's High-Level Advisory Group, which focused on analysing the future of the Nuclear Energy Agency, submitted a report to the Agency's Governing Board in which it stressed the total affinity with the inclusion of nuclear energy in the range of possible tools for fighting climate change and achieving sustainable development. Although the Secretariat agreed with the report in principle, it made a couple of nuances, concerned about the scope of each Agency's competence: firstly, it highlighted the difference between "facts" and "policy" and how it was necessary to communicate the facts in order to achieve a social consensus before starting the debate on specific objectives and policies. This task of diffusion was the responsibility of the Nuclear Energy Agency and needed to be analysed in order to know its success or failure and why. Secondly, the nuclear policy could not be treated in

[2]This is a key argument, for instance, in the Technology Roadmap - Nuclear Energy (IEA, 2010).

isolation, but within the debate concerning the entire energy mix, so the competencies of both Agencies should not be altered. The Governing Board backed the idea that the IEA was the best forum for the debate on nuclear policy (Bamberger, 2004). Two years later, during the updating of the Medium-Term Strategy, this same body modified the objectives set out avoiding the recommendations that expressly related nuclear energy to the environment or the Kyoto protocols. It preferred a more ambiguous formulation, referring to "address nuclear energy issues, consistent with the IEA Shared Goals" (Bamberger, 2004, pg. 211).

But the momentum for nuclear energy arising from concerns about greenhouse gas emissions from the electricity sector, security of energy supply, as well as the need for affordable electricity supply with stable production costs was again tempered by the aftermath of the financial crisis (2008-2009), the subsequent economic crisis and the accident at the Fukushima Daiichi (PNP) nuclear power plant in March 2011. And while the situation is beginning to improve, the amount of nuclear energy used is still too low to meet the Paris Agreement's goal of keeping global temperature growth below two degrees Celsius. In 2014, total nuclear-generated electricity accounted for 11% with an installed capacity of 398 GW (IEA, 2016e). To achieve this goal, the installed capacity should be 930 GW by 2050 and represent 17% of global electricity generation (IEA, 2015d).

The Agency is committed to a technology which, although it does not require major technological innovations, does require continuous development to maintain its competitiveness, investments (mainly in the development of human resources), the implementation of waste storage and treatment processes in nuclear development programmes and the strengthening of international safety systems. And, of course, government and social support.

4.3.2 Nuclear fusion

Unlike nuclear fission technology, nuclear fusion technology is far from being fully developed, although it has a priori great potential as an inexhaustible, clean and safe energy source. It is practically inexhaustible because it uses hydrogen obtained from seawater and lithium. It is clean because it does not produce greenhouse gases or highly radioactive waste fuel. Furthermore, theoretical studies have shown that the fusion reactor is, in contrast to the traditional fission reactor, inherently safe, since any incident leads to immediate shut-down of the chain reaction (IEA, 2006a). The problem with nuclear fusion is mainly technological, and indirectly also economic, since research needs the construction of large test reactors, which requires high investment and a commitment of decades. The hope is that fusion energy will be commercially viable from 2050 onwards (although since its inception, the projected date has been postponed as it approaches).

The Fusion Power Coordinating Committee (FPCC) is responsible for overseeing the Implementation Agreements aimed at research and development concerning fusion energy and which are of direct relevance to the progress of projects such as ITER and beyond. The ITER international collaborative project involving China, the EU, India, Japan, Korea, Russia and the United States, consists of the construction of a nuclear fusion reactor based on Tokamak technology; an advanced technology with an operational life expectancy of twenty years. The beyond ITER agenda focuses on fusion power plants, economic development, the environment, safety and social aspects of fusion energy. The EU, the United States and Japan are the members of the IEA that fund virtually all fusion technology research globally (IEA, 2006a).

4.4 Renewables

Measuring the actual share of renewable energy in the energy mix of countries presents several statistical challenges and is therefore often under-represented in the reports (IEA, 2013c). Political uncertainties, economic challenges, reductions in incentives and other alternative energy sources adversely affect the necessary investments (IEA, 2013c). On the other hand, some countries and regions have difficulties in integrating renewables into their electricity grids. Despite this, the foundations for the development of renewables remain strong. Renewable energies are becoming more competitive, although they need a market and policies that are favourable to investment. Since 1990, renewables have experienced an average annual growth of 2.2% worldwide. In the case of the OECD, total primary energy consumption from renewable sources has increased at an average annual rate of 2.6%. On the other hand, there has been a slight decline in the share of renewables in electricity generation due to diversification in the end-use of renewables. Most of the growth in renewable energy has taken place in the residential, commercial, industrial and transport sectors (IEA, 2016c).

4.4.1 The development of renewables: a long journey

The search for alternative sources to oil, including renewables, has been on the Agency's agenda from the start. By the time new Implementation Agreements (IA) were signed in 1976 and 1978 focusing on the use of solar energy (in heating and cooling systems), hydrogen, bioenergy and wind energy, the technology related to first-generation renewables (hydropower, geothermal and biomass combustion) had been in use for decades. In 1982, the Working Group on Renewable Energy Technologies (or the Working Group on Renewable Energy as it will be known later) was created as part of CERT, which will become the Agency's voice on renewable energy technology both within and outside the organisation (IEA, 2006b).

The first significant boost to the use of renewable energy within the framework of the Agency occurred in 1985. At the ministerial meeting held in July of that year, the Governing Board recognised the importance of renewable energies in the energy balances of some Member States and stressed the importance of promoting research and development in order to reduce their cost and achieve their potential in the medium and long term (IEA, 1985a), while respecting the particularities of each Member State (IEA, 1985c). Over the years and with technological progress, renewables have become much more attractive as primary energy sources, primarily because of their environmental sustainability.

Despite the willingness of member countries to promote the use of renewables, in the "Medium-Term Strategy: 1997-2000" the Agency warned that state policies contained competitive and financial constraints, and therefore set two objectives. The first referred to furthering the Implementation Agreements to achieve diversification of sources and reduce greenhouse gas emissions. The second sought to transfer technology to developing countries. One year later, when preparing the update of the strategy for the years 1999 and 2002, the Agency modified the first of the objectives and eliminated the second. Promoting renewables now faced both environmental and energy security issues. It also stressed the need to stimulate markets through incentives (Bamberger, 2004).

In the late 1990s, the Working Group on Renewable Energy Technologies and the Secretariat established the Renewable Energy Unit based at the Paris headquarters. Its main objective was to stimulate the global technology market both for renewables and for the distribution of other alternative sources. At the end of the G-8 summit in Okinawa (2000), the Agency, the Working Group and the Unit, together with other actors, participated in the formation of a new G-8 Renewable Energy Working Group to provide a set of recommendations to be presented at the next summit (IEA, 2006b). The interest of the IEA was reasserted following its participation in the 2002 Johannesburg World Summit on Sustainable Development. Since that year, the Agency has produced the annual publication *Renewables Information*.

Alongside the various internal groups or sectors devoted exclusively to the field of renewables, the IEA has been systematically cooperating with industry through the Renewable Industry Advisory Board and with the International Renewable Energy Agency (IRENA) since its foundation in 2009 (IEA, 2016a). The IEA considers its work as complementary and non-competitive to that of IRENA. A fundamental difference between the two organisations lies in their core missions, which are themselves a consequence of their distinct origin. While the IEA was established as an oil consumer club with few member states, IRENA was born within the UN and includes 101 members and 59 other applicants[3]. For the IEA, renewables are an element of the energy mix that can serve to increase the energy security of its members and reduce energy poverty in developing countries. On the contrary, renewables are the focus of all IRENA's efforts. Based on a bilateral agreement of 2012, the main area of cooperation is statistics and data collection, but IRENA and its member states also participate in some Renewable Energy Implementation Agreements.

4.4.2 Principles for effective policies

In 2008, in support of the G-8 Gleneagles Plan, the Agency produced a report entitled *Deploying Renewables: Principles for Effective Policies*, which analyses the results of renewable energy policies adopted between 2000 and 2005 in the electricity, heating and transport sectors. For each sector, the status of different renewable technologies was analysed. In the electricity sector, these included wind, biomass, biogas, geothermal, solar photovoltaic and hydropower. In heat generation, heats from biomass, geothermal energy and solar thermal energy were evaluated. Finally, ethanol and biodiesel were used for the analysis of the transport sector.

Among the different possible methods that the Agency could have chosen to carry out the study, the organisation decided to use one that combines effectiveness and efficiency factors. Its "policy efficiency indicator" is calculated by dividing the amount of renewable energy generated in a given year by the additional amount that could be generated if the estimated mid-term potential were to be reached by 2020.

$$\frac{Incremental\ \ RE\ \ generation\ \ (year)}{Remaining\ \ midterm\ \ 'realisable\ \ potential'\ \ (by\ \ 2020)}$$

The realisable potential is calculated by adjusting the long-term technological potential with the constraints that are inevitable in the medium term, such as maximum market growth rates. The medium-term potential for each renewable energy technology would depend on the country's resources and technological development.

With this formula, the Agency wanted to minimize biases in comparing states of different size, the unequal status of renewable energy development and varying levels of policy ambition, taking into account available resources (IEA, 2008). An initial conclusion reached by the Agency is that only a limited number of the countries studied had implemented policies to support the development of renewable energies with effective results. The best scenario corresponded to wind energy. Eight of the

[3]See the list of countries at http://www.irena.org/Menu/Index.aspx?mnu=Cat&PriMenuID=46&CatID=67

thirty-five countries studied had succeeded in promoting this energy source during the years of the study (IEA, 2008).

For the Agency, the success of the policies adopted, according to its efficiency indicator, was based on the coexistence of three factors: the level of political ambition expressed in the objectives set; the presence of a well-designed system of incentives; and the ability to overcome non-economic barriers that could prevent the proper functioning of the markets. It is precisely the latter factor, in the Agency's view, that poses the greatest risk to policy effectiveness. Although ambitious objectives have been set and attractive incentives exist, some elements such as administrative difficulties, obstacles to network access, inadequate electricity market, lack of information and training and social opposition are elements that can increase investment risk, raise costs and even kill a project (IEA, 2008). An unstable policy and regulatory framework would also be affected. The EU's renewable energy directive includes measures to remove such barriers.

Regarding the incentive schemes, the Agency considered them as a compensation for the market failures related to the internationalisation of climate change and environmental externalities and recalled that such schemes should be transitional, justifiable only during the transition process towards a competitive market integrating fully the renewables[4]. The design of each system of incentives, although it varies according to the energy source and the time of application, should follow a downward pattern until they disappear. Furthermore, if the objective is their full participation in a free and competitive market, renewable energy producers should progressively assume the risks involved. This is why, according to the Agency and always with the future in mind, the most market-oriented mechanisms are the most adequate. The most appropriate approach, according to its conclusions, would be to establish a system combining different incentive policies depending on the state of development of the technology (IEA, 2008).

In 2011, the Agency updated the study and published *Deploying Renewables: Best and Future Policy Practices*. It included the analysis of recent years (up to 2009) and increased the number of countries studied to the 56 most representative of all regions of the world. During these five additional years, the situation of renewable energies had changed considerably. While the previous report offered a very limited development scenario, this new work highlights the rapid expansion of renewable energy sources, in some cases becoming profitable and competitive despite that non-economic barriers remained a restraint on development according to the Agency's analysis.

[4]The Agency's approach to incentives for renewables is market-driven. Other international institutions, such as the state aid allowed for renewables within the EU, focus on environmental protection.

A difference with the previous analysis is the use of three qualitative indicators to identify which was the best policy: the policy impact indicator (PII), the remuneration adequacy indicator (RAI) and the total cost indicator (TCI). The first, the PII, assessed a country's success in increasing renewable energy generation using the WEO 450 development projections for 2030 as a benchmark. The second indicator, the RAI, analysed whether renewable energy producers were adequately remunerated. The last indicator, the TCI, indicated the level of premiums to be paid in a given year based on the additional generation achieved. This indicator was established by taking the total wholesale value of the power generation as a point of comparison. The Agency also warns that this indicator may overestimate the total costs of a policy by not considering the merit-order-effect.

The analysis concluded that the differences in impact and cost-effectiveness between the different economic support systems were smaller than the differences between countries that had implemented the same system. What mattered was the entire policy package (IEA, 2011a).

The development of renewable energies consists of three steps: inception, take-off and consolidation. The greater or lesser success of the policies depends on the adherence to the principles that govern them. If in 2008 the Agency established five general principles, in 2011 it will establish some overarching principles to the three stages plus specific ones for each of them (see Table 4.1).

Policy priorities in the initial phase should be aimed at creating a stable investment and legislative framework that encourages the development of renewable technologies. In the take-off phase, it is market growth and cost management that should attract the attention of policymakers. Neither should they forget the need for certain flexibility to adapt to market and technology developments, such as the desirability of removing non-economic barriers. In the last phase, the challenges are related to the full integration of renewables in energy markets and their well-functioning, which may imply a redesign of the markets to reward the energy security that renewables offer and to assure their continuity IEA (2011a).

The development of renewables in the markets and the possible adjustments that these need to make in order to provide a secure and global supply of sustainable and clean energy became a priority area of study for the Agency. In 2012, it published the first issue of the *Medium-Term Renewables Market Report* series. That date became the first year in which total investment in renewables was negative, since 2009 when the first significant reduction in biofuels was noted. The Agency points to policy stability, technology development leading to lower risks and the entry of new players as key factors for future investment (IEA, 2013c).

Table 4.1 – Best practice policy principles

Overarching principles		
Provide a predictable and transparent RE policy framework, integrating RE policy into an overall energy strategy and focusing on technologies that will best meet policy needs in the short and long term. The targets must be ambitious but also credible. Take a dynamic approach to policy implementation. Tackle non-economic barriers comprehensively, streamlining processes and procedures as far as possible. Identify and address in advance overall system integration issues that may arise.		
Inception	**Take off**	**Consolidation**
Develop a clear roadmap. Provide a mixture of support. Ensure that the necessary regulatory framework is in place and streamlined. Supporting R&D.	Ensure a predictable support environment. Include adaptive capacity as a key factor in policies. Provide appropriate incentives. Maintain public acceptance.	Deal with integration issues and focus on enabling technologies. Ensure that the market can operate with the incorporation of renewables and to progressively phase out economic support. Focus on non-economic barriers and implementation.

Source: Own elaboration based on table from IEA (2011a)

The latest reports in 2015 (IEA, 2015c) and 2016 (IEA, 2016d), while confirming this point, suggest a more dynamic deployment of renewable technologies and a greater commitment by both developed and developing countries in the context of the Framework Conference on Climate Change in Paris (COP-21). Economic growth is becoming decoupled from emissions and governments are beginning to consider solutions that improve energy security, reduce local pollution and help mitigate the effects of climate change, even when fossil fuel prices are low. But meeting the agreed target of keeping global average temperature increases below 2 °C requires higher decarbonization rates and accelerated penetration of renewable energy in all sectors.

4.5 Conclusions

The Agreement that gave rise to the Agency is the result of the conviction of the signatory states that cooperation in the field of energy should be institutionalised given the failure of previous *ad hoc* collaborations. Voluntary systems and non-binding agreements had proved to be ineffective in guaranteeing the energy security of consumer countries.

A key strategy designed by the IEA to reduce oil dependence has focused on diversification of both suppliers (geographical diversification) and alternative sources, although no single action plan has been established. On the contrary, the Agency recognises the plurality of its Member States and leaves it to each of them to decide on the configuration of their energy mix. It does recognise, however, that the use of alternative sources to oil and of carbon capture and storage technology is necessary to ensure a smooth and relatively quick transition to a low-emission economy and a safer, more sustainable and cleaner energy future.

The Agency does not consider alternative sources to be limited to renewables. It also takes into account coal, gas and nuclear energy. Thus, the objectives set for the medium and long term are developed around two major groups of sources: non-renewable and renewable. Both groups have been present since the early years, although with different emphasis. If in 1977, the Principles for an Energy Policy already mentioned the promotion of coal, gas and nuclear energy as mechanisms to gradually replace oil, it was not until 1985 that the Agency gave a significant boost to the use of renewable energies.

From tradition and experience, it is not surprising that coal was the first source that the Agency looked to as an alternative. At a time when environmental issues were secondary, coal offered great advantages over other sources because of its availability, ease of transport and experience in its use. The Agency sought to involve the private sector and so in 1979 it set up the Coal Industry Advisory Board (CIAB), a body composed of a variable number of companies related to this sector in both member and non-member countries. Since then, they have produced reports and encouraged governments to adopt various measures to promote the use of this source, paying special attention, since the 1990s, to CO_2 emissions into the atmosphere to accommodate environmental requirements. However, the future of coal is increasingly uncertain.

The insecurity of depending on the USSR as the main gas supplier, especially during the Cold War, led to the development of this resource. The Agency promoted the exploitation of the fields held by the member countries, as well as their international trade. Natural gas represents the most advantageous non-renewable alternative source. It is a flexible, safe, economically viable source, easily adaptable to the needs of demand and with relatively low greenhouse gas emissions. All of this makes it an ideal companion for renewables and a clear alternative to oil. However, unlike what it did with oil and despite the request of some states, the Agency has always been reluctant to create a collective action mechanism to deal with emergencies. It favours relying on the well-working of the markets and therefore focuses its efforts on collecting and systematising data on the markets and supporting technological projects aimed at reducing environmental impact. Its future will depend on accessibility and competitiveness. Prices, efficiency policies, the development of other sources, investment and the degree of exploitation of non-conventional gas will shape its development.

Nuclear power does not raise the challenges of greenhouse gas emissions of coal or the problems of insecurity due to dependence on a gas supplier, so in the mid-1970s it represented one of the most promising alternatives to oil. However, concerns about plant safety, storage of nuclear waste and possible military use have conditioned its development. The IEA, acting within its competence in the field of nuclear energy, continues to be committed to this source of energy, supporting technological development and defending its potential, both in the field of energy security and in the fight against climate change. It also defends the need for governmental and social support.

In an international context marked by environmental issues, the technological development of renewables has become for many the only way to achieve success against climate change. However, competitive and financial restrictions on their development were commonplace in the energy policies of states. As a result, the number of countries that could credit some positive outcome to their support policies for renewables was very limited. For example, as the Agency pointed out, between 2000 and 2005, only eight countries out of the thirty-five analysed had succeeded in fostering wind energy. Over the next five years, renewables expanded rapidly, although still not without removing non-economic barriers to their development. As for gas, the Agency identifies a poorly functioning market as the greatest risk to the progress of these energies, yet it also recognises the danger posed by an unstable policy and regulatory framework. To overcome these difficulties, the Agency has developed a set of principles that should guide the design of energy policies and devotes part of its efforts to the study of renewable energy markets.

The Agency has always been committed to the diversity of sources. Each one is different, with advantages and disadvantages over the others. The correct development of all of them depends, according to the IEA, on the stability of policies, technological development and future investment.

Chapter 5

Dealing with climate change

5.1 Introduction

Energy and sustainable development are linked strongly by the relationship between energy extraction, processing, use and environmental quality. The emissions released from the provision of energy services (mainly from the combustion of fossil fuels) drive environmental changes, including climate change (Najam and Cleveland, 2003). About 40% of the emissions between 1750 and 2011 remain in the atmosphere, the rest is stored on land and in the ocean (causing ocean acidification). Even without more anthropogenic emissions, the impacts associated with global mean surface temperature change will continue for centuries (IPCC, 2014).

Climate change encompasses different climate-related effects, i.e. patterns of behaviour of the weather over time. “Climate change is widely recognised as posing a profound threat to humankind, which, if not successfully addressed, may have catastrophic consequences” (Gunningham, 2012, pg. 120). However, until recently, the only or principal effect considered was global warming, a rise in terrestrial temperature which was once considered as positive. Thus, climate change was considered as a dispensable element of the international agenda, kept in the area of environmental policy. At present, however, climate change is a major concern in both international and regional policy as well as in economic groups. For the period 2016-2035 relative to 1986-2005, the global mean surface temperature change will increase in the range of 1.5 °C to 2 °C (IPCC, 2014). Facing climate change implies significant changes in consumer behaviour worldwide. It also affects the preference of some sources over others (Shaffer, 2009). Decision-making requires the assessment of diverse values and the use of analytic methods of several disciplines, as the risks can be understood qualitatively and/or quantitatively.

The rest of the text is organised as follows. Section 5.2 features the main international regime of climate change, and Section 5.3 describes both the need (Section 5.3.1) and the main strategies used to limit emissions (Section 5.3.2).

5.2 The UNFCCC: the main international regimen of climate change

The United Nations Conference on the Human Environment (UNCHE), held in Stockholm, June 5-16, 1972, also known as the First Earth Summit, was a first taking stock of the global human impact on the environment bringing the 113 participant nations (and non-state actors) to discuss its future. Triggered by the scientific evidence of human-induced environmental degradation and a growing awareness of the environment, the aim of the conference was to turn this into a more global issue. However, the different interests between the North-countries and the South-countries, made this impossible at this stage (Najam and Cleveland, 2003). Nevertheless, the Stockholm Declaration and the Stockholm Action Plan (UN, 1972) contain policy goals and objectives that have become recurrent. Principle 5 of the Stockholm Declaration states the need to not deplete the non-renewables and to ensure that its benefits are shared by all. Principle 6 demands to halt emissions of harmful substances in quantities greater than the absorptive capacity of the atmosphere. Principle 21 proclaims that “States have the sovereign right to exploit their own resources pursuant to their own environmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction”. The rest of principles refer to economic, liability and cooperation aspects. Climate change was raised for the first time. The Action Plan, in its Recommendations 57 to 59, stressed the need for the “collection, measurement and analysis of data relating to the environmental effects of energy use and production”, including the emissions of greenhouse gas and other particulates and radioactivity. Nuclear energy, mainly the subject of atmospheric nuclear testing, was of great importance at the conference, although the interest was due to nuclear weapons and not to nuclear as an energy source (Najam and Cleveland, 2003).

In June 27-30, 1988, the World Meteorological Organization (WMO) convened the conference entitled “Changing atmosphere: implications for global security” in Toronto. The Conference Statement (WMO, 1989, Summary, pg. 292) compared the consequences of the pollution resulting “from human activities, inefficient and wasteful fossil fuel use and the effects of rapid population growth” with those from a global nuclear war. Participants predicted “potentially severe economic and social dislocation for present and future generations, which will worsen international tensions and increase risk of conflicts among and within nations”. They called for immediate international cooperation and action, as “no country can tackle this problem in isolation”. Although recognised the first steps done in developing international law and practices to address pollution, it highlighted the lack of a comprehensive international framework. The Action Plan for the Protection of the Atmosphere (WMO, 1989, pgs. 296-299) proposed, among other measures, "set energy policies to reduce the emissions of CO_2 and other trace gases", establishing an initial reduction of 20% of 1988 levels by 2005. As to how to reach this goal, 10% should come by improving energy efficiency and the other 10% by "(i) switching to lower CO_2 emitting fuels, (ii) reviewing strategies for implementing renewable energy especially advanced biomass conversion technologies; (iii) revisiting the nuclear power option". Developed countries should lead the way. It also appealed for the creation of a comprehensive global convention.

Two bodies were established that year with the aim of better understanding scientific studies and to initiate governmental discussions of responses and strategies: The Intergovernmental Panel on Climate Change (IPCC) by the WMO and the United Nations Environment Programme (UNEP). The IPCC regularly produces reports presenting the latest state of knowledge in climate change and its impacts. The First Assessment Report (IPCC, 1990) declared that the global mean surface air temperature had increased by 0.3 °C to 0.6 °C over the previous 100 years. The same year, an ad hoc group of government representatives were gathered by UNEP and the WMO to discuss how to establish an international convention on climate change.

1992 was a key year. During the twenty years that have been passed since Stockholm, the Cold War had disappeared, energy have become a major concern for economic security, and the environment issues and the climate change have broken through the global policy agenda (Najam and Cleveland, 2003). That year, the United Nations Conference on Environmental and Development (UNCED), known as the Earth Summit, was held at Rio de Janeiro, June 2-14. At this Conference two main acts occurred: the adoption of the notion of sustainable development (advocated 5 years earlier by the World Commission on Environment and Development (WCED)) and the creation of the United Nations Framework Convention on Climate Change (UNFCCC) (Roberts and Huq, 2015).

Energy production and use (mainly fossil fuel combustion) represent the largest source of anthropogenic emissions (IPCC, 1990). The most comprehensive of the Rio documents, the Agenda 21, called for decreasing energy consumption, increasing energy efficiency and developing cleaner energy sources. Thus, according to Najam and Cleveland (2003), it embraced the two dimensions of energy policy under which climate policy has been discussed: the environmental dimension (emanating from specific energy production and consumption choices), and the economic dimension (derived from the central role of energy in economic growth).

The UNFCCC, "the nearest thing we have to a global convention dealing directly with energy concerns" on the words of Najam and Cleveland (2003, pg. 128), entered into force in 1994 with the goal of stabilising greenhouse gas concentrations at a level that would allow ecosystems to adapt naturally to climate change. It divided the countries in two categories (Annex I Parties and non-Annex I Parties), reflecting the "common but differentiated responsibilities and capabilities" 112 art. 3.1 of each one. However, it did not formulate clear time frames and legally-binding objectives to achieve its goal. In fact, the adoption of a binging or a non-binding ("pledge and review") system was the main issue while negotiation the UNFCCC (Bodansky and Diringer, 2010). It is a treaty, therefore under the Vienna Convention on the Law of Treaties it is "legally-binding". However, Article 4.2 does not reflect a legal obligation but a non-binding aim (Bodansky, 2016). In 1995 took place the first Conference of the Parties[1] (COP-1) in Berlin which ended up with the Berlin Mandate, an agreement of the Parties open the period of negotiations until 1997. In December of that year the parties met in Kyoto (COP-3) and agreed to the Kyoto Protocol, the first international agreement with legally binding targets for developed countries.

Like the Convention, the Kyoto Protocol (UNFCCC, 1998) did establish specific emission limitation or reduction commitments (a quantitative goal) for each one of the 37 developed countries listed in Annex B to the Protocol, which range from -8% to +10%, but no requirements were set for developing countries. Three countries, Iceland (+10%), Australia (+8%) and Norway (+1%), have permission to increase their emissions. Another three countries, New Zealand, Russian Federation and Ukraine, could maintain their levels. The rest of countries committed to reduce their emissions by 6-8%. The aggregated intended result was to reduce "their overall [anthropogenic carbon dioxide equivalent emissions of the greenhouse gases] (...) by at least 5 per cent below 1990 levels in the commitment period 2008 to 2012" (Article 3). To help countries to cost-effectively meet their targets, it includes three flexibility mechanism: Emissions Trading (ET) designed to trade in emissions permits among Annex B nations (Article 17); Joint Implementation (JI) or a facility for crediting emissions reducing projects in other Annex B nations (Article 6); and Clean Development Mechanism (CDM) which allows generating credits towards the Kyoto targets for investing in projects in developing nations (Article 12). The profits from these mechanisms contribute to fund the Adaptation Fund to finance adaptation projects in developing countries.

[1] All states that are Parties to the Convention are represented at the Conference of the Parties (COP), which is the supreme decision-making body. The COP review the implementation of the Convention and any other legal instruments adopted and take decisions to promote it.

The Protocol was adopted but the negotiation on the implementation did not finish until the COP-7 (celebrated in Marrakech in November, 2001) after the United States withdrawal from the process which permitted negotiators to accept provisions previously rejected. It also helped to the agreement setting more moderated emissions targets for Japan, Canada, and Russia, and provision of access to unrestricted emissions trading (Babiker et al., 2002). The Marrakesh Accords (UNFCCC, 2002) established clear rules regarding methodologies and the accounting of the emissions related to Land use, land use, land-use change and forestry (LULUCF); a compliance mechanism to help countries to apply the Protocol's rules and to determine consequences if they did not accomplish their commitments; and the Adaptation Fund. The Kyoto Protocol finally entered into force on February 16, 2005.

The first commitment period of the Kyoto Protocol covered the period 2008-2012, so the same year that came into force, it was necessary to start negotiations for a second round of binding commitments, to apply after 2012. But the international map of the emissions had changed since the adoption of the Convention. Emerging economies were among the main emitters and some of the Annex I Parties to the Protocol were reluctant to accept new binding commitments without some form of parallel agreement engaging the United States and the major emerging economies. Negotiations started in Bali in 2007, where two negotiating tracks were set: one studied the long-term cooperative action under the UNFCCC (by the Ad Hoc Working Group on Long-Term Cooperative Action under the Convention (AWG-LCA)); the other considered further commitments under the Kyoto Protocol (by the Ad Hoc Working Group on Further Commitments for Annex I Parties under the Kyoto Protocol (AWG-KP)). Two years later, the Copenhagen Accord was agreed. It was a nonbinding agreement emerged from an ad hoc political negotiation (Bodansky and Diringer, 2010).

Climate change was gaining momentum in many arenas outside the UNFCCC, but negotiations within were struggled to make progress. The high hopes and expectations set at COP-15 held in Copenhagen in December 2009 were once again unmet. The disagreements and the non-cooperative ambience blocked the negotiations. During the final hours of the summit, a handful of state or Government leaders agreed to the Copenhagen Accord, which recognised the need to limit global temperature increase to 2 °C above pre-industrial levels. All countries, developed and developing, were expected to take different mitigation actions (stated in point 4 and point 5 of the Accord). It also reached some progresses on technology and finance, with the pledge of $100 billion in climate aid to developing countries (UNFCCC, 2009). However, this Accord was a non-binding one and it did not include a mechanism for international cooperation. Also, the countries that had not participated and felt excluded, blocked the consensus necessary to give the Accord the official status, and it was only noted (Werksman and Herbertson, 2010). Many of the implementations had to be renegotiated at the next COP-16 held in Cancun in 2010. The Cancun Agreements (Decision 1/CP.16 and Decision 1/CMP.6) includes decisions under both negotiating tracks established in Bali. It also made progress on mitigation, adaptation, financing, technology and reducing emissions from deforestation and forest degradation in developing countries (REDD+) in developing countries. These, too, were not legally binding (Liu, 2011). This COP served to recover trust in the Convention.

One year before the end of the first commitment period of the Kyoto protocol, Parties, gathered in Durban, agreed to the "Durban Platform for Enhanced Action (ADP)", a platform launched to develop "a protocol, another legal instrument or an agreed outcome with legal force under the Convention applicable to all Parties" (UNFCCC, 2012, Decision 1/CP.17, pt. 2) to define the post-2020 regime. They also agreed to extend the Kyoto Protocol until 2020. Although this was formalised the following year in Doha (COP-18, November 2012), in December 2016 only about half of the countries required have ratified it, so it has not entered into force yet. Also in Doha, the timeline to negotiate a universal agreement by 2015 was established. And in Warsaw (COP-19, November 2013), countries were encouraged to submit their Intended Nationally Determined Contributions (INDC), informing their individual emissions reduction targets and a key element of the expected COP-21 (Paris, November 2015).

The outcome of the COP-21, the Paris Agreement (UNFCCC, 2015) reflects the ambition of all countries to "(hold) the increase in the global average temperature to well below 2 °C above pre-industrial levels and (to pursue) efforts to limit the temperature increase to 1.5 °C" (art. 2.1a) by "(reaching) global peaking of greenhouse gas emissions as soon as possible" and by "(balancing) between the anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty" (art. 4.1). This is, for some authors, the principal message which announce the end of the age of fossil fuels. Still, the contributions submitted, even if fully implemented, are not enough to accomplish this goal (Obergassel et al., 2016). Most key countries are not willing to undergo all the reforms needed. In 2009, the G-20 to put progressively an end to inefficient fossil fuel subsidies, still, it is estimated that in 2013 the production of fossil fuels received almost four times the number of subsidies received by renewables (Bast et al., 2015).

Although the Paris Agreement is a treaty (dependent on the UNFCCC) under international law, the formula adopted to avoid to be submitted to the Senate of United State for ratification, had, according to Obergassel et al. (2016), two prices to pay.

First, it is not a legal form supported by specific provisions of the Convention. Second, States are not bound to comply with emission reduction obligations or financing activities. Yet, they must communicate new national contributions every five years. This lack of legal bindingness may be a concern to whom see the legally binding character as a superior signal of commitment and assurance of compliance, however, it is seen by other as an advantage. Bodansky (2016) hints that transparency, accountability and precision could persuade a greater number of States to participate as well as to make more ambitions commitments, increasing, therefore, its effectiveness. The next years will show the correctness of this approach. Nevertheless, the Paris Agreement is accompanied by a "rulebook" which detailed rules and procedures for implementing the Agreement. Adopted at COP-24 in Katowice, Poland (2018), the Paris Rulebook addresses questions on how to prepare NDCs and country reports on the implementation of national objectives and on future reviews. However, the “book” is unfinished. Today still there is no agreement on the rules for markets and emissions trading and other forms of international cooperation, as set out in Article 6 of the Paris Agreement.

5.3 Limiting emissions

Without additional efforts, the changes and risks described above would become irreversible. To avoid this future, global net emissions of CO_2 would have to decrease drastically while we adapt to the new situation in order to secure and maintain our well-being as well as ecosystem goods, functions and services. Delaying mitigation and adaptation responses only makes the situation worse.

There are two main and complementary strategies for reducing and managing the changes and risks of climate change: adaptation and mitigation. The IPCC (2014) defines adaptation as “the process of adjustment to actual or expected climate and its effects in order to either lessen or avoid harm or exploit beneficial opportunities”. Meanwhile, mitigation is “the process of reducing emissions or enhancing sinks of greenhouse gases, so as to limit future climate change”. As the main source of greenhouse gas emissions is the combustion on fossil fuels, we will focus on mitigation.

5.3.1 The need for mitigation policies

Greenhouse gas (except for chlorofluorocarbons) are not the result of human invention, however, human action is key on their concentration levels in the atmosphere and, therefore, on the speed of climate change. Along with industrial development came a strong increase in energy consumption, especially of fossil fuels, which favours economic and social development, which drives energy consumption, thus closing a vicious circle that feeds itself. Anthropogenic greenhouse gas emissions increased by more than 80% between 1970 and 2010 (IPCC, 2014) and if the trend continues, that percentage will be around 130% by 2040 (Sovacool, 2011a).

According to the IPCC (2014), in 2010 nearly 35% of greenhouse gas emissions were released in the energy supply sector (electricity and heat, (25%); other energy sector (9,6%)), followed by agriculture, forestry and other land uses (AFOLU) (24%), industry (21%), transport (14%) and buildings (6,4%). Patterns of greenhouse gas emissions are shifting along with changes in the world economy, being the energy supply and industry sectors where emissions have increased the most, which highlights the importance of choosing the right energy mix. This idea is easily perceived when exploring the IEA's projections on CO_2 emissions in its three scenarios (Current, New Policies (NP) and 450)[2]. Table 5.1 shows: a) the % of increase of the total consumption; b) the % of increase (or decrease) of the consumption by source; c) the % of increase (or decrease) in total emissions; and d) the % of increase (or decrease) in the emissions by sources. The year base is 2014.

Table 5.1 – World's growth rates (2040-2014)

	2014	**2040**		
		Current	**NP**	**450**
		Primary energy demand		
Total	(13684 Mtoe)	(19636 Mtoe)	(17866 Mtoe)	(14878 Mtoe)
		44%	31%	9%
Coal	3926	36%	5%	-49%
Oil	4266	27%	12%	-22%
Natural gas	2893	63%	49%	14%
Nuclear	662	56%	78%	140%
Renewables	1937	63%	78%	141%
		CO_2 emissions		
Total	(32175 Mt)	(43698 Mt)	(36290 Mt)	(18427 Mt)
		36%	13%	-43%
Coal	14868	32%	1%	-71%
Oil	10955	26%	9%	-32%
Natural gas	6,351	62%	48%	3%

Source: Own creation with data from IEA (2016e)

[2] In the Current Policies Scenario, no new policies are implemented and the commitments of those already are sluggish. The New Policies Scenario takes into account the policies already in place and the aims and intentions announced, even if they have not been yet implemented. The 450 Scenario described an energy system consistent with the limit of the average global temperature increase in 2100 to 2 °C Celsius above pre-industrial levels.

To maintain warming below the limit of 2 °C relative to pre-industrial levels, the global anthropogenic greenhouse gas emissions should be reduced by 40 to 70% compared to 2010 by mid-century and be near zero level (or below) in 2100. Delaying additional measures will increase the challenges and the cost as it will require higher rates of emissions reductions; a much more rapid implementation of low-carbon energy (whose cost can increase substantially depending on the technology considered); and higher transitional and economic impacts. But the application of mitigation policy also has some risks, although not as severe of those from climate change. One aspect of concern is that it could have a negative impact on the revenues of major coal and oil exporters, however, the IPCC (2014) points to the availability of CCS as a way to reduce the adverse impact.

World economy is expected to grow, what will lead to a significant increase in gross domestic production associated with an increase in demand for energy services (Moomaw et al., 2011). Mitigation strategies can be cross-sectoral or focus on individual technologies and sectors. Although all have their value, due the interaction between sectors and, therefore, the intersections between mitigation measures and other societal goals, the first kind of strategies are more cost-effective. The main ones among these include decarbonization (i.e., reducing the carbon intensity) as well as improving efficiency and behavioural changes. All of them could reduce energy demand (improving primary energy intensity or the amount of energy used to generate one GPD unit) without compromising development. Reducing energy demand sooner than later provide more flexibility for reducing carbon intensity, reduce the risks linked to the supply-side and avoid lock-in to carbon-intensive infrastructures.

Decarbonization is faster in the electricity generation sector. In this sector, increasing the use of renewable and nuclear energy as well as the carbon capture and storage (CCS) technology and replacing coal-fired power plants with natural gas combined-cycle power plants or combined heat and power plants can substantially reduce emissions. In the transport sector, the challenges associated with energy storage and the relatively low energy density slow down switching to low-carbon fuels. Here, as well as in the building and industry sectors, mitigation measures include advances in technologies, changes in consumption patterns and the promotion of efficiency. Other mitigation options available in other economic sectors are reducing deforestation, forest degradation and forest fires; storing carbon in terrestrial systems; and providing bioenergy feedstocks (IPCC, 2014).

5.3.2 Main mitigation strategies adopted

International climate change cooperation can adopt distinct forms according to the degree of centralization and coordination, from international to sub-national.

The main mechanisms adopted cover market-based instruments and regulatory approaches. Market-based instruments include setting a carbon price (cap and trade systems and carbon taxes) and economic instruments in the form of subsidies (tax rebates or exemptions, grants, loans and credit lines) are seen as more efficient than regulatory approaches (such as energy efficiency standards) (Kosonen and Nicodème, 2009).

The UN (1992), in its Art. 3, listed a set of principles to guide international climate change policies. These include: “equity” and “common but differentiated responsibilities and respective capabilities” (3.1); “specific needs and special circumstances”, vulnerability and “disproportionate or abnormal burden” (3.2); precaution and cost-effective[ness] to ensure global benefits at the lowest cost, taking into account “different socio-economic contexts, be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and adaptation, and comprise all economic sectors” (3.3); “sustainable development” considering that “economic development is essential” (3.4); and cooperation preventing “arbitrary or unjustifiable discrimination or a disguised restriction on international trade” (3.5).

Those principles can also evaluate the different forms of international cooperation as it is done by the IPCC, which uses as criteria: environmental effectiveness, economic efficiency and cost-effectiveness, distributional considerations, and institutional feasibility. The environmental effectiveness shows the level of success in reducing the causes of impacts of climate change (reducing anthropogenic sources, removing greenhouse gases from the atmosphere or increasing resilience). Economic efficiency refers to the balance between social benefits and costs, while cost-effectiveness measures the environmental performance of a policy given at least cost. Distributional equity and fairness relate to burden and benefit sharing of the impacts of climate change and of mitigation actions themselves. The institutional feasibility relates to four sub-criteria: participation (number of parties, geographical coverage, share of total emissions covered); compliance of the parties; legitimacy of the regime; and flexibility of the mechanisms and/or institutions (Stavins et al., 2015).

According to UN data, reduction of aggregate greenhouse gas emissions in Annex I countries from 1990 to 2000 was larger than the aim implied in Article 4 of UNFCCC, however, much of it was due to factors not related to the measures adopted. The same occurred with the mitigations of the first commitment period of the Kyoto Protocol. The analysis of Stavins et al. (2015) shows how the absence of some Annex B parties (specially the United States, the largest emitter) and the lower than expected demand of Assigned Amount Units (AAUs) available from economies in transition limited its environmental effectiveness. With respect to cost-effectiveness and efficiency, depending on the estimates and assumptions adopted, some researchers have found the Protocol inefficient while others have found it cost-effective but insufficient (we offer a more detailed description of the tree market instruments in the next section). In terms of distributional equity and fairness, emphasise that economic situation and the level of emissions of some countries have changed since the Protocol was established, although the relation between inequality in income and inequalities in emissions persists. As for institutional feasibility, apart from the non-participation of important emitters such as the United States, underline that the high rate of ratification of the Kyoto Protocol (191 countries plus the EU) is likely due, in part, to the fact that non-Annex B countries do not have emissions-reduction commitments.

5.3.2.1 Carbon market mechanisms

Market-based approaches were integral to the design of the 1997 Kyoto Protocol. As explained by Martínez de Alegría et al. (2017a), the theory underlying emission permits was first stated in 1960 and applied to environmental problems one decade later (Brohé et al., 2009; Ellerman, 2005; Coase, 1960). The number and type of emission trading initiatives have changed over time, although there are two main categories: "Cap and Trade" systems and "Baseline and Credit" schemes (Martínez de Alegría et al., 2017a; Kossoy and Guigon, 2012; Brohé et al., 2009; Solomon, 1999).

Under the Cap and Trade systems, an emission reduction target or cap is set for a certain period. The total amount of the cap is split into emission permits (known as emission allowances), share by emitters (often are free but it can be also auctioned), each one permitting to emit one ton of emissions ($CO_{2\text{-eq}}$). After the period ends, the amount of emission permits obtained must be equivalent to the amount of greenhouse gas emitted by each emitter. However, sometimes an emitter can find himself with an excess or a default of allowances. In either case, he can turn to the carbon market to sell or buy them. The world's first large emissions trading system was the European Union Emission Trading Scheme (EU ETS), launched in 2005. It is organised in trading periods (or phases), each of one covering a different amount of years (2005-2007; 2008-12; 2013-2020; 2021-2030[3]). The second phase coincided with the first commitment period of the International Emissions Trading (IET) under the Kyoto Protocol (1998, Art. 17). The emission allowances are called European Union Allowances (EUAs) and Assigned Amount Units (AAUs) respectively. The main similarities and differences between the two systems, as well as the critical concern, are presented by Martínez de Alegría et al. (2017b). To meet their cap, the IET allows countries to transfer all type of the COP-approved units, which include, besides AAUs, Removal Units (RUs) (acquired through land use, land use change and

[3]In July 2015, the European Commission presented a legislative proposal for the revision of the EU emissions trading system (EU ETS) for the period after 2020.

forestry activities), Emission Reduction Units (ERUs) and Certified Emission Reductions (CERs) (both types obtained though projects explained below). According to Stavins et al. (2015), in theory, IET could have reduced abatements costs by as much as 50%, but its effectiveness was limited due to the same reasons which limited the environmental effectiveness of the Protocol.

Baseline and Credit schemes (also known as "project-based mechanisms") are based on the implementation of projects (or programs) aimed at preventing, reducing or capturing greenhouse gas from the atmosphere. It establishes an emission intensity for activities against a baseline and the reductions can generate emission permits (carbon credits), which can be traded (Martínez de Alegría et al., 2017a). Obvious examples are the two project mechanisms under the Kyoto Protocol, the Joint Implementation (JI) and the Clean Development Mechanism (CDM). Both allow an investor country to get emission credits (CERs and ERUs respectively) by investing in projects in a host country. They differ in that the former covers projects conducted in other Annex I countries while the latter involves projects in developing countries not included in Annex I, so the CERs transferred to Annex I countries represent a net increase of the total amount of Kyoto units (Shishlov and Bellassen, 2012).

The JI allows Annex B Parties to earn ERUs from an emission-reduction or emission removal project in another Annex B Party, what means that both partners have emission reduction commitments and the offsets are a zero-sum game for the atmosphere. The JI has a double purpose: first, reducing the emissions of host countries included in the Annex I; second, reducing the cost. JI is mainly intended for the private sector, although public can participate too. There are two different ways for a country to develop a JI project: if the host country satisfies all the eligibility criteria, the JI project can be developed under "Track 1", otherwise it would be under the so-called "Track 2", which resembles the CDM mechanism procedure and it is supervised by an international authority. The Kyoto Protocol (UNFCCC, 1998, art. 6) establishes as requisite for a JI project that "it must provide a reduction in emissions by sources, or an enhancement of removals by sinks, that is additional to what would otherwise have occurred". According to the UNEP DTU CDM/JI Pipeline Analysis and Database (2016), until 2012, nearly 864 ERUs were issued from the 761 JI projects. Table 5.2 shows the distribution of JI projects by different categories.

Considering that emissions of the buyers can increase in the same amount as the reductions of the host country, the global emissions should stay the same. However, the efficiency of the mechanism is at stake. A working paper of the Stockholm Environment Institute (Kollmuss and Schneider, 2015, pg. 5) affirms that "JI may have enabled global greenhouse gas emissions to be about 600 million tonnes of carbon dioxide equivalent ($tCO_{2\text{-eq}}$) higher" as host countries used their surplus AAUs to cover

Table 5.2 – JI and ERUs by category until 2012

Type	JI		ERUs (000)	
	projects	%	number	%
HFCs, PFCs & N2O reduction	67	9%	127925	15%
CH4 reduction & Cement & Coal mine/bed & Fugitive	306	40%	475362	55%
Renewables	139	18%	23291	3%
Energy efficiency	222	29%	207007	24%
Fuel switch	24	3%	24854	3%
Afforestation, Reforestation & Avoided deforestation	3	0.40%	5077	1%
Total	761	100%	863,516	100%

Source: Own elaborated with data from UNEP DTU CDM/JI Pipeline Analysis and Database (2016)

their ERUs without engaging in additional mitigation actions. Also, JI projects are not distributed among countries accordingly with the full potential as the rules applied to capture emission reductions achieved by these projects are usually stricter in countries without a surplus of emission units (Stavins et al., 2015).

Through the CDM, Annex B Parties can buy and use CER credits earned by emission-reduction (or emission removal) projects in developing countries (UNFCCC, 1998, art. 12). The CDM is also meant to contribute to sustainable development of the host country. It saw rapid growth, although with uneven geographical distribution. The vast majority of the projects are implemented in China, India, South Korea, Brazil and Mexico because of their high levels of emissions, strong institutional capacity and favourable investment climate, all very attractive characteristics (Shishlov and Bellassen, 2012). India used these and other market mechanisms in some 3,000 projects (40% registered with the UNFCCC) representing an investment of more than 1.6 trillion NIR and generating over 170 million CERs (GIZ, 2014). According to the UNEP DTU CDM/JI Pipeline Analysis and Database (2016), until 2012, nearly 1.5 billion CERs were issued from over 8000 projects. Table 5.3 shows the distribution of JI projects by different categories.

The CMD has raised criticism regarding economic efficiency, environmental integrity and contribution to sustainable development (Shishlov and Bellassen, 2012). Other authors, as summarise by Martínez de Alegría et al. (2017b), are concerned by the methodology (the approval of no additional projects and simplification), the coverage of forestry and forest-related projects (the impermanence of forests and leakage to other regions) and the sustainability of the projects (lack of guarantees). Meanwhile, Stavins et al. (2015) underline the main issues according to the evaluation

Table 5.3 – CDM and CERs by category until 2012

Type	CDM		CERs (000)	
	projects	%	number	%
HFCs, PFCs & N2O reduction	143	2%	775937	53%
CH4 reduction & Cement & Coal mine/bed & Fugitive	1250	15%	158593	11%
Renewables	5777	71%	397827	27%
Energy efficiency	749	9%	81150	5%
Fuel switch	128	2%	51716	4%
Afforestation, Reforestation & Avoided deforestation	58	1%	11319	1%
Total	8105	100%	1476543	100%

Source: Own elaborated with data from UNEP DTU CDM/JI Pipeline Analysis and Database (2016)

criteria of environmental effectiveness, cost-effectiveness, distributional considerations, and institutional feasibility. Thereby, the environmental effectiveness depends on by its "additionality"; the validity of the baseline from which emission reductions are calculated; and indirect emissions impacts (or "leakage"). Cost-effectiveness is higher when abatements costs are lower in developing countries but their contribution depends, in part, on the promotion of technological change in these countries. Distributional impacts relate to contributions to sustainable development and distribution of rents from the sale of CERs. Finally, regarding institutional feasibility, a third-party audit the other criteria, however multi-layered procedures have been introduced what has led to high transaction costs. In all issues experts have found reasons for concern about the efficacy of CDM projects. In 2012, a report on the evaluation of the CDM commissioned by the UNFCCC recommended several reforms.

The Paris Agreement did not address an international carbon market directly but includes an Article 6 (and the respective paragraphs in Decision 1/CP.21) with both market and non-market provisions. Through Cooperative Approaches (CA), Parties can use Internationally Transferred Mitigation Outcomes (ITMOs) to achieve their Nationally Determined Contribution (NDC) (Article 6.2). It establishes a mechanism to help mitigation and support sustainable development (referred as Mitigation and Sustainable Development Mechanism (MSDM) or Emissions Mitigation Mechanism (EMM) by different authors) with some similarities to the CDM and JI mechanisms of the Kyoto Protocol (Article 6.4). These provisions are seen by some as the foundation for more comprehensive carbon market cooperation and a chance to create an international price on carbon. The final part (Article 6.8) sets the framework for non-market approaches (Martínez de Alegría et al., 2017a; Marcu, 2016; Cames et al., 2016; IETA, 2016). The article is, however, the most problematic one when it comes to agreeing on how it should function, especially in achieving sound accounting rules to avoid double counting and the transition from the CDM to the mechanism set out in Article 6.4.

5.3.2.2 Subsidies

Fiscal instruments can be divided into two major categories: tax instruments and subsidies. The first ones are often labelled "pricing instruments", as they aim at influencing consumer behaviour by increasing prices. On the contrary, subsidies (or fiscal incentives in political language) are defined as any government action that lowers final price for consumers or the cost of productions or that raises the income of producers (Breton and Mirzapour, 2016). Subsidies might complement other tax instruments to correct inefficiencies derived from market imperfections or market failures (such as externalities, lack of information on the qualities of products, affordability constraints for consumers, undervaluation of long-term savings, high search costs of finding more energy-efficient products, and principal-agent problems) (Kosonen and Nicodème, 2009) and to motivate the development of new energy technologies or reducing emissions from activities that do not benefit from them.

But subsidies affect the price of energy, cost money to governments and their effectiveness may be reduced by the rebound effect (i.e. lower prices induce to buy or consume more) and free-riders (i.e. consumers would have bought the energy-efficient appliance in any case). Hence, the issue of a reform remains high on the international policy agenda, especially after the mitigation commitments made by the countries during the COP-21, the opportunities created by low energy prices and the continuous fiscal pressure in many countries (Coady et al., 2015). Many publications theorise about the benefits from decreasing energy subsidies. Although the findings must be viewed with caution, in their study which estimates of post-tax subsidies for 2013 and projections for 2015, Parry et al. (2014) concluded that a tax reform could reduce global CO_2 emissions over 20% and that implementing corrective taxes could mean a potential average income equivalent to 2.6 percent of world GDP while cutting pre-mature air pollution deaths by more than half. However, several factors can jeopardise a subsidy reform. One of the most important one is winning the favour of consumers, especially the low-income households, and particularly in the less developed countries or countries where the government or their affiliated companies directly control domestic prices of energy carriers (Breton and Mirzapour, 2016).

Subsidies to renewable energy technologies are essential, at less, in the emergence phase to compete with conventional technologies, otherwise, neither the motivation nor the diffusion to change technology would be sufficient (Menanteau et al., 2003).

However, according to IEA (2016e), the subsidies for fossil-fuel in 2015 were estimated at US$325 billion (nearly US$145 billion (44%) for oil, just over US$100 billion for electricity, around US$75 billion for natural gas, and US$1 for coal). Subsidies for all type of renewable sources were around US$150 billion, only around US$5 billion more than for oil.

There are different measures, in the form of subsides, that can be adopted to promote renewable sources, such as feed-in tariff (FIT), feed-in premium (FIP), and tradable green certificates (TGC).

The FIT and the FIP are generation-based, price driven incentives and involve the purchase by transmission system operators (TSOs) of a quantity of electricity generated by renewable sources for electricity utilities (thus, they ensure access to the grid) but they differ in the price received by the producer. While FIT strategy grants a fixed payment guaranteed for a specific period (generally between 10-25 years), the premium offered by FIPs schemes depends on the electricity price. The aim is to cover the cost disadvantage of generating electricity by renewable sources. An additional cost finally paid by the consumers as is added to the electricity bills. To design an efficient and effective FIT scheme, several aspects are needed to be considered. First, the determination of the level of tariff, based on the cost of the generation or on the value of that generation to the society. Second, it must provide technology-specific tariff levels (as each technology presents different cost) and ensure a diverse technology. Third, to establish the use of Flat Rate Tariff (constant amount for a defined technology, regardless of the generation costs) or Stepped Tariff (for the same technology, the tariff change based on the location and size of the plant and on the type of fuel. The last point, it must be designed to stimulate technology improvement and include the revision of tariffs (Nicolini and Tavoni, 2017; Cinelli, 2011; Menanteau et al., 2003).

Green Tradable Certificates (TGC) is a “quota mechanism”. The authorities determine the amount of electricity that must come from renewables and oblige the generators at their fulfilment. They can do that by generating the amount required or by buying the certificates with or without purchasing the renewable electricity. This creates a certificate market, converting TGC into a market-based instrument. The generators that not comply with its quota is doomed a penalty payment, which be used to finance the fund for renewable research, development and demonstration, or to the producers. Although this mechanism promotes the use of renewables, there are also some risks to consider. First, it establishes the quota but not the type of renewable technology, which could lead to the neglect of the development of promising but expensive technologies. Second, an excess of profits could generate large free-riding opportunities, harming the market (Nicolini and Tavoni, 2017; Cinelli, 2011; Menanteau et al., 2003).

5.3.2.3 Energy efficiency

Technology always has been the hope for solving most of the environmental disruptions caused by civilization. The question was not whether they were manageable but whether they would be taken on time and what social, economic and new environmental penalties would accompany them (Holdren and Ehrlich, 1974).

Energy efficiency (EE) is defined as "using less energy inputs while maintaining an equivalent level of economic activity or service" (EC, 2011, pg. 2). It can be seen as something abstract and intangible, measured in terms of energy not consumed or costs avoided but with benefits that go well beyond immediate cost savings, including increased GDP and other macroeconomic benefits, improved access to energy with more affordable energy services, reduced air pollution and some fiscal improvements for national and subnational entities. According to the IEA, the application of economically viable energy efficiency measures prevented the consumption of 122 million tonnes of oil equivalent (Mtoe) in 2014, limiting the increase in global demand to 0.7% instead of the 2.1% that would have resulted from failure to take action. Several institutions refer to EE as the largest available energy resource (IEA, 2016e, 2014b; EC, 2011; Bishop and Economy, 2015).

There is also a relation between investments in energy efficiency and emissions. As exposed in Table 5.4, the greater the investment in efficiency, the lower the emissions and the more feasible the goal of limiting temperature rise to two degrees Celsius. As reported by the IEA in its World Energy Outlook (2016e), of the US$1.858 billion invested in 2014, only 221 billion (12%) were spent in efficiency. Meet projected energy demand and mitigation by 2040 according to the 450 Scenario would mean an annual investment of US$2.998 billion, of which 47% would be for efficiency.

Opportunities to energy efficiency improvements are present across sectors and regions. Mandatory or voluntary regulatory approaches and information measures are widely used, most notably the efficiency standards. But energy efficiency also has to face several barriers and limits. The major constraint is the "rebound effect", where consumers, tempted by energy savings due to efficiency, increase the demand for energy services, keeping a slower demand growth (Bishop and Economy, 2015). In terms of barriers, authors have classified them as economical, organisational, behavioural, institutional and physical constraints areas, being the economic theories

Table 5.4 – Annual average energy supply investment (2016-2040) (billion, 2015 US$)

	2010-2015		**2040**			
			NP		**450**	
Supply	1637	88%	1744	65%	1596	53%
Fossil fuels	1112	68%	1065	61%	691	43%
Renewables	283	17%	299	17%	503	32%
Electricity networks	229	14%	322	18%	288	18%
Other low-carbon	13	1%	58	3%	114	7%
Energy Efficiency	221	12%	919	35%	1402	47%
Total investment	1858	100%	2663	100%	2998	100%

Source: Own elaboration based on the data offered by the IEA (2016b)

related to market failure the most frequently explained, including aspects such as information problems, unpriced energy costs and the spill over nature of research and development (Chai and Yeo, 2012; Sorrell et al., 2000).

Chapter 6

Industrial electricity prices in the European Union following restructuring: A comparative panel-data analysis

6.1 Introduction

Electricity is currently a prominent source of concern for economic, social, and political agents. The increased deterioration of the environment, including the problem of climate change, problems of security of supply in the European Union (EU), the depletion of fossil fuels, and continued aversion to the use of nuclear energy are all factors that have led to both increases in energy efficiency and the use of renewable and less polluting energy sources. However, setting up a competitive electricity sector in the EU is also a fundamental objective for all of the countries concerned.

Traditionally, the four activities of the electricity industry (generation, transmission (high voltage network), distribution (low voltage network), and retail service to end consumers) were vertically integrated. The industry worked as a regulated monopoly, and it is very common for there to be a small number of providers (government owned or municipal) in a highly regulated market. In these regulated markets, users have limited opportunities to switch to alternative suppliers. However, the early 1980s saw a process of restructuring the electricity sector across the world (Patterson, 1999; Erdogdu, 2013).

In general, electricity industry reform has had the following four dimensions:

i) unbundling (separation) of energy production and supply activities from the operation of transmission networks;

ii) opening entry to new competitors, including Independent Power Producers (IPP);

iii) allowing for third-party access and retail services; and

iv) privatising publicly owned assets.

European legislation remains neutral as regards this last dimension (for a more in-depth revision of the reasons and the economic theory underlying the electricity industry market-based reform and the privatisation reforms see Nepal and Jamasb (2015); Patterson (1999); Jamasb and Pollitt (2001) and Fiorio and Florio (2013)).

Electricity reform trends have been very diverse in the different EU Member States, with the United Kingdom as the first to implement comprehensive electricity reform at the end of the 1980s and France as a latecomer in implementing EU directives (Fiorio and Florio, 2007). In order to set up an Internal Energy Market (IEM), three packages of regulatory measures were adopted. These packages addressed improvements in market access and interconnection, better consumer protection, increased transparency, and supply adequacy. The first legislative package, passed in 1996, set rules for unbundling focusing on wholesale electricity markets. The second, in 2003, introduced amore specific set of regulatory rules related to tariff setting and the enforcement of network unbundling by Independent Energy Regulators (IER). The full opening of markets was envisaged by June 2007, extending the electricity reform to retail markets (Erdogdu, 2013; Martínez de Alegría et al., 2009; Larsen et al., 2006; Streimikiene et al., 2013; ACER/CEER, 2012, 2015; Glachant and Ruester, 2014). However, substantial inefficiencies relating to electricity markets were again detected. The main causes of the low level of competition in these markets were the high concentration of markets underpinned by insufficiently unbundled transmission system operators (TSOs) (EC, 2006; ACER/CEER, 2012). The third package of EU legislative acts on electricity sector reforms was adopted in 2009. The objective was to tackle the structural deficiencies in European electricity markets. Better cross-border coordination and greater independence for Independent Energy Regulators (IER) and TSOs were required (ACER/CEER, 2012; EC, 2014; Streimikiene et al., 2013).

The objective of this paper is to examine the impact of a number of factors closely linked to the regulatory reforms carried out in the EU on electricity prices for industrial consumers and on the ratio of industrial prices to household prices. As pointed out by Nagayama (2007), the Pi/Ph ratio is an indicator of enhanced competition. This author also asserts that as electricity sector reforms progress the cross-subsidy from industrial to residential users tends to be reduced and both electricity prices become cost-reflective so that the industrial price becomes lower in comparison to the residential price. We follow the earlier research line started by Steiner (2000) and subsequently continued by Hattori and Tsutsui (2004) and by Nagayama (2007).

Recently, Hyland (2016) looked at the restructuring of European electricity market, taking into account the possible endogeneity of the reform process. The purpose of the present study is specifically to contribute to a better understanding of the effects of the reforms that started in the 1990s in the 15 European Union countries (the EU-15), focusing on the 2003 to 2013 period, which includes the period between the 2nd and 3rd EU "electricity sector reform packages". The empirical econometric analysis is based on a panel data model for the period, including dynamic panel data techniques as proposed by Hyland (2016).

The rest of the article is organised as follows: Section 6.2 offers a review of the literature. Section 6.3 covers the data, including the explanation of the variables selected (Section 6.3.1) and descriptive statistics (Section 6.3.2). The econometric model and the methodology are addressed in Section 6.4. Results are delivered in Section 6.5. Section 6.5.1 focuses on the analysis of the static panel model, while Section 6.5.2 focuses on that of the dynamic panel model. Finally, Section 6.6 presents the conclusions and policy implications of the study.

6.2 Review of literature

The effect of regulatory variables on electricity prices can be analysed from different perspectives and econometric strategies. Likewise, the effect of electricity reform is difficult to assess because it includes different interrelated steps, can occur in different forms and models and is a dynamic process (Pollitt, 2009a,b). As explained by Nepal and Jamasb (2015), studying such reforms means tackling institutional and organisational issues, such as the degree of intervention, competition, and unbundling of vertically integrated organisations. Hence, market-based reform measures are multi-dimensional activities with many interacting factors and a wide variety of impacts that Social Cost Benefit Analysis (SCBA), econometric, and macro and micro-analyses based on efficiency and productivity may not adequately capture.

Some analyses of regulatory reforms are from the consumer's point of view. For instance, Bellantuono and Boffa (2007) analysed 10 EU Member States according to the quality of their residential customer protection measures, focusing on demand-side variables. Using a regression model they test the impact of retail market liberalisation on consumer prices in the electricity and gas markets, focusing on the possibility of customers choosing their supplier. They concluded that household prices are lower in Member States where the retail markets have been liberalised. Florio (2007) studied price signals and trends for the evaluation of reforms leading to market structure or ownership changes, focusing on the evolution of electricity prices in Italy, Germany, France, and the United Kingdom. He questions the validity of the "ideal pattern" of *privatisation and vertical disintegration*. Borenstein and Bushnell (2015) offer a review of restructuring in the electricity industry over the last two decades in the US and conclude that the "electricity rate changes since restructuring have been driven more by exogenous factors —such as generation technology advances and natural gas price fluctuations— than by the effects of restructuring".

Table 6.1 shows our summary of the multi-country studies of the impact of regulatory reforms on price in the power industry using panel data models. The study published by Steiner (2000) based on panel data from 19 OECD countries is considered to be the first significant attempt to assess this impact. It concluded that ownership is not necessarily correlated with increased competition and that reforms do not generally mean a reduction in market power; in particular, the introduction of legal third-party access (TPA) does not necessarily result in the actual entry of new retailers, as the effect of this variable is found to be not significant. In all countries and for the entire period analysed, industrial prices were found to be lower than household prices, suggesting that the benefits of reform are obtained disproportionately by industrial consumers and that price discrimination may increase under reform unless market power is reduced by structural measures (such as horizontal unbundling).

Hattori and Tsutsui (2004) re-examined the analysis by Steiner and their results are compared. While Steiner provides results only on random effects, Hattori and Tsutsui include both random and fixed effect estimation. They conclude that expanded TPA is likely to reduce industrial prices and increase the price differential between industrial and household customers; they also find that increases in private ownership may lead to a reduction in power prices, but may not alter the price ratio. They also find, contrary to expectations, that the introduction of a wholesale spot market may have resulted in an increase in power prices.

Using panel data from 25 developing countries for 1985 to 2001, Zhang et al. (2005) study the effect of the sequencing of privatisation, competition, and regulatory reforms in electricity generation. They concluded that "establishing an independent regulatory authority and introducing competition before privatisation is correlated with higher electricity generation, higher generation capacity and, in the case of the sequence of competition before privatisation, improved capital utilization".

Nagayama (2007) investigated panel data from 83 countries in Latin America, the former Soviet Union, and Eastern Europe from 1985 to 2002, focusing on the effect of different reform policy instruments on electricity prices in those countries. The study concluded that the introduction of a wholesale pool market and unbundling do not necessarily mean a reduction in power prices. Nevertheless, jointly with an independent energy regulator (IER), unbundling could mean a reductionin those prices.

Table 6.1 – Main findings of studies on the effects of regulatory reforms on electricity prices using panel-data models

Authors	Sample period and countries	Main conclusions
Steiner (2000)	19 OECD countries; 1986 to 1996	Ownership not necessarily correlated with increased competition; reforms do not generally mean reduction in market power; benefits of reform reaped disproportionately by industrial consumers.
Hattori and Tsutsui (2004)	19 OECD countries; 1987 to 1999	Extended TPA may reduce the industrial price and increase price differential between industrial and household customers; unbundling and introduction of wholesale spot market may result in a power price increase.
Nagayama (2007)	83 countries from Latin America, the former Soviet Union and Eastern Europe; 1985 to 2002	Introduction of wholesale pool market and unbundling may not lead to power price reduction; but jointly with an IER, unbundling may mean a reduction in those prices.
Nagayama (2009)	78 countries (Asia, Latin America, the former Soviet Union, Eastern Europe); 1985 to 2003	High prices drive market liberalisation, but market liberalisation does not necessarily lead to a reduction in electricity prices.
Erdogdu (2011a)	63 developed and developing countries; 1982 to 2009	No uniform pattern has been found to explain the impact of the reform process on the cross-subsidy levels and price-cost margins; power consumption, income level, and country-specific features may be relevant determinants for the aforesaid variables.
Erdogdu (2011b)	92 developed and developing countries; 1982 to 2009	Country-specific features seem to be more determinant for industry efficiency than the liberalisation process itself; a more decentralised market model with competition in the electricity sector has a limited increasing effect on power industry performance.
Moreno et al. (2012)	27 EU countries; 1998 to 2009	Small effect of greater penetration of renewables on household price increase; liberalisation reforms may not lead to less concentrated markets; less concentrated markets may not lead to lower household prices.
Erdogdu (2013)	27 countries around the world; 1974 to 2008	Progress towards electricity market reform is associated with lower policy support for R&D activities, threatening sustainable improvements in the electricity sector.
Fiorio and Florio (2013)	12 EU countries; 1975 to 2007	Public ownership is associated with lower net-of-tax household electricity prices in Western Europe.
Bacchiocchi et al. (2015)	27 EU countries; 1990 to 2011	Regulatory reforms reduced the price of energy in the EU15; the combined effects of privatisation and liberalisation are associated with higher prices in the New Member States.
Polemis (2016)	OECD countries; 1975 to 2011	A robust independent regulatory scheme is necessary in order to achieve a competitive power market.
Hyland (2016)	27 EU countries plus Norway; 2001 to 2011	Proposes the use of dynamic panel-data techniques to overcome the endogeneity problem detected between price trends and market reform.

The introduction of Independent Power Producers (IPP) and privatisation is associated with lower electricity prices but only in some of the regions analysed.

Nagayama (2009) suggested that high electricity prices were a driving force for the adopting of liberalisation measures in the countries analysed, but that the measures adopted did not necessarily lead to lower electricity prices.

Erdogdu (2011a) did not find a uniform pattern as regards the impact of reform on cross-subsidy levels and price-cost margins (the electricity price-cost margin in his study "includes items such as capital costs, transmission and distribution costs, accounting profit of the electricity utilities and so on"). Instead, power consumption, income level, and country-specific features may be relevant. Erdogdu (2011b) suggested that the application of liberal market models in electricity industries slightly increased efficiency in the power sector; he also detected a positive relationship between the reform process and the percentage share of transmission and distribution network losses, and found that the introduction of a decentralised market model with competition has a limited increasing effect on power industry performance. Erdogdu (2013) later suggested that progress towards electricity market reform is associated with lower policy support for research and development activities, threatening sustainable improvements in the electricity sector. Like Erdogdu (2011a), Erdogdu (2011b) found that some country-specific features (such as income level) are more important determinants for the industry than the reform process itself. These considerations are confirmed by Baek et al. (2014), who analysed the performance of the power industry after "liberalisation" of markets according to country-specific features and concludes that "liberalisation" increases competitiveness, depending on the liberalisation process adopted and on the economic environment.

The paper by Fiorio and Florio (2013), which focused on the evolution of residential electricity prices over nearly three decades in the EU15, found no uniform pattern in the effect of electricity reform measures, concluding that public ownership is associated with lower net-of-tax household electricity prices in Western Europe.

Similarly, based on the study of the effect of regulatory reforms on the EU-27 countries over the period from 1990 to 2011, Bacchiocchi et al. (2015) identified asymmetric effects of regulatory reforms within two country groups in the EU27, suggesting that although the reforms reduced the price of energy in the EU15, the combined effects of privatisation and liberalisation are associated with higher prices in the New Member States.

Based on the short-run cost function, in which capital stock is treated as a quasi-fixed factor input, a recent study by Ajayi et al. (2017) focused on performance in terms of cost efficiency for electricity generation in the power sector in OECD countries, accounting for the impact of electricity market structures. This study also considers the need to model latent country-specific heterogeneity in addition to time varying inefficiency.

Based on panel-data models, Moreno et al. (2012) focused on the effects of renewable energy sources on electricity prices using a sample of 27 EU countries for 1998 to 2009. Their results show that the introduction of renewables had a small final effect on the increase in household electricity prices, that liberalisation reforms may not necessarily lead to a less concentrated market structure, and that there is no evidence that less concentrated electricity markets lead to lower household prices.

The paper by Polemis (2016) analysed the effects of the regulatory reform on the performance of the electricity sector for 30 OECD countries from 1975 to 2011, outlining the need to implement a robust, independent regulatory scheme in order to achieve a competitive power market.

Several authors (Nagayama, 2009; Growitsch and Stronzik, 2014; Hyland, 2016) noted as an additional concern the possibility of endogeneity between price trends and market reform. As pointed out by Hyland (2016), "just as restructuring may affect prices, the decision to restructure may be influenced by prices"; she proposes the use of dynamic panel-data techniques to overcome the endogeneity problem.

6.3 Data

Our dataset is based on a panel consisting of 15 European Member States from 2003 to 2013, so the potential maximum number of observations is 165. However, missing data mean that the effective number of observations is lower; the panel is thus unbalanced.

6.3.1 Variables

For dependent variables in the analysis, we use industrial price before tax (Pi) and the ratio of industrial price to household prices (Pi/Ph).

Industrial prices (Pi) correspond to the Ie band from 2003 to 2007 and the Ic band from 2008 to 2014) adjusted for US$ constant 2010 Purchasing Power Parities (PPP)[1]. Household prices (Ph) are prices before tax (for the dc band). All prices are obtained from Eurostat (2015a). The US$ constant 2010 Purchasing Power Parities (PPP) are obtained from OECD (2015). There are some observations missing in the price data for the study period. Hattori and Tsutsui (2004) ensure that their results are robust by estimating the equation with and without these samples.

[1] Data extracted on 29 Oct 2015 14:44 UTC (GMT) from OECD Stat; this dataset contains Purchasing Power Parities (PPPs) for all OECD countries. PPPs are the rates of currency conversion that eliminate the differences in price levels between countries (OECD=100).

- For indicators not directly related to regulatory reform, we use the following variables:

  a) *Share of renewable energy in total electricity generation (in %)*, i.e., generated renewable electricity-ktoe (thousands of tons of oil equivalent/electricity generation of all sources-ktoe). Data are obtained from Eurostat (2015a). The increase in the share of total energy production accounted for by renewable generation sources and increasing environmental concern justify the use of this indicator.

  b) *Gross Domestic Product per capita (GDPpc)*: data obtained from Eurostat (2015a). As explained by Hyland (2016), *GDPpc* is a variable commonly included in reduced-form models that examine the determinants of electricity prices; it may also capture information about the structure of the economy and the overall level of economic development.

- For reform indicators, we use the following variables as a proxy of the regulatory and policy impacts that they are meant to assess:

  a) *Public ownership*: this variable measures the percentage of shares owned directly or indirectly by the government in the largest firm in the sector (% of shares owned by the government/100×6) (OECD, 2013).

  b) *Sector regulation (i.e., entry regulation)*: This variable measures the following 3 questions:

     – "Is there a liberalised wholesale market for electricity?" As explained by Hattori and Tsutsui (2004), this variable indicates whether there is a wholesale power pool market where hourly or half-hourly spot prices are determined. The variable takes a value of 6 if there is no such market and 0 when there is.

     – "How are the terms and conditions of third-party access (TPA) to the electricity transmission grid determined?" This takes a value of 0 if there is "regulated TPA", 3 if there is "negotiated TPA" and 6 if there is "no TPA". This variable is similar to the Retail Access or TPA used by Steiner (2000) and Hattori and Tsutsui (2004).

     – If there is regulated TPA, "What is the minimum consumption threshold that consumers must exceed in order to be able to choose their electricity supplier?" This variable takes a value of 0 if there is "no minimum consumption threshold", 6 when there is "no consumer choice" and other values in between.

c) *Vertical integration* (i.e., compared to *unbundling*): this variable measures the degree of vertical integration between a certain segment of the electricity sector and other segments of the industry[2]. This is similar to the unbundling indicator in Steiner (2000) and Hattori and Tsutsui's (2004) studies.

The scores for these three indicators ("public ownership", "sector regulation" and "vertical integration") range between 0 and 6 (from least to most restrictive). All data are obtained from OECD (2013). The methodology for the OECD indicators of regulation in energy, transport, and communications (ETCR) is described in detail in (Koske et al., 2015).

d) *Retail access or third-party access (TPA)*: data source Eurostat (2015a). To measure this effect we use the following two indicators or subvariables:
   - *The number of main electricity retailers*: retailers are considered as "main" if they sell at least 5% of the total electricity consumed nationwide. This 5% limit is set taking into account the criteria used by Eurostat (2015a).
   - *Total number of electricity retailers to end customers*.

The purpose of using these two indicators is to assess the functioning of the retail markets when (industrial or household) consumers can directly reap the benefits of the introduction of competition if the entry of new suppliers is facilitated and the engagement of consumers is promoted, enabling them to take full advantage of greater choice and better prices.

e) The following regulatory reform indicator is included as a potentially relevant variable for explaining changes in the dependent variables selected:
   - *Regulated prices*: data obtained from ACER/CEER (2015). This is a dummy variable where 1 corresponds to yes and 0 to no. (We use this variable as corresponding to the "Time to liberalisation" and "Time to privatisation" indicators in Steiner (2000) and Hattori and Tsutsui's (2004) studies. The reason is that their periods of analysis end in 1996 and in 1999 respectively (i.e., running into the launching of the EU's 1st "electricity sector reform package") while ours extends to just after the 2nd package and includes four years after the 3rd. We thus consider the variable "existence of regulated prices" as more useful for measuring

[2] Simple average over four segments: generation (including imported power), transmission, distribution, and retail services. The values of the variable are as follows: ownership separation=0; legal separation=3; accounting separation=4.5; no separation=6.

the level of liberalisation of the market, especially considering that, as pointed out by ACER, competition is compromised in countries where there are regulated enduser prices (ACER/CEER, 2015).

As illustrated in Table 6.2, the average increase in industrial prices in the EU-15 from 2003 to 2014 was 67%. It must be stressed however that there are reductions in the average industrial price in 2013 and 2014 (of 1% respectively), which may be a positive sign, especially if this change of trend is maintained in the coming years. However, a longer period of observation is needed.

Table 6.2 – Annual trend in Industrial prices (%) (adjusted for PPP in constant 2005 US$)

TIME GEO	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	% incr. (2003--2014)
Austria	10	12	5	20	14	9	-6	-1	-1	-3	-6	62
Belgium	-2	-2	25	-3	6	8	-6	6	-2	-3	-2	24
Denmark	-7	2	18	-13	25	-7	14	-2	2	7	8	50
Finland	-4	-3	1	-1	15	10	0	2	2	2	-1	26
France	1	1	1	2	7	8	5	5	5	1	0	42
Germany	4	9	10	5	-2	5	-7	-4	-1	0	-6	11
Greece	0	4	1	5	25	1	3	23	15	4	5	123
Ireland	3	11	11	12	26	-10	-3	5	13	0	-7	71
Italy	1	7	17	6				6	8	-6	-3	56
Luxembourg	2	9	11	9	-1	23	-15	1	7	-5	-3	39
Netherlands	–	–	7	4	-2	8	-11	-5	3	-1	-4	-2
Portugal	3	7	13	6	-9	17	-5	5	20	-1	3	72
Spain*	3	29	8	-1	31	12	3	4	7	3	-2	142
Sweden	-2	-7	27	-3	17	-6	18	4	-6	-2	-11	23
UK	0	21	38	15	5	4	-6	3	17	1	10	161
EU-15	1	16	13	4	1	6	6	3	6	-1	-1	67

Some data are missing for the Netherlands for 2003 and 2004, so the % corresponds to the variation between 2005 and 2014.

The average variation in industrial prices differs notably from one Member State to another. In the United Kingdom, Spain and Greece the Pi % increase is considerably higher than the EU-15 average (161%, 142%, and 123% respectively). By contrast, the Netherlands (with a reduction of 2% between 2005 and 2014), Germany, Sweden, and Finland (with increases of 11%, 23%, and 26% respectively) show % Pi increases considerably below the EU-15 average.

In regard to effects on price differential (Pi/Ph), industrial prices are lower than household prices in all countries and at all times. However, this difference tends

Table 6.3 – Trend in the price ratio (industrial prices (Pi)/household prices (Ph))

Member State	**% increase (2003–2014)**
Austria	6.6415
Belgium	-16.6535
Denmark	-2.2591
Finland	-15.9872
France	11.5891
Germany	-2.8107
Greece	-11.2854
Ireland	-14.3540
Italy	25.0180
Luxembourg	15.1552
Netherlands	-21.8205
Portugal	58.5687
Spain*	7.0988
Sweden	-20.1540
UK	38.2853
EU-15	11.6480

There are data missing for the Netherlands for 2003 and 2004, so the % corresponds to the variation between 2005 and 2014.

to increase in the Netherlands, Sweden, Belgium, Ireland, Germany and Denmark, where the Pi/Ph ratios have fallen by around 22%, 20%, 16%, 14%, 3% and 2% respectively (see Table 6.3). However, the gap decreases in the rest of the countries, which means that household consumers there paid comparatively more percentage-wise than industrial consumers in 2014 than in 2013. The average EU-15% increase is 11.6%, a figure that suggests that reforms have favoured household consumers more than industrial ones.

6.4 Econometric methodology

We formulate two independent regression equations to study the impact of restructuring, regulatory reforms, and other factors on industrial prices and the ratio of industrial to household prices following Steiner (2000) and Hattori and Tsutsui (2004). With the industrial price level being Pi, we first define the static panel-data model for country i at time t by:

$$Pi_{it} = c + h_i + R'_{it}b + X'_{it}g + \xi_{it} \quad i = 1; ...; I \; and \; t = 1; ...; T \tag{6.1}$$

and denoting the price ratio (industrial price/household price) as Pi/Ph, the static panel model is written as:

$$\left(\frac{Pi}{Ph}\right)_{it} = c + h_i + R'_{it}b + X'_{it}g + \xi_{it} \quad i = 1;...;I \; and \; t = 1;...;T \tag{6.2}$$

R' is a set of regulatory reform indicators and X' is a set of independent variables not directly related to regulatory reforms; hi indicates an unobservable time-invariant country-specific effect and X'_{it} is the normal disturbance term. Following Hattori and Tsutsui (2004), we assume that there is a country-specific effect, so we estimate a static fixed effect model. Country fixed effects are included to control for any unobserved country-specific characteristics that do not vary over time. Since we can assume that the unobserved country-specific characteristics are uncorrelated with the variables included, a random effect model is also considered.

To avoid the possible problem of heteroscedasticity or autocorrelation, we compute robust standard deviations using the HAC estimator.

Possible endogeneity of the reform process is likely to be an important issue for consideration in the estimation. It is accepted that EU legislation has been an important driver of reform in some countries, but other countries have restructured and liberalised much faster than mandated by EU policy. This implies potential causality and thus the regressors may be correlated with the error term. Therefore, we also estimate a dynamic panel model where we include a lagged dependent variable to capture the persistence of the price variable (i.e., it considers the effect that trends in electricity prices may have on the independent variables selected):

$$Pi_{it} = c + h_i + R'_{it}b + X'_{it}g + pi_{it-1}a + \xi_{it} \quad i = 1;...;I \; and \; t = 2;...;T \tag{6.3}$$

$$\left(\frac{Pi}{Ph}\right)_{it} = c + h_i + R'_{it}b + X'_{it}g + \left(\frac{Pi}{Ph}\right)_{it-1} a + \xi_{it} \quad i = 1;...;I \; and \; t = 2;...;T \tag{6.4}$$

The error terms in equations (3) and (4) are simultaneously autocorrelated and correlated with the lagged dependent variable. This is due to the way in which the equations are constructed, so an estimator that takes both issues into account is needed. Greene (2012) and Wooldridge (2002) argue that in this context a fixed-effects approach is not appropriate since the correlation biases the coefficient of the lagged dependent variable and of any explanatory variable correlated with the lagged dependent variable. Nickell (1981) shows that this problem is very substantial, especially when the time frame of the panel is short. To overcome the problem, a GMM estimator (Arellano and Bond, 1991) employing an instrumental variable estimator can be useful. The instruments for the lagged dependent variable are constructed using the second and subsequent Y lags. Lags from any endogenous regressors can also be used as instruments. One and two-step GMM estimators are computed.

6.5 Results

6.5.1 Results of the static panel-data analysis

We present the results of the regression analysis for industrial prices. The parameter estimates are shown in Table 6.4. Columns 1 and 2 present the results of the regression of the determinants of industrial electricity prices. The Hausman test indicates that the fixed effects model should be chosen, but we present the results of both models for the sake of comparison.

Table 6.4 – Static panel model

Variable	**Pi in constant 2010**		**Pi/Ph**	
	Fixed effects Robust errors (HAC)	**Random effects**	**Fixed effects Robust errors (HAC)**	**Random effects**
Constant	1.0889***	1.1197***	5.1470***	5.1794***
	(0.069)	(0.134)	(0.610)	(1.306)
Share of renewables in generation	0.3193***	0.3321***	5.3513***	5.4073***
	(0.078)	(0.097)	(0.756)	(0.950)
Public ownership	-0.0705***	-0.0690**	0.4214**	0.4427*
	(0.023)	(0.029)	(0.188)	(0.281)
Sector regulation	-0.0538***	-0.0578***	-0.4721***	-0.4852***
	(0.008)	(0.008)	(0.078)	(0.078)
Vertical integration	-0.0384***	-0.0429***	-0.0976	-0.1179
	(0.013)	(0.013)	(0.105)	(0.128)
Number of main retailers	-0.0206*	-0.0267**	-0.3480***	-0.3680***
	(0.011)	(0.011)	(0.055)	(0.103)
Number of retailers to end consumers	-0.0003***	-0.0003***	-0.0028***	-0.0028***
	(0.00007)	(0.00008)	(0.00045)	(0.00079)
Regulated prices	0.2890***	0.3035***	2.4135***	2.5173***
	(0.046)	(0.040)	(0.232)	(0.393)
GDPpc	0.0912***	0.0836***	0.4725***	0.4206*
	(0.033)	(0.026)	(0.103)	(0.256)
R^2	0.6245		0.5018	
Number of observations	150	150	149	149
Hausman Test		7.9042		3.2220

Robust standard errors are in parentheses.
***p < 0:01, **p < 0:05,*p < 0:1.

The main results for the static model (columns 1 and 3 in Table 6.4) are as follows:

Effects on industrial price (Pi) levels:

- The coefficient for *share of renewable energy in total electricity generation* is significantly positive in relation to the industrial price (Pi). This result is not unexpected because, with the exception of hydropower generation, these are new technologies installed in the EU-15 electricity markets, and may not yet have taken full advantage of the high potential of scale and knowledge economies. These results may be consistent with Moreno et al. (2012), who concluded that household prices tend to increase with the deployment of *renewable* energies. Moreover, it is also possible that industrial prices may have absorbed a larger part of the costs of introducing renewable energies than households.

- The coefficient for *GDPpc* is also significantly positive, as expected. This is consistent with Nagayama's (2009) result, which illustrates that such correlation is also positive in all areas except in Latin American countries.

- The coefficient for *share of public ownership* is significantly negative. This result is consistent with those of Zhang et al. (2005) and Steiner (2000)). The underlying reason may be that in some EU countries these are highly concentrated or monopolistic markets (Steiner, 2000; ACER/CEER, 2015). By contrast, Hattori and Tsutsui (2004) suggest that private ownership may lead to a reduction in power prices. This difference between their results and ours could be mainly due to study time frames.

- The coefficient for *vertical integration* is significantly negative. Our result suggests that unbundling or ownership separation does not necessarily have a positive effect on the reduction of industrial prices in the EU-15 electricity market. However, this does not fit with the results obtained by Kwoka and Pollitt (2010), who focus on the impact on performance of the wave of mergers which took place in the US electric power industry in 1994–2003 and find clear evidence that acquiring firms do not exhibit greater efficiency prior to merger, nor are acquired firms underperformers. As in the case of public ownership, this could be due to the existence of highly concentrated markets coupled with possible obstacles to third-party access (TPA), which may make it more difficult for new entrants to enter, and the consequent impossibility of new entrants offering lower electricity prices.

- *Retail access or third-party access (TPA)*. This variable is measured as the *number of main electricity retailers* and the *total number of electricity retailers to end customers*. As expected, the coefficients are significantly negative, so we conclude that the entry of new competitors may be effective in lowering industrial prices. This result is consistent with those of Steiner (2000) and Hattori and Tsutsui (2004).

- Unexpectedly, the coefficient for *sector regulation* is significantly negative. This finding is in line with the results of Zhang et al. (2005), who concluded that privatisation and regulation do not alone lead to obvious gains in economic performance, though there are some positive interaction effects. We note that their study used different dependent variables and focused on developing and transitional economies.

- Unexpectedly, the coefficient for *regulated prices* variable is significantly positive. It may be (as in the case of the variable *share of renewable energies*) that some of the costs derived from the regulatory reform process have been borne especially by industrial consumers. However, this variable is not found in any of the other panel-data analyses considered, so we cannot make an effective comparison.

We clarify that we have obtained the variable for sector regulation according to the OECD (2013) methodology, which considers three subvariables jointly. Our results suggest that when there is no *wholesale power market*, when there is no (or low) *third-party access (TPA)*, and when the *minimum consumption threshold* is higher (or *there is no consumer choice at all*), the industrial price tends to be lower. As can be seen, this result is inconsistent with our result suggesting that TPA is associated with lower Pi. This incongruity may be due to several reasons. As explained, it might be because the TPA as obtained from the OECD is measured in conjunction with the other two variables mentioned above, which may lead to a distorted result. It might also be due to the different sources used (Eurostat (2015a) versus OECD (2013)). Thus, a definitive conclusion as to the effect of the sector regulation variable cannot be obtained from the present analysis, and a more in-depth analysis is necessary to obtain more robust results, especially in terms of measuring the independent effects of the three sub-variables. We find that the result for the TPA variable obtained from Eurostat (2015a) is more consistent with the expectation that improved access leads to reduced prices.

Effects on price differential (Pi/Ph):

- The coefficient for *share of renewable energy in total electricity generation* is significantly positive (as in the industrial price analysis), which may favour household consumers. In other words, the effect of an increase in renewables is more noticeable in explaining industrial price increases. A possible explanation is that industrial prices are more open to market forces than household prices so, as explained for the case of the effect on Pi, some of the costs derived from the regulation reform process may have been borne especially by industrial consumers.

- Unexpectedly, the coefficient for *GDPpc* is significantly positive, which suggests that an increase in *GDPpc* is associated with a relative reduction in the household prices (compared to industrial prices).

- The coefficient for *public ownership share* is significantly positive. So, unexpectedly, public ownership is associated with a wider gap between Pi and Ph, which may favour household consumers over industry consumers. One possible explanation is yet again the lack of real competitive markets. These results are consistent with the significantly negative coefficient between public ownership and Pi, and are in line with the results of Steiner (2000). In Hattori and Tsutsui (2004) private ownership has no significant effect on the Pi/Ph ratio.

- The coefficient for *sector regulation* (i.e., *entry regulation*) variable is significantly negative. This result seems to contradict the results for *public ownership share*. As in the analysis of the effects on industrial price (Pi) levels, we cannot draw a final conclusion from this result. As mentioned above, we believe that a more in-depth analysis of the sector regulation variable is needed.

- The coefficient for *regulated prices* is significantly positive, which favours households over industrial consumers. Once again, a possible explanation is that when there is *public ownership* there is a greater tendency to have subsidised prices for households.

- We did not find a statistically significant result for *vertical integration*.

- As expected, the coefficients for the *number of main electricity retailers* variable is significantly negative, as is that for the *total number of electricity retailers to end customers*. Again, TPA for retail services is expected to increase in the level of competition in power markets, in which industrial customers participate. These results are consistent with those for the Pi effect as regards the TPA variable.

We reiterate that the different time periods considered, differences in the definition of the explanatory variables, and the diversity of the multi-country groups considered must be taken into account when comparing our results to those of prior studies.

6.5.2 Results of the dynamic panel-data analysis

Hyland (2016) emphasizes that it is important to consider possible endogenous effects and suggests that doing so may alter the results of panel-data analyses in this area. She affirms that "any analysis that ignores dynamics and possible endogeneity is likely to miscalculate the effects of restructuring". Considering this, we also estimate a dynamic model containing lags of the dependent variable and the rest of the predetermined explanatory variables (see Table 6.5). As can be observed, the results of the dynamic panel model are quite similar to those obtained from the static model. The signs of the coefficients obtained are identical in both models. The notable differences are the level of significance of the variables, which is lower in the dynamic model, and the effect of the number of main electricity retailers, which is insignificant when the dynamic model is applied to the effect on industrial prices, as is the GDPpc when the model is applied to the Pi/Ph ratio.

Table 6.5 – Dynamic panel model

Variable	**Pi in constant 2010**		**Pi/Ph**	
	One-step model	**Two-step model**	**One-step model**	**Two-step model**
Constant	0.0169* (0.010)	0.0264* (0.014)	0.1643** (0.072)	0.0982 (0.119)
Share of renewables in generation	0.2992* (0.175)	-0.1386*** (0.244)	7.8843*** (1.533)	7.204*** (2.186)
Public ownership	-0.0656* (0.036)	-0.1168*** (0.041)	0.7673*** (0.240)	0.8352*** (0.321)
Sector regulation	-0.0420*** (0.009)	-0.0330*** (0.004)	-0.4972*** (0.080)	-0.5009*** (0.101)
Vertical integration	-0.0366*** (0.014)	-0.0383*** (0.009)	0.1083 (0.089)	0.0381 (0.095)
Number of main retailers	-0.0168 (0.014)	-0.0343** (0.015)	-0.1460* (0.078)	-0.2558* (0.140)
Number of retailers to end consumers	-0.00011 (9.38e-05)	-1.747e-05 (7.50e-05)	-0.0014** (0.0006)	-0.0019*** (0.0006)
Regulated prices	0.3261*** (0.042)	0.2821*** (0.072)	2.5423*** (0.256)	2.418*** (0.300)
GDPpc	0.0665** (0.030)	0.0681* (0.039)	0.0451 (0.173)	0.0959 (0.231)
Pi (without taxes) lagged	-0.1889*** (0.058)	-0.1093 (0.075)		
Pi (with taxes) lagged			-0.1747*** (0.064)	-0.1336* (0.077)
Sargan Test ($Pr > c2$)	108.905 (p-value=0.00)	8.8915 (p-value=1.000)	77.1095 (p-value=0.0212)	12.5927 (p-value=1.000)
Arellano-Bond AR(1) test ($Pr > z$)	-1.9522 (p-value=0.0509)	-1.5290 (p-value=0.1263)	-3.0949 (p-value=0.0020)	-3.1166 (p-value=0.0018)
Arellano-Bond AR(2) test ($Pr > z$)	-4.0301 (p-value=0.0001	-2.7072 (p-value=0.0068)	-1.7404 (p-value=0.0818)	-1.8414 (p-value=0.0656)

Robust standard errors are in parentheses.

***p < 0:01, **p < 0:05,*p < 0:16.

6.6 Conclusions and policy implications

In the last twenty years, electricity market and regulatory reforms have been proposed as a way of increasing competition and reducing prices. Generally, these policy reform packages have included unbundling, market entry, *third-party access*, and privatisation of publicly owned assets. The EU has remained neutral on this last issue. This paper measures the impact of a number of variables closely linked to the regulatory reforms carried out in the EU-15 on industrial electricity prices and the differential between industrial and household prices.

Contrary to expectations, we observe that industrial prices increased by an average of 67% from 2003 to 2014, with wide variations from one EU-15 country to another. However, between 2013 and 2014, this price fell markedly, which may be a positive sign if this trend is maintained in the coming years. This may be the result of the last energy reform package launched in 2009.

In regard to the static panel-data model, when focusing on the effects on the industrial price, we observe that an increase in *GDPpc* and the *share of renewable energies in total electricity generation* tends to be associated with higher industrial prices. When the regulatory reform variables are studied, the effect of the power market reform is not always as expected and not all the measures analysed are associated with a reduction of industrial prices. Indeed, *unbundling*, *regulated prices*, and privatisation are not necessarily associated with lower prices, and they may indeed have effects contrary to expectations. Our results suggest that third-party access (measured as the *number of main electricity retailers* and the *total number of electricity retailers to end customers*) is related to lower industrial prices. A more in-depth analysis is needed to explain the unexpected result concerning the *vertical integration* variable.

With regard to effects on price differential, most of the variables analysed (*share of renewables*, *GDPpc; regulated prices; and public ownership*) lead us to affirm that because industrial prices are more open to market forces than household prices (which in turn may be more subject to political decisions or subsidised prices), some of the costs derived from the regulatory reform process may have been borne especially by these industrial consumers. Consistent with the findings obtained for effects on Pi, TPA is the only factor associated with a lower price differential. One exception is the *sector regulation* variable, the effects of which need to be analysed in greater depth.

As illustrated, although industrial prices are lower than household prices in all countries and at all times, the change in the differential varies, with the average increase for the EU-15 being 11.6%. This figure suggests that on average reforms have favoured household over industrial consumers. The underlying reason may be that in some EU countries, electricity markets are highly concentrated (Steiner, 2000; ACER/CEER, 2015). These findings are understandable if industrial consumers are more exposed to market forces than households while government policies are aimed at other goals (such as reducing energy poverty or winning elections). However, we agree with Steiner (2000) that industrial consumers that use more energy can benefit more directly from TPA (e.g., by arranging to have power supplied by a generator, thereby avoiding other parts of the supply chain). Our results suggest that TPA leads to a reduction in industrial prices. However, jointly considering most of the indicators analysed, our results suggest that *unbundling* does not necessarily guarantee an improvement in *TPA* and retail markets, especially when, as mentioned, monopolistic structures persist.

Comparing the static and dynamic panel models, we found that an increase in renewables in the energy mix tends to increase industrial prices under the static panel model; this result coincides with the findings of Moreno et al. (2012). The only notable difference is the level of significance of the variables, which is lower in the dynamic model. These results differ from those of Hyland (2016), who found that once the potential endogeneity of reform is accounted for very few electricity reform variables remain significant. However, we agree with her that accurate estimation of the long term effects of reform will need further analysis over longer time periods, as the restructuring and reform processes may not yet have had sufficient time to influence electricity prices; and that further research is needed in regard to the use of dynamic modelling.

Finally, as discussed there is no consensus among authors as to the effect of electricity reforms in different country groups based on panel data analysis. As shown in our analysis, the effects of the reforms have been very diverse in European Union Member States. With a view to drawing more robust conclusions and in line with the observations of other authors (Erdogdu, 2011a; Bacchiocchi et al., 2015, etc.), a more in-depth analysis by sub-groups of countries (e.g., The NordPool member countries versus other sub-groups of countries with sub-groups identified according to their price trends) is recommended, especially to better understand results around the Pi/Ph ratio (e.g. to better explain the positive coefficient of *GDPpc*). A more thorough analysis is also recommended, in particular, to better explain the causes of the unexpected results, especially those for the *sector regulation*, *unbundling* and the *regulated prices* variables.

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Appendix A. Supplementary data Supplementary data to this article can be found online at https://doi.org/10.1016/j.jup.2019.100956.

Part III

This section includes an English version of a book chapter (the original version is included as an Appendix) and an article submitted to:

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Chapter 7

The Indian energy outlook

7.1 Introduction

India is experiencing a fast and remarkable economic development. Growing at nearly 6% annually during the last two decades of the 20th century and at over 7% during this one, India has placed itself as one of the most dynamic economic powers worldwide. In 2014, it ranked eighth in the list of countries with the highest GDP (in US$ at constant 2005 prices), after the United States, China, Japan, Germany, the United Kingdom, France and Italy. India estimates necessary a sustained economic growth of 8-10% until 2030 to achieve the goals of human development and poverty eradication (Planning Commission, 2006).

In India, primary energy consumption has doubled since 1990, and with per capita energy consumption equivalent to one-third of the world average, the trend will continue to rise over the next few decades. According to statistical data of the International Energy Agency (IEA), the average annual growth until 2015 was 4% and will continue at an annual rate of 3% until 2040.

However, this correlation between energy demand and economic growth has two main characteristics that should be highlighted. First, it was the growth in the industrial sector and not in the service sector that accelerated the expansion of the economy. India has shown its willingness to change this situation. The "Make in India" initiative sought to increase the productive sector to account for 25% of GDP by 2020, by creating 100 million jobs. A change in the industrial weight in the economy, as well as an increase in the purchasing power of the population, would directly affect the country's energy consumption. The electricity sector is the one experiencing the highest demand growth, with an average annual rate of 4.4%. However, some 240 million Indians lack access to electricity, and the consumption of those who do is about ten times lower than OECD levels (IEA, 2014b, 2015b). India's energy policy underscores the reform of the electricity sector linked to cost reduction and rationale of fuel prices.

Second, the growth in energy demand has been much slower than economic growth mainly due, among other factors, to energy efficiency efforts. India's energy intensity, i.e., the amount of energy needed to generate one unit of Gross Domestic Product (in terms of purchasing power parity) is slightly below the world average, although there is still much room for improvement (IEA, 2015e).

Another characteristic that defines India is its population size. India has over 1.267 million people, making it the second most inhabited country worldwide. Only China surpasses it, although many predict that over the coming years they will swap places. The growth rates seem to indicate it: the annual population growth rate in China is below 1% since the start of the century, being 0.5% in 2014. That year, the growth rate in India was 1.2%.

All these factors have a strong influence on the country's energy sector. India faces large-scale challenges in meeting the demand and ensuring affordable energy supply in a context marked by the pressures of sustainability and climate change and where high energy price regulation for consumers, fuel subsidies and inconsistent energy sector reforms make investment difficult.

In order to deal with all this, the Integrated Energy Policy (IEP) was finally approved in December 2008. Of an inclusive nature, it integrates and monitors all areas related to the energy sector.

7.2 India's energy structure

India, with an energy demand close to 800 million tonnes of oil equivalent (Mtoe), is the third-highest energy-consuming country. It is surpassed by the United States and China and closely followed by Russia. And yet, its energy consumption per capita (tons of oil equivalent/population), in 2013 was 0.62, far from the 6.92 of the United States, 2.21 of China or 5.11 of Russia, even though these states have not the highest ratio[1]. In terms of energy consumption per capita, India would be at the same level as countries like Honduras (0.64), Ivory Coast (0.64), Zambia (0.66) or Colombia (0.65).

7.2.1 India in the international energy context

Tables 7.1 and 7.2 reveal significant differences between the energy structure of India and the other geographical areas. Unsurprisingly, the most notable differences arise when comparing India and the OECD. Nor is it unexpected to find the highest similarity with China. The differences with the non-OECD and the World are nuanced precisely by the weight of the two Asian countries in both areas.

[1]According to World Bank data, the three countries with the highest per capita consumption are Qatar, Iceland, and Trinidad and Tobago.

Table 7.1 – Structure of energy consumption 1990-2040 (in Mtoe)

	Coal	Oil	N. Gas	Nuclear	RE	Total	Pc.
				1990			
India	94	63	11	2	139	309	0.35
China	533	122	13	0	211	879	0.77
Non-OECD	1140	1163	819	74	849	4045	0.96
OECD	1080	1873	843	451	278	4525	4.24
World	2221	3237	1662	526	1126	8772	1.66
				2013			
India	341	176	45	9	204	775	0.61
China	2053	483	142	29	331	3038	2.24
Non-OECD	2900	1959	1529	135	1360	7883	1.33
OECD	1029	1908	1372	511	503	5323	4.21
World	3929	4219	2901	646	1863	13558	1.89
				2025			
India	568	273	81	28	257	1207	0.83
China	2070	647	317	167	448	3649	2.57
Non-OECD	3285	2451	1968	343	1775	9822	1.37
OECD	827	1682	1444	580	731	5264	3.93
World	4112	4545	3422	923	2507	15504	1.83
				2040			
India	934	458	149	70	298	1909	1.17
China	1978	710	456	287	589	4020	2.87
Non-OECD	3799	2891	2665	566	2318	12239	1.57
OECD	615	1342	1549	635	1026	5,176	3.71
World	4414	4735	4239	1201	3346	17935	1.96

The first striking observation is that, in absolute terms, only the OECD is showing a negative trend in the consumption of coal and oil. While this region will consume 465 Mtoe less coal and 531 Mtoe less oil in 2040, India will increase its consumption by 840 and 588 Mtoe respectively.

Another distinct difference between the two structures is that oil is not the main primary energy source in the Indian energy structure. In 2013, coal held by coal accounting for 44% of the total consumption. Oil is not even in second place, being slightly overtaken by renewables (26% versus 23%). it is worth mentioning, however, that the latter includes traditional biomass, which still represents a significant consumption in rural areas. Over the years, the weight of renewables will decline, mainly due to the replacement of traditional biomass by other types of energy.

The most noteworthy differences between Indian and Chinese energy structures

Table 7.2 – Structure of energy consumption 1990-2040 (in %)

	Coal	Oil	N. Gas	Nuclear	RE
1990					
India	30	20	4	1	45
China	61	14	1	0	24
Non-OECD	28	29	20	2	21
OECD	24	41	19	10	6
World	25	37	19	6	13
2013					
India	44	23	6	1	26
China	68	16	5	1	11
Non-OECD	37	25	19	2	17
OECD	19	36	26	10	9
World	29	31	21	5	14
2025					
India	47	23	7	2	21
China	57	18	9	5	12
Non-OECD	33	25	20	3	18
OECD	16	32	27	11	14
World	27	29	22	6	16
2040					
India	49	24	8	4	16
China	49	18	11	7	15
Non-OECD	31	24	22	5	19
OECD	12	26	30	12	20
World	25	26	24	7	19

Sources: Both tables were produced with IEA data. The population data were taken from the World Bank database. *Data on international bunkers are excluded. **China includes Hong Kong. ***Units in million tonnes of oil equivalent

have less to do with their composition than with their approach. In 1990, both fossil and renewables accounted for a significantly different share of the energy mix. While India had a relative balance (54% and 45%) thanks to traditional biomass, China preferred fossil fuels (76%), mainly coal (61%). These differences are expected to narrow by 2040. In both countries, renewables will account for 15-16% of total consumption, and fossil fuels nearly 80%. However, in the case of China, this would be mainly the result of a steady decline in coal consumption, a certain stagnation in oil consumption and an increase in gas use, in relative terms. In India, the upward trend is constant for all three sources.

Despite this closer alignment between the two structures, the weight of each of them in the non-OECD and global energy structures shows some distinct differences. For example, China will be primarily responsible for the increase in coal consumption among both non-OECD countries and in the World. In 2040, its coal consumption will constitute 52% of the total non-OECD use, and 45% of the world consumption, while India's figures remain at 25% and 21% respectively. The weight of both countries in oil consumption is significantly lower. India will continue to lag behind China, accounting for 16% of total non-OECD oil consumption and 10% of world consumption compared with 25% and 15% respectively for China.

7.2.2 Coal

Coal is the main primary energy source in India. It surpassed biomass in the mid-1990s, although its consumption increased sharply from 2005 onwards. India is already the third-largest coal market in the world (overtaking the European Union) behind China and the United States. These three states are responsible for 70% of total world consumption.

India uses coal principally to generate electricity. Between 2002 and 2012, three-quarters of the increase in electricity consumption came from coal-fired generation. However, in 2014 the annual per capita electricity consumption remained at 700 kilowatt-hours (an eighth of the annual per capita consumption in the European Union) as a quarter of India's population does not have access to electricity (IEA, 2014b). This fact, together with the continuing economic and demographic growth in the coming decades, the forecast of a substantial increase in consumption, at least in absolute terms. In relative terms, coal is expected to generate just over half of all electricity by 2040.

But this trend, as we will discuss in the next section, is also a source of concern, since, even though India ranks fourth globally in terms of coal reserves, and its reserve/production ratio in 2014 was 94 years, India is consuming more coal than it produces, resulting in a situation of growing dependence (BP, 2015). Coal production has slowed down since 2009, with an annual increase of between 1 and 3% (IEA, 2014b). A preeminent guideline set out in the IEP in its long-term strategy is the need to ensure its supply.

7.2.3 Oil

India is the fourth largest country worldwide in both oil consumption and imports, and the trend is clearly upward. Although oil is not the main primary energy source —in 2013 it represented only 23% of its energy mix— its evolution has always been rising, and forecast do not indicate otherwise. Between 1990 and 2013, oil consumption grew by 179%. By 2040, that rate is expected to increase as much as 627%.

One of the reasons for this increase lies in the growth of the transport sector. In 2009, the average number of people worldwide who owned a car was 125 per thousand, whereas in India it was only 12 per thousand. Estimates in 2011 suggested that this number could increase to about 100 people per thousand by 2035. In other words, in twenty-five years, the ratio of owners of a car in India would multiply by eight. Despite this, it would still be half the world average (IEA, 2011c). The transport sector, driven mainly by oil products, will grow as the country improves its terrestrial infrastructure (road and rail). In order to mitigate the impact of this growth in oil demand, the state employs formulas that involve the use of alternative fuels, especially those related to biofuels, as well as encouraging the use of mass public transport (EIA, 2014).

The economic sectors with the highest demand for oil following the transport sector are agriculture and industry.

The oil sector is one of the most deregulated and competitive in India. Currently, it is 100% open to foreign investment, and several non-national companies operate there. However, it also has a price-distorting mechanism, does not use all its national resources and lacks investment by the large international oil companies (Ahn and Graczyk, 2012).

Oil and gas management are closely linked. Currently, the Ministry of Petroleum and Natural Gas (MoPNG) oversees the entire oil and gas sector, from exploration and production to refining, distribution, marketing and pricing. It also implements the five-year oil plans and oversees the import, export and conservation of petroleum products.

7.2.4 Natural gas

Although in absolute terms it is possible to speak of an increase, the weight of natural gas in India's energy structure is still relatively low, standing at around 6% in 2013. By 2040, that amount is expected to increase up to 8%. These percentages are significantly lower when compared to the energy structures of the World, the OECD and the non-OECD region.

The evolution of an energy source's demand is susceptible to a variety of factors such as regulation and price, and in India, the situation is somewhat complicated. On the one hand, the Government of India, through the Gas Utilization Policy, establishes the distribution of domestic gas among the productive sectors while granting freedom of purchase and sale to the operators of imported gas (MoPNG, 2016).

On the other hand, in broad terms, two price regimes exist for domestically produced gas, depending on the fiscal system to which the field is subject: the Nomination regime or Administered Prices Mechanism (APM) and the non-APM mechanism (which sets prices according to the market) (Kar, 2015). In addition to this, there are transport costs, marketing margins and state taxes (Sen, 2015). The price of imported gas depends on the different types of supply contracts: long-term, short-term or spot. Short-term and spot contracts involve a considerably higher price than long-term contracts.

The APM was the tax system before the opening of the exploration and production sector (upstream). It still applies to the fields that already existed affecting most of the fields of the large companies. Under this system, and although there are some exceptions, the Government of India sets gas prices, which are considerably lower than market prices.

The second mechanism arises with the semi-liberalisation of the system. During the early 1990s, the "Discovered Sites" regime, known as the Pre-New Exploration Licensing Policy (Pre-NELP), was established, which allowed for joint initiatives between private and national companies. This tax system was replaced in 1999 by the New Exploration Licensing Policy (NELP), which aligned the conditions of public and private companies for exploration and production, based on Production Sharing Contracts between the operators and the central government.

In January 2014, India announced that it would adopt a new, simpler tax regime by replacing the current model with one of Revenue Sharing Contracts, although at the end of the first quarter of 2015 it had not yet been implemented (Sen, 2015).

This complexity in the gas pricing system has repercussions for the different sectors involved. Thus, the electricity sector and the fertilizer industry, the principal consumer sectors, operate in a highly regulated market, making it difficult for them to replace domestic natural gas consumption with imported natural gas, at least in the short term (Ahn and Graczyk, 2012).

Another factor affecting gas consumption is the existence or not of the necessary infrastructure to guarantee supply and ensure more widespread use of this source, both in industry and in cities. India lacks a fully integrated national gas network, especially in the southern and eastern parts of the country.

7.2.5 Renewable energy sources

The Twelfth Five-Year Plan developed by the Planning Commission of the Indian Government for the years 2012-2017, in Section 3.5, paragraph 14.185, notes that renewable energy represents an alternative energy source to hydrocarbons that help to ensure energy security, through diversification and reduction of dependence, while being a core element in the fight against climate change and sustainable development. Therefore, it points to the importance of enhancing efforts in renewable energy production. However, it also remarks that, despite the efforts made in recent years, India is behind other regions.

So the data shows. Despite the numbers and the fact that renewable energy consumption has increased in absolute terms, the relative values show the contrary. In 1990, renewable energy (including the most basic biomass) accounted for 45% of its energy mix. By 2013, that percentage had fallen to 26%. Estimates also show the same downward trend: 21% and 16% in 2025 and 2040, respectively. Also, India has admitted that only about 1% of its commercial energy used comes from renewable sources. One of the drawbacks to its development is the high cost per unit (Planning Commission of India, 2012).

However, it is worth remembering that this reduction is due to the replacement of biomass by other modern forms of energy. Ever since the New Economic Policy began in 1991, there has been an increasing number of people migrating to the cities, which influences the type of energy source used. Urban households have switched from biomass and waste to alternative sources such as hydrocarbons, nuclear, biofuels and other renewable sources (IEA, 2014b). At first glance, this would be a positive sign in the evolution of the energy model.

Also noteworthy is the fact that in 2011 India was the fifth country worldwide with the highest wind energy capacity and, in 2010, launched an ambitious plan to boost its solar energy capacity significantly (Ahn and Graczyk, 2012). The *Jawaharlal Nehru National Solar Mission* is one of eight projects in the National Climate Change Action Plan. The aim is to reduce the cost of solar energy generation through long-term policies, ambitious development plans, an aggressive R&D policy and the domestic production of raw materials, components and products. Split into three phases, this ambitious plan aims to deliver 20 GW of solar energy to the grid by 2022, positioning India as a global leader in solar power generation. The first phase concluded in 2013 and injected 1,100 GW into the grid, combining photovoltaic and thermal solar energy. The objective of Phase II is to obtain a cumulative solar capacity of 10 GW in 2017.

7.2.6 Nuclear energy

Regulated by the Nuclear Energy Act, the nuclear energy sector is the exclusive competence of the national government, whose commitment dates back to the country's independence. In 1948, it created the Atomic Energy Commission, and by 1954 it already had a Department of Atomic Energy. By the 1970s, India was one of the few countries that had achieved a complete nuclear fuel cycle, i.e., the full process from uranium exploration to nuclear fuel generation and reprocessing to waste management. This cycle enables the full energy potential of uranium to be used and reduces the amount of high-level waste per unit of electricity generated. On the other hand, only by using this system, thorium can produce energy (Grover, 2011). India has vast reserves of thorium but not uranium. Also, it did not sign the Nuclear Non-Proliferation Treaty, and so the country was excluded from international trade in this sector until 2008. Thus, India's nuclear programme, which is still in force, aims to exploit these reserves of thorium, thereby alienating the country from the international nuclear regime (Ahn and Graczyk, 2012).

The programme has three phases. The first phase uses Pressurized Heavy Water Reactors (PHWRs), which use uranium as fuel. The second phase uses Feedback Fast Reactors (FBRs) fed with plutonium from reprocessing plants, also developed during this phase. These reactors produce more fuel than they consume. During the final step, thorium-232 is transformed into uranium-233 using Advanced Heavy Water Pressure Reactors (AHWR). The programme is in its second phase. In total, India has 21 reactors in operation and a further seven under construction (Hidalgo Rama, 2015).

Currently, nuclear power accounts for less than one and a half per cent of the country's energy structure. By 2040, the percentage would be 4%, i.e. India would have increased its nuclear demand by about 35 times over 1990.

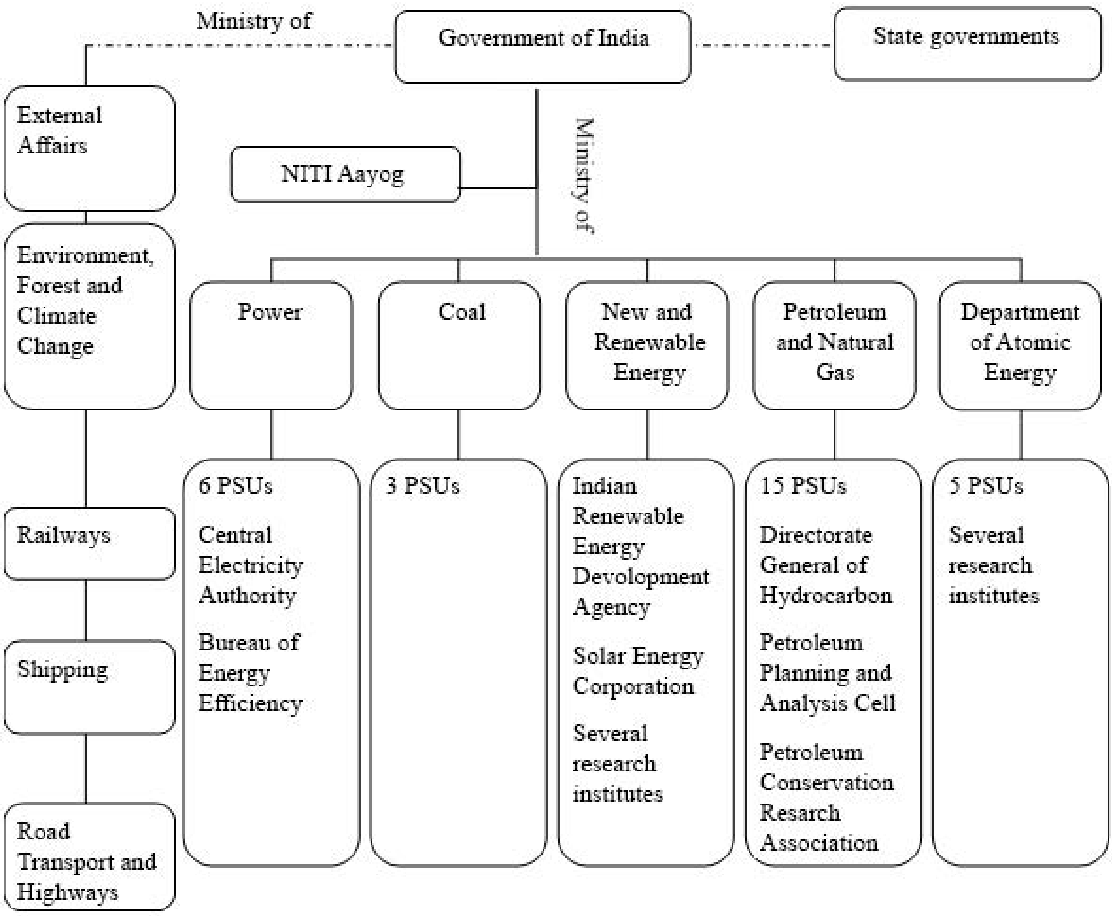
Regardless of the numbers and other states' reservations about this kind of energy as a result of accidents like the one in Fukushima in 2011, India still stands for developing its nuclear potential and capacity.

7.3 India's integrated energy policy

India is a federal state, consisting of 29 states and seven union territories or areas directly administered by the national government. Even though the Constitution of India divides jurisdiction between the central and federated governments by defining highly defined areas of competence (albeit in some matters the responsibilities are shared), there is some risk of duplication and inconsistencies when it comes to decision making. As Figure 7.1 shows, several ministries and entities are directly involved in energy policy and infrastructure, requiring substantial coordination efforts.

But this complex political and administrative structure has not impeded creating a coherent and consistent energy policy outlined in the 2008 Integrated Energy Policy (IEP), the National Action Plan on Climate Change (NAPCC), the coordination

Figure 7.1 – Main institutions in India with an influence on energy policy



In addition to these Ministries, the Ministries of Urban Planning, Water, Agriculture, Finance and Science and Technology are also involved in the electricity sector.

Source: IEA (2015e)

through the Planning Commission (now the National Institute for the Transformation of India Aayog (NITI Aayog)) and the National Determined Contribution (INDC) to the 2015 Conference of the Parties held in Paris (COP-21).

7.3.1 India's energy policy until 2006

India became independent in 1947 with an economic and developmental situation which was far from propitious. Jawaharlal Nehru as Prime Minister of the newly independent state, influenced by the Soviet model, adopted the so-called "Five-Year Plans" in 1951, as the framework for all policies adopted in India, including energy policies. Concerns were mainly about coal, oil and electricity supplies. Other issues such as energy-saving and efficiency only became a priority a few years later.

7.3.1.1 The coal sector

The coal sector is undoubtedly a prime focus of concern for India. It is the most controlled sector, with two large state-owned companies —the Government of India owns 80% of *Coal Indian Limited (CIL)* and 93% of *Neyveli Lignite Corporation Limited (NLC)*— managing around 90% of production.

The Ministry of Coal has responsibility for all aspects, including policies and strategies for exploration and development of reserves, production, distribution and supply projects and, in fact, for pricing. Several state governments also have significant, albeit limited, influence in this field.

In the early 1970s, the nationalisation of mining companies took place under the *Coal Mines (Nationalisation) Act 1973* aimed at ensuring rational and coordinated use and development. In 1976, captive producers or companies (public or private) were allowed to operate mines that required a significant and constant supply of coal. The production was only for self-consumption, and in the event of a surplus, this should be sold to CIL.

In 2000, prices were deregulated but not the distribution. The New Coal Distribution Policy (NCDP) was approved in 2007 to facilitate the supply of both core and non-core consumers at predicted prices (Ahn and Graczyk, 2012). However, the development of this policy has been hampered by legal supply obligations, subject to fines if not met, and the high price of imported coal needed to cover them.

In India, there is a market for long-term contracts and a market known as *e-auction* (or spot market). The two major mining companies (both national compa-nies) set the prices in the former. It also accounts for more than three-quarters of the production and is led by industrial consumers. Usually, electricity producers get a better price than other industries. The remainder is sold on the e-auction mar-ket at a considerably higher price, although lower than that of imported coal. This inequality between prices and the increase in imports undermine its long-term via-bility which is why there is a strong appeal to reform it. India contemplates moving towards an auction market in which all actors can participate and with prices in line with international ones (IEA, 2015e).

National production has not met the objectives of the Eleventh Five-Year Plan in recent years, what in turn, has caused moments of lack of supply at electricity generating plants. Furthermore, the quality of the product is worsening, and planning difficulties, environmental issues and doubts about expansion in production are halting the needed investments (Ahn and Graczyk, 2012). The prime solution given by experts to reverse this situation is the liberalisation of the sector. They also call for a technology-driven policy, notably clean carbon technology for electricity generation, and an improved extraction and transport infrastructure (Rao, 2011).

7.3.1.2 The oil industry

The discovery of oil in India was accidental. In 1886 the *Goodenough of McKillop Stewart Company* was drilling a well in Jaypore, Upper Assam, when it discovered oil. Three years later, it was the *Assam Railway and Trading Company (ARTC)* at Digboi who found oil.

The independence of India from the British Empire was a turning point in the oil industry. Before independence, only two companies produced oil: the *Assam Oil Company* in the north-east and the *Attock Oil Company* in the north-west. After independence, and knowing the importance of oil and gas for both industrial development and defence, India declared as a priority need the development of the oil industry in its Industrial Policy Resolution (IPR) of 1948 (Singh, 2010). The First Five-Year Plan (1951-1956) adopted by the Government of India opens the door to industrialisation. The Second Five-Year Plan, covering the period 1956-1961, established the Directorate of Oil and Natural Gas, subordinated to the Ministry of Natural Resources and Scientific Research. A few months later, the Directorate became the Petroleum and Natural Gas Commission and, in 1959, a statutory body by a Parliamentary act.

The IPR of 1956 classified the different industries into three groups by the government participation in them. It also envisages further involvement and cooperation (except in the sectors of air or rail transport, armaments, and nuclear energy) if judged appropriate at any time. The oil industry, along with coal and electricity generation and distribution, were included in the first category, i.e. their future remained solely in the hands of the Indian government (Government of India, 1956).

In those years, a delegation led by then Minister of Natural Resources, K.D. Malaviya, paid a visit to several European countries to study their oil industries and to facilitate training for Indian experts. Likewise, some American, German, Romanian and Soviet experts went to India to assist with this process. Of particular significance was the help of Soviet experts who drafted a geological and geophysical detailed plan for possible exploration. Drilling was conducted in Punjab, Cambay region and Brahmaputra valley in Assam. Further exploration studies were undertaken in the Ganga Valley (Planning Commission, 1961).

Over the next years, the Indian oil industry evolved at a remarkable pace until 1973, when the droughts, the oil crisis and the rising inflation brought it to a halt. The Sixth Five-Year Plan (1980-1985) included a specific section relating to energy. The document remarks the vital role of oil in all production activities, as well as its consumption rise in economic development. National energy policy was needed.

The key actions will be to accelerate exploitation of indigenous energy resources (coal, hydropower and nuclear), to manage oil demand, save energy, exploit renewable sources (forestry and biogas) to meet rural communities' energy needs, and lastly to strengthen new energy technology research and development (Planning Commission, 1980, chap. 15).

Government participation in the industry rose with the nationalisation of some private companies that were still operating in this field. But the Gulf War put an end to this strategy. The inflation rose while the foreign exchange reserves plummeted. To counteract these effects, India liberalised its economy. The exploration and production sectors opened to private investment. In 1997, the New Exploration Licensing Policy (NELP) was implemented. In April 2002, the dismantling of the administrative mechanism for setting oil prices (Singh, 2010), except for kerosene and LPG, was completed.

At the start of the 21st century, India announced its *India Hydrocarbon Vision 2025*, which sets out the guiding framework for hydrocarbon policies. With a high percentage of the energy needs covered by oil and gas and without sufficient indigenous production, energy security emerges as the main priority of the proposals. It also mentions a freer and more competitive market and more environmentally friendly product standards (Government of India, 2001).

Further liberalisation of the oil sector took place in 2006 when the Indian Parliament voted the Petroleum and Natural Gas Regulatory Board Act. The aim, according to the text, was to protect consumers' interests in this deregulated scenario by promoting fair trade and competition and by securing the adequate availability and equitable distribution of oil, oil products and natural gas (Government of India, 2006b).

7.3.1.3 Electricity and energy saving

Electricity was not regarded as a distinct sector for development until the Fourth Five-Year Plan (1969-1974). In the late 1960s, India understood that supply and demand balance had to be adjusted, and in 1974 it presented a report which suggested the replacement of oil with coal and an increase in electricity generation and transmission efficiency. It also proposed the establishment of an Energy Council to ensure the integration of the energy plan into the national strategy. Suggestions for balancing supply and demand continued in the report released in 1979 by the Energy Policy Working Group set up by the Planning Commission two years earlier (Dhanalekshmy, 2013).

The Inter-Ministerial Working Group on Energy Conservation (IMWG) was established in 1981. Its report of 1984 stated that the best way forward was to increase energy productivity and replace expensive (imported) energy with cheap (domestic) energy. India made this second point a priority (Dhanalekshmy, 2013).

But it was not until the 1990s that the Ministry of Energy set up a working group of representatives from different ministries to draft legislation on energy saving and efficiency activities. The Energy Saving Bill was approved in 1997. That year's Ninth Five-Year Plan (1997-2002) recognised that natural resources needed to be conserved and that the use of renewable sources should be encouraged (Dhanalekshmy, 2013). The subsequent five-year plans further promoted energy efficiency and energy savings in the various sectoral areas.

India has the status of being the first country to establish a ministry dedicated to renewables. In 1981, its government set up the Commission for Additional Sources of Energy (CASE) which became the Department for Non-Conventional Energy Sources (DNES) a year later. In 1992, it was transformed into the Ministry of Non-Conventional Energy Sources (MNES), and finally, in 2006, it was renamed the Ministry of New and Renewable Energy Sources (MNRE).

In 2003, MNES developed the Electricity Act, giving the first national boost to the development of renewable energies. The Act included preferential tariff elements and an obligation to purchase electricity generated by renewables for energy utilities, especially at the national level. This requirement forms the basis for the subsequent Renewable Energy Certificates. The 2005 National Electric Power Policy increased purchasing levels and introduced a public bidding mechanism. A year later, in 2006, the National Tariff Policy granted that the State Electricity Regulatory Commissions would set the minimum purchase percentage and specify a preferential rate for renewable energy in the states (MNRE, 2011).

7.3.2 Energy policy from 2006 onwards

2006 was an important year in the history of India's energy policy. In addition to the changes already mentioned, the Government of India proposed the current energy policy framework, which encompasses three clear objectives: energy security, access to energy and climate change mitigation. Overall, the ultimate aim is to satisfy energy demand in all sectors (including household demand). Supply must be reliable (without disruptions and sufficient to meet peak demand) and competitively priced. Moreover, production must use safe, clean and low-cost mechanisms as well as efficient and sustainable technology. This objective does not exclude the use of any energy source (conventional or non-conventional) or subsidies. It seeks an efficient and cost-effective energy system through a competitive market and coherent regulatory and fiscal schemes that guarantee a fair playing field for all actors. It uses direct aid to achieve social objectives and takes the "polluter pays" principle as a formula for tackling environmental impacts. It also offers many specific recommendations concerning the use of domestic resources (coal, renewable sources and nuclear), price (both for fuels and final energy), the reform of the electricity sector to attract private investment, the improvement of energy intensity through efficiency and demand-side management, and the development of R&D (Planning Commission, 2006).

In 2013, the former oil and natural gas minister Veerappa Moily announced that his ministry would work on an action plan to achieve energy independence by 2030. Yet, international actors, such as the International Energy Agency, have described it as very ambitious and unrealistic. His successor, Dharmendra Pradhan, who assumed office at the end of May 2014, reiterated that goal. Some of the proposed actions included increasing domestic fossil fuel production, developing resources such as methane and shale gas, acquiring overseas hydrocarbon reserves (upstream), reducing motor fuel subsidies and reforming oil and natural gas pricing systems. Besides these, there is the development and use of renewable energy sources (mainly solar and wind energy, as mentioned above) and energy efficiency (IEA, 2014b). Self-sufficiency is a recurrent principle in India's energy policies (Ahn and Graczyk, 2012).

The latest study of the IEA summarises India's principal domestic policy objectives and assumptions (existing policies and announced intentions) in seven areas. Table 7.3 lists them.

The long-term projections of various international organisations have been working for years on data for 2040-2050. In 2014 NITI Aayog launched the *India Energy Security Scenarios, 2047*. It is not a tool to make projections or closed estimates, but to create different scenarios based on energy demand (by sector) and energy supply (by source) data provided by the user. Identifying the most inefficient domain as well as knowing what percentage of imported energy (by source and in total) requires each scenario will facilitate (or is the objective) decision-making in energy security.

7.4 Security of supply and energy dependency

Each country's understanding of energy security varies according to its situation. Many definitions of the term exist, although the vast majority share three key elements: reliability of supply, affordability and sustainability. Two additional dimensions are availability and efficiency. In its Integrated Energy Policy (IEP) (2006), the Indian Government also interprets energy security in these terms. Energy supply is vital to the lives of all citizens, regardless of their economic status. It should be affordable (reasonably priced), secure and reliable (without supply disruptions and sufficient to cover peak demand).

Table 7.3 – Main energy policies for India

Sector	Policies
Cross-cutting policies	The National Missions linked to the 2008 National Action Plan on Climate Change, as well as the wind power targets.
	A continued levy on coal to support the National Clean Energy Fund.
Energy supply	Increase of fossil-fuel supply, notably of coal, in order to limit import dependence.
	Greater encouragement to private investment in energy supply.
	Faster bureaucratic procedures for energy projects.
Power sector	A strong push in favour of renewable energy, notably solar and wind power.
	Enhanced efforts to reach universal electricity access.
	Move towards mandatory use of supercritical technology in new coal-fired power generation.
	Expanded efforts to strengthen the national grid.
Transport	Fuel-efficiency standards for new cars and light trucks starting in 2016.
	Policy support for biofuels and natural gas, hybrid and electric vehicles.
	Promotion of the transport of goods by train.
Industry	Improving the manufacturing sector via de Make in India programme.
	Enhanced and promotion of efficiency measures.
Buildings	Urban planning and development in line with the 100 smart cities concept.
	Increase in the number of household appliances affected by mandatory standards.
	Incorporation of the building code in local and municipal by-laws.
	Subsidies for LPG as an alternative to solid biomass as cooking fuel.
Agriculture	Shift towards metered electricity consumption.
	Continued gradual reforms to energy pricing, promotion of micro-irrigation, groundwater management and crop diversification.

Source: Own elaboration from IEA (2015e)

However, the energy scenario is unsatisfactory. Two facts show that. The first is the gap between the demand and production figures. In 2013, while energy consumption was 775 Mtoe, production reached only 523 Mtoe. The second is the growth rate of each of these two variables: between 1990 and 2013, demand increased by almost 151% while production did not reach 79% rise. Bearing in mind the rising demand forecasts discussed above, the imbalance between the two will also increase.

7.4.1 Fossil fuels: production, dependency and emergency system

7.4.1.1 Production

India lacks the energy resources needed to meet the rising demand on its own. It has 0.6% of the world oil reserves, 0.4% of the world gas reserves (one-half of the recoverable reserves are conventional gas, and the other half is unconventional gas) and 7% of the world coal reserves (Planning Commission, 2006). A considerable but insufficient amount. The traditional perception suggests that coal is abundant, but experts warn of the dangers of this "myth". The 2006 energy policy already highlighted the false security that this belief can generate by not considering the final amount suitable to be extracted. The Eleventh Five-Year Plan (2007-2012) indicated that total coal reserves would support the rate of production for 140 years. However, mineable coal reserves (45%) would run out in about 45 years if the production increase remained at 5% per year. Therefore, it was essential to boost exploration and drilling (Planning Commission, 2007).

Since 2005, with the inflow of private capital, investment in energy supply has been increasing. Yet it remains insufficient to meet the challenges of growing demand. The IEA assessed that a cumulative investment of $2.8 trillion would be needed by 2040. Over 45% would go to electricity generation and another 30% to transmission and distribution. The remaining 25% ($696 billion) would be for the oil industry ($285 billion), gas ($212 million) and coal ($199 billion) (IEA, 2015b).

Table 7.4 – Indian production of PES 1990-2040 (in Mtoe)

	Coal	**Oil**	**N. Gas**	**Nuclear**	**RE**
1990	94	35	11	2	140
2000	131	37	23	4	155
2010	214	43	43	7	190
2020	298	35	32	17	237
2030	443	31	46	43	274
2040	648	31	75	70	297

Source: Own elaboration with data from IEA

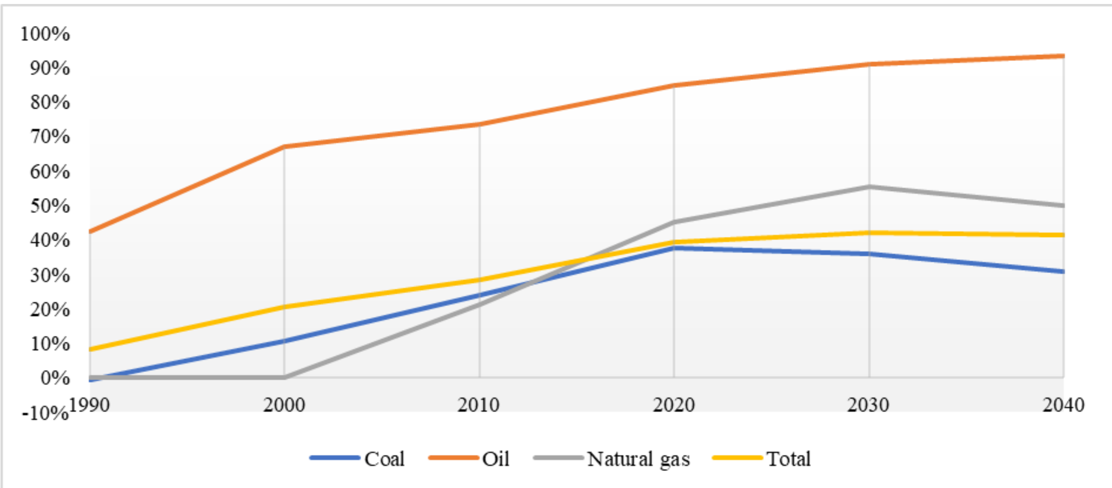
Over the past few years, estimates and projections of the energy balances of countries have been altered by the development of technology to exploit unconventional oil and gas. For states such as the United States, this possibility means switching from being an importer to an exporter. While this is not the case in India, it does not ignore its potential. Some studies indicate that methane coal reserves are at around 2.6 trillion cubic metres, but only 11% would be recoverable. As for shale gas, different studies provide different results in terms of the total value of the reserves, spread over the Cambay, Gondwana, Krishna-Godavari and Cauvery basins. In October 2013, India established guidelines for the policy on exploration and exploitation of non-conventional fuels by national oil companies. Work started in the Cambay Basin (MoPNG, 2015).

7.4.1.2 Dependency

Import-dependency affects all three fossil fuels, albeit in very different ways. As seen in the Figure 7.2, oil dependency far exceeds that of coal and natural gas and even doubles the country's average total dependency levels. The Figure also shows that natural gas dependency has increased sharply since 2003, while coal's upward trajectory has been steady. It is noteworthy, however, that the three fossil fuels have experienced similar dependency growth, close to 30%. More precisely, oil growth has varied by 33%, gas by 32% and coal by 28%.

The outlook for the second decade of the twenty-first century differs from this situation. Estimates suggest a steady total dependence of about 40%. Again, each fuel will behave differently. There is a continued, albeit slower, increase in oil dependence throughout the period observed, while coal and gas dependence levels drop, albeit at different times. While the decline in dependency on coal should begin in the next decade, gas will probably need another ten years of growth before it decreases.

Figure 7.2 – Dependency on fossil fuels 1990-2040 (in %)



Source: Own elaboration with data from IEA

India is one of the few countries to have a high oil dependence while exporting a significant number of refined products (IEA, 2015b). During 2013-2014, the country imported 75% of the oil and gas consumed and about a quarter of the coal. Concretely, over 189 million metric tons of crude oil and almost 17 million metric tons of petroleum products were imported (2.4% and 9.13% more than the previous year), nearly 13 million metric tons of liquefied natural gas (a decrease of 4.65% compared to last year) and almost 167 million metric tons of coal (14.45% more than in 2012-2013) MoPNG (2016). The IEA forecast suggested that India would become the world largest coal importer by 2020 (IEA, 2015e).

Table 7.5 – Imports and exports of fossil fuels (in Mtoe)

	Coal		Oil		Natural gas	
	Imports	**Exports**	**Imports**	**Exports**	**Imports**	**Exports**
1990	4	0	30	-3	0	0
1995	9	0	49	-4	0	0
2000	15	-1	85	-8	0	0
2005	26	-1	115	-24	6	0
2010	71	-1	185	-61	11	0
2013	101	-1	210	-71	15	0

Source: Own elaboration with data from IEA

Another characteristic of India's oil imports includes the concentration in a small number of states, especially in the Gulf, despite the substantial number of states from which it imports fossil fuels. According to UN (2017) data, the list of countries has tripled since the 1990s, surpassing, in recent years, one hundred. However, in 2013, more than 60% of India's oil imports came from Saudi Arabia, Iraq, Kuwait, Venezuela and Nigeria. 86% of the imported gas came from Qatar, Saudi Arabia and the United Arab Emirates. And an over 85% of coal imports were supplied by Indonesia, Australia and South Africa.

The increase in imports, in addition to the geopolitical implications, also affects the country's economy. Firstly, India uses part of the foreign exchange reserves to pay for them. Secondly, it increases the exposure to price volatility. Thirdly, India has to allocate more resources to mitigate the impact of high prices by of subsidies (Government of India, 2006a). For instance, oil and gas imports in 2013-2014 amounted to US$170-180 billion for the state coffers. With this in mind, India has stepped up efforts to exploit coal, oil and gas reserves but mainly structural problems have prevented the desired results.

7.4.1.3 The emergency system

A crucial issue in an energy dependency situation is how to respond to a supply crisis. Coal imports do not represent a risk in this respect as market disruptions are unusual. Moreover, a large volume comes from projects of Indian companies abroad (IEA, 2014a). As for oil, Indian companies are present in 25 countries and participate in oil and gas fields in South America, Africa, Southeast Asia and the Caspian

Sea region. However, most of the imports come from the Middle East (mainly from Saudi Arabia, Iraq, Iran, Kuwait and the United Arab Emirates for oil and Qatar for gas) where these firms have limited direct access to investment. To reduce the risks of supply disruption, the MoPNG advocates the creation of an energy corridor with Central Asia and the Middle East. It also recommends long-term supply contracts (MoPNG, 2015).

Due to the oil crisis of 1973, the consumer countries members of the International Energy Agency devised a response system based on the storage of strategic reserves equivalent to at least 90 days of net imports. In January 2004, India resolved to establish the Indian Strategic Petroleum Reserves (ISPR) system. In 2008, it approved to start the first phase of the project by building three reserves in Mangalore (Karnataka), Padur (Karnataka) and Vishakhapatnam (Andhra Pradesh) with a total capacity of 39.3 million barrels. In December 2011, MoPNG announced the second phase of the project: the construction of four more reserves in Padur (Karnataka), Bikaner (Rajasthan), Rajkot (Gujarat) and Chandikhol (Odisha) with a capacity of 92 million barrels. These should be completed by 2020.

The construction of the reserves is under the responsibility of the Oil Industry Development Board (OIDB). The Indian Strategic Petroleum Reserves Limited (ISPRL), owned by OIDB and managed by members of MoPNG and OIDB, was established for their implementation and management.

On the other hand, as mentioned above, natural gas has different prices in India according to its origin, resulting in various markets. Furthermore, the highest price corresponds to imported gas, which limits its demand. This fact explains why the concept of emergency or supply crisis in the gas sector is different from that in other countries, such as the IEA members IEA (2014a). There are virtually no natural gas storage facilities in India.

Indian industry is not obliged to maintain a minimum of reserves. Nor is there any measure to reduce consumption in a supply crisis.

7.4.2 Non-fossil fuels and energy efficiency

Due to their abundance (and wider geographical distribution as well), the lowering of operating costs in some cases (although they still need subsidies) and the concern for both security and the environment, the development of renewables is at a favourable moment. The experts anticipate a remarkable role for wind and solar photovoltaic energy in India's energy supply albeit both will have to face the problem of variability or intermittency of generation caused by factors such as wind intensity, seasonality, weak distribution networks or high peaks in demand at specific times of the day.

Nuclear power will also expand. According to the IEA forecast, by 2040 India's nuclear capacity will be sevenfold over 2014, becoming the second state with the most progress in installed nuclear capacity, surpassed only by China (IEA, 2015b).

An additional way for India to control its energy demand and the risks associated with energy security is energy efficiency. The *Perform, Achieve and Trade (PAT)* initiative, announced by the Indian government in 2008 under the National Mission for Energy Efficiency Improvement (NMEEE), part of the National Action Plan on Climate Change (NAPCC), aims to improve energy efficiency among large energy-intensive industries through certificate trading. The program establishes a specific energy consumption for each designated consumer based on the base year and the final year, which is verified by an accredited body. Consumers who have exceeded the required targets receive as many energy-saving certificates as metric tons of oil equivalent they have saved.

During the compliance period, consumers can negotiate certificates (fulfilled savings) or market "obligations" (based on future savings). If at the end of that time, the target has not been exceeded, the consumer can buy certificates from other consumers or satisfy a fee (CCAP, 2011).

Other sectors have different measures. Other sectors have different measures. For instance, SMEs benefits from financial support and awareness-raising measures; the transport sector profits from incentives for fuel-saving; and the construction sector have both an energy consumption code (Energy Conservation Building Code (ECBC), 2007) for commercial buildings and minimum consumption standards for household appliances.

The required annual investment in energy efficiency for end use is at nearly $60 billion. This requirement is a great challenge considering the different obstacles that each sector presents. The main challenges for consumer-intensive industries include reducing costs and the international environment. Medium and small enterprises face the problem of financing as well as the lack of knowledge, a problem they share with the residential construction sector. On the other hand, household expenditure on energy efficiency is relatively small in comparison with that on electricity (IEA, 2015b). Public aid for the adequacy and awareness of possible savings seems indispensable for energy security. Moreover, it will also help to combat another of the prime energy challenges of India's policy, that of energy poverty.

7.5 Energy poverty and the electricity sector

The Indian population is mostly young and resides in rural areas. Life expectancy is 66 years, 29% is under 15 years (in Spain this percentage is 15%), and only one-third of the total population lives in cities. These cities generate 63% of the country's economic activity. It is expected that, by 2030, almost half of the population will live in urban areas, which means more cities and more inhabited. By the 2030s, the biggest cities in India will outnumber many leading countries in terms of population (MoF, 2016). According to data from the Indian Ministry of Urban Development, the number of cities increased by 2,774 units over ten years, reaching a total of 7,935 in 2011. Of these, 53 had one million or more inhabitants, and another 412 had more than 100,000. As the population grows, the demand for each service will increase five to seven times.

7.5.1 Energy poverty in India

The most widely used definition of energy poverty refers to access to clean, affordable and stable energy services, which are reliable and of consistent quality. Two of the factors that directly affect a country's energy poverty level are the state of the electricity sector and the clean fuel consumption ratio. In India, the rate of growth of the electricity sector is one of the highest, according to the IEA's New Policies scenario, with an annual average of 4.4%. Electricity demand currently accounts for 15% of the total final consumption. However, some 240 million people, had no access to electricity (IEA, 2016b) and those who are connected suffer constant supply disruptions. Although electricity capacity has increased an annual average of 7.72% since 2006 (6.75% between 2013 and 2014) (MoSPI, 2015), electricity generation not only does not meet demand, but forecasts point to a worsening of the situation (Ahn and Graczyk, 2012).

Also noteworthy is the high use of traditional biomass. Different reports indicated that more than eight hundred million (66% of the population) use traditional biomass for cooking (IEA, 2015e). Despite these figures, the increased weight of commercial energy to the detriment of non-commercial denotes some improvement. According to the Twelfth Five-Year Plan (2012-2017), this change is the result of replacing traditional biomass (wood and animal waste) with clean fuels (Planning Commission of India, 2012). India has promoted, mainly through subsidies, the use of liquefied petroleum gas (LPG) as an alternative fuel for cooking (IEA, 2015e).

Although energy poverty is a global issue, there are differences between urban and rural areas, the latter being the most affected. Commercial fuels and electricity are predominant in the energy consumption of urban households. In the case of rural households, the main fuel remains traditional biomass. This difference may reflect the economic inequality between the two areas but may also be due to the lack of alternatives (areas without access to electricity). This deficiency results in the use of less efficient fuels and a higher energy consumption in relative terms.

A second major difference lies in the percentage of energy expenditure that residents in both areas spend on unclean solid fuels and kerosene. While less than a quarter of the urban population spends more than 50% of its energy expenditure on these fuels, in the rural areas, the population spends more than 80%. Simultaneously, rural households pay more for every unit of useful energy consumed. Prices can be as much as 35% higher (Ganesan and Vishnu, 2014; Bhide and Rodríguez Monroy, 2011).

Not surprisingly, the electricity sector shares importance in energy policies along with security and sustainability concerns.

7.5.2 Reforms and projects

From 1991, with the beginnings of economic liberalisation, the entry of private capital was allowed first in generation and distribution and, at the end of the decade, also in transmission. However, neither the efforts to accelerate investment through incentives (*Mega Power Policy 1995*) nor the subsequent constitution of the Central Electricity Regulatory Commission (CERC) or state commissions achieved the expected results. The electricity sector remained commercially unviable at the beginning of the 21st century.

The reforms led, however, to the promotion of rural electrification efforts. In 2001, the "Energy for All by 2012" initiative was launched. In addition to universal energy, the objectives set by the Ministry of Energy were to provide enough energy to increase GDP by 8%, reliable and high-quality energy, an optimal cost price and the commercial viability of the industry (Niez, 2010).

The 2003 Electricity Act continued to promote competition and non-discrimination in generation, transmission and distribution. The Act also removed the need for licenses for thermal and self-consumption generation. At the same time, it introduced stronger measures to control consumption and fraudulent use as well as financial support mechanisms for certain groups. It also required, as it has already been mentioned, the purchase of a certain amount of electricity generated by renewable energies.

The criteria used to define whether a zone is electrified have changed over the years. Until 1997, in order to determine whether a *revenue village* (a small administrative region with defined boundaries and which may include several villages) was electrified or not, it was sufficient to consume electricity within the administrative boundaries of the area. That year that requirement changed, stipulating that consumption must take place in the inhabited area. In 2004, two much more restrictive criteria were applied: on the one hand, a requirement for basic infrastructure (transformer and/or distribution channels) in the inhabited area, including a match between supply and demand in at least one village, and in any of the public sites/buildings; on the other hand, access to electricity must be available to at least 10% of all households. As a result of these changes, many areas considered electrified became part of the non-electrified areas (Niez, 2010).

The 2005 National Electricity Policy outlines the initiatives and programmes aimed at meeting the objectives of the 2003 Act. It includes aspects such as rural electrification, cost recovery and energy conservation. The 2006 National Pricing Policy focuses on strengthening the financial viability of the sector and making it attractive to investors.

In 2005, India launched the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) plan as part of the Electricity for All by 2012 initiative. Subsidised at 90% by the central government (the states would provide the remaining 10% through their own resources and/or loans from financial institutions) and implemented by the state-owned *Rural Electrification Corporation (REC)*, it aimed to provide electricity to all households (including those in rural areas) by 2009. An overambitious target. During the first years, the implementation process was too slow, consequently, the deadline was changed and new conditions were introduced to make it easier to implement.

Nevertheless, the implementation of RGGVY's plan was a turning point in efforts to provide electricity to rural India. State governments were obliged to develop rural electrification plans describing both the model to be followed (grid integration or autonomous systems) and the technologies available, their compliance with environmental standards, and the number of households that needed to be connected and their distance from the grid.

As a first option, an attempt was made to connect the households to the electricity distribution network. If grid connection was not feasible or profitable, then decentralised distribution and generation systems were chosen, fed by both renewable and conventional sources. As a general rule, they opted for the most efficient option with the lowest marginal cost. It also aimed to install at least one transformer in each village and provide a free service for all families below the poverty line.

In July 2015, the RGGVY was incorporated into a new scheme, the *Deen Dayal Upadhyaya Gram Jyoti Yojana Gram (DDUGJY)*, whose main objectives are the separation of distribution networks between agricultural and non-agricultural consumers to reduce load disconnection, strengthen local transmission and distribution infrastructure and improve metering (IEA, 2015b).

A second major initiative to fight energy poverty focuses on increasing the capacity of coal plants. It must not be forgotten that it remains the dominant fuel in electricity generation and although its weight will fall steadily over the next 25 years, it will still be over 50% in 2040. However, a large proportion of coal plants use inefficient generation technology which, combined with poor coal quality and the Indian climate, means that average efficiency is below 35%, less than that of the plants in China or the United States. The *Ultra Mega Power Projects (UMPP)* are inter-state projects of large coal plants (each plant with a minimum capacity of 4,000 MW) operating at temperatures and pressures above the critical point of water, which improves efficiency. On average, each coal plant's efficiency will increase from 29% in 2012 to 36% in 2040 (IEA, 2014b).

7.5.3 Further considerations

Alongside demand and generation capacity, the initiatives to achieve universal access to energy need to consider several other considerations related to infrastructure and investment in the electricity sector.

An electricity grid consists of three main elements: the generating plants (producing electricity), the transmission grid (carrying electricity from generating plants to demand centres where transformers will reduce voltage) and the distribution grid (carrying electricity to the final consumer). India's national electricity grid consists of five interconnected regional grid zones, each with different generating capacity and mix. The transmission lines represent only 5% of the length of the network. The rest are distribution lines. It is also characterised as one of the world's most lost-generating networks, driven, according to the IEA, by technical factors derived from age and poor maintenance, and by commercial factors, including theft, inaccurate consumption measurement and inadequate tax collection (IEA, 2015e).

It is essential to contain and, as far as possible, reduce the costs of generation, transport and distribution. The technology used by various sources may be costly and may require a large first investment effort, but it is justified by increased efficiency and reduced fuel expenditure. On the other hand, initiatives aimed at promoting the use of such fuels must take into account their future lower cost.

Among the possible options, India has shown great interest in what is known as the *Smart Grid*, "an electricity network that can intelligently integrate the actions of all users connected to it —generators, consumers and those that do both— in order to efficiently deliver sustainable, economic and secure electricity supplies" (MoP, 2019). To this end, in 2010 it created the *India Smart Grid Forum* (a public-private initiative).

In any case, the reform of India's electricity sector will depend, to a large extent, on the investments. According to the IEA's New Policies scenario forecast, the investment required for electricity supply in India between 2015 and 2040 would amount to more than US$2.1 trillion (at 2014 prices). Over US$1.25 trillion would be

Table 7.6 – Investment in electricity supply 2015-2040 (billion, 2014 US$)

	Cumulative	**Average Annual**
Generation	1268	49
Coal	354	14
Gas	66	3
Nuclear	96	4
Hydro	141	5
Other renewables	611	23
(Solar)	*364*	*14*
Transmission and distribution	845	33
Total	2113	82

Sources: Own elaboration with data from IEA.

spent on generation and another 845 billion on transmission and distribution. These figures are equivalent to an average annual investment of 49 billion and 33 billion respectively (IEA, 2015b).

To meet such investments, in addition to public funds, it is expected greater participation of the private sector at both national and international levels. India's size, growth potential and current context make it an attractive country for investors, although it is not risk-free. Therefore, the country is working to broaden the range of financing options and reduce the long-term cost through initiatives such as India's infrastructure debt funds or a foreign exchange hedge service (IEA, 2015b).

7.6 Climate change in India

The Article 48-A of the Constitution of India states that "[t]he State shall endeavour to protect and improve the environment and to safeguard the forests and wild life of the country". However, the emphasis of Indian governments on economic growth and poverty eradication has increased the degree of pollution and environmental degradation.

With the entry of the environmental issue on the international agenda, India is under constant pressure to take more concrete action for mitigation. The country needs to find ways to continue growing but sustainably.

Climate change gained prominence on the international agenda as India began to liberalise its economy. The aim was to develop industry and infrastructure in order to achieve the ultimate goal of economic growth. India's response to the Earth Summit

Table 7.7 – CO_2 emissions (in Mt and tons per capita)

	Year	India	China*	OECD	non-OECD	World
Coal						
	1990	396	1942	4142	4175	8316
	2000	629	2399	4216	4659	8875
	2010	1093	6009	4182	8923	13105
	2020	1713	7499	3659	11422	15081
	2030	2274	7570	2825	12500	15325
	2040	2907	7123	2195	13328	15523
Oil						
	1990	164	308	5030	3165	8815
	2000	266	594	5560	3548	9108
	2010	429	1004	5108	4693	10893
	2020	646	1410	4693	5972	11811
	2030	919	1745	4065	6895	12294
	2040	1221	1755	3556	7454	12489
Gas						
	1990	21	28	1928	1879	3807
	2000	42	124	2594	2062	4656
	2010	113	201	3050	3141	6192
	2020	156	549	3301	3999	7311
	2030	261	885	3584	5063	8672
	2040	390	1140	3776	6189	10024
Total emissions from fossil sources						
	1990	581	2278	11100	9219	20938
	2000	937	3117	12370	10269	22639
	2010	1635	7214	12340	16757	30190
	2020	2515	9458	11653	21393	34203
	2030	3454	10200	10474	24458	36291
	2040	4518	10018	9527	26971	38036
Total emissions from fossil sources per capita						
	1990	0,7	2,0	10,4	2,2	4,0
	2000	0,9	2,5	10,7	2,1	3,7
	2010	1,3	5,4	9,9	2,9	4,4
	2020	1,8	6,7	8,9	3,3	4,4
	2030	2,3	7,2	7,7	3,4	4,3
	2040	2,8	7,2	6,8	3,5	4,2

Sources: Own elaboration with data from the IEA. Population data from the World Bank database. *Includes Hong Kong.

in Rio de Janeiro in 1992 and beyond must be understood in that context (Kandlikar and Sagar, 1999).

India acknowledges its growing influence in global climate negotiations through its growing economic power, and that its participation is necessary to achieve a meaningful positive outcome in these negotiations. However, the India must weigh this objective against other national priorities, notably economic and social, including poverty reduction (Atteridge et al., 2012).

India's response to climate change has been marked by other concerns such as sovereignty, equity and economic development (Bisht, 2012).

7.6.1 The national approach

India's Environmental Policy of 2006 is a clear example of the position advocated. With its 2006 Environmental Policy, India declares its commitment to international efforts to combat climate change while defending the need to strike a balance between sustainable development and the right to human and economic development. It makes all members of society, whether natural or legal persons, public or private, national or international, responsible for success. As concrete objectives, it establishes conservation and efficiency in the use of natural resources; intragenerational and intergenerational equity; integration of environmental considerations in economic and social development; good environmental governance and improvement of human, technical and economic resources (MoEF, 2006).

In addition to the National Action Plan on Climate Change (NAPCC) adopted in 2008, to which we will refer later, the energy strategies presented by the Government of India aimed at both mitigation and adaptation. Mitigation strategies address the causes of climate change and require altering the current behaviour of certain practices that aggravate the problem. The concept of adaptation refers to the adoption of policies and practices to prepare conditions to cope with the effects of climate change. It is impossible to avoid and dictates societal accommodation (Meadowcroft, 2009; UN, 2016).

Among the first ones are those aimed at obtaining a cleaner and more efficient energy system, improving the energy efficiency of the industrial sector, adapting urban centres, recycling waste, transforming the transport network into a safe, clean and sustainable network, planned reforestation, reducing pollution and increasing private and civil participation. The attempts to create national carbon markets are an example. The Government of India launched the *Perform, Achieve & Trade (PAT)* initiative Under the framework of the National Mission for Greater Energy Efficiency (NMEEE). It affects 478 plants (designated consumers) in eight energy-intensive industrial sectors accounting for one-third of total energy consumption (MoF, 2016).

Adaptation strategies focus on agriculture, water, health, coastal areas and island, disaster management, protection of biodiversity and the Himalayan ecosystem, rural security, regional strategies, and knowledge management and capacity building. Developing countries are most affected by the effects of climate change as they rely heavily on natural resource systems for subsistence and have fewer resources to adapt to change (Meadowcroft, 2009).

Both mitigation and adaptation initiatives have their national investment fund. The National Clean Environment Fund (NCEF) relies mainly on carbon taxes introduced in 2010. Up to 2015, it had raised nearly US$2.7 billion, used in 46 projects. The National Adaptation Fund for Climate Change (NAFCC) is more modest. The US$55.6 million complement to sectoral spending by different ministries.

Other instruments that promote a cleaner energy model include the conversion of fossil fuel (gasoline and diesel) subsidy system to a tax system; the creation of tax-free bonds to finance renewable energy projects; and economic support from the central government to the different states in the area of reforestation.

7.6.2 The international approach

In the early 1990s, the Indian Non-Governmental Organization (NGO) *Centre for Science and Environment* challenged the results of the work of the *World Resources Institute (WRI)*. After measuring the current emission levels for the different states, the WRI identified India as one of the most polluting countries due to the number of methane emissions from rice cultivation. The NGO not only questioned the assumptions behind the calculations but also advocated a differentiation between "luxury emissions" (from northern [developed] countries) and "survival emissions" (from southern [developing] countries). It also recommended counting per capita emissions as well as noting historical responsibility (Michaelowa and Michaelowa, 2011).

India justifies differentiated and historical responsibility with three arguments. First, the Indian contribution to total greenhouse gas emissions between 1850 and 2000 was approximately 2%, considerably lower to 57% of the United States and the EU combined. According to India, this fact proves that developed countries have a historical responsibility that is not shared by countries, or at least not in the same proportion. The distinction between Annex I countries (industrialised countries) and Non-Annex I countries (developing countries) in the UNFCCC satisfied India on this matter (Michaelowa and Michaelowa, 2011).

Second, India ranks third on the list of most polluting countries since 2008. However, the emissions per capita are below the average of the most developed countries. In 2013, its emissions were 1.49 tons compared to 16.18 tons in the United States. The average per capita that year was 9.55 in the OECD.

Table 7.8 – CO_2 emissions (in % of total emissions)

Year	India	China	OECD	non-OECD	World
1990	3	11	53	44	100
2000	4	14	55	45	100
2010	5	24	41	56	100
2020	8	28	34	63	100
2030	10	28	29	67	100
2040	14	26	25	71	100

Source: Own elaboration with data from IEA. *The difference between the total emissions and the sum of the data offered is because international bunkers are not included

However, critics of both first arguments point to India's upward trend in emissions and reject the idea that limited past liability is an excuse for inaction. Furthermore, the assumption that India needs to increase emissions on behalf of the most disadvantaged population does not always correspond to reality, as it is often not these people who benefit from the projects undertaken (Dubash, 2009).

Third, India understands conditional technology transfer and financial aid from developed countries as a potential source of dependency that could lead to a loss of sovereignty (Bisht, 2012).

Over the years, India's attitude has been changing, relaxing or hardening, but it has always held developed countries accountable and argued for differentiation of responsibilities (Michaelowa and Michaelowa, 2011). It has also sought the support of other developing countries to create a common front in the multilateral negotiations (Bisht, 2012).

India signed and ratified the Kyoto Protocol in 2002 as a Non-Annex I country, so it was not obliged to meet specific emission reduction targets and it has been aligned with the Group of 77 (G-77) since the beginning of the meetings, with the BASIC group (Brazil, South Africa, India and China) since the meeting in Copenhagen in 2009 and with the Like Minded-Group of Developing Countries (LMDC) since the Durban Conference in 2011 (Embajada de India, 2016). However, its foreign policy interests have influenced its approach to climate change. The aspiration of India to become a global power and gain recognition as such, some concerns about regional security as well as its economic interests, have encouraged the search for a broader geopolitical alignment, particularly with the United States and China. And bilateral climate talks can promote state-to-state relations. Also, according to some experts, China's announcement in 2009 to reduce the intensity of its emissions sparked fears in India of becoming alienated from international talks (Atteridge et al., 2012). As a result, India developed a voluntary statement of targets to reduce the intensity of its emissions over GDP by 20-25% by 2020, compared to 2005 levels. Between 2005 and 2010, it had achieved a 12% reduction (2008).

India's willingness to further commitment, provided that it does not obstruct economic growth, can be seen in the adoption of the 2008 National Action Plan on Climate Change (NAPCC) (Michaelowa and Michaelowa, 2011). The NAPCC encompasses eight missions covering the areas of solar energy, energy efficiency, sustainable habitat (urban planning), water, the Himalayan ecosystem, forests, sustainable agriculture and strategic knowledge on climate change.

From an energy perspective, the first two missions stand out. One is supply-driven, and the other is demand-driven. The *Jawaharlal Nehru National Solar Mission (JNNSM)* aims to significantly increase the share of solar energy in the energy structure. Its goal for 2030 is to bring solar thermal energy into line with coal. The *National Mission for Enhanced Energy Efficiency (NMEEE)* aims at better management of consumption, mainly by the industry.

However, these missions are not without their critics. In particular, there is concern regarding their focus on adaptation rather than mitigation. Furthermore, there are doubts about the sustainability of the entire Action Plan because the commitment to reduce emissions stipulates not to exceed the per capita emissions level of developed countries (Bisht, 2012).

In preparation for the twenty-first Conference of the Parties to the United Nations Framework Convention on Climate Change in Paris 2015 (COP-21), all states submitted their national action plans. India's Intended National Determined Contribution (INDC) (Government of India, 2015) follows the same principles stated above. Under the title "Working towards climate justice", the text recalls India's limited historical contribution to the problem of climate change, the responsibility of developed countries and their inadequate response so far, and it rejects the assumption that developing countries should feel guilty for aspiring to fulfil their "right to grow". It also stressed the need for technology transfer from developed to developing countries, and in particular to India, yet this should not result in a market mechanism that favours the former.

It advocated an agreement based on climate justice, the principles of equity and differentiated responsibility. It should be comprehensive and responsive to the different areas of adaptation, mitigation, finance, technology transfer, capacity building, transparency and support, but safeguarding the genuinely necessary space for the development of developing countries such as India.

Of the eight measures presented in the INDC for the period 2021 to 2030, only three are concrete. The first is the continuation of the objective of reducing the intensity of its emissions over GDP presented in Kyoto. This time, the target is a 33-35% reduction from 2005 levels. The second measure aims to achieve a cumulative 40% capacity of non-fossil fuels in the electricity matrix. The third is to create a carbon sink of 2,500 to 3,000 million tonnes of $CO_{2\text{-eq}}$.

India also calls for funding and international technology transfer as well as staff training to meet climate change targets. Government estimates suggest that, between 2015 and 2030, India will need US$2.5 trillion (at 2014-2015 prices).

On technology, India is concerned about the cost of intellectual property rights and advocates global R&D collaboration to enable technology transfer free of this cost. It also advised covering these rights with a special allocation from the Green Investment Fund.

Chapter 8

Assessing the energy trilemma through the diversity of the energy mix: The case of India

8.1 Introduction

Sustainable development requires that the objectives of promoting growth, alleviating poverty and protecting the environment be reconciled. The planning of strategies to ensure sustainable development is a complex, ongoing process that must consider constraints such as budgets, conflicting purposes and technological limitations (Solangi et al., 2019). Consistently with the Brundtland Report, the term "energy trilemma" is used to describe the challenge of balancing three potentially competing goals: energy security, climate change and energy poverty.

According to the IEA (2007) price and physical availability are the main elements of energy security while the concentration of fossil fuel resources is the longest-lasting cause of energy insecurity as they are mostly in what the Agency describes as politically sensitive regions. The production and use of energy (mainly, but not exclusively, from fossil sources) has a negative impact on the environment. The effects of climate change will be devastating if that impact is not mitigated and effectively managed. Energy poverty, i.e. a level of energy consumption insufficient to meet certain basic needs (González-Eguino, 2015), is widespread and persistent (Dubash and Florini, 2011) and has become a widely recognised social challenge (Bouzarovski et al., 2014).

Although countries are currently developing and implementing strategies to transform their national energy systems into low-carbon energy systems (Rubio-Varas and Muñoz-Delgado, 2019), implementing policies to address all three objectives poses a major challenge as they cover areas whose demands (Gunningham, 2013) are perceived as competing. For example, Dubash and Florini (2011) warn of potential incompatibility between security of supply and climate change when there is a dependence on fossil fuels. Fossil fuel subsidies can help alleviate energy poverty and improve security by promoting the production of domestic resources, but they often increase insecurity by consuming a high percentage of public spending and forestalling investment in infrastructure (Gunningham, 2013); they may also increase emissions as they can encourage consumption and discourage efficiency (Ürge Vorsatz and Tirado Herrero, 2012). Renewables raise concerns due to their intermittent nature (Ang et al., 2015) and the effects of large-scale infrastructures on communities, indigenous peoples and the environment (Villavicencio Calzadilla and Mauger, 2018).

McCollumey and Riahi (2011) call for a more holistic policy approach, supported by a new generation of integrated decision-making tools. Abu-Rayash and Dincer (2019) claim that conducting a solid sustainability assessment is both wise and crucial before entering the implementation phase of new ideas. Quantitative analyses enable decision makers to understand the implications of different development paths, to explore contexts and limits, the consequences of doing nothing, the feasibility of achieving various objectives and goals and the implementation of different broad measures (Howells and Roehrl, 2012).

One important element to consider is that each country's situation is different so each uses its range and ratio of energy sources (which characterise a dynamic energy mix (Rubio-Varas and Muñoz-Delgado, 2019)) to meet the energy demand from users of energy services (Ranjan and Hughes, 2014). Diversity is closely associated with sustainability and precaution in energy strategies (Stirling, 1994), and is widely perceived as a powerful tool in assessing energy systems (Cooke et al., 2013). Best achieved through a combination of fuel sources with a preference for domestic supplies (Helm, 2002), it increases the choice of sources (supply-side), uses (demand-side) and competition (Lo, 2011) and is therefore essential for the long-term stability and survival of an energy system (Ranjan and Hughes, 2014).

Many very different attempts have been made to address the issue of assessing sustainability. Dutta et al. (2020) are among the authors who focus on clean energy stock indexes, while others such as Solangi et al. (2019) focus on how energy strategies are planned. A summary of the relevant literature can be found in Abu-Rayash and Dincer (2019). They analyse 19 studies and conclude that there are no universally adopted models or accepted sets of indicators, with some studies focusing only on one or two problematic areas. They also find that current assessment models may imply double counting when indicators are examined in greater depth. Similar conclusions are reached by Sun et al. (2020).

The same general conclusions can be applied to trilemma-related literature. Furthermore, researchers have adopted two main types of strategy. On the one hand there are qualitative/theoretical studies based on national energy legislation and policies (Holley and Lecavalier, 2017) from the viewpoints of energy governance (Gunningham, 2013) or energy justice (McCauley, 2018). On the other hand there are quantitative studies, which can be classified into two main categories: those that make projections (e.g. Stempien and Chan (2017)) and those that draw up descriptive, comparative analyses of countries. Among the latter, Heffron et al. (2015) assert that the energy trilemma can be resolved through energy justice. They develop an Energy Justice Metric (EJM) for China, the EU and the United States and for different energy infrastructures in the United Kingdom; the WEC produces an annual Energy Trilemma Index that ranks countries on their overall performance in achieving a sustainable mix of policies; Song et al. (2017) propose an interval decision-making problem and apply a Stochastic Multicriteria Acceptability Analysis to measurements of country-specific energy performance for the top 10 countries based on the 2015 Energy Trilemma Index.

This paper falls into the field of quantitative studies, though neither subcategory truly applies to it as it analyses only the case of India from 1990 to 2014 and does not seek to offer any projections or solutions. The study assumes two premises. First, it is essential to consider all three areas simultaneously if the goal of providing adequate, affordable, reliable access to energy within a framework that is environmentally friendly, socially acceptable and economically viable is to be achieved. "No one 'policy action' will have only a positive outcome and it is important to consider the potential negative outcomes" (Heffron and Talus, 2016a, pg. 4). As stated by Ang et al. (2015), energy security policies should be assessed from a sustainability perspective to avoid short-sighted policies that address short-term energy security but contribute to longer-term challenges. At the same time, sustainable energy policies must meet the precondition of energy security. In addition, both security and sustainability energy policies need to promote (or at least not hinder) access to clean, affordable energy for all sectors of society, and policies that aim to reduce energy poverty should not increase insecurity or harm the environment.

Second, the energy mix is identified as a common denominator, variations in which affect each area directly, so that it appears explicitly or implicitly in all discussions of the energy trilemma. As stated by Rubio-Varas and Muñoz-Delgado (2019), a varied energy mix can reduce the social and economic effects derived from risk contingencies and offer alternatives for responding to a possible interruption in the energy supply or a sudden increase in energy prices. It can also be an instrument for environmental purposes, as decarbonisation will require changes to the current energy mix. However, according to the said authors, if the energy mix is based on a domestically produced source(s) it could be counterproductive, as it could increase cost and dependency. Diversity has been used as an indicator to analyse different energy subjects, e.g. Chalvatzis and Ioannidis (2017) assess the security of energy supply in all EU countries using diversity indices and dependency metrics while Ioannidis et al. (2019) test energy diversity against energy intensity and emissions intensity to tackle the issues of supply security and sustainability.

This paper contributes to the literature by investigating the consequences of changes in a country's energy mix, (i.e. the diversity index (DI)) on each of the three energy trilemma issues (i.e. the security index (ESI), emission index (EI) and energy development index (EDI)) individually and simultaneously.

From an econometric perspective, regression analysis establishes the cause-effect relationship between variables, confirms the statistical relevance of diversity in the three pillars of the trilemma and analyses the cross-effects between all the variables. The procedure applied differs from others in that it considers the effect of the diversity of the energy mix on the three pillars both individually and simultaneously. Chalvatzis and Ioannidis (2017) also use diversity as a variable in their study, but their focus is energy security in EU countries. Moreover, all primary energy sources (PES) are considered, covering all sectors. Previous research has focused on fossil fuels, particularly in the energy security area (Lefèvre, 2010; Vivoda, 2009) and in renewables (Gielen et al., 2019).

The results of this analysis could help policy-makers and other actors understand the implications of implementing measures that favour one or more energy sources over others under a sustainability framework. This is of great relevance given the need to reduce dependence on conventional energy sources to sustain the environment (Solangi et al., 2019). They could also be useful to academics engaged in making projections to solve the energy trilemma as a complementary tool for testing their proposals.

The rest of the text is organised as follows: Section 8.2 presents the general methodology for constructing the variables and the data. Section 8.3 describes the econometric model and Section 8.4 sets out the results. Section 8.5 presents the discussion and conclusions.

8.2 Methodology

Indicators are widely used (see examples in Abu-Rayash and Dincer (2019) as proxy variables to quantify and analyse performance by providing useful information for analysis and policy design. Bazilian et al. (2010) identify three types used in the field of sustainable development and energy: single indicators, a set of individual non-aggregated indicators (or "dashboard") and composite indicators (CI). The latter are considered by Nussbaumer et al. (2012) to be the best suited to issues that require a framework in which various elements must be captured, such as sustainable development or poverty. They see composite indices as an attempt to overcome the shortcomings of one-dimensional indicators while producing a result that condenses information into a single, easy-to-interpret metric.

To build a CI, a comprehensive indicator framework is first selected, then weights are assigned to the indicators before they are aggregated. Sun et al. (2020) state that indicators are selected dynamically, depending on the user's perspective, and may be selected to meet specific needs and priorities.

8.2.1 Variables

For the research four composite indices are used.

8.2.1.1 Diversity Index (DI)

Diversity indices help to compare various energy supply structures within a country or between countries but also to analyse the evolution of such structures. Different indices use one, two or three factors, e.g. Jun et al. (2009) use the Hirschman–Herfindahl index (HHI) to analyse the cost of energy security in terms of supply disruption and price volatility in the Korean electricity market; the UK government DECC (2015) uses the Shannon–Wiener index (SWI) to indicate the diversity of supply of primary fuels and the diversity of electricity generated from different fuels; Skea (2010) and Yoshizawa et al. (2009) use the Stirling index (StI) to compare energy system diversity and to assess diversity with the aim of developing a specific diversity incentive in various countries. The most widely used are the so-called dual concept indicators, which combine two properties (variety and balance) in a single indicator (Cooke et al., 2013) although none of them can be described as the best index to use (Ioannidis et al., 2019). *Variety* can be defined as the number of options into which the quantity in question can be partitioned. All else being equal, the more varied a system is, the more diverse it is. *Balance* represents quantity across the relevant options, so the more equal the fractions are, the more even the balance is and the greater the diversity. By contrast, the dominance of a single option is inversely related to diversity. Stirling (1998), whose work has been recognised as significant and comprehensive in relation to energy systems (Cooke et al., 2013), includes a third property —*disparity*— , which represents the degree of difference between the intrinsic characteristics of the various options. It is important to take this property into account because ignoring the different levels of disparity between the options has a major effect on solutions for promoting diversity within an energy system (Skea, 2010).

The first question to consider is how to classify the energy system. There are classifications based on location, scale and ownership of supply facilities but, as Cooke et al. (2013) highlight, the primary method of structuring data collection is by type of fuel or primary energy sources (PES). This primary categorisation subsumes characteristics such as intermittency, flexibility, environmental risk, supply chains, technology maturity and import dependence.

The next step is to declare the values of variety, balance and disparity. The first two are simple mathematical statements. As can be worked out from their definitions, variety is the number of PES while balance is a calculation of their relative proportions. Disparity is a more complex concept, as it is inherently qualitative (Stirling, 1994) and related to the different nature and characteristics of each option (Rubio-Varas and Muñoz-Delgado, 2019), such as fuel sourcing or technology class (Skea, 2010). Disparity is also affected by variety. Cooke et al. (2013) affirm that, in general, the higher the number of options the greater the variety but the lower the average disparity. Thus, if there are two energy systems, one with two options (wind and nuclear) and the other with three (onshore wind, offshore wind and nuclear), the former would have a variety of two and a large disparity while the latter would have a variety of three and a potentially lower average disparity, as the difference between onshore wind and offshore wind is minor.

Stirling's basic equation for diversity measurement is:

$$StI = \sum_{ij(i \neq j)}^{N} d_{ij} p_i p_j \tag{8.1}$$

where:
N is the total number of PES
d_{ij} is the disparity between i and j
p_i is the proportion of i
p_j is the proportion of j

Variety is defined by eight PES types: Coal, Oil (crude oil and petroleum products), Natural Gas, Nuclear, Hydro, Other Renewables, Biomass and Electricity (imported). The ratio that represents (imported) electricity is too small, but it is included due its use to calculate the Energy Development Index (EDI).

Balance is the share of each PES in the total primary energy supply (TPES).

Disparity is quantified by taking the distance between two options for each individual attribute and combining them in n-dimensional Euclidean space using a conventional geometrical/sums of squares approach (Skea, 2010; Stirling, 2007). It is based on three characteristics:

1. Type of fuel: the physical form of each option. This addresses several infrastructure, environmental and other policy issues. The attributes are fossil (1), nuclear (0), renewable (-1) and imported (2).

2. Technology: the technological characteristics of the option. The attributes are steam cycle (2), combustion turbine (1), hydraulic turbine (0), other renewable (-1) and imported (-2).

3. Scale: linked to the system integration implications. The attributes are large (1), medium (0) and small (-1).

Given that there are eight options and that Euclidean distance is calculated by pairs of elements, there are 28 measures (i.e. 8!/2!(8-2)!)

$$d(p,q) = d(q,p) = \sqrt{(q_1 - p_1)^2 + (q_2 - p_2)^2 + \cdots + (q_n - p_n)^2} = \sqrt{\sum_{i=1}^{n} (q_i - p_i)^2} \quad (8.2)$$

where:
d is the distance (a min-max normalisation)
p,q is each possible pair of elements
$1 \ldots n$ are n characteristics of each element

The diversity index score is always between 0 (total concentration) and 1 (maximum diversity). All properties (variety, balance and disparity) are intrinsically related to each other and none of them is more important than any other.

8.2.1.2 Energy Security Index (ESI)

There is no unanimous definition of energy security (see the compilations by Sovacool (2011b) and Winzer (2012)). The definition in current use covers not just the traditional concern of security of supply but also a number of other aspects. References are often found in the literature to energy security in terms of availability/reliability, accessibility, affordability and sustainability. Extensive reviews of the evolution of the concept can be found in Cherp and Jewell (2014); Ang et al. (2015); Sovacool (2016) and Holley and Lecavalier (2017). The precise meaning of availability/reliability, accessibility, affordability and sustainability varies in different policies and within the literature (Holley and Lecavalier, 2017), but these are the same concepts that other authors, such as McCauley (2018), identify with the issues of the energy trilemma. This evidences a close link between them, but a broad definition may also lead to duplications of factors and erode the concept so that it becomes synonymous with broader concepts such as sustainable development (Kruyt et al., 2009) and therefore becomes the framework under which the other two areas are addressed. Also, as (Winzer, 2012, pg. 41) notes, "[a] narrower concept can more easily be quantified, facilitates the trade-off between different policy goals and can reduce the double counting of aspects that lie on the conceptual boundaries".

Kruyt et al. (2009) provide an interesting review of indicators used to measure energy security and identify import dependence as one of the most commonly used. In this paper the *ESI* is calculated by measuring India's primary energy demand (PED) using the Net Energy Import Dependency (NEID) index. The PED is calculated by assessing both domestic production and the net imports (defined as imports minus exports) of the sources.

The NEID index, established by the Asia Pacific Energy Research Centre (APERC) (APERC, 2007), is based on the Shannon Index. It reflects the impact of both diversification and imports. As observed by Kruyt et al. (2009), the specification of a fuel's role in the energy mix makes this indicator more refined than mere import numbers. The final value is between 0 (the country relies on domestic sources to meet its primary energy demand) and 1 (the country is highly dependent on imports).

$$NEID = 1 - \left(\frac{SWI_{importreflective}}{SWI}\right) = 1 - \left(\frac{-\sum c_i p_i ln_i \,/\, lnN}{-\sum p_i ln_i \,/\, lnN}\right) \tag{8.3}$$

where:
c_i is the correction factor for $p_i(c_i = 1 - m_i)$; m_i is the share of net imports in PES of i
p_i is the share of PES i in TPES
$i = 1 \ldots N$ is the primary energy source index (N is the number of PES)

8.2.1.3 Emissions Index (EI)

Environmental sustainability has become more prominent due to climate change concerns. It is frequently approached in terms of emissions, the preventing of waste emissions and promoting of renewable sources and the depletion of non-renewables (Ang et al., 2015; Holley and Lecavalier, 2017; Sovacool and Brown, 2010). Addressing climate change entails significant changes in consumer behaviour worldwide. It also affects the preference of some sources over others (Shaffer, 2009). Yet, while the promotion of renewable energies can reduce the need to import energy and they are generally more sustainable than conventional energy sources, they can also undergo issues related to system integration (IPCC, 2011), intermittency, operating costs and water and food safety Ang et al. (2015). Hence, assessment tools need to assess the short- and long-term effects on society, the economy, the environment and other elements (Abu-Rayash and Dincer, 2019).

The EI is calculated via the Emission Intensity Indicator (EII), which gives the level of GHG emissions (CO_2) per unit of economic activity (GDP). The EII is a function of two other major elements: energy intensity and the carbon factor:

$$\frac{CO_2}{GDP} = Energy\ intensity\ x\ Carbon\ factor = \frac{TPES}{GDP} x \frac{CO_2}{TPES} \tag{8.4}$$

Energy intensity indicates the ratio of gross domestic consumption of energy to gross domestic product (GDP). It reflects the level of energy efficiency and the overall economic structure of a country and is thus affected by economic and behavioural factors as well as by other country-specific issues. Energy intensity tends to be higher in developing countries due to their high levels of energy-intensive manufacturing industries (Baumert, 2005). In India, energy demand has grown at a slower pace than economic growth due, among other factors, to energy efficiency efforts (IEA, 2015b). Consequently, energy intensity has decreased over time and is now below the world average (IEA, 2020b), though there is still considerable room for improvement.

The carbon factor shows the carbon content of energy consumed (Baumert, 2005). Ang (1999, pg. 945) describes it as "the summation of the product of the fuel carbon emission factor (given by the carbon emission per unit of energy use) and the fuel consumption share over all fuel types". It can therefore be represented as follows:

$$\frac{C}{E} = \sum_i c_i \frac{E_i}{E} = \sum_i c_i p_i \tag{8.5}$$

where:
C is CO_2 emissions
E is the total primary energy demand or TPES
c_i is the carbon emission factor for fuel i
p_i is the share of PES i in TPES.

The result is a value between 0 (lower emissions intensity) and 1 (higher emissions intensity). The fuel with the highest carbon content is coal, followed by oil and gas. Changes in the carbon factor occur when there are changes in the fuel mix, and this is closely correlated with the indigenous endowments of countries.

8.2.1.4 Energy Poverty and the Energy Development Index (EDI)

The third issue of the trilemma, energy equity, has been studied from two different perspectives based on a distinction between developed and developing countries. This has provided two streams of definitions depending on whether the stress is on affordability (*fuel poverty*) or accessibility (*energy poverty*) (Bouzarovski, 2018). Fuel poverty is commonly defined as the need to spend more than 10% of household income on paying energy bills (Sovacool, 2015). Initially the focus was on heating, but the definition has broadened to include all energy uses (Boardman, 2012), such as hot water, electricity and other essential household needs (Castaño-Rosa et al., 2019). Energy poverty often refers to the problems of inadequate access to modern energy in developing countries, involving a range of economic, infrastructural, social equity, education and health concerns (Bouzarovski et al., 2014). Access to modern energy is often understood as access to a minimum level of electricity and to safer, more sustainable fuels and stoves for cooking and heating at household level, as well as access to modern energy to permit productive economic activity and the provision of public services at community level (IEA, 2020a). This is the concept utilised in this paper.

How to measure energy poverty has also been the subject of debate. Pachauri and Spreng (2011) identify three alternative but complementary approaches: (i) the technological threshold, focused on access to modern energy services and counting the population with no access to such services (e.g. the World Bank database); (ii) the physical threshold, focused on the minimum energy consumption associated with basic necessities (e.g. the IEA (2020a)); and (iii) the economic threshold, focused on the minimum or maximum percentage of income that it is reasonable to spend on energy (e.g. the 10% threshold, the 2M indicator, the Minimum Income Standard (MIS) indicator (Moore, 2012) and the Low Income High Costs (LIHC) (Hills, 2012)). Meanwhile, Meyer et al. (2018) set out a barometer of objective and subjective indicators under which *measured* energy poverty highlights excessive energy expenditure with respect to income and housing cost; *hidden* energy poverty highlights the existence of self-rationing practices; and *perceived* energy poverty seeks to capture the actual experience of being in a situation of energy poverty. Composite measurement approaches include the Energy Development Index (EDI) (IEA, 2012), the Multi-dimensional Energy Poverty Index (MEPI) (Nussbaumer et al., 2012) and the Energy Poverty Index (EPI) (Mirza and Szirmai, 2010). This study uses the EDI, for reasons of data availability.

The main indicators used in the calculation of EDI are household and community. The *household* indicator considers access to electricity (calculated as the geometric mean of the share of the population with access to electricity and per capita residential electricity consumption) and access to modern fuels. The *community* indicator is based on per capita public sector electricity consumption and the share of productive uses in total final consumption (the industry, transport, services, agriculture/forestry, and fishery sectors). To calculate per capita public services electricity consumption, the public sector's share in the services sector (the final consumption (percentage of GDP) by the government, expressed as a fraction of total value added from services in GDP) is multiplied by the electricity consumption of the service sector.

The final score is obtained by calculating the average of the averages for household indicators and community indicators, which gives equal weighting to each indicator. It can be expressed as:

$$EDI = \frac{Household + Community}{2} = \frac{\frac{\sqrt{(a*b)}+c}{2} + \frac{d+e}{2}}{2} \tag{8.6}$$

where:
a is the share of the population with access to electricity
b is the per capita residential electricity consumption
c is the share of modern fuels in total final residential consumption (excluding electricity)
d is the per capita public sector electricity consumption
e is the share of productive uses in total final consumption

The result is a value between 0 (lower energy development, i.e. higher energy poverty) and 1 (higher energy development, i.e. lower energy poverty).

8.2.2 Data

The study analyses how energy diversity affects all three issues of the energy trilemma in India for the period 1990 to 2014. India faces major energy challenges in meeting growing demand in an affordable and environmentally sustainable manner given, for instance, that it consumes more energy than it produces and is therefore an energy dependent country; coal remains the main source of primary energy (IEA, 2020a) and although the government has made progress over 210 million Indians do not have access to electricity (WB, 2020).

The beginning of the sample period is dictated by the availability of data. All the information related to PES is taken from the IEA (2016b) database. The CO_2 emissions data are taken from the Emissions Database for Global Atmospheric Research (EDGAR, 2015) and the economic data from the WB (2016) database.

There are four variables: the independent one is the diversity or composition of the energy mix (*Diversity Index (DI)*) and the three dependent variables are energy security (*Energy Security Index (ESI)*), climate change (*Emissions Index (EI)*) and energy poverty (*Energy Development Index (EDI)*). Each variable has a value in the range of 0 to 1. The calculations show the following:

India's Diversity: India's *DI* decreases over the years studied. This can be explained by the increase in the consumption of oil, coal (whose Euclidean distance is 0) and natural gas and the decrease in biofuels.

India's Energy Security: India's *ESI* worsens over the years, mostly driven by an increase in consumption (especially of fossil fuels), denoting the country's inability

Table 8.1 – Meaning of a value closer to 0 or 1

Index	Value closer to 0	Value closer to 1
DI	Concentration	Higher diversity
ESI	(b) More security (= energy independent)	(w) Less security (= energy dependent)
EI	(b) Less emissions intensity	(w) More emissions intensity
EDI	(w) Less energy development	(b) More energy development

Note: The (b) indicates an improvement and the (w) a worsening of the situation

to meet consumption needs through production, its growing energy dependency and the insufficiency of the measures adopted.

India's Emissions: India's emission intensity (*EI*, i.e. kilotons of $CO_{2\text{-eq}}$ per current US$) decreases over the years analysed. High economic growth, reflected in GDP, counterbalances the increase in emissions.

India's Energy Poverty: In the period studied the *EDI* increases, showing the positive results of the efforts of the Indian Government.

8.3 Econometric methodology

To estimate the cause-and-effect relationship between the *DI*, *ESI*, *EI* and *EDI* a regression analysis is proposed.

Once the strong relationships between all the variables are confirmed (which reinforces the premise that they must all be considered when implementing energy policies), the hypothesis that diversity of sources is statistically significant in energy security, emissions intensity and energy development was tested. To that end, the effect of diversity on the other three variables was calculated equation by equation. *DI* is the independent variable and the other three are the dependent variables. The following equation system was drawn up:

$$y_{1t} = \alpha_1 + \beta_1 x_t + \mu_{1t}; \;\; t = 1 \ldots T \tag{8.7}$$

$$y_{2t} = \alpha_2 + \beta_2 x_t + \mu_{2t}; \;\; t = 1 \ldots T \tag{8.8}$$

$$y_{3t} = \alpha_3 + \beta_3 x_t + \mu_{3t}; \;\; t = 1 \ldots T \tag{8.9}$$

where:
α_t is the independent variable: *DI*
y_1, y_2 and y_3 are the dependent variables: *ESI*, *EI* and *EDI*
β_1, β_2 and β_3 are the parameters to be estimated
μ_1, μ_2 and μ_3 are the error terms

The cross-effects between all these variables were analysed. The underlying idea was to see how changes in the *DI* aimed at improving one of the dependent variables (i.e. *ESI*) affected each of the other two (*EI* and *EDI*). The effect that these two other variables, *ceteris paribus*, have on the dependent variable analysed is also shown. To that end, the following system of equations was designed:

$$y_{1t} = \alpha + \beta_{11}x_t + \beta_{12}y_{2t} + \beta_{13}y_{3t} + \mu_{1t};\ \ t = 1 \ldots T \quad (8.10)$$

$$y_{2t} = \alpha + \beta_{21}x_t + \beta_{22}y_{1t} + \beta_{23}y_{3t} + \mu_{2t};\ \ t = 1 \ldots T \quad (8.11)$$

$$y_{3t} = \alpha + \beta_{31}x_t + \beta_{32}y_{1t} + \beta_{33}y_{2t} + \mu_{3t};\ \ t = 1 \ldots T \quad (8.12)$$

The simultaneity problem arises if one (or more) of the explanatory variables is determined together with the dependent variable, i.e. when the relationship is two-way or simultaneous between the endogenous variable, Y, and some of the covariables, X. In such cases it is better to consider the set of variables determined simultaneously, so in the system there is an equation for each of the jointly endogenous variables.

In a model of this type it is not possible to estimate the parameters of each equation without taking into account the information provided by the other equations of the system. If each equation is estimated individually, it is assumed that the explanatory variables are distributed independently of the random term and in this situation Ordinary Least Squares (OLS) estimators are biased and inconsistent. Thus, they are generally not as efficient as Seemingly Unrelated Time Series Equations (SUTSE) estimation, which uses Feasible Generalised Least Squares (FGLS) with a specific form of the variance-covariance matrix. SUTSE is, in fact, equivalent to OLS when the error terms are uncorrelated between the equations (so that they are truly unrelated). FGLS is a two-step method where the first step is to compute OLS using the residuals to estimate the elements of the variance-covariance matrix $\sum \{\sigma^2\}$. In the second step the model is estimated by Generalised Least Squares (GLS). The estimator is unbiased and consistent.

In the specification proposed, the effect of the diversity variable is allowed to be different in the three equations.

8.4 Results

As pointed out in Section 8.2, all indices are coded 0-1 but the meaning of the trends changes (see Table 8.1).

Table 8.2 shows descriptive statistics and the correlations between the variables considered. All correlations are significant at 5% and quite large. To check multicollinearity, the variance inflated factor and the condition number were computed. No multicollinearity problem was found.

Table 8.2 – Descriptive statistics and correlations of the variables used

	Descriptive Statistics		Correlations			
	Mean (SD)	Min/Max	DI	ESI	EI	EDI
DI	0.147 (0.00865)	0.129/0.159	1			
ESI	0.223 (0.0611)	0.129/0.336	-0.9848*	1		
EI	0.00189 (0.000578)	0.00107/0.00277	0.9023*	-0.9284*	1	
EDI	0.396 (0.0183)	0.371/0.429	-0.9918*	0.9898*	-0.9309*	1

Note: Critical value at 5% (two-tailed) = 0.3961

Table 8.3 shows the results of the first part of the analysis. The values of the R^2 coefficient reveal that the relationship between the *DI* and the remaining variables is high enough to be considered as one of the main factors in the changes in the variables studied. Many of the possible indicators (population, GDP, energy efficiency, etc.) were considered in compiling the different indices.

The results also show that diversity is statistically highly significant in all cases. The negative sign in the case of *ESI* and *EDI* means that an increase in the *DI* implies a lower *ESI* and *EDI*. For the *EI*, a positive value means that when the *DI* increases, so does the *EI*. In other words, the more diverse its energy mix the better India's energy security situation is, but the worse its emission intensity and its level of energy poverty are.

Table 8.3 – Regression model: DI as independent variable

Independent variable	Dependent variable		
	ESI	EI	EDI
coefficient	-6.95801***	0.06031***	-2.09800***
Std. error	0.24505	0.00576	0.05399
t - ratio	-28.39	10.47	38.86
R-square	0.96992	0.81416	0.98372
T	25	25	25

Note: Significance level: *(10%), **(5%), ***(1%)

Finally, the last part of the study analyses the variables jointly, i.e. it is postulated that the *DI*, *EI* and *EDI* are possible explanatory variables for the *ESI*. The analysis was performed for each of the dependent variables, with the explanatory variables adjusted according to each case.

The series analysed show a very strong trend, but it is well known that two time series with a stochastic trend may appear to be related when they are not, particularly when they have the same trend component (a common stochastic trend). In that case, the series are said to be cointegrated (Stock and Watson, 2011). To avoid this problem when estimating regressions between non-stationary series (in mean and/or variance) the trend must be removed. The variables are transformed here to make them stationary in mean and variance to mitigate this trend and its possible effect on subsequent joint regression analysis. To that end, the logarithmic rate of change is calculated, i.e.

$$\nabla \log (y_t) = \log (y_t) - \log (y_{t-1}) \cong \frac{y_t - y_{t-1}}{y_{t-1}} \tag{8.13}$$

where the logarithm makes the series stationary in variance and the differentiation makes it stationary in mean. Moreover, this transformation has a simple economic interpretation since it is an indicator of the relative growth of the variable. A test of the stability of the core variables to obtain reliable regression results is needed. We perform the unit root test using the approach of Dickey-Fuller (Augmented) and observe the p-value corresponding to the statistic, so as to judge whether the variable is stationary (Table 8.4). The p-values are lower than 5%, so the null hypothesis that the unit root exists is rejected, which means that the variables are stationary. Table 8.4 shows the results for the different equations with the log-differenced variables.

Table 8.4 – Seemingly Unrelated Time Series Equations (SUTSE)

Explanatory variables	**Dependent variable**			**ADF unit root test**		
	ESI	EI	EDI	ADF statistic	p-value	Test result
Constant	0.03420** (0.013)	-0.02574 (0.035)	0.00259** (0.001)			
DI	0.31464 (1.045)	-4.20304* (2.395)	-0.27944*** (0.075)	-4.50206	0.001821	stationary
ESI	–	0.936755* (0.466)	0.0175168 (0.0181)	-3.79154	0.003009	stationary
EI	0.16577* (0.082)	–	-0.01618** (0.007)	-6.01154	5.5410^5	stationary
EDI	220455 (2.273)	-11.50570** (5.179)	–	-4.05503	0.005063	stationary
R-square	0.03099	0.18128	0.34276			
T	24	24	24	23	23	23

Note: Standard deviation in brackets. Significance level: *(10%), **(5%), ***(1%)

In the first column, the *ESI* is considered as the dependent variable. The results show a change in the sign of the *DI* from that in Table 8.3, which means that now has a negative effect. Nevertheless, that effect is outweighed by a decrease in its significance (from very significant to not significant). Equally, the negative effect of *EDI* is offset by its non-significance. In fact, of the three variables considered as explanatory, only *EI* is statistically significant. This means that a rise in *EI* increases the import dependency of the country, which is consistent with the data, i.e. the increase in demand for fossil fuel has considerably increased imports. This also strengthens the argument that the use of renewables and clean technology to promote emission abatement enhances energy independence and thus increases energy security.

The second column shows the results for the *EI* variable. In this case all the variables considered have a significant effect, which is positive in the cases of the *DI* and *EDI* and negative in that of *ESI*. As in the previous case, the sign of *DI* changes and its significance decreases, making it the second most significant variable behind *EDI*, which, as already noted, measures access to clean, modern energy services. In this case too, the joint significance test shows that all three variables are jointly significant.

Finally, the last column shows the analysis for the *EDI*. Unlike the other two variables, here neither the sign nor the significance of the *DI* changes, i.e. this is the most influential variable and it maintains its negative effect, though that effect is attenuated by the positive effect of the *EI*, which is also statistically significant. Likewise, the joint significance test shows that all three variables are jointly significant.

8.5 Discussion and conclusions

Sustainable development means simultaneously addressing the issues of energy security, environmental sustainability and energy poverty (known as the energy trilemma). All three issues are rooted in the energy mix. Thus, the question is whether the diversity of the energy mix (*DI*) can be used as a watchdog in setting policies to address them. After analysing the situation of each area in India from 1990 to 2014, this paper uses a regression analysis to observe the effects of the (*DI*) on each of the three energy trilemma issues, (namely *ESI*, *EI* and *EDI*) individually and simultaneously.

The *DI* shows a concentration of India's energy mix due to increased consumption from fossil sources. This could initially appear as a negative aspect under the assumption that diversity is better than concentration. However, as noted above in the Introduction, diversity may also have its drawbacks, so to judge whether or not it is a good thing would be inappropriate at this point. On the other hand, the increase in fossil fuels is expected to have a negative impact on climate change and, potentially, on energy poverty. However, these variables indicate the opposite. The improvement in *EI* can be explained by economic growth (a key item in India's energy policy (Mohan and Topp, 2018)), surpassing and offsetting the increase in emissions. The result for *EDI* can be explained by the improvements in all the indicators considered in calculating it (see Section 8.2.1.4), especially those related to access (in households) and use (public services) of electricity. Electricity can be generated from any source of energy (fossil and non-fossil). Concerning *ESI*, India is a net importer of fossil fuels, so an increase in their consumption negatively affects its energy security.

The results of the equation by equation analysis reveal that if diversity increases, energy security improves but emissions intensity and energy poverty worsen. These results coincide (but inversely) with the notes above, i.e. they question the idea that diversity is better in all cases. Looking at India's energy policy one could argue at this point that its drive to promote fossil fuels (especially coal) has not had the expected effect on improving energy security but has had it on economic growth and, indirectly, on climate change (lower emission intensity) and energy poverty (increased electricity generation).

The cross-effects analysis shows a close relationship between the different variables, with diversity sometimes even being displaced as the most relevant one. For example, *EI* is the most influential variable in *ESI*, *EDI* in *EI* and *DI* in *EDI*. This also reveals changes in the sign of *DI*, so that the increase in diversity, which previously showed a positive effect, now shows a negative one (*ESI* and *EI*). This not only demonstrates the importance of considering all variables together, but also the importance of this study in considering the diversity of the energy mix as a monitoring element.

The negative effect of *DI* on *ESI* and *EDI* once again raises doubts as to whether a diverse energy mix is a positive thing. The above analysis suggests that India's drive to increase fossil fuel consumption led to more concentration but also to improvements in two of the problems of the trilemma. However, the positive effect of *DI* on *EI* (i.e. if diversity increases *EI* improves), the significance of *EI* on *ESI* (i.e. an improvement in *EI* would positively affect *ESI*) and the positive relationship between *EI* and *EDI* (i.e. each impacts the other positively to a considerable extent) suggest that India could perform better on the trilemma by increasing its use of renewables (accompanied by clean technologies).

This paper seeks to propose a new procedure for analysing the problem of the energy trilemma by quantitatively examining the effects of diversity, i.e. of the energy mix, on energy security, climate change and energy poverty both individually and simultaneously. As far as we know, it is the first and only approach to the problem in which all the relationships (direct and indirect) between the variables of interest are considered simultaneously. Comparing the results of the joint analysis with those of the individual analysis shows not only the relevance of such an exercise but also the potential for using it as a preliminary step for decision-making on policies that will result in a considerable change in the energy mix.

More studies are needed for deeper, broader implications to be drawn. As future lines of research it is suggested that other countries be analysed; that simple rather than composite indicators be used; that the proposed model be estimated both using the canonical Correlation Analysis (CCA) and allowing interrelationships between the non-observable parts of the model, which allows for the recording of more complex behaviour; and that dynamics be introduced into in the model through lagged covariates.

Part IV

Chapter 9

Conclusions and future lines of research

9.1 Main conclusions

The main conclusions drawn during the development of this thesis are detailed below.

∗ **The states prefer a "soft" global energy governance.**

The myriad approaches and schools of thought emphasize the plurality of actors (governmental and non-governmental) and the different levels of action (local, regional, national and international) in order to address the new challenges related to energy, whose repercussions extend beyond not only national borders, but also the ability of governments to manage them. In this context, global energy governance refers to the process of creating and implementing standards for international collective action in this field. This, in turn, implies defining the actors, the agenda, the negotiation of policy measures, as well as the application, control and compliance with the rules and agreements. However, the fact remains that governments continue to function as prominent international actors. As a result, there is little motivation to establish a supranational authority endowed with a system governed by what is as alluded to as hard law, i.e. legally binding and enforceable obligations. Instead, governments reserve that competence for themselves and demonstrate their proclivity towards soft-law arrangement, i.e. non-binding participation, as evidenced in Chapter 5. It is notable that the UNFCCC remains a treaty, and therefore binding, even if the text of its formation does not reflect this condition. Furthermore, states have opted to proceed from a binding agreement (the Kyoto Protocol) to a more flexible system, wherein states set their own goals and targets, despite the presence of rules that promulgate accountability and ambition (the Paris Agreement).

This anarchy, traditionally perceived in International Relations parlance as the lack of a supra-state body, does not signify chaos or misgovernment of the sector. Instead, it entails a complex system consisting of a plurality of multilateral organisations and forums, which endeavour, through cooperation, to address the different aspects related to energy by surmounting the constraints of its own birth —as well as the challenges arising from the overlapping of its functions —from fragmentation to dependency relationships. International organizations such as the IEA was founded not on the idea of achieving desirable energy governance, but on the conviction that cooperation in the field of energy should be institutionalised considering the indisputable failure of previous ad hoc collaborations, particularly on oil-related energy security issues.

∗ **Although international cooperation is necessary, the policies must be implemented at the national level, which is why it is essential to take their particularities into consideration. Equally, it is not feasible to design a single energy mix. Each state is responsible for the decisions concerning the utilisation of energy resources to meet its demand as well as to ensure compliance with international commitments.**

The diagram of the energy sector (Section 2.4.3) illustrates its international scope. The major current energy problems do not recognize the geopolitical boundaries established by humans. This implies that it would be futile to address them from a nation-state perspective. While it is indisputable that the international approach is vital, it is at the national level that the vast majority of initiatives must be carried out. Therefore, it is imperative to understand and include the specific geographical, social, economic and legislative characteristics of each territory, as well as the energy resources at its disposal. For instance, the IEA does not establish an identical energy mix for all Member States or restrict use to a particular type of source in the long-term strategy to ensure energy security and reduce oil dependence based on diversification. Instead, it sets out some common guidelines (the use of all alternative sources to oil as well as of carbon capture and storage technology) while each state is free to decide the composition of its energy mix with a view to meeting its needs.

In addition to subsidies, regulation or deregulation is one of the factors identified by experts as a possible influential cause on energy prices and, consequently, on the economic and social development of any country. Chester and Morris (2011) claim that the reform undertaken in the EU's electricity sector, i.e. its liberalisation or deregulation, has resulted in higher prices leading more households into fuel poverty. However, the analysis of the impact of the electricity sector's restructuring on industrial electricity prices and on the ratio of industrial to domestic prices, in 15 EU countries between 2003 and 2013 (Chapter 6) shows that although industrial prices are lower than household prices in all countries and at all times, reforms have typically favoured households to the detriment of industrial consumers. This could be possibly attributed to the fact that industrial prices are more open to market forces than household prices. However, the effects are not uniform across all countries; therefore, it is necessary to re-emphasise the significance of taking the specific characteristics of each country into consideration.

In fact, "permanent national sovereignty over resources is recognised under international law and its exercise is established under national constitutions" (Heffron et al., 2018b, pg. 40). Meanwhile, governments are required to balance national and international priorities and commitments.

∗ **Energy policies must be defined, considering their impacts on all three major energy issues (the energy trilemma) that global energy governance should address: energy security, energy poverty and climate change. Yet, this is one of the great challenges owing to the palpable lack of consensus on what concept means and implies as well as to their conflicting and competing interest.**

In broad terms, as Van de Graaf and Colgan (2016) posit, the scope of the GEG is any issue closely related to energy that goes beyond the national level. In reality, this is limited by the issues that make up the agenda of the concerned parties while complying with such requirements. Due to the diversity of actors (as already highlighted in Chapter 2, Section 2.5), these issues are not systematically understood in the same way, whether in number or scope. However, it is common to refer to three areas identified in this work as energy security, environmental issues primarily associated with climate change and energy poverty. The balance of these areas is referred to as the energy trilemma.

The design and implementation of policies aimed at addressing the three areas simultaneously poses a great challenge due to the lack of consensus as to the meaning and implications of each area on the one hand and, to their conflicting interests on the other hand. The disparity in meaning is especially notable in the case of energy security, which is reflected both in the studies that analyse the perceptions of the stakeholders and those that explore the temporal evolution of the concept. This, in turn, results in a large number of definitions and elements to be considered. A brief review of the temporal evolution of the concept has shown the manner in which its definition has been broadened to incorporate certain parameters as a result of historical events and the accompanying concern for issues such as the affordability and equity of energy services along with climate change, reaching the point of considering the entire energy system (every single possible aspect) as the goal of energy security, which would displace sustainability as the frame of reference for energy policies. This approach to the concept is neither shared by many authors nor in this thesis. Without denying the relevance of all the dimensions identified by the different authors in energy security, the study performed by Sovacool (2016) suggests that the key dimensions for energy poverty and climate change (especially in the first case) are considered less relevant than others, which would presumably dictate the path of energy policies. In order to achieve a good balance between the three areas of the energy trilemma, it is thus necessary to adopt a narrower definition so that each of the conflict areas can be considered as being of similar importance.

Climate change is ascribed to the excessive accumulation of greenhouse gases in the atmosphere. The difference in the definitions of climate change is premised on whether or not to include (e.g. UNFCCC and IPCC) the distinction between natural and anthropogenic causes. It is the latter that makes the difference with previous climate changes by radically accelerating the process. This threatens the biosphere's capacity to adapt and, consequently, our existence (as we know it). Climate change is responsible for global warming, rising sea levels, intensified tropical storms, reduced snow and ice, heightened intensity/frequency of extreme weather events, increased precipitation at high latitudes and decreased precipitation in the subtropics, as well as changing microclimates that have an effect on food production. In addition, these effects could lead to other unpleasant consequences such as increased insecurity of access to natural resources and a widening gap between the Northern and Southern regions.

Reducing greenhouse gas emissions is essential if the fight against climate change is to be won, but doing so at the right time and without hindering economic development is an onerous task. On the one hand, as evidenced in Chapter 5, despite the apparent interest of several states in finding solutions, the process of negotiation and promulgation of agreements, whether binding or not, is long and tedious, with major discordances between the parties who do not always adhere to the calendar. On the other hand, the results of the measures adopted (either through market mechanisms or through fiscal instruments) have not been able to meet expectations either with regard to environmental effects or in terms of equity, being considered as insufficient by some and inefficient by others. Decarbonisation (i.e. reducing carbon intensity), efficiency and changes in consumer behaviour are measures that could potentially reduce energy demand without compromising economic development. However, studies that have analysed the decoupling between emissions and economic growth point to the remoteness of such an objective. Efficiency gains, for example, are constrained by the so-called rebound effect, i.e. consumption increases due to perceived efficiency savings. In addition, the development of energy efficiency must also deal with many economic (arising from the market and other failures), institutional, organisational and physical barriers.

Energy poverty has conventionally been studied from two different perspectives following the traditional North-South distinction, i.e. developed and developing countries, thus providing two streams of definitions depending on whether the emphasis is on price (affordability) or access (understood as accessibility rather than availability). Although fuel poverty is typically the most common term that alludes to this precariousness in the first stream and energy poverty in the second one, some authors use the terms interchangeably while others prefer to find comprehensive definitions, for example, considering energy poverty in terms of justice. This is because regardless of where it occurs, this problem affects households based on their level of income and tends to exacerbate poverty, damage health, undermine equity and hinder social development.

Much of the efforts to combat energy poverty have focused on the development of electricity networks, which is an insufficient strategy. As seen in Chapter 2, Section 2.3.1, there are many reasons why electricity has become the preferred energy carrier since its commercialisation. From an economic viewpoint, they are distinguished for their high final conversion efficiency, productivity and flexibility. Other notable attributes include ease of delivery, cleanliness, absence of odour, ease of use and safety. Electricity can be generated from each and every PES and transformed into every single energy service, which denotes a clear advantage over the other energy carriers. However, the majority of the world's electricity continues to be generated from fossil fuels. As a case in point, it has been observed that in India, coal is still expected to account for 40% of electricity production in 2040. Changing this system or adapting it to the new demands of the fight against climate change is not an easy task. If production from fossil fuels is maintained, it would be necessary to develop a carbon capture and storage industry of immense proportions. If the change comes from generation through renewables, salient features of the electricity industry infrastructure would inexorably be affected. Moreover, any step towards a system based on nuclear generation would be required to overcome a number of socio-economic and technical obstacles. Also, as seen in Chapter 3 Section 3.4.3, in some cases people prefer getting energy services generated by other energy carriers although access to electricity is not a problem. In fact, it is pertinent to remember that one of the major elements of Reddy's definition of energy poverty is "lack of choice". The effort should, therefore, focus on providing clean and affordable energy services.

Today, it is difficult to envision an energy discourse that does not include at least two of the pillars of the energy trilemma. However, this has not been the usual practice, as can be deduced from the evolution of the concept of energy security. Coalescing key elements from the other areas implies that it was previously not considered necessary to relate to these areas. This individualistic approach entails the risk of developing policies that are beneficial for one area but harmful for another, since, as pointed out in Chapter 2, their needs and priorities do not always converge. Although the majority of identified trade-offs relate to energy security and climate change (e.g., the IEA initially favoured coal as a clear alternative to oil, outpacing other energy sources in terms of availability, ease of transport and experience in its usage), trade-offs between energy security and energy poverty, energy poverty and climate change, as well as between all three, mainly due to issues affecting energy prices (e.g., fossil fuel subsidies), have also been identified. Therefore, it becomes evident that the three problems need to be addressed in an integrated manner.

∗ **Although countries are currently developing and implementing strategies to transform their national energy systems into low-carbon energy systems, the "new energy transition" characterised by the (almost) exclusive use of renewable sources is far from happening. Therefore, the establishment of energy policies needs to take into account each and every energy source, along with its advantages and disadvantages.**

Using the energy mix as an indicator of the international, regional or national energy context is not uncommon. As Rubio-Varas and Muñoz-Delgado (2019) postulates, the energy mix is crucial in determining aspects such as energy efficiency, energy intensity, energy security and carbon intensity. In this context, the energy mix refers to the set of primary energy sources used to satisfy energy needs. It can be more or less varied and comprise of national and/or imported resources. The oil crisis of the 1970s highlighted the underlying weakness of the consuming countries' energy mix, (hardly varied and dependent on imports) so that the theory of diversity gained strength. A diverse energy mix can reduce the risks of supply disruption or uncompetitive pricing, catalyse the mitigation of greenhouse gases and offer local alternatives to isolated communities. However, diversity can also be counterproductive if, for example, the original energy mix mainly consists of one or more national resources (in this case, diversity implies importing resources that would increase cost and dependency).

In expounding the different energy sources (Chapter 2, Section 2.3), it has been established as to how their expansion has been linked to technological development promoted by development issues (e.g., coal with the steam engine and oil with the explosion and diesel engines) and/or safety issues (e.g., the development of gas after the 1973 oil crisis). However, if technological development was important with regard to the use of PES, it is central in the development of energy converters that, in turn, are key to the so-called energy transitions. These transitions meanwhile, are defined by a long-term major alteration of the energy mix accompanied by a long-term structural change in the energy system, which are both local (they do not occur simultaneously worldwide) and heterogeneous (they are not uniform in terms of the area of occurrence). Technical innovation, new energy markets and growing demand for more efficient, economical and flexible energy services are driving these changes. Yet, it also requires the willingness of a market to pay more for the services generated with the new technology and that the response of the usual suppliers must not discourage consumers from changing and adopting the new offer (e.g. improving competitiveness). For example, when studying the effects of reforms in the electricity sectors on prices, it has been observed that higher use of renewables increased electricity prices, possibly because, they were new technologies installed in the EU-15 electricity markets at least during the period analysed and with the exception of hydropower generation, and may not yet have taken full advantage of the high potential of scale and knowledge economies.

Renewable sources are perceived to be the best option for addressing the conflicting relationships between the three pillars of the energy trilemma and achieving the acclaimed transition to a low-emission energy system. These clean sources are geographically dispersed and inexhaustible. However, they also have some characteristics that can reduce or delay their implementation, such as their intermittence and the fact that it is used primarily in electricity generation (and some heat), so important sectors such as transport need a profound transformation to incorporate them. Also, it is essential to exacerbate the possible negative effects of large infrastructure on communities, indigenous populations and the environment. On the other hand, as York and Bell (2019) state, a real energy transition has never transpired and is unlikely to happen at least for quite some time, which is why it is imprudent to dismiss other energy sources. Of the three fossil sources, gas has certain characteristics that distinguish it from the group (for example, its competitiveness in electricity and heat production, and its low-emission performance). Therefore, it is considered a worthy companion to renewables. Nuclear energy also offers the advantage of being clean, but is fraught with certain shortcomings, such as waste, plant safety and security in the field of weapons development (in the case of fission) and the state of technology development (in the case of fusion). It is for this reason that its use remains modest. As far as fossil fuels are concerned, the international path endorsed is that of reducing (even completely halting) their consumption. For the moment thigh, they continue to be used, accompanied by technological advances such as capture and storage, as well as other market mechanisms adopted to control the emission levels.

∗ **Diversity can be a useful tool to assess the consequences that a substantial change in the energy mix will have on the three pillars of the energy trilemma simultaneously. The model developed can be used by policy-makers, stakeholders and analysts before any decision is made.**

The final part of the work has analysed the impacts of the diversity of the energy mix on the three pillars of the trilemma, both individually and simultaneously, using as a case study framework the data from India between 1990 and 2014. In energy terms, India is characterised as a fossil fuel importing (dependent) country, with high rates of energy poverty and greenhouse gas emissions (in non per capita terms). Primarily focused on economic development, the main element of its energy policy was to ensure the supply of coal, oil and electricity since its independence and until the 1980s. In the 1980s, energy had a specific section in the development plans, identifying as main elements the accelerated exploitation of national energy resources (coal, hydro and nuclear energy), management of oil demand, energy saving, the exploitation of renewable sources (forestry and biogas) to address the energy needs of rural communities, as well as the intensification of research and development of new energy technologies. From 2006, the ultimate goal of its energy policy is to meet energy demand in all sectors (including household) in a reliable (without cut-offs and sufficient at peak times), affordable (competitive prices), clean and efficient manner. Put differently, it entails tackling the three problems of the energy trilemma in an integrated manner. Not a single source of energy (conventional or non-conventional) is excluded.

Whilst confirming the thesis of the strong linkage between all the variables, the econometric model demonstrates that diversity (DI) is statistically significant for each of the other variables that measure energy security (ESI), climate change (EI) and energy poverty (EDI). Additionally, the analysis shows a positive effect of DI on EI, the significance of EI on ESI and a positive relationship between EI and EDI.

The results of the cross-effect analysis reveal interesting changes in significance and sign in DI in comparison to the individual analysis. This illustrates the relevance of conducting more comprehensive studies integrating all dimensions and prove the pertinence of the approach.

The findings also suggest that diversity is not always the best option.

In terms of the effectiveness of India's energy policies, the results confirm the manner in which the economic growth has been the priority for the country, as well as the insufficiency of the measures taken.

9.2 Future lines of research

The topic of this thesis is sufficiently broad, diverse, complex and interesting to be able to stimulate many more quantitative and non-quantitative research studies. Due to the changes in sign and relevance between the analysis of cross effects and equation by equation, coupled with the novelty of the model used in this work (the results could not be compared with those of other analyses), it is advisable to conduct further studies. As future lines of research, it is suggested that other countries be analysed (individually or by panel analysis); that longer time periods be studied, even incorporating projected scenarios; that different diversity indices be used to compare results; that simple indicators be used rather than their composite counterparts; that the proposed model be estimated using other correlation models and allowing interrelationships between non-observable parts, thereby enabling the recording of more complex behaviour; and that dynamics be introduced into in the model through lagged covariates.

These quantitative studies may be complemented by a more in-depth theoretical-descriptive analysis of the energy policies and initiatives from the perspective of diversity.

Appendix

Appendix A

La seguridad energética a través de la diversificación en los países de la OCDE

1 Introducción

La Agencia Internacional de la Energía constituye, desde hace más de cuatro décadas, un foro de coordinación de la política energética para sus miembros, convirtiéndose en uno de los principales actores de la gobernanza energética global. Fundada en noviembre de 1974 en el marco de la primera crisis petrolera, su mandato principal contiene un doble objetivo: promover la seguridad energética entre sus países miembros y proporcionar información fiable sobre la manera de garantizar una energía segura, asequible y limpia, tanto para los países miembros como no miembros.

El Acuerdo sobre el Programa Internacional de Energía (PIE) no sólo ponía de relieve la necesidad de diseñar un sistema de emergencia para una actuación inmediata en caso de una complicación en el suministro, sino también de situar las actuaciones de los Estados miembros en un horizonte temporal más amplio con el objetivo de reducir la dependencia del petróleo. Dos documentos —el Programa de Cooperación a Largo Plazo y Principios y Objetivos del Grupo en Política Energética aprobados en 1976 y 1977 respectivamente— desarrollarán el contenido de este nuevo campo de actuación. Medidas y áreas de actuación basadas en la diversificación de fuentes. la eficiencia y el ahorro energético, y en la investigación y desarrollo que han ido ganado relevancia al retroceder la percepción de crisis de suministro a corto plazo al estilo de las habidas en los años setenta.

La Agencia no establece un patrón idéntico para todos los Estados. Las particularidades de cada uno recomiendan adoptar el mix energético que cada cual considere más apropiado[1]. No obstante, gran parte de los esfuerzos de la Agencia se centrarán

[1] IEA, *Meeting of the Governing Board at Ministerial Level 15-16 May 2001 – Communiqué*, Paris, 2001.

en impulsar la búsqueda de fuentes alternativas a los combustibles fósiles (principalmente al petróleo) y en el desarrollo y uso de la tecnología de captura y almacenamiento de carbono para asegurar una transición "rápida" y serena a una economía baja en emisiones y a un futuro energético más seguro, sostenible y limpio[2]. El compromiso de los países miembros con esta estrategia quedó reflejado en el Capítulo III del Programa de Cooperación a Largo Plazo[3]. En él acordaron impulsar los programas nacionales y adoptar medidas de cooperación.

Este capítulo está dedicado a la estrategia de la AIE para promover la diversificación de fuentes y reducir la dependencia exterior del petróleo que caracterizaba a la mayoría de sus miembros[4]. Así, analizaremos cómo en los momentos iniciales el carbón fue impulsado como una de las alternativas al petróleo más al alcance de la mano, si bien su significación ha ido disminuyendo ante el avance de la agenda medioambiental. Por otra parte, el gas ganó también posiciones en la estructura energética de los Estados miembros, teniendo a su favor la menor generación de emisiones. Pero sin duda fue la energía nuclear la que contribuyó en mayor medida a atenuar el predominio petrolero. En último término, aunque las energías renovables formaban parte de los planes de diversificación desde el comienzo, veremos cómo tendría que discurrir más de una década para que comenzara a ganar peso entre las opciones energéticas.

2 Las fuentes fósiles alternativas

En los *Principios para una Política Energética* de 1977 se determinaron como objetivos generales de la diversificación energética el reemplazo progresivo del petróleo en la generación eléctrica mediante la promoción del uso y comercio de carbón, el desarrollo y promoción del gas natural (y las infraestructuras necesarias para su transporte) y la expansión de la capacidad de generación nuclear. Dado el estado del desarrollo tecnológico, la AIE apostó por el I+D energético con varios Acuerdos de Implementación sobre tecnologías para la diversificación energética. A ello se sumó la inclusión de proyectos de colaboración y el establecimiento de un clima favorable

[2]IEA, *Communiqué of the 2009 Meeting of the IEA Governing Board at Ministerial Level*, October, 2009.

[3]IEA, "Decision adopting the Long-Term Co-operation Programme", 29-30 January 1976, en R. Scott, *The history of the International Energy Agency: The first twenty years*, Paris, OCDE/IEA, 1995, Vol. III.

[4]La AIE entiende por fuente alternativa toda fuente que no sea el petróleo, incluyendo el resto de fuentes fósiles (el carbón y el gas natural tendrán un papel destacado) y la energía nuclear. En el debate político sobre el cambio climático se suele identificar fuentes alternativas con fuentes renovales más la nuclear, es decir, se habla de las fuentes alternativas a todas las fuentes fósiles.

a las inversiones energéticas que permitiera el flujo de capitales públicos y privados hacia el sector[5].

2.1 El carbón

En la época de la fundación de la AIE, el sector del carbón representaba la principal alternativa al petróleo debido a la tradición y experiencia. En un momento en el que la Agencia todavía no valoraba las cuestiones medioambientales, el carbón aventajaba a otras fuentes en su disponibilidad (existente en los países consumidores), su facilidad de transporte y la amplia experiencia en su uso. Por ello, la Agencia empezó a impulsar la utilización de carbón como principal combustible, tanto en la generación eléctrica como en el sector industrial; a coordinar el desarrollo de políticas de producción, exportación y consumo de carbón en los países miembros; y, por último, a elaborar políticas que solucionaran con anticipación los previsibles "cuellos de botella" de las infraestructuras.

Por otra parte, el discurso de que en poco tiempo la disponibilidad de petróleo, así como de otras fuentes de energía, a un precio razonable sería insuficiente si no se tomaban las medidas oportunas había tomado fuerza. En mayo de 1979, el Consejo de Gobierno de la Agencia adoptó los Principios para la Acción de la AIE sobre Carbón (*Principles for IEA Action on Coal*). Tomando como base el estudio *Steam Coal Prospects to 2000* y con una perspectiva a largo plazo en mente, se insta a los gobiernos a adoptar las políticas necesarias para el estímulo de inversiones en carbón. Las medidas debían satisfacer las necesidades particulares de cada Estado al tiempo que garantizasen el abastecimiento de los demás. También debían controlar el impacto medioambiental de la extracción, uso y transporte a niveles aceptables y reducir las incertidumbres de los inversionistas y de los mercados. Debido a la diversidad de los requisitos de cada Estado, la Agencia señaló la necesidad de que las medidas fueran adoptadas en un contexto de cooperación internacional y se propuso a sí misma como la mejor opción[6]. En el verano de ese mismo año se creó el Consejo Asesor de la Industria del Carbón (*Coal Industry Advisory Board (CIAB)*), que representa a un número variable de empresas de diferentes características del sector en los países miembros y no miembros (los representantes son nombrados por tres años) y que funciona como foro de consulta. En 1982, el Consejo estructuró el sistema de información sobre el carbón, que desde 1983 se materializa en la publicación anual *Coal Information*, trabajo de referencia para el sector en todo el mundo.

Pero la preocupación por el medio ambiente, sobre todo en lo relativo a emisiones de CO_2 a la atmósfera, vino a cuestionar la conveniencia del uso del carbón.

[5] R. Scott, *The history of. . .* , *op. cit.*, vol. III, pp. 79-90.
[6] R. Scott, *The history of. . .* , *op. cit.*, vol. III, pp. 220-222.

En la 6ª Conferencia Marco sobre Cambio Climático (COP6) celebrada en La Haya en noviembre de 2000, el CIAB manifestó su preocupación por lo que creía era un insuficiente entendimiento por parte de los gobiernos del potencial del carbón para garantizar las necesidades energéticas globales, así como por la posibilidad de que los proyectos relacionados con el desarrollo de tecnología para un carbón limpio quedasen excluidos de los mecanismos de flexibilidad del Protocolo de Kioto.

La no inclusión tendría, a su entender, efectos negativos sobre el desarrollo de las mismas y las emisiones de gases de efecto invernadero. El CIAB instó, tanto a la Agencia como al resto de participantes, a considerar al carbón no como el origen del problema, sino como parte integral de la solución. Ante estos supuestos apuntó que bajo los artículos 6, 12 y 17 del Protocolo ninguna fuente de energía debería ser excluida y recomendó adoptar diferentes medidas que permitieran controlar de forma eficaz las emisiones[7]. Años más tarde, las bases del discurso argumentativo siguen siendo las mismas: el reconocimiento de la importancia del carbón y del desarrollo de la tecnología ligada a un uso limpio del mismo[8]. Convertir el carbón en una fuente limpia de energía también es parte de los objetivos de los Acuerdos de Implementación (IA).

A pesar de los esfuerzos, en 2013 casi la mitad de las emisiones mundiales de CO2 (el 46 %) se debían al consumo de carbón[9]. El CIAB denuncia el escaso y lento desarrollo de las medidas relacionadas con un uso limpio del carbón y critica la posición de los gobiernos que continúan negando la urgencia de actuar contra las emisiones de CO2 y centran sus políticas en promover un cambio de recurso a favor del gas natural y de las fuentes renovables. Tampoco comparte la oposición pública contra la utilización del carbón. Considera que es resultado de una percepción errónea de que se puede satisfacer la creciente demanda energética mundial y los objetivos de mitigación del cambio climático al mismo tiempo que se reduce el uso de carbón. Esta oposición social motiva a los gobiernos a adoptar medidas que retrasan todavía más el desarrollo de las plantas de carbón[10]. La Agencia sigue apostando por el desarrollo del carbón como fuente alternativa, aunque acompañada de medidas que combatan los efectos de la alta concentración de gases de efecto invernadero y que garanticen un consumo más eficiente[11]. El lento desarrollo e implementación de la tecnología

[7] Coal Industry Advisory Board, *Efficient Coal Use*, *Energy Diversity*, *Effective Trading Mechanisms and Compliance. Views on Major issues to be debated at the 6th Conference of the Parties to the Framework Convention on Climate Change*, 2000, pp. 3-8.

[8] IEA, *21st Century Coal. Advanced Technology and Global Energy Solution, Paris, OECD/IEA, 2013.*

[9] IEA, *CO2 emissions from fuel combustion highlights 2015*, Paris, OECD/IEA, 2015.

[10] Coal Industry Advisory Board, International Coal Policy Developments in 2012, 2012, pp. 1-20.

[11] IEA, *World Energy Outlook 2015. Resumen Ejecutivo. Spanish Translation*, Paris, OECD/IEA, 2015, p. 7.

de captura y almacenamiento de carbono, no hace sino resaltar la necesidad de intensificar los esfuerzos en su comercialización, especialmente si se quiere alcanzar el reto planteado en la cumbre de París de limitar el incremento de la temperatura global en 1,5°C[12].

2.2 El gas natural

La utilización de gas en la generación de electricidad es atractiva por varias razones. Primero, es una fuente de energía muy flexible basada en una tecnología segura y económicamente viable. Segundo, el tiempo empleado en la construcción de una planta de gas natural es menor que el tiempo necesario para construir, por ejemplo, una central nuclear. Además, la producción de la planta es fácilmente adaptable a la demanda del momento, lo que también convierte el gas en un acompañante ideal de las energías renovables. Condición que se consolida porque el gas emite menos gases de efecto invernadero que otros combustibles fósiles, lo que incrementa su aceptación como fuente de energía en el contexto de la lucha contra el cambio climático.

Al igual que el carbón y la energía nuclear, la AIE declara al gas natural como una fuente de energía alternativa al petróleo en muchas de sus aplicaciones, especialmente en generación eléctrica. En pocas décadas, el gas natural se ha convertido en una fuente primaria imprescindible. Tanto el Acuerdo sobre el PIE[13] como el Programa de Cooperación a Largo Plazo (PCLP) marcan el proceso[14].

Durante sus primeros años de vida, la Agencia mostró un interés modesto por el gas natural. El punto de inflexión se produjo en 1979. Ese año, el Consejo de Gobierno acordaba "la necesidad de impulsar tanto la producción propia como el comercio internacional de gas natural" por ser el combustible alternativo más fácilmente disponible[15]. Sin embargo, la Agencia era consciente de que aumentar su consumo significaba incrementar las importaciones. Se corría el riesgo de cambiar la dependencia del petróleo por una dependencia de gas natural. En plena Guerra Fría, la inquietud por el predominio de la URSS como proveedor de esta fuente primaria de energía era manifiesta. Una preocupación que posteriormente se vio justificada. En 1990 y 1992 Moscú cortó el abastecimiento a las repúblicas bálticas para influir en el movimiento independentista, primero, y como represalia por tener que retirar sus tropas de la región, después. En 1993 y 1994, Rusia redujo el suministro de gas a Ucrania para obtener de ésta una mayor cesión en el control de la flota del Mar Negro.

[12] IEA, *World Energy Outlook 2016*, Paris, OECD/IEA, 2016, pp. 208 y 313.

[13] IEA, *Agreement on an International Energy Program* (as amended 9 May 2014), art. 42, https://www.iea.org/media/aboutus/iep.pdf.

[14] IEA, "Decision adopting the Long-Term Co-operation Programme", 29-30 January 1976, en R. Scott, *The history of...*, *op. cit.*, vol. III.

[15] Disponible en R. Scott, *The history of...*, *op. cit.*, vol. III.

En este escenario de necesidad y preocupación simultáneas, la diversidad de proveedores se consideró como una medida clave en la estrategia a seguir. La Agencia pidió tanto a los gobiernos como a las empresas que tuviesen en cuenta el factor seguridad a la hora de evaluar el coste total del suministro y de elegir proveedor. La seguridad del gas será entendida por la Agencia en términos de mercado[16]. Por otro lado, se entendió necesario adoptar protocolos de actuación ante posibles interrupciones que garantizasen el suministro de los países individuales y que evitaran la vuelta al uso de petróleo[17] y un retroceso al punto de partida. Las reservas estratégicas de emergencia de gas fueron calificadas por la Agencia en 2008 como un mecanismo ineficaz y caro[18]. En 2011 se habían convertido en un mecanismo valioso[19]. La única medida colectiva que podría ser utilizada sería, según apuntan algunos analistas, ajustar la respuesta de emergencia del petróleo (abrir las reservas) para paliar los efectos negativos en la economía de un país causado por una interrupción en el suministro de gas[20]. La Agencia optó por adoptar el papel de supervisor y coordinador en caso de necesidad[21].

En cuanto al futuro del gas natural, el mayor o menor incremento de su consumo dependerá de su accesibilidad y de su competitividad con respecto al resto de sectores. En los últimos años su consumo ha aumentado en las regiones que más ajustes deben hacer para reducir sus altos niveles de emisiones de CO_2 pero retrocede en otras regiones como la Unión Europea. Varias son las causas que generan dudas sobre el futuro del gas natural. Por una parte, una de las principales razones de la desaceleración en el crecimiento global de la demanda de gas se encuentra en los sistemas de generación de electricidad[22]. Los precios son competitivos, pero las políticas de eficiencia, la competencia con las renovables (y en algunos lugares también con el carbón) y la falta de inversión limitan su expansión[23]. Por otra parte, mientras la demanda se desaceleraba la oferta aumentaba, lo que indiscutiblemente ha afectado al precio, lo cual, a su vez, repercute en futuras inversiones. A esto hay que añadir los costes del transporte para países que no tienen grandes reservas a su alcance. Si se

[16]IEA, *Security of Gas Supply in Open Oil Markets*, Paris, OECD/IEA, 2004 en Arianna Checchi, Arno Behrens and Christian Egenhofer, *Long-Term Energy Security Risks for Europe: A Sector-Specific Approach*, CEPS Working Documents, n.º 309/January 2009, p.14.

[17]IEA, *Ministerial Statement and Conclusions on Natural Gas9 July 198. IEA/GB(85)46 and Annex I*, en R. Scott, *The history of ... vol. III*, *op. cit*, pp. 240-241.

[18]Paweł Jakubowski, Rafał Miland and Maciej Woźniak, *Energy supply crisis management mechanisms*, New Direction, Bruxelles, 2011, p. 18.

[19]IEA, *Gas Emergency Policy: Where do IEA Member Countries Stand?*, OECD/IEA, París, 2011, p. 4.

[20]Paweł Jakubowski, Rafał Miland and Maciej Woźniak, *op. cit*.

[21]IEA, *Gas Emergency Policy*, *op.cit.*, p. 4.

[22]IEA, *World Energy Outlook 2016*, Paris, OECD/IEA, 2016, p.162.

[23]IEA, *World Energy Outlook 2015. Resumen Ejecutivo. Spanish Translation*, Paris, OECD/IEA, 2015, p.6.

quiere promover nuevos proyectos de gas natural licuado (ya que se predice que el exceso de capacidad se acabe a mitad de la próxima década) para evitar la volatilidad de los precios, la industria necesitará reducir significativamente los costes.

Además, aunque la intensidad de carbono del gas es menor que la de cualquier otro combustible fósil, lo que le confiere cierta ventaja en la transición hacia un sistema energético decarbonizado, no es lo suficientemente baja como para adoptar un papel destacado de cumplirse con el objetivo de los 2 °C. Sin olvidar las dudas generadas debido a la incertidumbre del alcance de las fugas de metano a lo largo de la cadena de suministro[24]. Pero en el marco del Acuerdo de París que, con arreglo a los niveles de compromiso que encierra en la actualidad, rebasa todavía dicho objetivo, el gas —diferencia del carbón y también del petróleo, que sufren fuertes caídas en su peso específico— ve reforzado su protagonismo, siendo de gran importancia en la transición hacia escenarios climáticos más exigentes. De mantenerse los niveles de compromiso citados en el tiempo, el gas se habrá convertido, para 2035, en la principal fuente de energía en los países de la OCDE.

Quizás la mayor incertidumbre sobre la futura participación del gas en el mix energético global proviene del desarrollo de las explotaciones del gas no convencional. La rápida expansión de las exportaciones de este gas —en particular el gas de esquisto o *shale gas*— en Estados Unidos, hizo pensar en la posibilidad de una "edad de oro". Sin embargo, la oposición de algunos gobiernos y parte de la sociedad civil a la explotación de estos recursos debido a los posibles riegos medioambientes y sociales que la tecnología extractiva conlleva dificultan el proceso. Para solventar este problema, la Agencia desarrolló, en 2012, sus denominadas "Reglas de Oro", agrupadas en siete apartados que cubren aspectos como la transparencia, la responsabilidad, la tecnología o el compromiso medioambiental[25]. La adopción de estas medidas implicaría un incremento del coste de inversión, pero también tendría un impacto directo en la demanda, así como una alteración del orden geopolítico y comercial del gas[26]. En la actualidad el gas no convencional representa en torno al 60 % del crecimiento del suministro mundial de gas, pero su desarrollo fuera de Norteamérica sigue sin despegar.

En resumen, la actuación de la Agencia en el área del gas se centra en la recopilación y sistematización de datos sobre los mercados de gas, al igual que hace sobre los mercados de petróleo. En cuanto a la cooperación tecnológica, ésta se centra principalmente en reducir el impacto medioambiental. Así se refleja en los Acuerdos de

[24] IEA, *World Energy Outlook 2016*, *op. cit*., pp.161-163.

[25] Fatih Birol et al., "Golden Rules for a Golden Age of Gas", *World Energy Outlook Special Report on Unconventional Gas*, Paris, OECD/IEA, 2012, pp. 13-14.

[26] IEA, *Golden Rules for a Golden Age of Gas. Resumen Ejecutivo*, Paris, OECD/IEA, 2012, pp. 2-3.

Implementación sobre combustibles fósiles, que promueven, entre otras medidas, la captura y almacenamiento de carbono.

3 La energía nuclear

Aunque la mayor parte de la historia de la energía nuclear se centra en la energía nuclear de fisión, hace ya varios años que se investiga la energía nuclear de fusión, mucho más potente y limpia pero muy costosa y toda¬vía en un estado primario de desarrollo.

3.1 Energía nuclear de fisión

Cuando se fundó la Agencia Internacional de la Ener¬gía, la energía nuclear de fisión se consideraba, junto con el carbón, una de las alternativas al petróleo importado más prometedoras. En 1974, la energía eléctrica de origen nuclear ya se basaba en una tecnología madura, excepto en la cuestión de los residuos, y estaba asentada en muchos de los países de la OCDE. Al contrario que en el caso del gas, la preocupación por el suministro era casi inexistente ya que estaba garantizado por la existencia de abundantes reservas de uranio en los países miembros. Sí existían, sin embargo, importantes recelos sobre la seguridad de las plantas, el almacenamiento de residuos nucleares y la no proliferación de armamento nuclear. Aspectos clave que han marcado el desarrollo de esta energía a lo largo de los años.

Al igual que con otros elementos de la política energética a largo plazo de la AIE, la energía nuclear cuenta con un primer reconocimiento y apoyo en el Acuerdo PIE, el cual incorpora todos los temores anteriormente mencionados y la necesidad del uso de la energía nuclear y la potenciación de la cooperación tecnológica sobre el enriquecimiento de uranio[27]. Una diferencia con otras fuentes de energía es el reparto de competencias, ya que la AIE no es la única organización encargada de la energía nuclear ligada a la OCDE. Mientras que la AIE se centra en las cuestiones políticas desde la adopción del Programa de Cooperación a Largo Plazo en 1976, la Agencia para la Energía Nuclear (AEN) gestiona los aspectos técnicos y tecnológicos. La AEN fue creada en 1958 y a ella pertenecen todos los miembros de la OCDE, excepto Nueva Zelanda y Polonia.

A pesar de las diferentes posturas nacionales sobre el uso de energía nuclear (todavía presentes) explícitamente recogidas en las Conclusiones de la reunión ministerial de 1977[28], el Programa de Trabajo sobre Energía Nuclear de la Agencia[29] arrancó

[27] IEA, *Agreement on an International Energy Program…*, *op. cit*.

[28] R. Scott, *The history of the International Energy Agency: The first twenty years*, vol. II, Paris, OECD/IEA, 1994, pp. 186-187.

[29] Disponible en R. Scott, *The history of…*, *op. cit*., vol. III, pp. 243-246.

en 1978 con la intención de evaluar la capacidad de esta energía para contribuir a la sustitución del petróleo y al cumplimiento de los objetivos generales de la AIE. Pero los accidentes nucleares de Three Mile Island (Estados Unidos) en 1979 y de Chernóbil (URSS) en 1986 supusieron dos serios reveses. Su potencial, las negativas consecuencias de no usarla y el compromiso de mejorar la seguridad[30] no consiguieron acallar las dudas sobre la seguridad, la gestión de los residuos y la contaminación medioambiental frenando su desarrollo. Aun así, la Agencia no cesó en sus esfuerzos. A principios de los 90 volvió a insistir en la "sustancial contribución" —real y potencial— de la energía nuclear en el conjunto del suministro energético de los Estados miembros[31], tanto para reforzar la seguridad energética como para reducir las emisiones de los gases de efecto invernadero[32].

Ante las proyecciones que indicaban un continuo descenso de generación de energía nuclear, la Agencia propone en la "Estrategia a Medio Plazo: 1997-2000" dos objetivos: por un lado, mantener su competencia en cuestiones de energía nuclear pero sin que eso significase una injerencia o duplicidad en las competencias de la Agencia de la Energía Nuclear o de la Agencia Internacional para la Energía Atómica y, por otro, evaluar las oportunidades y consecuencias de la eliminación gradual de plantas nucleares no deseadas.

En diciembre de 1997, el Grupo Asesor de Alto Nivel perteneciente a la OCDE centrado en el análisis del Futuro de la Agencia de Energía Nuclear le traspasa al Consejo de Gobierno de la Agencia un informe en el que destaca la total afinidad con la inclusión de la energía nuclear en el abanico de posibles herramientas para combatir el cambio climático y conseguir un desarrollo sostenible. El Secretariado, aunque de acuerdo con el informe en principio hizo, sin embargo, un par de matizaciones preocupado por el ámbito competencial de cada Agencia: en primer lugar, remarcó la diferencia entre "hechos" y "política" y cómo era necesario una difusión de los hechos para conseguir un consenso social antes de comenzar el debate sobre objetivos y políticas concretas. Esta tarea de difusión era competencia de la Agencia de la Energía Nuclear y necesitaba ser analizada para conocer su éxito o fracaso y el porqué de este. En segundo lugar, la política nuclear no podía ser tratada de forma aislada, sino dentro del debate concerniente a todo el mix energético, por lo que las competencias de ambas Agencias no debían alterarse. El Consejo de Gobierno respaldó la idea de que era la Agencia Internacional de Energía el mejor foro para el debate sobre la política nuclear[33]. Dos años más tarde, durante la actualización de la Estrategia a medio

[30]Véase R. Scott, *The history of… vol. II.. op. cit.*, pp. 188-190.

[31]Comunicado del Consejo de Gobierno, 3 Junio 1991, párrafo 13. Disponible en R. Scott, *The history of…, op. cit.*, vol. III.

[32]Este argumento es clave, por ejemplo, en la Hoja de Ruta Tecnológica – Energía Nuclear. IEA, *Technology Roadmap – Nuclear Energy*, Paris, OECD/IEA, 2010.

[33]Véase R. Scott, *The history of… vol. IV.. op. cit.*, pp. 209-210.

plazo, ese mismo órgano modificó los objetivos planteados evitando las recomendaciones que expresamente relacionaban la energía nuclear con el medioambiente o los protocolos de Kioto. Prefirió una formulación más ambigua, haciendo referencia a "cuestiones sobre energía nuclear, de acuerdo con los Objetivos Compartidos de la AIE"[34].

Pero el impulso a la energía nuclear consecuencia de la preocupación por las emisiones de gases de efecto invernadero del sector eléctrico, la seguridad del suministro de energía, así como la necesidad de un suministro eléctrico asequible con costes de producción estables se vio de nuevo moderado por las secuelas de la crisis financiera (2008-2009), la posterior crisis económica y por el accidente de la central nuclear de Fukushima Daiichi (PNP) en marzo de 2011. Aunque la situación comienza a mejorar, la cantidad de energía nuclear utilizada sigue siendo demasiado baja para cumplir con el propósito del Acuerdo de París de mantener el crecimiento de la temperatura global por debajo de los dos grados Celsius. En 2014, la electricidad total generada por la energía nuclear suponía el 11 % con una capacidad instalada de 398 GW[35]. Para lograr ese objetivo, la capacidad instalada debería ser, en 2050, de 930 GW y representar el 17 % de la generación mundial de electricidad[36].

La Agencia sigue apostando claramente por una tecnología que, aunque no necesite de grandes innovaciones tecnológicas, sí precisa de un desarrollo continuo para mantener su competitividad, de inversiones principalmente en el perfeccionamiento de los recursos humanos, de la implantación de sistemas de almacenamiento y tratamiento de los desechos radioactivos en los programas de desarrollo nuclear, así como del refuerzo de los sistemas internacionales de seguridad. Y, por supuesto, del apoyo gubernamental y social.

3.2 Energía nuclear de fusión

En contraste con la tecnología de la fisión nuclear, la tecnología de la fusión nuclear está lejos de su desarrollo pleno, aunque ofrece a priori un gran potencial como fuente energética inagotable, limpia y segura. Es prácticamente inextinguible porque usa hidrógeno obtenido del agua del mar y litio. Es limpia porque no produce gases de efecto invernadero, ni combustible gastado altamente radioactivo. Además, estudios teóricos han mostrado que el reactor de fusión es, en contraste con el reactor tradicional de fisión, inherentemente seguro, ya que cualquier incidente conduce a la paralización de la reacción en cadena[37]. El problema con la fusión nuclear es principalmente tecnológico, e indirectamente también económico, ya que la investigación

[34] *Ibídem*, p. 211.
[35] IEA, *World Energy Outlook 2016*, *op. cit*.
[36] IEA, *Technology Roadmap – Nuclear Energy*, Paris, OECD/IEA, 2015.
[37] IEA, *From ITER to power plants - the roadmap to fusion power*, Paris, OECD/IEA, 2006.

necesita la construcción de grandes reactores de prueba, lo que requiere una inversión elevada y un compromiso de décadas. La esperanza está en que la energía de fusión sea comercialmente viable a partir de 2050 (aunque desde sus comienzos, la fecha proyectada se ha ido retrasando a medida que se acercaba).

El Comité de Coordinación de la Energía de Fusión (FPCC por su sigla en inglés) es el encargado de supervisar los Acuerdos de Implementación destinados a la investigación y al desarrollo en diferentes ámbitos de la energía de fusión y que tienen una importancia directa en el desarrollo de proyectos como el ITER y de programas como el "más allá de ITER". El proyecto de colaboración internacional ITER en el que participan China, la UE, India, Japón, Corea, Rusia y Estados Unidos, consiste en la construcción de un reactor de fusión nuclear basado en la tecnología Tokamak, una tecnología avanzada que cuenta con una esperanza de vida operativa de veinte años. El programa "más allá de ITER" se centra en las plantas de energía de fusión, el desarrollo económico, el medioambiente, la seguridad y los aspectos sociales de la energía de fusión. La Unión Europea, Estados Unidos y Japón son los miembros de la AIE que financian prácticamente la totalidad de la investigación en tecnología de fusión a nivel global[38].

4 Energías renovables

La medición de la participación real de las energías renovables en el mix energético de los países presenta una serie de retos estadísticos por lo que con frecuencia quedan infrarrepresentadas en los informes[39]. Las incertidumbres políticas, los retos económicos, las reducciones en los incentivos y la competencia de otras fuentes de energía afectan negativamente a las inversiones necesarias. Por otra parte, algunos países y regiones tienen dificultades al tratar de incluir las renovables en sus redes eléctricas. A pesar de lo dicho, los fundamentos para el desarrollo de las renovables continúan siendo sólidos. Las energías renovables están ganando en competitividad, si bien necesitan de un mercado y de políticas favorables a la inversión[40]. Desde 1990, las renovables han experimentado, a nivel mundial, un crecimiento anual medio del 2,2 %. En el caso de la OCDE, el consumo total de energía primaria a partir de fuentes renovables ha aumentado a un ritmo anual medio del 2.6 %. Por otra parte, la diversificación en el uso final de la energía generada a partir de renovables se ha traducido en un ligero descenso en cuanto a su participación en la generación de electricidad.

[38] IEA, *From ITER to…*, *op.cit.*, p. 4.
[39] IEA, *Renewable Energy. Medium-Term Market Report 2013*, Paris, OECD/IEA, 2013, p. 23.
[40] *Ibídem*, pp 14-16.

La mayor parte del crecimiento de las energías renovables ha tenido lugar en los sectores residencial, comercial, industrial y transporte[41].

4.1 El desarrollo de las renovables: una larga trayectoria

La búsqueda de fuentes alternativas al petróleo, incluidas las renovables, forma parte de la agenda de la Agencia desde el principio. Para cuando en 1976 y 1978 se firmaron los nuevos Acuerdos de Implementación (IA) centrados en el uso de la energía solar (en sistemas de calefacción y refrigeración), del hidrógeno, de la bioenergía y de la energía eólica, la tecnología relacionada con las renovables de primera generación (hidroenergía, geotermal y combustión de biomasa) hacía décadas que se utilizaba. En 1982, se creó el Grupo de Trabajo sobre las Tecnologías de las Energías Renovables (o el Grupo de Trabajo sobre las Energías Renovables como se conocerá después), integrado en el CERT, que se convertirá en la voz de la Agencia en cuanto a tecnología de las renovables tanto dentro como fuera de la organización[42].

El primer impulso notable a la utilización de las ener¬gías renovables en el marco de la Agencia se produjo en 1985. En la reunión ministerial celebrada en julio de ese año, el Consejo de Gobierno reconoció la importancia de las energías renovables en los balances energéticos de algunos Estados miembros e insistió en la importancia de impulsar la investigación y su desarrollo para reducir su coste y alcanzar su potencial en el medio y largo plazo[43], siempre respetando las particularidades de cada uno[44]. Con los años y los avances tecnológicos, las renovables se han convertido en fuentes primarias de energía mucho más atractivas, debido, fundamentalmente, a su sostenibilidad medioambiental.

A pesar de la voluntad de los países miembros de potenciar el uso de las renovables, en la "Estrategia a Medio Plazo: 1997-2000", la Agencia advertía de que las políticas de los Estados contenían restricciones competitivas y financieras, por lo que estableció dos objetivos. El primero hacía referencia a seguir impulsando los Acuerdos de Implementación para lograr la diversificación de fuentes y reducir las emisiones de gases de efecto invernadero. El segundo se basaba en la transferencia de tecnología a los países en vías de desarrollo. Un año más tarde, al elaborar la actualización de la estrategia para los años 1999 y 2002, la Agencia modificó el primero

[41] IEA, *Key Renewables Trends Excerpt from: Renewables information 2016*, Paris, OECD/IEA, 2016, pp. 3 y 6-8.

[42] IEA, *Mobilising Energy Technology*, Working Party on Renewable Energy Technologies, Paris, OECD/IEA, 2006, pp. 35-36.

[43] IEA, *1985 Communique. International Energy Agency. Meeting of the Governing Board at Ministerial Level*, Julio 1985. Disponible en R. Scott, *The history of…*, *op. cit.*, vol. III, p. 412.

[44] IEA, *Ministerial Recommendation on Electricity, Coal, Nuclear Power and other Energy Sources*, en R. Scott, *The history of…*, *op. cit.*, vol. III, p. 216.

de los objetivos y eliminó el segundo. La promoción de las renovables se veía ahora afectada tanto por cuestiones medioambientales como de seguridad energética. También incidió en la necesidad de estimular los mercados mediante incentivos[45].

Al final de los años 90, el Grupo de Trabajo sobre las Tecnologías de las Energías Renovables y el Secretariado crearon la Unidad para las Energías Renovables con sede en la oficina central de París. Su principal objetivo era estimular el mercado global de la tecnología tanto para las renovables como para la distribución de otras fuentes alternativas. Al finalizar la cumbre del G8 del año 2000 en Okinawa, la Agencia, el Grupo de Trabajo y la Unidad, junto con otros agentes, participaron en la formación de un nuevo Grupo de Trabajo sobre Energías Renovables del G8 para elaborar una serie de recomendaciones que serían presentadas en la siguiente cumbre[46]. El interés de la AIE se reafirmó tras su participación en la Cumbre Mundial de Johannesburgo sobre Desarrollo Sostenible de 2002. Desde ese año, la Agencia cuenta con la publicación anual *Renewables Information*.

Además de los diferentes grupos o sectores internos dedicados exclusivamente al ámbito de las renovables, la AIE coopera sistemáticamente con la Industria a través del Consejo Asesor para la Industria de la Energía Renovable y con la Agencia Internacional de las Energías Renovables (IRENA) desde su fundación en 2009[47]. La AIE considera su trabajo como complementario y no competitivo con el de IRENA. Una diferencia fundamental entre las dos organizaciones se halla en sus misiones principales, a su vez consecuencia de sus diferentes orígenes. Mientras la AIE se estableció como un club de consumidores de petróleo con pocos Estados miembros, IRENA nace en el seno de la ONU e incluye a 101 miembros y otros 59 que han solicitado su adhesión[48]. Para la AIE, las renovables son un elemento del mix energético que puede servir para aumentar la seguridad energética de sus miembros y reducir la pobreza energética en los países en vía de desarrollo. Por el contrario, las renovables acaparan todos los esfuerzos de IRENA. Basado en un acuerdo bilateral de 2012, el área de cooperación principal es la de estadística y recopilación de datos, pero IRENA y sus Estados miembros también participan en algunos Acuerdos de Implementación sobre energías renovables.

[45]Véase, Craig S. Bamberger, *The history of the International Energy Agency: The first thirty years*, Paris, OCDE/IEA, 2004, vol. IV, pp. 211-212.

[46]IEA, *Mobilising Energy Technology*, Working Party on Renewable Energy Technologies, Paris, IEA/OCDE, 2006, p.36.

[47]Véase http://www.iea.org/aboutus/faqs/renewableenergy/

[48]Se puede ver una lista en http://www.irena.org/Menu/Index.aspx?mnu=Cat&PriMenuID=46&CatID=67

4.2 Principios para unas políticas efectivas

En 2008, en apoyo al Plan de Gleneagles del G8, la Agencia elaboró un informe titulado *Deploying Renewables: Principles for Effective Policies* en el que se analizan los resultados de las políticas sobre energías renovables adoptadas entre los años 2000 y 2005 en los sectores de electricidad, calefacción y transporte. Para cada sector se analizaba la situación de diferentes tecnologías renovables. En el sector de la electricidad se incluían la eólica, la biomasa, el biogás, la geotérmica, la solar fotovoltaica y la hidroeléctrica. En la generación de calor se valoraban el calor de la biomasa, la energía geotérmica y la energía solar térmica. Por último, el etanol y el biodiesel se reservaban para el sector del transporte.

Entre los diferentes métodos posibles que la Agencia podría haber elegido para realizar el estudio, la organización decidió utilizar uno en el que se combinan factores de eficacia y eficiencia. Su "indicador sobre la eficiencia de las políticas" se calcula dividiendo la cantidad de energía renovable generada durante un año determinado entre la cantidad adicional que se podría generar si se alcanzase el potencial calculado a medio plazo para 2020.

$$\frac{Incremental\ \ RE\ \ generation\ \ (year)}{Remaining\ \ midterm\ \ 'realisable\ \ potential'\ \ (by\ \ 2020)}$$

El potencial alcanzable se calcula ajustando el potencial tecnológico a largo plazo con las restricciones inevitables en el medio plazo como, por ejemplo, las tasas máximas de crecimiento del mercado. El potencial a medio plazo para cada tecnología de energía renovable dependería de los recursos del país y de su desarrollo tecnológico.

Con esta fórmula, la Agencia quería minimizar los sesgos al comparar Estados de diferente tamaño, desigual situación de desarrollo de las energías renovables y variados niveles de ambición de las políticas, teniendo en cuenta los recursos disponibles[49]. Una primera conclusión a la que llegó la Agencia es que sólo un número limitado de los países estudiados había implementado políticas de apoyo al desarrollo de las renovables con resultados eficaces. El mejor escenario correspondía a la energía eólica. Ocho países de los treinta y cinco analizados habían conseguido, durante esos años de estudio, impulsar esta fuente de energía[50].

Para la Agencia, el éxito de las políticas adoptadas, según su indicador de eficiencia, se basaba en la coexistencia de tres factores: el nivel de ambición política expresada en los objetivos establecidos; la presencia de un sistema de incentivos bien diseñado; y la capacidad de superar las barreras no económicas que pudiesen impedir

[49] IEA, *Deploying Renewables. Principles for Effective Policies*, Paris, IEA/OECD, 2008, pp. 15-16.
[50] Ibídem, p. 174.

el correcto funcionamiento de los mercados. Es precisamente este último factor, en opinión de la Agencia, el que supone un mayor riesgo en la efectividad de las políticas. Aunque se hayan marcado unos objetivos ambiciosos y existan incentivos atractivos, las dificultades administrativas, los obstáculos para acceder a la red, un inadecuado mercado eléctrico, la falta de información y de formación y la oposición social son elementos que pueden incrementar el riesgo en las inversiones, aumentar los costes e incluso acabar con un proyecto. De igual forma afectaría un marco político y normativo inestable[51]. La directiva sobre energías renovables de la UE incluye medidas para la eliminación de barreras de este tipo.

En cuanto a los sistemas de incentivos, la Agencia los consideraba como una compensación por los fallos del mercado relacionados con la internacionalización de las externalidades relativas al cambio climático y medioambiente y recordaba que han de ser transitorios, solo justificables mientras dure el proceso de transición hacia un mercado competitivo en el que las renovables participen de forma totalmente integrada[52]. El diseño de cada sistema de incentivos, aunque varíe según la fuente energética y el tiempo de aplicación, debe incluir un patrón de más a menos, hasta su desaparición. Además, si el objetivo es su participación plena en un mercado libre y competitivo, los productores de energía renovable deberían ir, progresivamente, asumiendo los riesgos que esto conlleva. Por ello, los mecanismos con una mayor orientación de mercado son, según la Agencia y siempre pensando en el futuro, los más apropiados. Lo más acertado sería, según sus conclusiones, establecer un sistema combinando diferentes políticas de incentivación dependiendo del estado de desarrollo de la tecnología[53].

En 2011, la Agencia actualizó el estudio y publicó Deploying Renewables: Best and Future Policy Practics. Incluyó el análisis de los últimos años (hasta 2009) y aumentó el número de países estudiados a los 56 más representativos de todas las regiones del mundo. Durante esos cinco años añadidos, la situación de las energías renovables había cambiado considerablemente. Si el anterior informe ofrecía un escenario de desarrollo muy limitado, este nuevo trabajo pone de relieve la rápida expansión de las fuentes de energía renovables, en algunos casos llegando a ser rentables y competitivas a pesar de que las barreras no económicas seguían siendo, según el análisis de la Agencia, un freno al desarrollo.

Una diferencia con el anterior análisis es el uso de tres indicadores cualitativos para identificar cual era la mejor política: el indicador de impacto de la política (*PII*), el

[51] *Ibídem*, pp. 175-176.

[52] La aproximación de la Agencia a los incentivos de las renovables está marcada por el mercado. Otras instituciones internacionales, como las ayudas estatales permitidas a las renovables en el seno de la UE ponen el énfasis en la protección medioambiental.

[53] IEA, *Deploying Renewables. Principles…*, *op. cit.*, pp. 176-178.

indicador sobre la adecuación de las retribuciones (*RAI*) y el indicador del coste total (*TCI*). El primero, el PII, evaluaba el éxito de un país en el incremento de generación de un tipo de energía renovable utilizando como punto de referencia las proyecciones del *WEO 450* de desarrollo para 2030. El segundo indicador, el RAI, analizaba si los productores de energía renovable recibían la apropiada remuneración. El último de los indicadores, el TCI, indicaba el nivel de primas que debían ser abonadas en un año determinado según la generación adicional conseguida. Para establecer este indicador se tomaba como punto de comparación el valor total al por mayor de la generación de energía. La Agencia también advierte de que este indicador puede sobreestimar los costes totales de una política al no considerar el efecto del orden según los costos marginales a corto plazo (*merit-order-efect*).

El análisis concluyó que las diferencias en cuanto a impacto y rentabilidad entre los diferentes sistemas de apoyo económico eran menores que las diferencias entre países que habían aplicado un mismo sistema. Lo importante era el paquete de medidas en su conjunto[54].

El desarrollo de las energías renovables consta de tres fases: la fase de inicio, la fase de despegue o expansión y la fase de consolidación. El mayor o menor éxito de las políticas depende de la adhesión a los principios que las rigen. Si en 2008 la Agencia establecía cinco principios generales, en 2011 establece (ver Table A.1) unos principios comunes a las tres fases más otros específicos para cada etapa.

Las prioridades de las políticas en la fase inicial deben dirigirse a crear un marco de inversión estable y un marco legislativo que fomente el desarrollo de las tecnologías renovables. En la fase de despegue son el crecimiento del mercado y la gestión de los costes los aspectos que deberían atraer la atención de quienes diseñan las políticas. Estos tampoco deberían olvidar la necesidad de una cierta flexibilidad que permita adaptarse a la evolución del mercado y de las tecnologías, como la conveniencia de eliminar las barreras no económicas. En esta última fase, los retos están relacionados con la plena integración de las renovables en los mercados energéticos y su correcto funcionamiento, lo cual puede implicar un rediseño de los mismos que premie la seguridad energética que las renovables ofrecen y garantice su continuidad[56].

carácter negativo, desde que en 2009 se notase la primera reducción considerable en los biocombustibles. La Agencia apunta a la estabilidad de las políticas, el desarrollo de tecnología que conlleve una disminución de los riesgos y la entrada de nuevos agentes como factores clave para la inversión futura[57].

[54]IEA, *Deploying Renewables. Best and Future Policy Practice*, Paris, OECD /IEA, 2011, pp. 18-19.
[56]*Ibídem*, pp. 164-166.
[57]IEA, *Renewable Energy. Medium-Term Market Report 2013*, Paris, OECD/IEA, 2013, pp. 161-165.

Tabla A.1 – Principios para las políticas renovables

Principios comunes
Establecer un marco de políticas previsible y transparente, integrado en una estrategia energética global y centrada en la tecnología más adecuada para conseguir los objetivos, tanto a corto como a largo plazo. Los objetivos deben de ser ambiciosos, pero también realistas.
Adoptar un enfoque dinámico en la aplicación de políticas.
Abordar las barreras no económicas racionalizando los procesos y los procedimientos todo lo posible.
Identificar y abordar de antemano los posibles problemas de integración que puedan ir surgiendo.

Inicio	**Despegue**	**Consolidación**
Elaborar una hoja de ruta clara. Proveer un sistema de ayudas mixto. Asegurarse de que existe un marco regulatorio apropiado y en funcionamiento. Apoyar la investigación y desarrollo.	Asegurar un contexto de apoyo estable. Incluir la capacidad de adaptación como un factor clave en las políticas. Proveer un sistema de incentivos adecuado. Concentrarse en las barreras no económicas y la implementación.	Tratar los problemas de integración y facilitar el uso de las tecnologías. Asegurar que el mercado funciona con la incorporación de las renovables y retirar progresivamente las ayudas. Mantener la aceptación social.

Fuente: Elaboración propia[55].

Los últimos informes realizados en 2015 y 2016 , aunque reiteran esa postura, ya apuntan un despliegue de las tecnologías renovables más dinámicas y un mayor compromiso por parte de los países, tanto desarrollados como en desarrollo, en el contexto de la Conferencia Marco sobre el Clima de París (COP 21). El crecimiento económico se está desligando de las emisiones y los gobiernos comienzan a considerar soluciones que mejoran la seguridad energética, reducen la contaminación local y ayudan a mitigar los efectos del cambio climático, incluso cuando los precios de los combustibles fósiles son bajos. Pero para cumplir con el objetivo acordado de mantener el aumento de la temperatura media global por debajo de los 2° C es necesario mayores tasas de decarbonización y acelerar la penetración de las energías renovables en todos los sectores.

5 Conclusiones

La firma del Acuerdo internacional que dio origen a la Agencia es resultado de la convicción de los Estados firmantes de que la cooperación en materia de energía debía institucionalizarse ante el fracaso de las anteriores colaboraciones *ad hoc*. Los sistemas voluntarios y acuerdos no-vinculantes se habían mostrado inoperantes para garantizar la seguridad energética de los países consumidores.

Una de las principales estrategias diseñadas por la AIE para la reducción de la dependencia del petróleo se ha centrado en la diversificación tanto de suministradores (diversificación geográfica) como de fuentes alternativas, aunque no se establece un plan de acción común. Por el contrario, la Agencia reconoce la pluralidad de realidades de sus Estados miembros y deja en manos de cada uno de ellos la elección en la composición de su mix energético. Sí reconoce, sin embargo, que el uso de fuentes alternativas al petróleo y de la tecnología de captura y almacenamiento de carbono es necesario para asegurar una transición cómoda y con cierta celeridad, a una economía baja en emisiones y a un futuro energético más seguro, sostenible y limpio.

La Agencia cuando se refiere a fuentes alternativas no limita éstas a las renovables. También tiene en cuenta al carbón, el gas y a la energía nuclear. Así, los objetivos establecidos para el medio y largo plazo se desarrollarán alrededor de dos grandes grupos de fuentes: las norenovables y las renovables. Ambos grupos han estado presentes desde los primeros años aunque con distinta intensidad. Si en 1977, en los *Principios para una Política Energética*, la Agencia ya mencionaba la promoción del carbón, del gas y de la energía nuclear como mecanismos para sustituir paulatinamente al petróleo, no será hasta 1985 cuando la Agencia impulse notablemente la utilización de las energías renovables.

Por la tradición y la experiencia no sorprende que la primera fuente en la que se fijase la Agencia como alternativa fuese el carbón. En un momento en el que las cuestiones medioambientales eran secundarias, el carbón aportaba grandes ventajas frente al resto de fuentes por su disponibilidad, facilidad de transporte y experiencia en su uso. La Agencia buscará la participación del sector privado por lo que creó, en 1979, el Consejo Asesor de la Industria del Carbón (CIAB), órgano compuesto por un número variable de empresas relacionadas con este sector tanto en países miembros como no miembros. Desde entonces, han realizado informes y se ha instado a los gobiernos a adoptar diversas medidas que favorezcan el uso de esta fuente, prestando especial atención, desde la década de los noventa, a las emisiones de CO_2 a la atmósfera para acomodar las exigencias medioambientales. Sin embargo, el futuro del carbón es cada vez más incierto.

La inseguridad de depender de la URSS como proveedor principal de gas natural, especialmente durante la Guerra Fría, motivó el desarrollo de este recurso. La Agencia promovió la explotación de los yacimientos de los países miembros, así como su comercio internacional. El gas natural representa la fuente alternativa no renovable que más ventajas aporta. Es una fuente flexible, segura, económicamente viable, fácilmente adaptable a las necesidades de demanda y con emisiones de gases de efecto invernadero relativamente bajas para ser un combustible fósil. Todo ello le convierte en un acompañante idóneo para las renovables y una clara alternativa al petróleo.

Sin embargo, a diferencia de lo que hizo con el petróleo y a pesar de la petición de algunos Estados, la Agencia siempre se ha mostrado reacia a crear un mecanismo de acción colectiva para afrontar situaciones de emergencia. Prefiere confiar en un buen funcionamiento de los mercados, por lo que centra sus esfuerzos en la recopilación y sistematización de datos sobre éstos y en apoyar proyectos tecnológicos destinados a reducir el impacto medioambiental. Su futuro dependerá de la accesibilidad y de la competitividad. Los precios, las políticas de eficiencia, el desarrollo del resto de fuentes, la inversión y el grado de explotación del gas no convencional marcarán su desarrollo.

La energía nuclear no presenta los retos por las emisiones de gases de efecto invernadero del carbón ni plantea los problemas de inseguridad por depender de un proveedor del gas, por lo que a mediados de los años setenta representaba una de las alternativas al petróleo más prometedoras. Sin embargo, los recelos sobre la seguridad de las plantas, el almacenamiento de los residuos nucleares y la preocupación por un posible uso militar han condicionado su desarrollo. La AIE, dentro de sus competencias en materia de energía nuclear, sigue apostando por esta fuente de energía, apoyando el desarrollo tecnológico y defendiendo su potencial, tanto en el ámbito de la seguridad energética como en la lucha contra el cambio climático. Sostiene, igualmente, la necesidad de un apoyo gubernamental y social.

En un contexto internacional marcado por las cuestiones medioambientales, el desarrollo tecnológico de las renovables se ha convertido para muchos, en el único camino que garantiza el éxito contra el cambio climático. Sin embargo, las restricciones competitivas y financieras a su desarrollo eran algo habitual en las políticas energéticas de los Estados. Como resultado, el número de países que podían acreditar algún resultado positivo a sus políticas de apoyo a las renovables era muy limitado. Por ejemplo, tal y como apuntó la Agencia, entre los años 2000 y 2005, sólo ocho países de los treinta y cinco analizados habían conseguido impulsar la energía eólica. Durante el siguiente lustro, las renovables experimentaron una rápida expansión, aunque eso no significase la eliminación de las barreras no económicas a su desarrollo. Al igual que en el caso del gas, la Agencia ve en un incorrecto funcionamiento de los mercados el mayor riesgo al progreso de estas energías, aunque también reconoce el peligro que supone un marco político y normativo inestable. Para superar estas dificultades, la Agencia ha desarrollado una serie de principios que deberían servir de guía en el diseño de las políticas energéticas y dedica parte de sus esfuerzos al estudio de los mercados de energías renovables.

La Agencia siempre ha apostado por la diversidad de fuentes. Cada una es diferente, con ventajas y desventajas sobre las demás. El correcto desarrollo de todas ellas dependerá, según la AIE, de la estabilidad de las políticas, el desarrollo tecnológico y la inversión futura.

Appendix B

El escenario energético de India

1 Introducción

India está experimentando un rápido y notable desarrollo económico. Creciendo anualmente casi al 6 % durante las dos últimas décadas del siglo XX y a más del 7 % durante este siglo, India se ha posicionado como una de las potencias económicas mundiales más dinámicas. En 2014 ocupaba el octavo puesto de la lista de países con un mayor PIB (en US$ a precios constantes de 2005), después de Estados Unidos, China, Japón, Alemania, Reino Unido, Francia e Italia[1]. Para lograr sus objetivos de desarrollo humano y erradicación de la pobreza, el Gobierno indio estima necesario un crecimiento económico constante hasta 2030 situado entre el 8 y el 10 %[2].

En India, el consumo de energía primaria se ha duplicado desde 1990 y con un consumo energético per cápita equivalente a la tercera parte de la media mundial, la tendencia es que continúe al alza durante las próximas décadas. Según se puede concluir de los datos estadísticos de la Agencia Internacional de la Energía (AIE), el crecimiento medio anual hasta 2015 fue del 4 % y continuará a un ritmo del 3 % anual hasta 2040.

Pero en esta relación entre demanda y economía es necesario hacer dos apuntes. Primero, el crecimiento de la economía no ha estado motivado por un crecimiento del sector industrial sino por el sector servicios. El Gobierno ha mostrado su intención, con la iniciativa *Make in India* de cambiar esta situación aumentando el sector productivo para que suponga el 25 % del PIB en 2020, creando cien millones de puestos de trabajo. Un cambio del peso industrial en la economía así como el incremento del poder adquisitivo de la población tendrá efectos directos en el consumo energético del país. El sector eléctrico es el que mayor crecimiento en la demanda

[1] Para los datos anuales véase la Base de Datos del Banco Mundial, http://datos.bancomundial.org/

[2] Planning Commission, *Integrated energy policy: report of the expert committee*, Government of India. 2006, p. v.

experimenta, con una media del 4,4 % anual. Sin embargo, unos 240 millones de indios carecen de acceso a la electricidad y el consumo de aquellos que sí tienen acceso es unas diez veces inferior respecto a los niveles de la OCDE[3]. La política energética de India enfatiza la reforma del sector eléctrico ligada a la reducción de costes y la racionalización de los precios de los combustibles.

En segundo lugar, el crecimiento de la demanda energética se ha realizado a un paso mucho menor que el crecimiento económico, debido, entre otros factores, a los esfuerzos destinados a la eficiencia energética. La intensidad energética de la India, es decir, la cantidad de energía que se necesita para generar una unidad de Producto Interior Bruto (en términos de paridad de poder adquisitivo) está ligeramente por debajo de la media mundial, aunque todavía existe un gran margen para la mejora[4].

Otra característica que define a India es el tamaño de su población. India cuenta con más de 1.267 millones de habitantes, lo que le convierte en el segundo país más poblado del mundo. Solo China le supera, aunque no son pocos los que vaticinan que en los próximos años intercambiarán posiciones. Los ratios de crecimiento así parecen indicarlo: en China la tasa anual de crecimiento de población se encuentra por debajo del 1 % desde el cambio de siglo, siendo del 0,5 % en 2014. Ese año la tasa en India fue del 1,2 %.

Todos estos factores tienen una fuerte influencia en el sector energético del país. India se enfrenta a grandes desafíos para satisfacer la demanda originada por el aumento de la población y el crecimiento económico, garantizar el suministro de energía asequible en un contexto marcado por las presiones derivadas de la sostenibilidad y de la lucha contra el cambio climático y donde la alta regulación de los precios de la energía para los consumidores, los subsidios a los combustibles y la inconsistente reforma del sector energético dificultan la inversión.

Para hacer frente a todo ello, en diciembre de 2008, se aprobó definitivamente la Política Energética Integrada (IEP). De carácter incluyente, integra y supervisa todos los ámbitos relacionados con el sector energético.

2 La estructura energética de la India

La India, con una demanda energética cercana a los 800 millones de toneladas de petróleo equivalente (Mtoe), es el tercer país consumidor de energía. Le superan Estados Unidos y China y le sigue de cerca Rusia. Y sin embargo, su consumo energético per cápita (toneladas de petróleo equivalente/población), en 2013 era de 0,62, muy lejos del 6,92 de Estados Unidos, del 2,21 de China o del 5,11 de Rusia, aun no siendo

[3] IEA, *World Energy Outlook 2014*, OECD/IEA, Paris, 2014, p. 235 y IEA, India Energy Outlook. World Energy Outlook Special Report 2015, Paris 2015, p. 19.

[4] IEA, *World Energy Outlook 2015*, OECD/IEA, Paris, 2015, p. 430.

estos Estados los de mayor ratio en el mundo[5]. En el consumo energético per cápita, India estaría en el mismo nivel que países como Honduras (0,64), Costa de Marfil (0,64), Zambia (0,66) o Colombia (0,65).

Tabla B.1 – Estructura del consumo energético 1990-2040 (en Mtoe)

	Carbón	Petróleo	Gas	Nuclear	RE	Total	Pc
				1990			
India	94	63	11	2	139	309	0.35
China	533	122	13	0	211	879	0.77
No OCDE	1140	1163	819	74	849	4045	0.96
OCDE	1080	1873	843	451	278	4525	4.24
Mundo	2221	3237	1662	526	1126	8772	1.66
				2013			
India	341	176	45	9	204	775	0.61
China	2053	483	142	29	331	3038	2.24
No OCDE	2900	1959	1529	135	1360	7883	1.33
OCDE	1029	1908	1372	511	503	5323	4.21
Mundo	3929	4219	2901	646	1863	13558	1.89
				2025			
India	568	273	81	28	257	1207	0.83
China	2070	647	317	167	448	3649	2.57
No OCDE	3285	2451	1968	343	1775	9822	1.37
OCDE	827	1682	1444	580	731	5264	3.93
Mundo	4112	4545	3422	923	2507	15504	1.83
				2040			
India	934	458	149	70	298	1909	1.17
China	1978	710	456	287	589	4020	2.87
No OCDE	3799	2891	2665	566	2318	12239	1.57
OCDE	615	1342	1549	635	1026	5,176	3.71
Mundo	4414	4735	4239	1201	3346	17935	1.96

2.1 La estructura energética de India en el contexto internacional

Observando los datos de las Tablas B.1 y B.2 se aprecian notables diferencias entre la estructura energética de India y la estructura energética de otras zonas geográficas. No es de extrañar que las mayores diferencias se presenten al comparar la de la India con la de los países OCDE. Tampoco sorprende que muestre una mayor similitud con

[5]Según datos del Banco Mundial, los tres países con mayor consumo per cápita son Catar, Islandia, Trinidad y Tobago.

Tabla B.2 – Estructura del consumo energético 1990-2040 (en %)

	Carbón	Petróleo	Gas	Nuclear	RE
			1990		
India	30	20	4	1	45
China	61	14	1	0	24
No OCDE	28	29	20	2	21
OCDE	24	41	19	10	6
Mundo	25	37	19	6	13
			2013		
India	44	23	6	1	26
China	68	16	5	1	11
No OCDE	37	25	19	2	17
OCDE	19	36	26	10	9
Mundo	29	31	21	5	14
			2025		
India	47	23	7	2	21
China	57	18	9	5	12
No OCDE	33	25	20	3	18
OCDE	16	32	27	11	14
Mundo	27	29	22	6	16
			2040		
India	49	24	8	4	16
China	49	18	11	7	15
No OCDE	31	24	22	5	19
OCDE	12	26	30	12	20
Mundo	25	26	24	7	19

Fuente: Ambas tablas se han elaborado con datos de la AIE. Los datos de población han sido tomados de la base de datos del Banco Mundial. * Se excluyen los datos sobre bunkers internacionales. **China incluye a Hong Kong. ***Unidades en millones de toneladas de petróleo equivalente.

la de China. Las diferencias con las estructuras de los países no OCDE y del mundo quedan matizas, precisamente, por el peso de los países asiáticos en ambas.

La primera observación que llama la atención es que, en términos absolutos, tan solo la OCDE mantiene una tendencia negativa en el consumo de carbón y petróleo. Mientras esta región consumirá 465 Mtoe de carbón y 531 Mtoe de petróleo menos en 2040, India aumentará su consumo en 1.445 y 588 Mtoe respectivamente.

Otra diferencia notable entre ambas estructuras es que el petróleo no es la principal fuente de energía primaria en la estructura energética de India. En 2013 ese puesto lo ocupaba el carbón con el 44 % del consumo total. El petróleo ni siquiera se sitúa en segundo lugar, siendo superado ligeramente por las renovables (26 % frente a un 23 %). Es preciso matizar, no obstante, que en este último grupo se incluye la biomasa tradicional, la cual todavía representa un consumo importante en las zonas rurales. Con los años, el peso de las renovables descenderá, debido principalmente, a la sustitución de biomasa tradicional por otro tipo de energía.

Las principales diferencias entre las estructuras energéticas de India y China no se basan tanto en su composición como en su aproximación. En 1990, tanto el peso de los combustibles fósiles como el de las renovables eran considerablemente distintos en cada una de ellas. Mientras India mantenía un cierto equilibrio (54 % y 45 %) gracias a la biomasa tradicional, China apostaba claramente por los fósiles (76 %), principalmente por el carbón (61 %). En 2040 estas diferencias se habrán reducido. En ambos países, las renovables representarán un 15-16 % del consumo total mientras que los combustibles fósiles estarán cerca del 80 %. Sin embargo, en el caso de China esto se deberá principalmente, siempre en términos relativos, a un constante descenso en el consumo de carbón, un cierto estancamiento en el consumo de petróleo y un incremento del uso del gas. En India la tendencia al alza es constante para las tres fuentes.

A pesar de esta aproximación entre ambas estructuras, el peso de cada una de ellas en las estructuras energéticas de la no OCDE y del mundo muestra algunas diferencias claras. Por ejemplo, será China el principal responsable del incremento del consumo de carbón tanto entre los países no OCDE como a nivel mundial. En 2040 su consumo representará el 52 % del consumo total de carbón en la no OCDE y el 45 % del consumo mundial, mientras que los datos de India se quedan en el 25 % y el 21 % respectivamente. Mucho menor es el peso de ambos países en el consumo de petróleo. India seguirá por detrás de China, suponiendo el 16 % del consumo total de petróleo en la no OCDE y el 10 % del consumo mundial frente a los respectivos 25 % y 15 % de China.

2.2 El carbón

El carbón es la principal fuente de energía primaria en India. Superó a la biomasa a mediados de la década de los noventa, aunque será a partir de 2005 cuando su consumo experimente un fuerte incremento. India ya es el tercer mayor mercado mundial de carbón (superando a la Unión Europea) por detrás de China y Estados Unidos. Estos tres Estados son responsables del 70 % del consumo total mundial.

La mayor parte del consumo de carbón en India está destinada a la generación de electricidad. Entre 2002 y 2012, las tres cuartas partes del incremento en consumo eléctrico fueron cubiertas por la generación proveniente del carbón. Sin embargo, el consumo eléctrico anual per cápita sigue siendo bajo con 700 kilovatios/hora (lo que viene a ser una octava parte del consumo anual per cápita de la Unión Europea), debido a que un cuarto de la población de la India no tiene acceso a la electricidad[6]. Este dato, unido a la persistencia del crecimiento económico y demográfico en las próximas décadas, refuerza la fuerte previsión alcista en el consumo de esta fuente de energía, al menos en términos absolutos. En términos relativos, se espera que para 2040 el carbón genere algo más de la mitad de la electricidad total.

Pero esta tendencia, como desarrollaremos en el siguiente apartado, también es origen de preocupación, puesto que a pesar de que la India es el cuarto país del mundo con mayores reservas de carbón, y su ratio de reservas/producción en 2014 era de 94 años, India consume más carbón del que produce, y esa dependencia se está incrementando[7]. La producción de carbón se ha ralentizado desde 2009, con un incremento anual de entre el 1 y el 3 %[8]. Una de las principales pautas establecidas en la IEP en su estrategia a largo plazo es la necesidad de garantizar su suministro.

2.3 El petróleo

India es hoy el cuarto país mundial tanto en el consumo como en la importación de petróleo y la tendencia es claramente alcista. Aunque el petróleo no es la principal fuente de energía primaria —en 2013 tan solo representaba el 23 % de su matriz energética— su evolución siempre ha sido al alza y las proyecciones no indican lo contrario. Entre 1990 y 2013, el consumo del petróleo experimentó una tasa de crecimiento del 179 %. Para 2040, esa tasa habrá aumentado hasta el 627 %.

Una de las razones que explica esta evolución reside en el crecimiento del sector transportes. En 2009, mientras la media mundial era que 125 personas de cada mil fueran propietarias de un coche, en India esa cifra era tan solo de 12 personas por cada mil. Las expectativas en 2011 indicaban que ese número aumentaría a unas 100 personas en 2035. Es decir, en veinticinco años el ratio de propietarios de un coche se multiplicaría por ocho. A pesar de ello, seguiría siendo la mitad de la media mundial[9]. El sector del transporte, impulsado principalmente por los productos derivados del petróleo, crecerá a medida que el país mejore las infraestructuras terrestres (carretera y ferrocarril). Para mitigar el impacto de este crecimiento en la demanda de petróleo, el Gobierno está manejando fórmulas que implican el uso de combustibles alternativos, especialmente relacionados con los biocombustibles, así como la incentivación del uso de los transportes colectivos[10].

[6] IEA, *World Energy Outlook 2014*, *op. cit.*, pp. 197-198.
[7] British Petroleum, *BP Statistical Review of World Energy June 2015*, p.30.
[8] IEA, *World Energy Outlook 2014*, *op. cit.*, p. 198.
[9] IEA, *World Energy Outlook 2011*, OECD/IEA, Paris, 2011.
[10] US EIA, *India*, 2014.

Tras el sector del transporte, los sectores económicos que más petróleo demandan son la agricultura y el sector industrial.

El sector del petróleo es uno de los más liberalizados y competitivos de la India. Actualmente está abierto al 100 % a la inversión extranjera y son varias las compañías no nacionales que operan allí. Sin embargo, también se caracteriza por la existencia de un mecanismo que distorsiona los precios, por la no utilización de todos sus recursos nacionales y por la falta de inversión por parte de las grandes compañías petroleras internacionales[11].

La gestión del petróleo y la gestión del gas están fuertemente ligadas. Actualmente, el Ministerio de Petróleo y Gas Natural (MoPNG) supervisa todo el sector de petróleo y gas, desde la exploración y producción, hasta el refino, la distribución, la comercialización y los precios. También implementa los planes quinquenales relativos al petróleo y supervisa la importación, exportación y conservación de los productos derivados.

2.4 El gas natural

Aunque en términos absolutos se pueda hablar de un aumento, el peso que el gas natural tiene en la estructura energética de la India todavía es relativamente escaso, situándose en 2013 en torno al 6 %. Para 2040, se estima que esa cifra aumentará a un 8 %. Porcentajes muy inferiores si los comparamos con las estructuras energéticas del mundo, del conjunto de países OCDE y de la región de los países no OCDE.

La evolución de la demanda de una fuente de energía puede verse afectada por factores como la regulación y el precio, y en India, la situación es compleja. Por un lado, el Gobierno, mediante la Política de Utilización de Gas, establece la distribución del gas nacional entre los sectores productivos mientras que otorga libertad de compra y venta a los operadores de gas importado[12]. Por otra, existen, en términos generales, dos regímenes de precios para el gas de producción nacional, según el sistema fiscal al que se encuentre sometido el yacimiento: el Mecanismo de Precios Administrados (APM) y el mecanismo no APM (que fija los precios según el mercado)[13]. A esto hay que añadir los costes de transporte, los márgenes de comercialización y los impuestos estatales[14]. El precio del gas importado depende de los diferentes tipos de contratos de suministro: a largo plazo, a corto plazo o a precio corriente (o

[11] S. J. Ahn, y D. Graczyk, *Understanding Energy Challenges in India: Policies, Players, and Issues*, Paris, IEA, p. 58.

[12] Ministry of Petroleum and Natural Gas, Government of India, http://petroleum.nic.in/docs/abtng.pdf.

[13] S. K. Kar, "Natural Gas to Drive Green and Sustainable Developments in India", Atul Sharma y Sanjay Kumar Kar (Eds), *Energy Sustainability Through Green Energy*, *Springer India*, 2015, p. 400.

[14] Anupama Sen, *Gas Pricing Reform in India: Implications for the Indian gas landscape*, Oxford Institute for Energy Studies, abril 2015, p. 7.

spot). Los contratos a corto plazo y los contratos a precio corriente suponen un precio considerablemente más elevado que los contratos a largo plazo.

El APM era el sistema fiscal anterior a la liberalización del sector de exploración y producción (*upstream*). Se mantiene para los yacimientos que ya existían afectando a la mayoría de los yacimientos de las grandes compañías. Bajo este sistema, y aunque contempla alguna excepción, el Gobierno fija los precios del gas, siendo estos considerablemente más bajos que los precios del mercado.

El segundo mecanismo surge con la semi-liberalización del sistema. Durante los primeros años de la década de los noventa, se establece el régimen de los "Yacimientos Descubiertos", conocido como Pre-Nueva Política de Licencias de Exploración o Pre-NELP, que permitía iniciativas conjuntas entre empresas privadas y nacionales. En 1999 este sistema fiscal fue sustituido por la Nueva Política de Licencias de Exploración (NELP), que igualaba las condiciones de las empresas públicas y privadas para la exploración y producción, basado en contratos de reparto de la producción (*Production Sharing Contracts*) entre las compañías explotadoras y el Gobierno central.

En enero de 2014, el Gobierno anunció que iba a adoptar un nuevo régimen fiscal más simple, sustituyendo el actual modelo por uno de contratos de reparto de ingresos (*Revenue Sharing Contracts*), aunque a finales del primer cuatrimestre de 2015 todavía no se había implementado[15].

Esta complejidad en el sistema de precios del gas repercute en los diferentes sectores demandantes. Así, el sector eléctrico y la industria de fertilizantes, los principales sectores consumidores, operan en un mercado altamente regulado, por lo que es complicado que puedan sustituir el consumo de gas natural nacional por importado, al menos a corto plazo[16].

Otro de los factores que afectan al consumo de gas es la existencia o no de la infraestructura necesaria que garantice el suministro y permita un uso más generalizado de esta fuente, tanto en la industria como en las ciudades. India carece de una red nacional de gas totalmente integrada, especialmente en las zonas del sur y del este del país.

2.5 Las energías renovables

El Décimo Segundo Plan Quinquenal elaborado por el Comisión de Planificación del Gobierno indio para los años 2012-2017, en su apartado 3.5, punto 14.185 observa que las energías renovables representan una fuente de energía alternativa a los hidrocarburos que ayudan a garantizar la seguridad energética, mediante la diversificación

[15] *Ibídem*, p. 7.
[16] S. J. Ahn y D. Graczyk, *op. cit.*, pp. 70-71.

y la reducción de la dependencia, al tiempo que son un elemento clave en la lucha contra el cambio climático y el desarrollo sostenible. Señala, por tanto, la necesidad de incrementar los esfuerzos en la producción de energía de fuentes renovables. Sin embargo, también reconoce que, a pesar de los esfuerzos realizados en los últimos años, India se encuentra por detrás de otras regiones.

Así lo demuestran los datos. A pesar de las cifras y de que en términos absolutos el consumo de renovables haya ido en aumento, los datos relativos presentan el escenario opuesto. En 1990, las energías renovables (incluyendo la biomasa más primaria) representaban un 45 % de su matriz energética. Para 2013, ese porcentaje había bajado hasta situarse en el 26 %. Y las proyecciones siguen la misma tendencia a la baja: 21 % en 2025 y 16 % en 2040. Además, el Gobierno reconoce que tan solo alrededor del 1 % de la energía comercial utilizada en India es renovable. Uno de los inconvenientes para su desarrollo es el alto coste por unidad[17].

Es necesario recordar, no obstante, que esta reducción se debe a que la biomasa primaria está siendo sustituida por otras formas de energía más modernas. Desde el inicio de la Nueva Política Económica en 1991, cada vez es más la población que migra a las ciudades lo que influye en el tipo de fuente de energía que se consume. Los hogares urbanos han cambiado la biomasa y los residuos tradicionales por otras fuentes como los hidrocarburos, la nuclear, los biocombustibles y otras fuentes renovables[18]. Esto, en principio, sería un dato positivo en la evolución del modelo energético.

También es destacable que en 2011 India fuese el quinto país con la mayor capacidad de energía eólica en el mundo y en 2010 pusiera en marcha un ambicioso plan para aumentar significativamente su capacidad de energía solar[19]. El *Jawaharlal Nehru National Solar Mission* es uno de los ocho proyectos del Plan Nacional de Acción contra el Cambio Climático. Se busca reducir el coste de la generación de energía solar a través de políticas a largo plazo, ambiciosos planes de desarrollo, una política agresiva de I+D y la producción nacional de materias primas, componentes y productos. Dividido en tres fases, el objetivo de este ambicioso plan es integrar en la red 20 GW de energía solar para el año 2022, transformando a la India en un líder global en la generación de energía solar. La primera fase finalizó en 2013 e introdujo 1,100 GW a la red, entre energía solar fotovoltaica y térmica. El objetivo de la fase II es obtener una capacidad solar acumulada de 10 GW en 2017.

[17] Planning Commission, *12th Five-Year Plan*, Government of India, New Delhi.
[18] US EIA, *op. cit*.
[19] S. J. Ahn y D. Graczyk, *op. cit*., p. 72.

2.6 La energía nuclear

Regulado por la Ley de Energía Nuclear y de exclusividad del Gobierno central, el compromiso del Gobierno indio con el sector de la energía nuclear data de la independencia del país. En 1948 creó la Comisión para la Ener¬gía Atómica y en 1954 ya disponía de un Departamento de Energía Atómica. Para la década de los setenta, India era uno de los pocos países que habían logrado un ciclo de combustible nuclear completo, es decir, realizar todo el proceso desde la exploración de uranio hasta la gestión de residuos, pasando por la generación de combustible nuclear y su reprocesamiento. El ciclo de combustible nuclear completo permite utilizar todo el potencial energético del uranio y reduce la cantidad de residuos de alta actividad por unidad de electricidad generada. Por otra parte, solo utilizando este sistema se puede emplear el torio para la generación de energía[20]. India cuenta con grandes reservas de torio pero no de uranio, además, no firmó el Tratado de No Proliferación Nuclear, por lo que el país estuvo excluido del comercio internacional en este sector hasta 2008. Por ello, el programa nuclear implementado en la India, todavía vigente, busca explotar esas reservas de torio, lo que le aparta del régimen nuclear global[21].

El programa cuenta con tres fases. La primera fase utiliza reactores de agua pesada a presión (PHWRs), los cuales utilizan como combustible el uranio. En la segunda fase se utilizan reactores rápidos realimentados (FBRs) que se alimentan de plutonio procedente de plantas de reprocesado que también han sido desarrolladas durante esta etapa. Estos reactores producen más combustible que el que consumen. La última fase, el torio-232 se transforma en uranio-233 mediante los reactores avanzados de agua pesada a presión (AHWR). El programa se encuentra en la segunda fase. En total, India cuenta con 21 reactores en funcionamiento y otros 7 en construcción[22].

En la actualidad, la energía nuclear representa menos del uno y medio por ciento de la estructura energética del país. En 2040, el porcentaje será del 4 %, es decir, India habrá aumentado su demanda nuclear unas 35 veces respecto a 1990.

A pesar de las cifras, y de la resistencia de otros Estados a este tipo de energía debido a accidentes como el de Fukushima de 2011, India sigue siendo partidaria de desarrollar su potencial y capacidad nuclear.

[20] R B Grover, "Policy Initiatives by the Government of India to Accelerate the Growth of Installed Nuclear Power Capacity in the Coming Years", *Energy Procedia*, vol. 7, 2011, p. 76.

[21] S. J. Ahn, y D. Graczyk, *op. cit.*, p. 81.

[22] Ismael Hidalgo Rama, *El Mercado de la energía nuclear en India*, Oficina Económica y Comercial de la Embajada de España en Nueva Delhi, junio 2015, pp. 6-7.

3 Una política energética integrada

India es un Estado federal, integrado por 29 estados y 7 territorios unidos o zonas administradas directamente por el Gobierno central. A pesar de que la Constitución divide el poder entre el Gobierno central y los Gobiernos federados definiendo áreas competenciales muy concretas (aunque en algunas materias las competencias son compartidas), existe un cierto riesgo de duplicación y de inconsistencias a la hora de tomar decisiones. Como muestra la Figure B.1, India dispone de varios ministerios y entidades, cada uno responsable de una parte de la política e infraestructura energética, lo que precisa de un importante trabajo de coordinación.

Pero esta estructura política y administrativa compleja no ha sido impedimento para crear una política energética coherente y consistente, tipificada, como se verá con más detalle en el desarrollo de las páginas siguientes, en la Política Energética Integrada de 2008, el Plan Nacional de Acción sobre el Cambio Climático, la coordinación de la Comisión de Planificación (ahora el Instituto Nacional para la transformación de la India Aayog (NITI Aayog)) y, más recientemente, con la Contribución Nacional Determinada (INDC) a la Conferencia de las Partes de París 2015 (COP 21).

3.1 La política energética de India hasta 2006

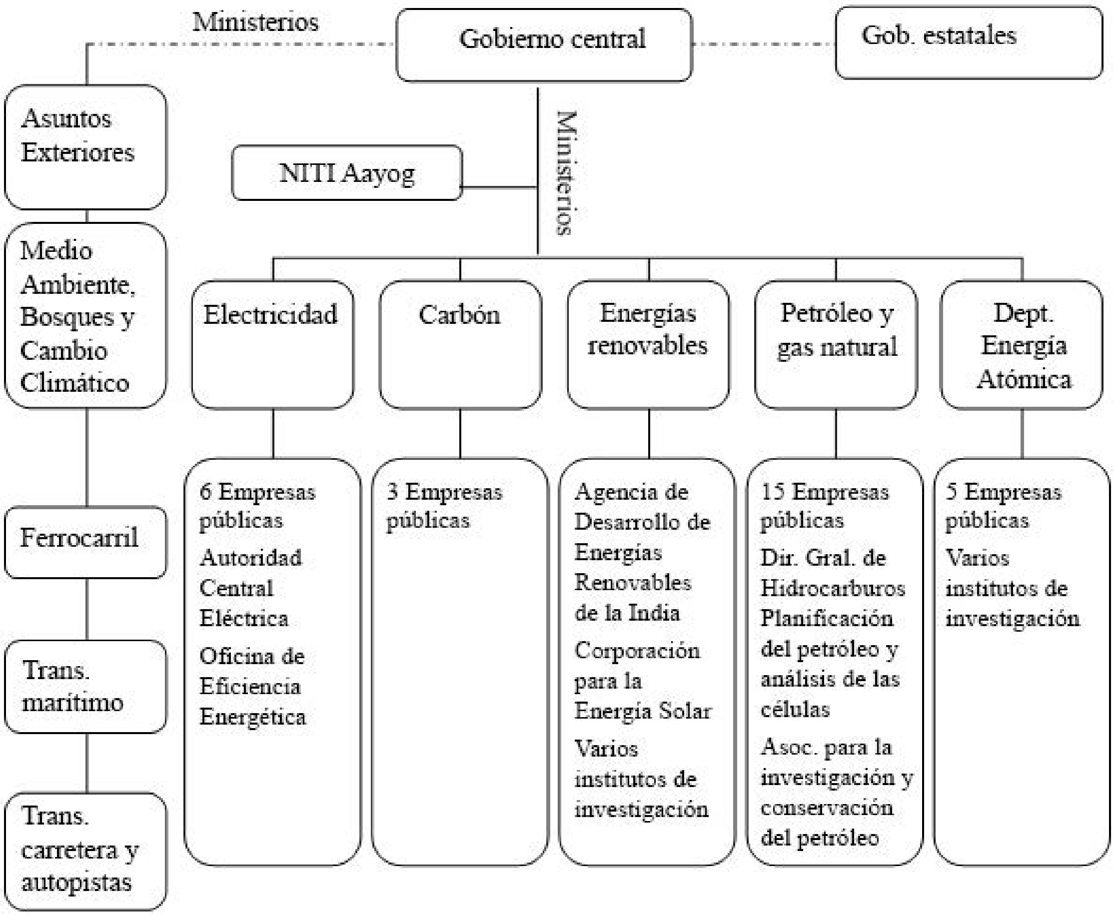
India se independizó en 1947 con una situación económica y de desarrollo nada favorable. El Gobierno del nuevo Estado independiente, con Jawaharlal Nehru como primer ministro, influenciado por el modelo soviético, adoptó, desde 1951, los llamados "Planes Quinquenales" que formarán el marco de las políticas adoptadas en India, incluidas las políticas energéticas. La principal preocupación será el suministro de carbón, petróleo y electricidad. Otras cuestiones, como el ahorro energético, no serán prioritarias hasta pasados varios años.

3.1.1 El sector del carbón

El sector del carbón supone, sin duda, un importante centro de preocupación para el Gobierno indio y es el sector más controlado, con dos grandes compañías estatales —el Gobierno posee el 80 % de *Coal Indian Litimed* (CIL) y el 93 % de *Neyveli Lignite Corporation Limited* (NLC)— que gestionan alrededor del 90 % de la producción.

El Ministerio del Carbón es el responsable de todos los aspectos, incluyendo las políticas y estrategias de exploración y desarrollo de reservas, los proyectos de producción, distribución y suministros y, en la práctica, el precio. Los diferentes Gobiernos de los estados federados también poseen, aunque restringida, una considerable influencia en el sector.

Figura B.1 – Principales instituciones del sector energético de India



Además de estos ministerios, también participan en el sector eléctrico el de urbanismo, el de aguas, el de agricultura, el de finanzas y el departamento de ciencia y tecnología.

Fuente: Elaboración propia basada en IEA, *World Energy Outlook 2015*.

A principios de la década de los setenta, se produjo la nacionalización de las empresas mineras mediante la *Coal Mines (Nationalisation) Act 1973* con el objetivo de asegurar un uso y desarrollo racional y coordinado. En 1976 se permite la explotación de minas por parte de los *captive producers* o compañías (públicas o privadas) que requieren de un gran y constante abastecimiento de carbón. La producción solo puede ser para el autoconsumo y en caso de excedente, este debe venderse a CIL.

En el año 2000 se desregularizaron los precios pero no la distribución. En 2007, se aprobó la Nueva Política de Distribución del Carbón (NCDP) para facilitar el suministro a los consumidores de sectores básicos y no básicos a precios predeterminados[23]. Sin embargo, las obligaciones legales de suministro, gravadas con multas si no se cumplen, y el alto precio del carbón importado, necesario para cubrirlas, han

[23] S. J. Ahn y D. Graczyk, *op. cit.*, p.47.

dificultado el desarrollo de esta política.

En India se puede hablar de un mercado ligado a contratos a largo plazo y del conocido como *e-auction* (o mercado de *spot*). En el primer tipo, los precios son establecidos por las dos principales compañías mineras (ambas compañías nacionales), supone más de las tres cuartas partes de la producción y está protagonizado por consumidores industriales. Habitualmente, los generadores de electricidad suelen obtener un mejor precio que otro tipo de industrias. El resto se vende en el mercado *e-auction*, a precios considerablemente más altos, aunque menores que los precios del carbón importado. Esta desigualdad entre los precios y el incremento de las importaciones hacen que este sistema sea cada vez menos sostenible por lo que existen presiones para que se modifique. El Gobierno está considerando moverse hacia un mercado de subastas en el que todos los actores puedan participar y con unos precios conforme a los precios internacionales[24].

La producción nacional no ha cumplido en los últimos años con los objetivos del Décimo Primer Plan Quinquenal lo que ha conducido a momentos de falta de suministro en las plantas generadoras de electricidad. Además, la calidad del producto está empeorando y las dificultades en la planificación, los asuntos relacionados con el medio ambiente y las dudas sobre la expansión en la producción están paralizando las necesitadas inversiones[25]. La principal solución que los expertos ofrecen para revertir esta situación es la liberalización del sector. También se apunta a una política centrada en la tecnología, especialmente en la tecnología de carbón limpio para la generación de electricidad y en una mejora de las infraestructuras, tanto de extracción como de transporte[26].

3.1.2 La industria petrolera

El descubrimiento de petróleo en India fue casual. En 1886, *Goodenough of Mckillop Stewart Company* estaba perforando un pozo en Jaypore, Upper Assam, cuando descubrió petróleo. Tres años más tarde, en 1889, lo haría la *Assam Railway and Trading Company* (ARTC) en Digboi.

La independencia de la India del Imperio británico marcó un antes y un después en la industria petrolera del país. Antes de la independencia solo dos compañías producían petróleo: la Assam Oil Company en el noreste y la Attock Oil Company en el noroeste. Tras la independencia, conociendo la importancia del petróleo y del gas, tanto para el desarrollo industrial como para la defensa, el Gobierno estableció, en

[24]IEA, *India Energy Outlook... op. cit.*, pp. 107-108.

[25]S. J. Ahn y D. Graczyk, *op. cit.*, p. 46.

[26]Véase S. Narsing Rao, "Coal Sector in India and its Reform Strides", en R. K. Mishra, Ranjit Sinha y R. B. Rybakov (Eds), *India and Russia. Problems in Ensuring Energy Security*, Academic Foundation, New Delhi, 2011, p. 130 y S. J. Ahn y D. Graczyk, *op. cit.*, p. 56.

su Declaración de Política Industrial de 1948, el desarrollo de la industria petrolera como una necesidad prioritaria[27]. En el Primer Plan Quinquenal adoptado por el Gobierno indio, se abre la puerta a la industrialización. En el Segundo Plan Quinquenal, que cu¬bría el periodo de 1956-1961, se estableció la Dirección de Petróleo y Gas Natural, subordinada del Ministerio de Recursos Naturales e Investigación Científica. A los pocos meses, la Dirección se convirtió en la Comisión de Petróleo y Gas Natural y en 1959, mediante un acto parlamentario, en un órgano estatutario.

En 1956 el Gobierno adoptó la Resolución de la Política Industrial (IPR), en la que se categorizaba a las diferentes industrias en tres niveles, dependiendo del grado de participación del Gobierno en cada una de ellas. También se dejaba abierta la puerta al incremento de esa participación así como la posibilidad de aumentar la cooperación con entidades privadas (excepto en el sector del transporte aéreo o ferroviario, en el armamentístico y en la energía nuclear) si así se estimara oportuno en algún momento. La industria del petróleo (junto con el carbón y la generación y distribución de electricidad) se incluyó en la primera categoría, es decir, su futuro quedaba exclusivamente en manos del Gobierno[28].

Durante esos años, una delegación dirigida por el entonces Ministro de Recursos Naturales, K. D. Malaviya, visitó una serie de países europeos con el objetivo de estudiar sus industrias petroleras y facilitar el aprendizaje de los expertos indios. De igual manera, diferentes expertos estadounidenses, alemanes, rumanos y soviéticos viajaron a la India para prestar su apoyo al proceso. De especial importancia fue la ayuda de los expertos soviéticos quienes dibujaron un plan geológico y geofísico detallado sobre posibles prospecciones. Se realizaron perforaciones en Punjab, en la región de Cambay y en el valle de Brahmaputra en Assam. También se realizaron estudios en el valle de Ganga[29].

Durante los siguientes años, la industria petrolera en India se desarrolló a un ritmo considerable hasta 1973, cuando las sequías, la crisis del petróleo y la creciente inflación le pusieron freno. En el Sexto Plan Quinquenal (1980-1985), la energía tiene un apartado específico. En él se reconoce su importancia vital en toda actividad productiva y el incremento de su consumo en el desarrollo económico. Se razona necesaria una política energética nacional. Sus principales elementos serán la explotación acelerada de los recursos energéticos nacionales (carbón, energía hidráulica y energía nuclear); la gestión de la demanda de petróleo; el ahorro de energía; la explotación de las fuentes renovables (silvicultura y biogás) para satisfacer las necesidades

[27] Bhupendra Kumar Singh, *India's Energy Security: The Changing Dynamics*, Pentagon Press, 2010.
[28] Government of India,*Industrial Policy Resolution*, 30 de abril, 1956.
[29] Planning Commission India, *3rd Five Year Plan*,, New Delhi.

energéticas de las comunidades rurales; y la intensificación de la investigación y desarrollo de nuevas tecnologías energéticas[30].

La participación del Gobierno en la industria se incrementó, nacionalizando algunas de las empresas privadas que todavía participaban en este sector. Pero la Guerra del Golfo puso fin a esta estrategia. La inflación subió y las reservas de divisas se desplomaron. Para contrarrestar estos efectos, India liberalizó su economía. El sector de la exploración y producción abrió sus puertas a la inversión privada. En 1997 se introdujo la Nueva Política de Licencias de Exploración. En abril de 2002 terminó el desmantelamiento del mecanismo administrativo de fijación de los precios del petróleo[31] excepto para el queroseno y GLP.

A comienzos del siglo XXI India formula su *India Hydrocarbon Vision 2025*, donde se establece el marco guía de las políticas en el sector de hidrocarburos. Con un alto porcentaje de las necesidades energéticas cubiertas por el petróleo y el gas, y sin una producción autóctona suficiente, la seguridad energética se convierte en el principal elemento de las propuestas. También se menciona un mercado más libre y competitivo y estándares en los productos a favor del medio ambiente[32].

Otro impulso a la liberalización del sector petrolero se produjo en 2006, cuando el Parlamento indio aprobó el Proyecto de Ley del Consejo Regulador del Petróleo y Gas Natural. El objetivo, según el texto, era proteger los intereses de los consumidores en este escenario desregulado promoviendo el comercio justo y la competencia y garantizando una disponibilidad adecuada y una distribución equitativa del petróleo, de los productos derivados y del gas natural[33].

3.1.3 La electricidad y el ahorro energético

Hasta el Cuarto Plan Quinquenal (1969-1974) no se considera la electricidad como un sector independiente para el desarrollo. A finales de la década de los sesenta, el Gobierno se dio cuenta de la necesidad de ajustar los balances de oferta y demanda y en 1974 presentó un informe en el que sugería sustituir el petróleo por el carbón y aumentar la eficiencia en generación y transmisión de electricidad. También se sugería la creación de un Consejo de Energía que asegurara la integración del plan de la energía con el plan nacional. Las recomendaciones para equilibrar oferta y demanda continuaron en el informe presentado en 1979 por el Grupo de Trabajo sobre Política Energética constituido por la Comisión de Planificación dos años antes[34].

[30] Planning Commission India, *6th Five Year Plan*, New Delhi.

[31] Bhupendra K. Singh, *India's Energy Security: The Changing Dynamics*, pp. 4-5.

[32] Government of India, *India Hydrocarbon Vision 2025*, Nueva Delhi, 2001.

[33] Parliament of India, *The Petroleum and Natural Gas Regulatory Board Bill*, Nueva Delhi, 2005.

[34] Sivani Dhanalekshmy, "The Energy Efficiency Policy Initiatives and Energy Security: Experiences from India", en, *Global Energy Policy and Security*, Springer, 2013, p. 217.

En 1981 se constituyó el Grupo de Trabajo Interministerial sobre Conservación de Energía (IMWG). En su informe presentado en 1984 afirmaba que el mejor camino a seguir era el aumento de la productividad energética y la sustitución de energía cara (importada) por energía barata (nacional). Daba prioridad a este segundo punto[35].

Pero no fue hasta la década de los noventa cuando el Ministerio de Energía creó un grupo de trabajo, compuesto por representantes de diferentes ministerios para elaborar una legislación sobre las actividades de ahorro y eficiencia energética. En 1997 se aprobó el Proyecto de Ley para el Ahorro de Energía. El Noveno Plan Quinquenal que comenzaba ese año (1997-2002) reconoció la necesidad de conservar los recursos naturales y la necesidad de fomentar el uso de fuentes renovables[36]. Los siguientes planes quinquenales han seguido fomentando la eficiencia y el ahorro de energía en los diferentes sectores.

A India le corresponde la condición de ser el primer país que estableció un ministerio dedicado a las renovables. En 1981, el Gobierno creó la Comisión de Fuentes Adicionales de Energía (CASE) que se convirtió, un año más tarde, en el Departamento para las Fuentes de Energía no Convencionales (DNES). En 1992 se transformó en el Ministerio de Fuentes de Energía no Convencionales (MNES) y, finalmente, en 2006 cambió su nombre por el de Ministerio de Energías Nuevas y Renovables (MNRE).

El MNES desarrolló, en 2003, la Ley de Electricidad, dando el primer impulso nacional al desarrollo de las ener¬gías renovables. Esta ley incorporó elementos de tarifas preferenciales y la obligación de compra de electricidad producida por renovables para las empresas de servicios públicos de energía, especialmente en el ámbito nacional. Este requisito derivó, con posterioridad, en los Certificados de Energía Renovable. La Política Nacional de Energía Eléctrica de 2005 incrementó los niveles de compra e instauró un proceso de licitación pública. Un año más tarde, en 2006, la Política Nacional de Tarifas estableció que las Comisiones Estatales Reguladoras de Electricidad fijaran el porcentaje mínimo de compra y concretasen un tipo preferencial para la energía renovable en sus estados[37].

3.2 La política energética a partir de 2006

2006 va a ser un año importante en la historia de la política energética de India. Además de los cambios ya mencionados, ese mismo año el Gobierno planteó el marco de la política energética actual, que engloba tres objetivos claros: la seguridad energética, el acceso a la energía y la mitigación del cambio climático. De forma general,

[35] *Ibídem*, p. 218.
[36] *Ibídem*.
[37] Ministry of New and Renewable Energy (MNRE), *Annual Report 2011*, Government of India, 2011.

el objetivo final propuesto es satisfacer la demanda energética de todos los sectores (incluida la demanda de los hogares). La demanda tiene que ser fiable (sin cortes y suficiente en los picos de demanda) y tener precios competitivos. Asimismo, ha de ser generada utilizando mecanismos seguros, limpios y con el menor coste posible así como con tecnología eficiente y sostenible. Para ello, no se descartan ni los subsidios, ni el uso de ninguna fuente de energía (convencional o no convencional). Busca un sistema energético efectivo y rentable mediante un mercado competitivo y un sistema de regulación e impositivo consistente, que garanticen la igualdad de condiciones para todos los actores. Se apoya en las ayudas directas para lograr los objetivos sociales y asume el principio de "quien contamina, paga" como fórmula para afrontar los impactos medioambientales. También ofrece una serie de recomendaciones más específicas relativas al uso de recursos nacionales (tanto del carbón como de las renovables y nuclear), al precio (tanto de los combustibles como de la energía final), la reforma del sector eléctrico para hacerlo atractivo a inversiones privadas, la mejora de la intensidad energética mediante la eficiencia y la gestión de la demanda, y el desarrollo de la I+D[38].

En 2013, el entonces ministro de petróleo y gas natural, Veerappa Moily, anunció que su ministerio trabajaría en un plan de acción para conseguir la independencia energética para 2030. Un plan que actores internacionales como la Agencia Internacional de la Energía han calificado como muy ambicioso e irreal. Su sucesor, Dharmendra Pradhan, quien asumió el cargo a finales de mayo de 2014, ha reiterado este objetivo. Entre las medidas propuestas estaban el incremento en la producción nacional de combustibles fósiles, el desarrollo de recursos como el gas metano y el gas de esquisto, adquisiciones de reservas de hidrocarburos (*upstream*) en el extranjero, la reducción de los subsidios a los combustibles para motores y las reformas en los precios del petróleo y del gas natural. A todas estas pautas se suman las destinadas al desarrollo y aprovechamiento de las fuentes de energía renovables (principalmente la energía solar y la energía eólica, como ya se ha apuntado anteriormente) y a la eficiencia energética[39]. La autosuficiencia es un principio recurrente en las políticas energéticas de la India[40].

En el último estudio realizado por la Agencia Internacional de Energía se destacaban las principales políticas indias en siete áreas y que se han recogido en la Table B.3. Las proyecciones a largo plazo de diferentes organizaciones internacionales ya trabajan, desde hace años, con datos relativos a 2040-2050. En 2014, el NITI Aayog, el órgano sucesor de la Comisión de Planificación, puso en marcha la herramienta *India*

[38] Planning Commission, *Integrated energy policy…*, *op. cit.*, pp. xiii – xxx.
[39] US EIA, *op. cit.*
[40] S. J. Ahn y D. Graczyk, *op. cit.*, p. 17.

Energy Security Scenarios, 2047. No es una herramienta para hacer proyecciones o estimaciones cerradas, sino para crear diferentes escenarios basándose en los datos de demanda (por sectores) y suministro energético (por fuentes) proporcionados por el usuario. La posibilidad de identificar el sector menos eficiente así como de saber qué porcentaje de la energía (por fuentes y de forma agregada) tendría que ser importado en cada escenario, permitirá (o ese es el objetivo) tomar decisiones en materia de seguridad energética.

Tabla B.3 – Principales políticas energéticas de India

Sector	**Políticas**
Políticas transversales	Las "Misiones Nacionales" unidas al Plan Nacional de 2008 y los objetivos sobre la energía eólica.
	Tasa sobre el carbón para apoyar el Fondo Nacional de la Energía Limpia.
Suministro	Aumento de la oferta de combustibles fósiles, especialmente del carbón para reducir las importaciones.
	Incremento del estímulo a la inversión privada en el suministro energético.
	Aceleración de los trámites burocráticos para proyectos energéticos.
Sector eléctrico	Impulso a las energías renovables, especialmente solar y eólica.
	Aumento de los esfuerzos necesarios para lograr el acceso universal a la electricidad.
	Avance en el uso obligatorio de nueva tecnología de generación térmica de carbón.
	Fortalecimiento de la red nacional.
Transporte	Estándares de eficiencia de combustibles para coches y camiones ligeros nuevos a partir de 2016.
	Apoyo a los biocombustibles, gas natural y vehículos híbridos y eléctricos.
	Fomento del transporte de mercancías por tren.
Industria	Mejora del sector manufacturero mediante la iniciativa *Make in India*.
	Mejora e impulso de la eficiencia energética.
Edificios	Planificación y urbanización siguiendo el concepto "100 ciudades inteligentes".
	Aumento del número de electrodomésticos afectados por los estándares obligatorios.
	Incorporación del código en construcción en las ordenanzas locales y municipales.
	Ayudas al GLP como alternativa a la biomasa tradicional como combustible para cocinar.
Agricultura	Acercarse a un sistema de medición del consumo eléctrico.
	Reformas graduales y continuas en el precio de la energía, la promoción de micro-riegos, gestión de las aguas subterráneas y la diversificación de cultivos.

Fuente: Elaboración propia a partir de información publicada en el *World Energy Outlook 2015*.

4 La seguridad de suministro y la dependencia energética

La interpretación del significado de seguridad energética varía según la situación de cada país. Existe un gran número de definiciones del término, aunque la gran mayo¬ría comparten tres elementos clave: fiabilidad del suministro, asequibilidad y sostenibilidad. Otros dos elementos complementarios serían la disponibilidad y la eficiencia. En el documento que recoge la Política Energética Integrada (IEP)[41], el Gobierno indio también interpreta la seguridad energética en estos términos. El suministro energético es un factor esencial para la vida de todos los ciudadanos, independientemente de su situación económica. Ha de ser un suministro asequible (que tenga un precio razonable), seguro y fiable (sin cortes de suministro y suficiente para cubrir los picos de demanda).

Pero el escenario energético que presenta es un escenario insatisfactorio. Dos datos así lo muestran. El primero es la diferencia entre la demanda y la producción. En 2013, mientras el consumo energético era de 775Mtoe, la producción alcanzaba tan solo las 523Mtoe. El segundo es el ratio de crecimiento de cada uno: entre 1990 y 2013, la demanda había aumentado casi en un 151 % mientras que la producción no alcanzó el 79 % de incremento. Teniendo en cuenta las previsiones al alza de la demanda, expuestas anteriormente, el desequilibrio entre ambos datos también irá en aumento.

4.1 Producción, dependencia y sistema de reservas de los combustibles fósiles

4.1.1 Producción

India carece de los recursos energéticos necesarios para hacer frente, por sí sola, al incremento de demanda. Posee el 0,6 % de las reservas mundiales de petróleo, el 0,4 % de las reservas mundiales de gas (la mitad de las reservas recuperables son de gas convencional y la otra mitad es gas no convencional) y el 7 % de las reservas mundiales de carbón[42]. Un porcentaje considerable en este último caso, aunque no suficiente. La percepción tradicional apunta a una abundancia de carbón, sin embargo, los expertos advierten sobre los peligros de este “mito”. En la política energética de 2006 ya se señalaba la falsa seguridad que esta creencia puede generar al no tener en cuenta la cantidad finalmente extraíble. El Décimo Primer Plan Quinquenal (2007-2012) indicaba que las reservas totales de carbón soportarían el ritmo de producción durante 140 años. Sin embargo, las reservas de carbón extraíbles (el 45 %)

[41] Planning Commission, *Integrated energy policy… op. cit.*, p. v.

[42] India Energy Security Scenarios http://www.indiaenergy.gov.in/background.php y AIE, *World Energy Outlook 2015… op. cit.*, p. 522. La Agencia aumenta el porcentaje de reservas de carbón hasta el 12 %.

se acabarían en unos 45 años si el incremento de producción se mantenía en el 5 % anual. Era, por tanto, imprescindible impulsar la exploración y la perforación[43].

Desde 2005, con la entrada de capital privado, la inversión en el suministro energético ha ido en aumento. Sin embargo, todavía es insuficiente para hacer frente a los retos que plantea el incremento de la demanda. La AIE calcula necesaria una inversión acumulada de 2,8 billones de dólares hasta 2040. Más del 45 % de esa cantidad estaría destinada a la generación de electricidad y otro casi 30 % a la transmisión y distribución. Casi el total del 25 % restante, es decir, 696 mil millones de dólares tendrían como finalidad la industria del petróleo (285 mil millones), gas (212 millones) y carbón (199 mil millones)[44].

Tabla B.4 – Producción de energía 1990-2040 (en Mtoe)

	Carbón	**Petróleo**	**Gas**	**Nuclear**	**RE**
1990	94	35	11	2	140
2000	131	37	23	4	155
2010	214	43	43	7	190
2020	298	35	32	17	237
2030	443	31	46	43	274
2040	648	31	75	70	297

Fuente: Elaboración propia con datos de la AIE.

Durante los últimos años, los cálculos y las proyecciones de los Estados en cuanto a sus balances energéticos se han visto alteradas por el desarrollo de la tecnología que permite explotar el petróleo y gas no convencional. Para algunos Estados, como Estados Unidos, esta posibilidad supone pasar de ser importador a ser exportador. Este no es el caso de India, aunque tampoco ignora su potencial. Los estudios estiman unas reservas de carbón metano aproximadas a los 2,6 billones de metros cúbicos, pero tan solo el once por ciento sería recuperable. En cuanto al gas de esquisto, diferentes estudios aportan diferentes resultados en cuanto al valor total de las reservas, repartidas por las cuencas de Cambay, Gondwana, Krishna-Godavari y Cauvery. En octubre de 2013, el Gobierno estableció las líneas para la política sobre exploración y explotación de los combustibles no convencionales por las empresas de petróleo nacionales. Las obras para la explotación de un pozo en la cuenca de Cambay ya han comenzado[45].

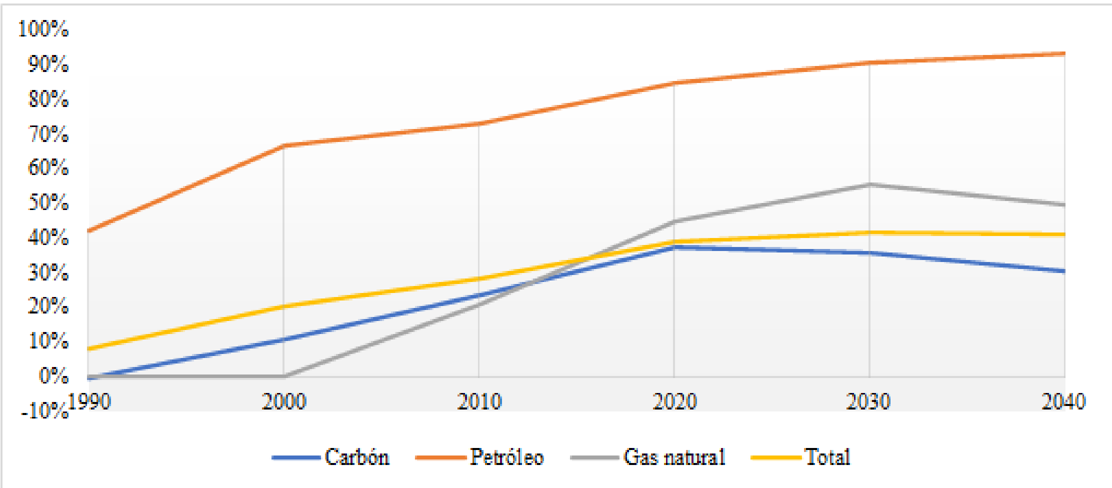
[43] Planning Commission, *11th Five Year Plan. Vol III*, Government of India, New Delhi, pp. 334 y 371.
[44] IEA, *India Energy Outlook… op. cit*, p. 164.
[45] Ministry of Petroleum and Natural Gas, *Annual Report 2013-2014*, Government of India, pp. 22-23 y 34.

4.1.2 Dependencia

La dependencia de las importaciones afecta a los tres combustibles fósiles, aunque de forma muy diferente. Como queda reflejado en el siguiente gráfico, el nivel de dependencia del petróleo supera ampliamente al del carbón y gas natural, e incluso duplica los niveles medios de dependencia total del país. En el gráfico también se observa cómo el grado de dependencia del gas natural ha experimentado un incremento más que considerable a partir de 2003 mientras que la trayectoria alcista del carbón ha sido constante. Destacar, no obstante, que los tres combustibles fósiles han experimentado un crecimiento de dependencia similar, próximo al 30 %. En concreto, la del petróleo ha variado un 33 %, la del gas un 32 % y la del carbón un 28 %.

Este escenario varía a partir de la segunda década de este siglo cuando se espera que la dependencia total se estabilice en torno al 40 %, aunque aquí, también, el comportamiento individual de las fuentes será distinto. El nivel de dependencia del petróleo continuará incrementándose, si bien de forma más moderada, durante todo el periodo observado. Por su parte, tanto el carbón como el gas descenderán, aunque en diferentes momentos. Si la dependencia del carbón comenzará su descenso a partir de la próxima década, el gas necesitará otros diez años de incremento antes de caer.

Figura B.2 – Dependencia combustibles fósiles 1990-2040 (en %)



Fuente: Elaboración propia con datos de la AIE.

India es uno de los pocos países con una gran dependencia de petróleo, pero que a la vez exporta una cantidad significativa de productos refinados[46]. Durante el año 2013-2014, el país importó el 75 % del petróleo y gas consumidos y alrededor de

[46]IEA, *World Energy Outlook 2015… op. cit.*, p. 440.

una cuarta parte del carbón. Esto significa que se importaron más de 189 millones de toneladas métricas de petróleo crudo y casi 17 millones de toneladas métricas de productos derivados (un 2,4 % y 9,13 % más que el año anterior), casi 13 millones de toneladas de gas natural licuado (lo que supuso un descenso del 4,65 % en relación al año anterior) y casi 167 millones de toneladas métricas de carbón (un 14,45 % más que en 2012-2013)[47]. Según las proyecciones de la Agencia Internacional de la Energía, India se convertirá en el mayor importador de carbón antes de 2020[48].

Tabla B.5 – Importaciones y exportaciones de combustibles fósiles (en Mtoe)

Año	**Carbón**		**Petróleo**		**Gas natural**	
	Import.	**Export.**	**Import.**	**Export.**	**Import.**	**Export.**
1990	4	0	30	-3	0	0
1995	9	0	49	-4	0	0
2000	15	-1	85	-8	0	0
2005	26	-1	115	-24	6	0
2010	71	-1	185	-61	11	0
2013	101	-1	210	-71	15	0

Fuente: Elaboración propia con datos de la AIE.

Otra de las características de las importaciones de energía de India es la concentración de las mismas en un número reducido de Estados, especialmente del Golfo, a pesar del considerable incremento en el número total de Estados de los que importa combustibles fósiles. Según datos de Naciones Unidas[49], la lista de países se habría triplicado desde la década de los noventa, superando, en los últimos años, el centenar. Sin embargo, en 2013, más del 60 % de las importaciones de petróleo de India vinieron de Arabia Saudí, Irak, Kuwait, Venezuela y Nigeria. El 86 % del gas importado era de Catar, Arabia Saudí y Emiratos Árabes. Por su parte, más del 85 % de las importaciones de carbón las suministró Indonesia, Australia y Sudáfrica.

El incremento de las importaciones, además de las implicaciones geopolíticas, también tiene un efecto en la economía del país. Por un lado, parte de las reservas de divisas se utilizan para pagar el coste de las importaciones, por otro, aumenta la exposición al impacto de la volatilidad de los precios y, por último, el Gobierno tiene que destinar más recursos a atenuar el impacto de los altos precios por medio de subsidios[50]. Como ejemplo, las importaciones de petróleo y gas para 2013-2014 su-

[47] Ministry of Petroleum and Natural Gas, *op. cit.* y Ministry of Coal, http://coal.nic.in/content/production-supplies.
[48] IEA, *India Energy Outlook… op. cit.*, p. 111.
[49] Naciones Unidas, http://comtrade.un.org/
[50] India Energy Security Scenarios, http://www.indiaenergy.gov.in/background.php.

pusieron a las arcas del Estado entre 170-180 mil millones de US$. Ante estos datos, el Gobierno de la India ha reforzado los esfuerzos por explotar las reservas de carbón, petróleo y gas. Sin embargo, los problemas, principalmente estructurales, han impedido que los resultados fuesen los deseados.

4.1.3 Sistema de reservas anticrisis

Una de las principales preocupaciones en una situación de dependencia energética es cómo responder a una crisis de suministro. Las importaciones de carbón no representan un riesgo en este sentido ya que las interrupciones en el mercado no son normales. Además, un volumen importante proviene de proyectos de empresas indias en el extranjero[51]. En cuanto al petróleo, las compañías indias están presentes en 25 países y participan en yacimientos de petróleo y gas en América del Sur, África, el sudeste de Asia y la región del mar Caspio. Sin embargo, la mayoría de las importaciones provienen de Oriente Medio (principalmente de Arabia Saudí, Irak, Irán, Kuwait y Emiratos Árabes para el petróleo y Catar para el gas) donde estas empresas tienen poco acceso directo a la inversión. Para reducir los riesgos de corte de suministro, el MoPNG defiende la creación de un corredor energético, mediante oleoductos y tuberías transnacionales, con Asia Central y con Oriente Medio. También aboga por establecer contratos de suministro a largo plazo[52].

Debido a la crisis del petróleo de 1973, los países consumidores miembros de la Agencia Internacional de la Energía, idearon un sistema de respuesta basado en el almacenamiento de reservas estratégicas, equivalentes, como mínimo a 90 días de importaciones netas. En enero de 2004, el Gobierno de la India decidió establecer su propio sistema de Reservas Estratégicas de Petróleo (SPR). En 2008 se aprobó dar comienzo a la primera fase del proyecto, construyendo tres reservas en Mangalore (Karnataka), Padur (Karnataka) y Vishakhapatnam (Andhra Pradesh) con una capacidad de 39,3 millones de barriles en total. En diciembre de 2011, el MoPNG anunció la segunda fase del proyecto: la construcción de otras cuatro reservas más en Padur (Karnataka), Bikaner (Rajasthan), Rajkot (Gujarat) y Chandikhol (Odisha) con capacidad de 92 millones de barriles. Estas se esperan que estén finalizadas para 2020.

La construcción de las reservas está bajo la responsabilidad del Consejo para el Desarrollo de la Industria del Petróleo (OIDB). Para su implementación y gestión se creó la Indian *Strategic Petroleum Reserves Limited* (ISPRL), propiedad de OIDB y dirigida por miembros del MoPNG y del OIDB.

Por su parte, como ya se ha mencionado en el apartado anterior, el gas natural tiene diferentes precios en la India, dependiendo del origen, lo que se traduce en

[51] IEA, *Energy Supply Security*, OECD/IEA, Paris, 2015, p. 516.
[52] Ministry of Petroleum and Natural Gas, *op. cit.*, p. 6.

varios mercados con precios muy diferentes, siendo considerablemente más alto el que corresponde al gas importado. Esto reduce el número de demandantes de este tipo, por lo que el concepto de emergencia o crisis de suministro en el sector del gas es diferente al concepto que se tiene en otros países, como por ejemplo, los miembros de la AIE[53]. Prácticamente no existen instalaciones de almacenamiento de gas natural en India.

La industria india no tiene la obligación de mantener un mínimo de reservas. Tampoco existe ninguna medida que pida reducir el consumo en una situación de crisis de suministro.

4.2 Las fuentes no fósiles y la eficiencia energética

Debido a su abundancia (y mayor proporcionalidad en su distribución geográfica), al abaratamiento de los costes de explotación en algunos casos (aunque todavía necesiten subsidios) y a la preocupación tanto por la seguridad como por el medio ambiente, el desarrollo de las fuentes de energía renovables se encuentra en un momento favorable. La energía eólica y la energía solar fotovoltaica están llamadas a tener un papel importante en la oferta energética de la India, aunque tendrán que hacer frente al problema de la variabilidad o intermitencia de la generación causada por factores como la intensidad del viento, la estacionalidad, la debilidad de las redes de distribución o los altos picos de demanda en momentos concretos del día.

También incrementará su presencia en India la energía nuclear. Según las previsiones de la Agencia, en 2040 India habrá multiplicado por siete su capacidad nuclear en relación con la capacidad de 2014, convirtiéndose en el segundo Estado con un mayor incremento de capacidad nuclear instalada, tan solo superada por China[54].

Otra forma que India tiene de controlar su demanda energética y, por tanto, los riesgos asociados con la seguridad es la eficiencia energética. La iniciativa *Perform, Achieve and Trade* (PAT), anunciada por el Gobierno en 2008 dentro de la Misión Nacional de Mejora de la Eficiencia Energética (NMEEE) como parte del Plan de Acción Nacional sobre el Cambio Climático (NAPCC), tiene como objetivo mejorar la eficiencia energética entre grandes industrias que usan la energía en forma intensiva mediante el comercio de certificados. El programa establece un consumo energético determinado para cada consumidor designado sobre el año base y el año final que se verifica mediante un organismo acreditado. Los consumidores que hayan superado los objetivos requeridos reciben tantos certificados de ahorro energético como toneladas métricas de petróleo equivalente hayan ahorrado.

[53] IEA, *Energy Supply… op. cit.*, pp. 540-553.
[54] IEA, *India Energy Outlook… op. cit.*, p. 137.

Durante el periodo de cumplimiento los consumidores pueden negociar certificados (ahorros cumplidos) o comercializar "obligaciones" (basadas en ahorros futuros). Si al final del periodo de cumplimiento no se ha superado el objetivo, el consumidor puede comprar certificados de otros consumidores o pagar una sanción[55].

Para otros sectores, el Gobierno ha puesto en marcha otro tipo de medidas. Por ejemplo, para las PYMES se han impulsado medidas de concienciación y de apoyo financiero; en el sector transporte se han introducido medidas para el ahorro de combustible; y en el sector de la construcción, existen tanto un código de consumo energético (Código para la Conservación de Energía en la Construcción (CCCE), 2007) para los edificios comerciales como unos estándares mínimos de consumo en los electrodomésticos.

La inversión anual necesaria en eficiencia energética para uso final se estima cercana a los 60 mil millones de dólares. Un gran desafío si se consideran los diferentes obstáculos que cada sector presenta. Los principales retos para las industrias de consumo intensivo están relacionados con la amortización y el entorno internacional. Las medianas y pequeñas empresas se enfrentan al problema de la financiación y a la falta de conocimiento, problema, este último, que comparten con el sector de la construcción residencial. Por su parte, el gasto de los hogares en eficiencia energética es relativamente pequeño en comparación con el gasto en electricidad[56]. Las ayudas públicas para la adecuación y la concienciación del ahorro posible se antojan indispensables además de ayudar, por otra parte, a combatir otro de los grandes retos energéticos de la política de India, como es el de la pobreza energética.

5 Pobreza energética y el sector eléctrico

La población de India se caracteriza por ser joven y todavía mayoritariamente rural. La esperanza de vida está en 66 años, un 29 % es menor de 15 años (en España ese porcentaje es del 15 %) y tan solo un tercio de la población total vive en urbes. Estas ciudades generan el 63 % de la actividad económica del país. Se espera que, para 2030, casi la mitad de la población viva en núcleos urbanos, lo que supone más ciudades y más pobladas. En la década de 2030 las ciudades más grandes de la India serán más grandes que muchos países importantes[57]. Según datos del Ministerio de Urbanismo indio, el número de ciudades aumentó en 2.774 unidades en apenas diez años, alcanzando un total de 7.935 en 2011. De ellas, 53 tenían un millón o más de

[55] Center for Air Clean Policy, *The Perform, Achieve, and Trade Scheme for Industrial Energy Efficiency. India*, http://ccap.org/assets/CCAP-Booklet_India_PAT.pdf.

[56] IEA, *India Energy Outlook… op. cit.*, p. 163.

[57] Ministry of Finance, "Climate Change and Sustainable Development", *Economic Survey 2014-2015*, vol. 2, Government of India, p. 128.

habitantes y otras 412 superaban los cien mil. A medida que la población aumenta, la demanda de cada servicio se multiplicará de cinco a siete veces.

5.1 La pobreza energética en India

La definición más extendida de pobreza energética es aquella que hace referencia al acceso a servicios energéticos limpios, asequibles y estables, suministrados de forma fiable y con una calidad constante. Dos de los factores que afectan directamente al nivel de pobreza energética de un país son el estado del sector eléctrico y el ratio de consumo de combustibles limpios. En India, la tasa de crecimiento del sector eléctrico es una de las más altas, según el escenario de Nuevas Políticas de la AIE, con una media anual del 4,4 %. El consumo de electricidad supone, en la actualidad, el 15 % de la energía final consumida. No obstante, cerca del 20 % de la población, unos 240 millones de personas, carece de acceso a la electricidad[58] y aquellos que sí están conectados sufren constantes interrupciones de suministro[59]. A pesar de que la capacidad eléctrica ha aumentado una media anual de 7,72 % desde 2006 (un 6,75 % entre 2013 y 2014)[60], la generación de electricidad no solo no cubre la demanda, sino que las proyecciones indican que la situación va a empeorar[61].

También es notable el alto uso de biomasa tradicional. Los datos proporcionados en los diferentes informes, indican que, más de ochocientos millones (un 66 % de la población) seguía utilizando biomasa tradicional para cocinar[62]. A pesar de estas cifras, un dato positivo es el incremento del peso de la energía comercial en la demanda energética en detrimento de la energía no comercial. Un cambio que viene promovido, según apunta el Décimo Segundo Plan Quinquenal, por una sustitución de la biomasa tradicional (madera y residuos animales) por combustibles limpios[63]. El Gobierno ha promovido, principalmente a través de subsidios, el uso del gas licuado de petróleo (LPG) como combustible alternativo para cocinar[64].

Aunque la pobreza energética es un problema que afecta a todo el territorio, existen diferencias entre las zonas urbanas y las zonas rurales, siendo estas últimas las más perjudicadas. El consumo energético de los hogares en las ciudades está dominado por los combustibles comerciales y por la electricidad. En el caso de los hogares

[58] IEA, *World Energy Outlook 2015… op. cit.*, pp. 433 y 436.

[59] En el 5 Plan Quinquenal, se reconoce que, en futuros estudios, los datos puedan variar al corregir algunas diferencias en los cuestionarios utilizados para recoger la información en distintas áreas.

[60] Central Statistics Office, *Energy Statistics 2015*, Ministry of Statistics And Programme Implementation, Government of India, New Delhi, p. 10.

[61] S. J. Ahn, y D. Graczyk, *op. cit.*, p. 34.

[62] IEA, *World Energy Outlook 2015… op. cit.*, p. 437.

[63] Planning Commission, *12th Five-Year Plan… op. cit.*

[64] IEA, *World Energy Outlook 2015… op. cit.*, p. 437.

rurales, el principal componente del consumo energético sigue siendo la biomasa tradicional. Esta diferencia puede ser reflejo de la desigualdad económica entre ambas zonas pero también puede deberse a la falta de alternativas (zonas sin acceso a la electricidad). Una consecuencia de esta situación es un mayor consumo energético relativo, ya que se deben usar combustibles menos eficientes.

Otra de las diferencias principales reside en el porcentaje del gasto de energía que los residentes de ambas zonas destinan a combustibles sólidos no limpios y al queroseno. Mientras menos de una cuarta parte de la población urbana destina más del 50 % de su gasto en energía a estos combustibles, en las zonas rurales, más del 80 % de la población lo hace. Al mismo tiempo, los hogares rurales pagan más por cada unidad de energía útil que consumen. Los precios pueden ser incluso un 35 % más altos[65].

No es de extrañar, por lo tanto, que el sector eléctrico comparta importancia en las políticas energéticas junto a las inquietudes por la seguridad y la sostenibilidad.

5.2 Reformas y proyectos

A partir de 1991, con el inicio de la liberación económica, se permitió la entrada de capital privado primero en la generación y en la distribución y, a finales de la década, también en la transmisión. Sin embargo, ni los esfuerzos por acelerar la inversión mediante incentivos *(Mega Power Policy 1995*) ni la posterior constitución de la Comisión Central de Energía Eléctrica (CERC) o de las comisiones estatales obtuvieron los resultados esperados. El sector eléctrico continuaba siendo comercialmente inviable a principios del siglo XXI.

Las reformas, no obstante, han tenido como resultado la promoción de esfuerzos para la electrificación de las zonas rurales. En 2001 se lanza la iniciativa "Energía para todos en 2012". Los objetivos marcados por el Ministerio de Energía eran, además de energía para todos, garantizar el suministro suficiente como para incrementar el PIB en un 8 %, una energía fiable y de calidad, un precio de coste óptimo y la viabilidad comercial de la industria[66].

La Ley de Electricidad de 2003 continuará con los esfuerzos, promocionando la competencia y la no discriminación en la generación, transmisión y distribución. También elimina la necesidad de licencias para la generación térmica y la generación para autoconsumo. Por otra parte, establece medidas para un mayor control del

[65]Véase Karthik Ganesan and Rajeev Vishnu, *Energy Access in India - Today, and Tomorrow*, Council on Energy, Environment and Water Working Paper 2014/10, New Delhi, junio 2014, p. 7 y Anjali Bhide and Carlos Rodríguez Monroy, "Energy poverty: A special focus on energy poverty in India and renewable energy technologies", *Renewable and Sustainable Energy Reviews*, vol. 15, n.º 2, February 2011, p. 1059.

[66]IEA, *Comparative study on rural electrification policies in emerging economies*, OECD/IEA, Paris, 2010, p. 72.

consumo y del uso fraudulento al tiempo que introduce mecanismos financieros de apoyo para ciertos grupos. También incluye, como ya se ha mencionado, la obligación de comprar una cierta cantidad de electricidad generada por energías renovables.

Los criterios utilizados para definir si una zona está electrificada han cambiado con los años. Hasta 1997, para determinar si una *revenue village* (una pequeña región administrativa con fronteras definidas y que puede incluir varias aldeas) estaba electrificada o no, bastaba con que se produjera cualquier uso de electricidad dentro de los límites administrativos de esa zona. Ese año se añade que el uso debe realizarse en la zona habitada. En 2004 se incorporan dos criterios mucho más restrictivos: por una parte, es necesario una infraestructura básica (transformador y/o canales de distribución) disponible en la zona habitada, que incluya un ajuste entre el suministro y la demanda en al menos una aldea y en cualquiera de los lugares/edificios públicos; además, al menos un 10 % del total de los hogares deben tener electricidad. Tras este cambio, muchas zonas consideradas como electrificadas pasaron a formar parte de las no electrificadas[67].

La Política Nacional de Electricidad de 2005 detallará las iniciativas y programas destinados a cumplir con los objetivos de la Ley de 2003. En ella se incluyen aspectos como la electrificación de las zonas rurales, la recuperación del gasto y la conservación de ener¬gía. Por su parte, la Política Nacional de Precios de 2006 se centrará en reforzar la viabilidad financiera del sector y en hacerlo atractivo a los inversores.

En 2005, el Gobierno puso en marcha, en el marco de la iniciativa "Electricidad para todos en 2012", el plan *Rajiv Gandhi Grameen Vidyutikaran Yojana* (RGGVY). Subvencionado en un 90 % por el Gobierno central (los estados aportarían el 10 % restante a través de recursos propios y/o préstamo de las instituciones financieras) e implementado por la empresa pública *Rural Electrification Corporation* (REC), tenía como objetivo proveer de electricidad a todos los hogares (incluidos los de las zonas rurales) para 2009. Un objetivo demasiado ambicioso. Su implementación fue demasiado lenta durante los primeros años, por lo que esa fecha se ha ido modificando, a la vez que también se han ido introduciendo nuevas condiciones para mejorar y facilitar su implementación.

A pesar de ello, la puesta en marcha del plan de RGGVY marcó un punto de inflexión en los esfuerzos por proveer de electricidad a las zonas rurales de la India. Los Gobiernos estatales estaban obligados a elaborar planes de electrificación rural que describiesen tanto el modelo a seguir (integración en red o sistemas autónomos) como las tecnologías disponibles, su adecuación a las normas medioambientales, y el número de hogares que necesitaban ser conectados y su distancia de la red.

[67] *Ibídem*, p. 66.

Como primera opción, se intentaba conectar los hogares a la red de distribución eléctrica. En el caso de que la conexión a la red no fuese factible o rentable, entonces se optaba por sistemas descentralizados de distribución y generación, alimentados tanto por fuentes renovables como fuentes convencionales. Como norma general se elegía la opción más eficaz y con menor coste marginal. Asimismo, se buscaba instalar al menos un transformador en cada pueblo y proveer un servicio gratuito para todas las familias que estuviesen por debajo del umbral de la pobreza. En julio de 2015, el RGGVY se incorporó a un nuevo esquema, el *Deen Dayal Upadhyaya Gram Jyoti Yojana* (DDUGJY), cuyos principales objetivos son la separación de las redes de distribución entre los consumidores agrícolas y los no agrícolas para reducir la desconexión de la carga, reforzar la infraestructura de transmisión y distribución local y mejorar la medición[68].

Otra gran iniciativa del Gobierno indio para luchar contra la pobreza energética se centra en aumentar la capacidad de las plantas de carbón. No hay que olvidar que sigue siendo el combustible rey en la generación de electricidad y aunque su peso relativo irá en continuo descenso durante los próximos veinticinco años, en el 2040 seguirá siendo superior al 50 %. Sin embargo, una gran parte de las plantas de carbón utilizan una tecnología de generación ineficaz, que junto a la mala calidad del carbón y al clima indio, hacen que la eficiencia media esté por debajo del 35 %, inferior a la eficiencia de las plantas de China o de Estados Unidos[69]. Los *Ultra Mega Power Projects* (UMPP) son proyectos inter-estatales de plantas de carbón de grandes dimensiones (cada planta con un mínimo de 4.000 MW de capacidad) que operan a temperaturas y presiones por encima del punto crítico del agua, aumentando la eficiencia. De media, la eficiencia de cada planta de carbón pasará del 29 % en 2012 al 36 % en 2040[70].

5.3 Consideraciones adicionales

Además de la demanda y la capacidad de generación, las iniciativas destinadas a lograr el acceso universal a la energía necesitan tener en cuenta otra serie de consideraciones relacionadas con la infraestructura y la inversión del sector eléctrico.

Una red eléctrica se compone de tres elementos principales: las plantas generadoras (producen electricidad), la red de transmisión (llevan la electricidad de las plantas generadoras a los centros de demanda donde los transformadores reducirán el voltaje) y la red de distribución (llevan la electricidad hasta el consumidor final). La red

[68] IEA, *India Energy Outlook… op. cit.*, p. 29.
[69] IEA, *World Energy Outlook 2014… op. cit.*, p. 436.
[70] IEA, *World Energy Outlook 2014… op. cit.*, p. 235.

eléctrica nacional de India está compuesta por cinco zonas de redes regionales interconectadas, cada una con una capacidad y una matriz generadora diferente. Las líneas de transmisión representan tan solo el 5 % de la longitud de la red. El resto son líneas de distribución. También se caracteriza por ser una de las redes mundiales con mayores pérdidas (de generación de electricidad), impulsadas, según apunta la AIE, por factores técnicos derivados de la edad y del mal mantenimiento, y por factores comerciales, entre los que se encuentran los robos, una medición inexacta del consumo y una inadecuada recaudación de impuestos[71].

Es imprescindible contener y, en la medida de lo posible, reducir los costes de generación, transporte y distribución. La tecnología utilizada por diversas fuentes puede ser costosa y requerir un gran primer esfuerzo en la inversión, pero se justifica por el aumento de la eficiencia y la reducción en el gasto de combustible. Por otra parte, las iniciativas destinadas a favorecer su uso deben tener en cuenta el futuro abaratamiento de la misma.

Entre las posibles opciones para mejorar la red eléctrica, el Gobierno de India ha mostrado un gran interés en lo que se conoce como la "red inteligente" (*Smart Grid*), la cual se define como "una red eléctrica que puede integrar de forma inteligente las acciones de todos los usuarios conectados a ella —generadores, consumidores y aquellos que son ambos— con el fin de proporcionar de forma eficiente un suministro eléctrico sostenible, económico y seguro"[72]. Para ello, creó el *India Smart Grid Forum* (una iniciativa público-privada) en 2010.

Tabla B.6 – Inversión en el suministro de electricidad 2015-2040 (en billones US$ 2014)

	Acumulado	**Media anual**
Generación	1 268	49
Carbón	354	14
Gas	66	3
Nuclear	96	4
E. Hidráulica	141	5
Otras renovables	611	23
(Solar)	*364*	*14*
Transmisión y Distribución	845	33
Total	2 113	82

Fuente: Elaboración propia con datos de la AIE.

[71] IEA, *India Energy Outlook 2015… op. cit.*, p. 95.
[72] Ministry of Power, Government of India, http://www.indiasmartgrid.org/sgg1.php.

En cualquier caso, la reforma del sector eléctrico de la India dependerá, en gran medida, de la inversión y financiación disponible. Según las proyecciones de la AIE en su escenario de Nuevas Políticas, la inversión necesaria para el suministro de electricidad en India entre 2015 y 2040 supondría más de 2,1 billones de US dólares (a precios de 2014). Más de un billón y cuarto de US dólares se emplearían en la generación y otros 845.000 millones en la transmisión y distribución. Estas cifras equivalen a una inversión media anual de 49.000 millones y 33.000 millones respectivamente[73].

Para satisfacer esta inversión, además de los fondos públicos, se espera una mayor participación del sector privado, tanto nacional como internacional. Su tamaño, el potencial de su crecimiento y el actual contexto hacen de India un país atractivo para los inversores, aunque no está libre de riesgos. Por ello, el Gobierno trabaja en ampliar la gama de opciones de financiación y en reducir el coste a largo plazo mediante iniciativas como los fondos de deuda de infraestructura de la India o un servicio de cobertura de divisas[74].

6 Cambio climático

El artículo 48-A de la Constitución de India afirma que “el Estado se esforzará en proteger y mejorar el medio ambiente y salvaguardar los bosques y la fauna del país”. Sin embargo, el énfasis de los Gobiernos indios en el crecimiento económico y en la erradicación de la pobreza ha elevado el grado de polución y de degradación del medio ambiente.

Con la entrada de la cuestión medioambiental en la agenda internacional, India está bajo constante presión para que adopte medidas más concretas a favor de la mitigación. El país necesita encontrar el modo de seguir creciendo pero de forma sostenible.

El cambio climático se incorporó a la agenda internacional al mismo tiempo que India comenzaba la liberalización de su economía. Se buscaba desarrollar la industria y las infraestructuras para, con ello, lograr el objetivo último del crecimiento económico. La respuesta de India ante la cumbre de la Tierra de Río de Janeiro en 1992 y posteriores ha de entenderse en ese contexto[75].

India reconoce su cada vez mayor influencia en las negociaciones globales sobre el clima por su creciente poder económico, así como que su participación es necesaria para lograr un resultado positivo significativo en ellas. Sin embargo, el Gobierno

[73] IEA, *India Energy Outlook… op. cit.*, p. 165.
[74] *Ibídem.*, p. 170.
[75] Milind Kandlikar y Ambuj Sagar, “Climate change research and analysis in India: an integrated assessment of a South–North divide”, *Global Environmental Change*, vol. 9, n.º 2, julio 1999, p. 125.

Tabla B.7 – Emisiones CO_2 (en MT y toneladas per cápita)

	Año	India	China*	OCDE	no OCDE	Mundo
Carbón						
	1990	396	1942	4142	4175	8316
	2000	629	2399	4216	4659	8875
	2010	1093	6009	4182	8923	13105
	2020	1713	7499	3659	11422	15081
	2030	2274	7570	2825	12500	15325
	2040	2907	7123	2195	13328	15523
Petróleo						
	1990	164	308	5030	3165	8815
	2000	266	594	5560	3548	9108
	2010	429	1004	5108	4693	10893
	2020	646	1410	4693	5972	11811
	2030	919	1745	4065	6895	12294
	2040	1221	1755	3556	7454	12489
Gas						
	1990	21	28	1928	1879	3807
	2000	42	124	2594	2062	4656
	2010	113	201	3050	3141	6192
	2020	156	549	3301	3999	7311
	2030	261	885	3584	5063	8672
	2040	390	1140	3776	6189	10024
Emisiones totales fuentes fósiles						
	1990	581	2278	11100	9219	20938
	2000	937	3117	12370	10269	22639
	2010	1635	7214	12340	16757	30190
	2020	2515	9458	11653	21393	34203
	2030	3454	10200	10474	24458	36291
	2040	4518	10018	9527	26971	38036
Emisiones totales fuentes fósiles per cápita						
	1990	0,7	2,0	10,4	2,2	4,0
	2000	0,9	2,5	10,7	2,1	3,7
	2010	1,3	5,4	9,9	2,9	4,4
	2020	1,8	6,7	8,9	3,3	4,4
	2030	2,3	7,2	7,7	3,4	4,3
	2040	2,8	7,2	6,8	3,5	4,2

Fuente: Elaboración propia con datos de la AIE. Datos de población de la base de datos del Banco Mundial.
*Incluye a Hong Kong.

indio debe sopesar este objetivo con otras prioridades nacionales, especialmente, económicas y sociales, incluyendo la reducción de la pobreza[76].

[76]Aaron Atteridge et al., “Climate Policy in India: What Shapes International, National and State Policy?”, *AMBIO*, vol. 41, n.º 1, 2012, p. 68.

La respuesta que India ha venido adoptando ante el problema del cambio climático ha estado marcada por otras preocupaciones como las cuestiones de soberanía, equidad y desarrollo económico[77].

6.1 La respuesta nacional

La Política Medioambiental de India de 2006 es un claro ejemplo de la postura defendida. Con ella, India declara su compromiso con los esfuerzos internacionales en la lucha contra el cambio climático a la vez que defiende la necesidad de encontrar un equilibrio entre el desarrollo sostenible y el derecho al desarrollo humano y económico. Hace responsables del éxito a todos los miembros de la sociedad, ya sean personas físicas o jurídicas, entidades públicas o privadas, nacionales o internacionales. Como objetivos concretos, establece la conservación y eficiencia en el uso de los recursos naturales; la equidad intrageneracional e intergeneracional; la integración de las consideraciones ambientales en el desarrollo económico y social; la buena gobernanza ambiental y la mejora de los recursos humanos, técnicos y económicos[78].

Además del Plan de Acción Nacional sobre el Cambio Climático (NAPCC) adoptado en 2008, y al que haremos mención más adelante, las estrategias energéticas presentadas por el Gobierno indio se dirigen tanto a la mitigación como a la adaptación. La mitigación se ocupa de las causas del cambio climático y requiere un cambio en el comportamiento actual de ciertas prácticas que agravan el problema. La adaptación se refiere a la adopción de políticas y prácticas para preparar condiciones que hagan frente a los efectos del cambio climático. Se admite que es imposible evitarlo y requiere un acomodo de la sociedad[79].

Entre las primeras destacan las destinadas a obtener un sistema energético más limpio y eficiente, mejorar la eficiencia energética del sector industrial, la adecuación de los centros urbanos, el reciclaje de los residuos, la transformación de la red de transporte en una red segura, limpia y sostenible, la reforestación planificada, la reducción de la contaminación y la participación privada y civil en la lucha contra el cambio climático. Un ejemplo son los intentos de crear, en el ámbito nacional, mercados de carbono. Bajo el marco de la Misión Nacional para una mayor Eficiencia Energética (NMEEE) se está llevando a cabo la iniciativa, *Perform, Achieve & Trade* (PAT), que afecta a 478 plantas (consumidores designados) en ocho sectores indus-

[77] T. C. Bisht, "Energy Security and Climate Change Challenges: India's Dilemma and Policy Responses", *Energy Security in the Era of Climate Change: The Asia-Pacific Experience*, 2011, pp. 117-118.

[78] Ministry of Environment and Forest, *National Environment Policy*, Government of India, 2006.

[79] James Meadowcroft, "Climate change governance", *World Bank Policy Research Working Paper Series*, 2009, p. 7; Sistema de Naciones Unidas sobre el cambio climático, http://www.un.org/es/climatechange/adaptation.shtml.

triales de alto consumo energético que representan un tercio del consumo total de energía[80].

Las estrategias para la adaptación ponen su énfasis en la agricultura, el agua, la salud, las zonas costeras e islas, la gestión de desastres, la protección de la biodiversidad y del ecosistema del Himalaya, la seguridad en las zonas rurales, las estrategias regionales y la gestión de conocimiento y construcción de capacidades. Los países no desarrollados son los más afectados por los efectos del cambio climático al depender en gran medida de los sistemas de recursos naturales para la subsistencia y tener menos recursos para adaptarse al cambio[81].

La mayor parte de la financiación de estas estrategias depende de las fuentes presupuestarias, ya que forman parte de programas sectoriales a largo plazo, aunque también existen otros mecanismos de financiación como los fondos nacionales e instrumentos fiscales e incentivos para las emisiones bajas en carbono.

Cada grupo de iniciativas, las destinadas a la mitigación y las que buscan la adaptación, cuenta con un fondo nacional de inversión propio. El Fondo Nacional para un Medio Ambiente Limpio se nutre, principalmente, de los impuestos al carbón introducidos en 2010. La recaudación hasta 2015 era de unos 2.700 millones de US$, que se utilizan en 46 proyectos. Mucho más discreto es el Fondo Nacional para la Adaptación. Sus 55,6 millones de USD se usan como complemento al gasto sectorial realizado por los diferentes ministerios.

Entre el resto de instrumentos fiscales que buscan incentivar un modelo energético más limpio se encuentran la reconversión de un sistema de subsidios a los combustibles fósiles (gasolina y diésel) a un sistema impositivo, la creación de unos bonos libres de impuestos para financiar proyectos de energía renovable y el apoyo económico desde el Gobierno central a los diferentes estados en materia de reforestación.

6.2 La respuesta ante la comunidad internacional

A comienzos de la década de los noventa, la organización no gubernamental india *Centre for Science and Environment* rebatió los resultados del trabajo realizado por la organización *World Resources Institute* (WRI). Esta, tras calcular el nivel de emisiones corrientes de diferentes Estados, señalaba a India como uno de los más contaminantes debido a la cantidad de emisiones de metano derivada del cultivo de arroz. La organización india no solo cuestionó los supuestos en los que se habían basado los cálculos, sino que abogó por una diferenciación entre “emisiones de lujo” (propias de los Estados del norte) y “emisiones de supervivencia” (propias de los Estados del sur).

[80] Ministry of Finance, *op. cit.*, p. 125.
[81] James Meadowcroft, *op. cit.*, p. 7.

También propuso que las emisiones se contabilizasen per cápita y que se tuviera en cuenta la responsabilidad histórica[82].

India basa sus argumentos sobre la responsabilidad diferenciada e histórica en tres puntos. Primero, si se considera la cantidad de gases de efecto invernadero acumulada, la participación de India entre 1850 y 2000 era de un 2 %, muy inferior al 57 % que representaban las emisiones de Estados Unidos y la Unión Europea en conjunto para ese periodo. Esto demuestra, según India, que los países desarrollados tienen una responsabilidad histórica que no comparten los países en vías de desarrollo, o al menos no en la misma proporción. La distinción entre países del Anexo I (países industrializados) y países No Anexo I (países en vías de desarrollo), establecida en la Convención Marco sobre el Clima de las Naciones Unidas satisfizo a India en este punto[83].

Tabla B.8 – Emisiones CO_2 (en % de las emisiones totales)

Año	**India**	**China**	**OCDE**	**no OCDE**	**Mundo**
1990	3	11	53	44	100
2000	4	14	55	45	100
2010	5	24	41	56	100
2020	8	28	34	63	100
2030	10	28	29	67	100
2040	14	26	25	71	100

Fuente: Elaboración propia con datos de la AIE. *La diferencia entre las emisiones totales y la suma de los datos ofrecidos se debe a que no están incluidos los bunkers internacionales.

Segundo, desde 2008, India ocupa el tercer puesto de la lista de países más contaminantes. Sin embargo, la cantidad de emisiones per cápita está por debajo de la media de los países más desarrollados. En 2013, eran de 1,49 toneladas frente a las 16,18 toneladas de Estados Unidos. La media de la OCDE para ese año era de 9,55 toneladas por habitante.

No obstante, los críticos con ambos argumentos apuntan a la tendencia alcista de las emisiones de India y rechazan la idea de que una responsabilidad pasada limitada sea excusa para la inacción. Además, el argumento de que India necesita aumentar las emisiones en nombre de los más necesitados no siempre se corresponde con la realidad, pues a menudo no son éstos los beneficiados de los proyectos realizados[84].

[82]K. Michaelowa y A. Michaelowa, "India in the international climate negotiations: from traditional nay-sayer to dynamic broker", CIS Working Paper No. 70, Center for Comparative and International Studies, ETH and University of Zurich, Zurich, Switzerland, 2011, p. 6.

[83]*Ibídem*, p. 7. Véase también Navroz K. Dubash, "Towards a Progressive Indian and Global Climate Politics", Centre for Policy Research, New Delhi, September 2009, pp. 2-3.

[84]Navroz K. Dubash, *op. cit.*, p. 6.

Tercero, la transferencia tecnológica y la ayuda financiera condicionadas por parte de los países desarrollados son entendidas por el Gobierno indio como una posible relación de dependencia que podría derivar en una pérdida de soberanía[85].

India ha adoptado una actitud cambiante a lo largo de los años, relajándose o endureciéndose, pero siempre responsabilizando a los países desarrollados de la situación, defendiendo las responsabilidades diferenciadas[86] y buscando el apoyo de otros países en vías de desarrollo para constituir un frente común en las negociaciones multilaterales[87].

India firmó y ratificó el Protocolo de Kioto en 2002 como país del No Anexo I, por lo que no estaba obligada a cumplir con objetivos concretos de reducción de emisiones. Además, está alineada con el Grupo de los 77 desde el comienzo de las reuniones, con el Grupo BASIC (Brasil, Sudáfrica, India y China) desde la reunión en Copenhague en 2009 y con el Grupo de los Países en Desarrollo Afines (un grupo de entre 25 y 30 países) desde la Conferencia de Durban en 2011[88]. Sin embargo, los intereses de su política exterior han influido en su postura ante el cambio climático. La aspiración de India de convertirse y ser reconocida como potencia mundial, así como las preocupaciones sobre la seguridad regional y sus intereses económicos, incentivan la búsqueda de un alineamiento geopolítico más amplio, en particular con Estados Unidos y China. Las conversaciones bilaterales en materia climática pueden favorecer las relaciones entre los Estados. Además, el anuncio de China en 2009 de reducir la intensidad de sus emisiones creó en India, según algunos expertos, el temor de que la aislaran de las conversaciones internacionales[89]. India hizo su propia declaración de objetivos de reducir voluntariamente la intensidad de sus emisiones sobre el PIB para 2020 en un 20-25 %, respecto a los niveles de 2005. Entre 2005 y 2010 había conseguido una rebaja del 12 %[90].

La disposición de India de adquirir un mayor compromiso, siempre y cuando no obstaculice el crecimiento económico, se observa en la adopción del Plan de Acción Nacional sobre el Cambio Climático (NAPCC) de 2008[91]. El Plan se divide en ocho misiones que cubren las áreas de la energía solar, la eficiencia energética, un hábitat sostenible (planificación urbana), el agua, el ecosistema del Himalaya, los bosques, una agricultura sostenible y el conocimiento estratégico sobre el cambio climático.

[85] T. C. Bisht, *op. cit.*, pp. 118-119.

[86] K. Michaelowa and A. Michaelowa, *op. cit.*, p. 6.

[87] T. C. Bisht, *op.cit.*,pp. 117-118.

[88] *Diplomacia india en el trabajo. Cambio Climático*, www.embajadaindia.org/.

[89] Aaron Atteridge et al., *op. cit.*, pp. 70-71.

[90] *India's Intended Nationally Determined Contribution: Working towards climate justice*, https://www4.unfccc.int/sites/submissions/INDC/Published/20Documents/India/1/INDIA/INDC %20TO %20UNFCCC.pdf.

[91] K. Michaelowa and A. Michaelowa, *op. cit.*, p. 8.

Desde una perspectiva energética destacan las dos primeras misiones. Una orientada al suministro y la otra a la demanda. La *Jawaharlal Nehru National Solar Mission* (JNNSM), intenta incrementar significativamente la cuota de energía solar en la estructura energética. Su objetivo para 2030 es equiparar la energía térmica de origen solar con la originada por carbón. La *National Mission for Enhanced Energy Efficiency* (NMEEE) busca una mejor gestión del consumo, principalmente por la industria.

Sin embargo estas misiones no están libres de críticas ya que se les acusa de estar más orientadas a la adaptación que a la mitigación. Por otra parte, también se cuestiona la sostenibilidad de todo el Plan de Acción debido a que el compromiso sobre la reducción de emisiones indica que no se podrá superar el nivel de emisiones per cápita de los países desarrollados[92].

Como paso previo a la celebración de la vigésimo primera Conferencia de las Partes de la Convención Marco de Naciones Unidas sobre el Cambio Climático de París 2015 (COP 21), se solicitó que todos los Estados presentasen su plan nacional de acción. La Contribución Nacional Determinada[93] (INDC), presentada por India se mantiene en la misma línea expresada anteriormente. Bajo el título de "Trabajando hacia una justicia climática", en el texto se recuerda la limitada contribución histórica de India al problema del cambio climático, la responsabilidad de los países desarrollados y su inadecuada respuesta hasta ahora, y se rechaza la idea de que los países en vías de desarrollo se deban sentir culpables por querer llevar a cabo su "derecho a crecer". También insiste en la necesidad de una transferencia de tecnología de los países desarrollados a los no desarrollados, y en particular a India, que no sea sinónimo de un mecanismo de mercado favorable a los primeros.

El acuerdo que defiende estaría basado en la justicia climática, en los principios de equidad y en la responsabilidad diferenciada. Debería ser comprehensivo y responder a las diferentes áreas de adaptación, mitigación, finanzas, traspaso de tecnología, creación de capacidades, transparencia y apoyo, pero salvaguardando el espacio genuinamente necesario para el desarrollo de los países en vías de desarrollo como India.

De las ocho medidas presentadas en el INDC para el periodo 2021 a 2030, tan solo tres tienen un carácter concreto. La primera es la continuación del objetivo de reducir la intensidad de sus emisiones sobre el PIB presentado en Kioto. Esta vez, el objetivo fijado es la reducción de un 33-35 % respecto a los niveles de 2005. La segunda medida apunta a conseguir un 40 % acumulado de capacidad de combusti-

[92]T. C. Bisht, *op. cit.*, p. 121.
[93]*India's Intended… op. cit.*

bles no fósiles en la matriz eléctrica. La tercera de estas medidas apuesta por crear un sumidero de carbono de 2.500 a 3.000 millones de toneladas de CO2 equivalente.

India también hace un llamamiento a la necesidad de financiación y de transferencia de tecnología internacional así como a la capacitación de personal para cumplir con objetivos en la lucha contra el cambio climático. Las estimaciones del Gobierno apuntan a que, entre 2015 y 2030, India necesitará 2,5 billones de US$ a precios de 2014-2015.

En cuanto a la tecnología, India muestra su preocupación por el coste de los derechos de propiedad intelectual y aboga por una colaboración global en I+D que permita una transferencia de tecnología libre de ellos. También sugiere que sean asumidos por una partida especial del Fondo Verde de Inversión.

Appendix C

Other publications

The following is a list of publications related to this thesis which have not been included in it:

del-Río, B. Fernández-Sainz, A. and Martinez de Alegria, I. (2019) Diversity or Concentration of Sources in the Management of the Energy Trilemma? The Case of India, *Journal of Clean Energy Technologies*, vol. 7, no. 3, pp. 32-35.

Martínez de Alegría, I., Molina, G. and del-Río, B. (2017) Carbon Markets: Linking the International Emission Trading Under the United Nations Framework, in Wei-Yin Chen, John M. Seiner, Toshio Suzuki et Maximilian Lackner MBA (eds.), *Handbook of Climate Change Mitigation and Adaptation*, Springer, pp 313-339.

Martínez de Alegría, I., Fernández-Sainz, A., Alvarez, I., Basañez, A. and del-Río, B. (2017) Carbon prices: Were they an obstacle to the launching of emission abatement projects in Espagne in the Kyoto Protocol period?, *Journal of Cleaner Production*, vol. 148, pp. 857-865.

del-Río, B. (2016) La gobernanza global de la energía. *Anuario Español de Derecho Internacional*, 32:439-473. ISSN: 0212-0747. doi: 10.15581/010.32.439-473.

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