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Quantifying international energy justice: The cost of electricity within footprint accounts

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ABSTRACT

This research quantifies the international electric payments embodied in goods and services, for the purpose of moving towards a clear and fair electric exchange within international footprint accounts. The electric consumption and related cost of 43 countries that represent 84% of global Gross Domestic Product (GDP) has been calculated, shifting from traditionally used Production-Based Accounting (PBA) to Consumption-Based Accounting (CBA). This research has identified not only the electric cost for what is produced in each country, but also the electric cost embodied in imported and exported goods and services. The difference between Production- and Consumption-Based Accounts has been defined as "Hidden Electric Cost" (HEC). Secondly, we have calculated the hypothetical national electric cost if countries were to produce within their own borders all the goods and services they consume. The difference between the current electric footprint cost and hypothetical self-sufficiency cost has been referred to as "Justice in Electricity Costs" (JIEC), an indicator which shows how much a country would have to spend to achieve electric sovereignty. This indicator reveals that there are countries (usually developed ones) that would face greater costs than what they currently pay by outsourcing the production of goods to other less developed countries. The study shows that, from the 43 countries analysed, and the Rest of the World (RoW) considered a 44th one, the ten most developed ones are spending on average 14.36% more on electricity than declared, and the ten least developed ones, 1.35% less than declared. At the same time, the 10 most developed countries would have to spend even 0.86% more to achieve electrical sovereignty, while for the ten least developed countries this would mean savings of 1.04%. In addition, a more specific analysis has been made for the textile and agriculture sectors, showing the ten countries with the highest Human Development Index (HDI) among those analysed would have to spend 438.75% more on average to pay for imported electricity at national price and achieve electric sovereignty for the textile sector, and 24.4% more for the agriculture sector. In the interests of achieving fair global electric payments, it would be appropriate for countries to take these variations in payments into account in international relations so as to move towards greater international justice.

1. Introduction

The current ongoing rise in importation of raw materials, food, manufactured products and even services from developing to so-called developed countries is changing globalised consumption patterns (Wiedmann and Lenzen, 2018). Given internationalised markets and standardised product prices, Northern countries are outsourcing heavy industries as a strategy to reduce production costs of final products, and as collateral effect national energy consumption is reduced (Akizu-Gardoki et al., 2021; Arto Olaizola et al., 2016). In this context, the differences in payments for energy and manpower between Northern and Southern countries are causing concern around equity and fair payments, since the risks and externalities are affecting the lower social

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Abbreviations

CBA	Consumption-Based Accounts
EU	European Union
GDP	Gross Domestic Product
GMRIO	Global Multi-Regional Input-Output
GTAP	Global Trade Analysis Project
HDI	Human Development Index
HEC	Hidden Electric Cost
IEA	International Energy Agency
IMF	International Monetary Fund
IO	Input-Output
JIEC	Justice in Electricity Costs
OECD	Organization for Economic Cooperation and Development
PBA	Production-Based Accounts
RoW	Rest of the World
TPELF	Total Primary Electric Footprint
TPELS	Total Primary Electric Supply
TPES	Total Primary Energy Supply
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNSTATS	United Nations Statistics Division
UPV/EHU	University of the Basque Country
USSR	Union of Soviet Socialist Republics
WIOD	World Input-Output Database

classes or countries more intensely (Sovacool et al., 2016). Thus, there is concern about how to define whether differences in costs for consumed natural and human resources are fair. As it stands, northern countries are used as sustainable energy systems models without taking into account the energy consumed in outsourced industries that are feeding national needs. As an example, Switzerland is referred to as one of the world's leaders in climate change action and achieving sustainable development goals (Wendling, 2020) but at the same time, due to its location, size, and the lack of natural resources, it is a country highly dependent on foreign trade (ICEX, 2011). Similarly, Luxemburg, a recognised European leader country in green finance and sustainable development goals (Rahman, 2019), has an energy system which is characterised by high import dependence; in 2018 86% of its electricity supply was imported (IEA, 2020). While most western developed countries are perceived as energy transition carriers, countries like China with large exports are accused of being the main causes of damage to global environmental and public health (Gracie, 2015), (Buckley, 2021) and the destination of its produced goods and respective responsibilities are not clearly shown.

This unfair relationship among countries, occurring when natural resources and respective impacts need to be shared, has polarised countries into so-called developed and non-developed ones. A number of definitions of development and different criteria have been used to classify countries. A common economic criterion for their classification promoted by the Organization for Economic Cooperation and Development (OECD) divided countries into developed ones, or those with high income (OECD, 2020); and developing countries, which covers most countries in Africa, Latin America and Asia; and those "in transition" to capitalism, such as in Eastern Europe and the former USSR (IMF, 2020). The phenomenon of the emergence of so-called least developed or underdeveloped countries occurred mainly at the end of the Cold War. The North-South division became popular in the field of international relations in the late 60's, with the decolonisation process in Asia and Africa. Until then, international relations were dominated by East-West conflict. It was only in the mid-1960s and early 1970s that the so-called 'North-South dialogue' became a key issue on the international agenda, which marked an important change in the dynamics of politics and the world economy (Prado, 1998). The United Nations Conference on Trade and Development (UNCTAD) and other UN agencies promoted the classification of countries into the following four categories: Southern countries, in reference to developing countries; Northern countries, referring to developed countries; Eastern countries, as a term for transition countries; and finally, least developed countries. In 1990 the United Nations Development Programme (UNDP) created the Human Development Index (HDI) to analyse each country's extent of development. The intention was to create a development index that was not only based on economic considerations, but also introduced other variables focused on people and their capabilities, as well as the dimensions of health and education (UNDP, 2019). The use of the HDI indicator in energy transition studies has already shown that most developed countries have a clear pattern of consuming Hidden Energy Flows (HEF) from less developed ones. Actually, the 10 most developed countries are consuming 18.5% more energy than that accounted by the International Energy Agency (IEA), due to imported products and services (Akizu-Gardoki et al., 2021). In contrast, the 10 least developed countries have been detected to consume 1.6% less energy for their own uses than the one declared by IEA (Akizu-Gardoki et al., 2021).

The geospatial separation between production and consumption is leading to the displacement of environmental and social impacts (Wiedmann and Lenzen, 2018). Northern countries consume most of the resources, whereas southern countries face the corresponding social and environmental impacts (Garmendia et al., 2016), and thus, the way of sharing the responsibility for those impacts needs to be addressed internationally (Lenzen et al., 2012). An increasing number of voices have highlighted that, by leaving developed countries, multinationals have not only relocated factories, but also pollution. This is China's case, where not only industrial manufacturing and production itself but also energy infraestructures, such as coal transportation from inland regions to energy-consuming areas in the east of the country, cause significant environmental and social impacts (Méndez, 2014). Incipient proposals regarding shared responsibility for the socio-environmental impacts generated by low-cost production have been formulated (Gallego and Lenzen, 2005). Nevertheless, when applying the theory to real actions to boost international equality, it is highly challenging to reach agreements (Eisenstein, 2017). Multinationals blame consumers for wanting everything at the lowest price, and the impoverished countries blame rich countries, their accommodated end-consumers and their producing companies. Explicit and systematic strategies are needed to reach energy sustainability (Chen et al., 2020). Furthermore, strong nations argue that outsourcing industries are helping non-developed countries to increase their national Gross Domestic Product (GDP) (Hussain and Ajmair, 2015). In contrast, energy sovereignty seems to have gained relevance in recent decades, since current hyperconnectivity may be a threat to humanity, given that, in cases of unpredictable crisis, it causes the consequent emergencies to spread rapidly (World Economic Forum, 2013). Such would be the case of the recent COVID-19 crisis. Therefore, to adapt to these new realities, it would be necessary to prioritise resilience as opposed to the traditionally sought cost reduction (NAEC, 2020).

In this complex international panorama, an "unfair" payment for energy consumption, and in particular for electricity, entails social and environmental impacts. As the human impact on the environment increases, the difference in distribution of these damages between southern and northern countries increases. There is a change in ecosystem services, but the distribution of damage and what the driving forces are has not been assessed (Srinivasan et al., 2008). In connection with the different classifications of the countries according to their development level, trends have already been detected that identify master and servant countries, where servant countries are the ones enabling the high development of master countries (Alsamawi et al., 2014).

Given this context, the philosophy of Ecological Economics has advocated, the need for Consumption-Based Accounts (CBA) (Afionis et al., 2017; Kander et al., 2015; Steininger et al., 2016), since traditional Production-Based Accounts (PBA) have limitations in making the embodied impacts of international trade visible. Net importer countries have the privilege of being able to maintain their level of well-being at the expense of energy consumption in other countries (Akizu-Gardoki et al., 2020). There must be international acknowledgment of this fact and the establishment of a clear methodology for visualising these international flows of embodied energy (Akizu-Gardoki et al., 2018).

Furthermore, due to the non-acknowledgment of developed countries' outsourced energy consumption and the difficulty understanding "energy" as a field that goes beyond "electricity", existing "sustainable energy transition" policies focus mainly on national actions related to electric supply and consumption, such as renewable energy cooperatives. This is not harmful, but could reflect a narrow view of the international energy reality. The current global direct residential electricity consumption represents only 3.35% of global energy consumption (Akizu et al., 2017). In this research, not only residential electricity but also industrial electricity has been considered, and Table 1 shows the exact amount of the Total Primary Energy Supply (TPES) that this represents, which is 40.93% if transformation and distribution losses are included. If losses are not taken into account, Total Primary Electric Supply (TPELS) makes up 18.71%. Thus, the scope of action of this research has been increased from the traditional 3.35% electric energy consumption by inhabitants, to 40.93% electric consumption by the same inhabitants, significantly extending the bounds of our understanding of electricity, all while being aware that the conclusions of this paper still need to be combined with non-electric energy consumption in order to be used in national strategies. Fig. 1 shows the differences between TPES, TPELS including electric losses and TPELS without electric losses in country level (deeper national electric system efficiency information in Supplementary Table S2). It must also be taken into account that the transition towards a sustainable energy model needs to be accompanied by an estimated reduction of 50.16% of the global average energy consumption, from the current TPES (21.67 MWh·cap^{-1}·yr^{-1}) shown in Table 1, to the sustainable 10.8 MWh·cap^{-1}·yr^{-1} (O'Neill et al., 2018).

Within this international panorama, the goal of this research is to analyse the payments for residential and industrial electricity consumed by the selected 43 countries plus the Rest of the Word (RoW) as country number 44. The main goal is to compare the amount paid for electricity consumed in the 43 countries and RoW according to PBA accounting, with that paid according to the CBA accounts, thus revealing the Hidden Electric Cost. In addition, the result of the cost that each of these countries would incur for electricity if all the imported products were nationally manufactured is also presented, and defined as Justice in Cost.

Thus, this research tackles, for the first time, not only the fair visualisation of the embodied electric consumption beyond the national geographical borders, but also the significance of quantifying the discrepancies in the economic payments for the embodied electricity consumption. There is a gap to quantify how to model the international energy justice, and in this case more specifically focusing on electricity, this article proposes for the first time a quantitative way of approaching it. Specifically, two indexes have been designed in order to tackle the international energy injustice. Firstly, a Hidden Electric Cost (HEC) has been designed in order to calculate which is the hidden electric expense of a country embodied in imported/exported product and services. Secondly, a Justice in Electricity Cost index (JIEC) has been designed so as to calculate how fair/unfair the payment of the imported hidden electricity has been according the national electric price.

This is an analysis within the framework of energy justice (Sovacool and Dworkin, 2015), and aims to serve as a decision-making tool that allows a better understanding of the current international electric reality. There is a grim reality in the current international energy injustice. While large sport utility vehicles are being refilled at American petrol stations, we are concerned about why family members have been fighting in Iraq to get cheaper oil, without seeing the ethical connection behind the personal oil demand and military causalities in the Middle East (Sovacool and Dworkin, 2015). Generally, Kantian logic has been applied to energy fairness, which holds "each person as an end" (Sovacool and Dworkin, 2015), even though the individuals are not aware of it. To make energy transitions fair, a broader understanding of energy justice is critical, and justice behind the embodied energy has already been identified as a goal to be accomplished (van Bommel and Höffken, 2021). If global fairness in resource consumption is a goal, as stated in international agendas (European Commission, 2016; IPCC, 2014; UNEP, 2017), indicators to measure it, such as those proposed in this study, need to be regarded as essential, and empirical evidence of particular forms of energy justice remains scarce (Hanke et al., 2021). Energy Justice has also been addressed within the framework of the Sustainable Development Agenda, in an effort to understand the transition towards universal clean energy access (Ciplet, 2021). The energy transitions driven in some countries like the United States are producing winners and losers, and policy makers have highlighted the need for more precise identifiers around energy justice to address these disparities (Carley et al., 2021). Furthermore, an effort to quantify the national initiatives to support energy justice has been made in the USA (Carley et al., 2021). Nevertheless, there is a gap to quantify how to model said international energy justice. Further practical analyses have been carried out in order to help end consumers understand to what extent different technological innovations (solar photovoltaic installation, electric vehicle, low carbon heating, or energy services contacting) may benefit the global energy justice (Sovacool et al., 2019). Nevertheless, at a country level, no indicator has been developed to understand how fair current energy payments are with respect to imported energy embodied in acquired goods and services. Thus, our research aims to shed light on the international justice behind the electric use and respective payments in those imported goods and services, going beyond the Kantian philosophy, and taking a community- or nation-based approach to responsibility (as in the capability or aptitude to respond to a problem or a fact: *responsum habilitas*).

Furthemore, special attention has been paid to the textile and agriculture sectors, these being significant sectors in international trade among the 17 sectors studied. The textile energy footprint in China went from 4.1 Mt in 1991 to 99.6 Mt in 2015, putting the textile sector in China in the spotlight in terms of pressure to reduce energy consumption (Wang et al., 2017). In the case of Portugal, 30% of total primary energy consumption corresponds to the industrial sector, which is more than what it produces internally (just 28%) and of which 6% is consumed in the textile sector (Costa et al., 2019). With regards to the agriculture sector, between the years 1950 and 2000, global food production has doubled, which has had an important impact on the environment, especially in terms of water and energy used. Global food systems are

Table 1
The global average TPES (Total Primary Energy Supply) and TPELS (Total Primary Electric Supply) are shown and the percentage that TPELS represents form TPES.

TOTAL PRIMARY ENERGY SUPPLY (TPES) (MWh·cap^{-1}·yr^{-1})	21.67	
	Including transformation and distribution losses	Excluding transformation and distribution losses
TOTAL PRIMARY ELECTRICITY SUPPLY (TPELS) (MWh·cap^{-1}·yr^{-1})	**8.869**	**4.508**
TOTAL PRIMARY ELECTRICITY SUPPLY (TPELS) (%)	**40.93%**	**20.80%**

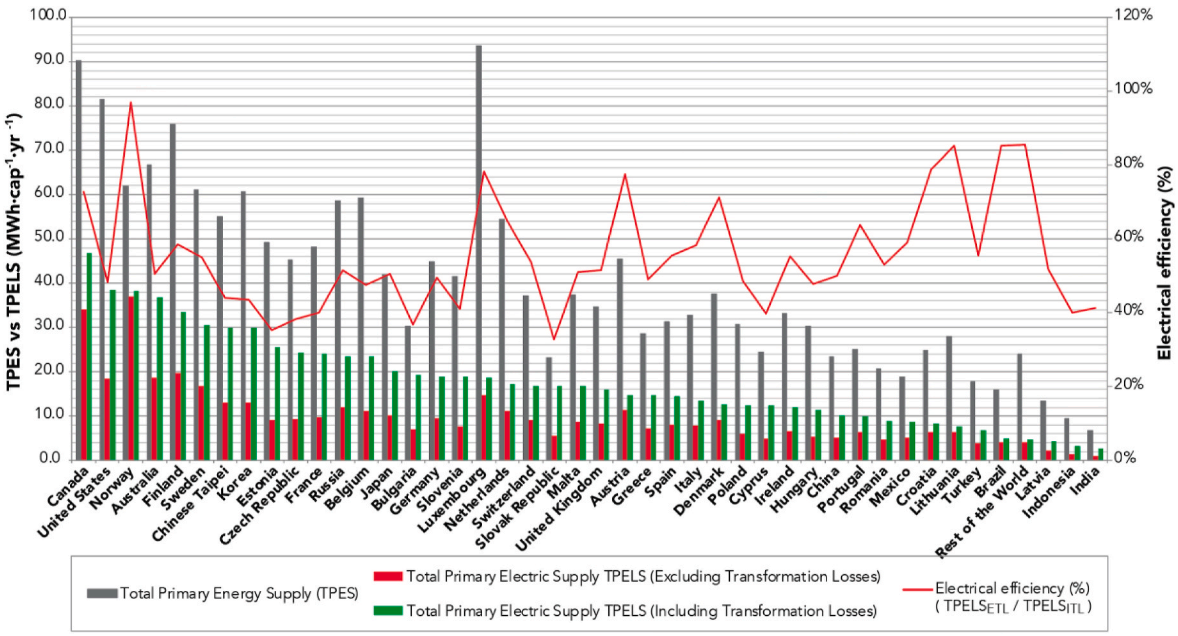

Fig. 1. Identification of national Total Primary Energy Supply (TPES) and the portion corresponding to electricity, measured in Total Primary Electric Supply (TPELS) both with and without losses, and the corresponding efficiency.

more and more fragile and affected by variations in energy accessibility and energy prices (Khan and Hanjra, 2009).

Accordingly, the main objective of this paper is to calculate the amount spent by the 43 countries and RoW analysed on electricity use in industrial and residential sectors. The aim is to make a comparison for each country among the expense according to PBA accounting, the expense according to CBA accounting, and the expense that each of these countries would have if they carried out their entire production within their own borders. Firstly, the total electric cost to the countries will be analysed, and secondly, the specific results pertaining to the textile sector and the agriculture sector will be presented. The intention is for this analysis to serve as a tool that contributes to the international energy justice debate.

Forty-three countries are analysed in this paper, including 34 with a Very High HDI, 7 with a High HDI and 2 with a Medium HDI (UNDP, 2011). These 43 countries represent 84% of the world's GDP (UNSTATS, 2011) and 63% of the world's population (WorldBank, 2011). In addition, the Rest of the World (RoW) is analysed showing data from the rest of the countries as a single region. RoW is composed of 46 countries with Low a HDI, 41 with a Medium HDI, 46 with a High HDI and 13 with a Very High HDI.

2. Methodology

2.1. Global multi-regional input output (GMRIO) methodology

In this research, the well-recognised Global Multi-Regional Input-Output methodology (Owen, 2017; Wiedmann and Lenzen, 2018) has been used to calculate the cost of electricity consumed according to CBA accounting. This methodology is commonly used for CBA calculations regarding energy use, since it allows us to include the amount and provenance of energy embodied in international trade (Akizu-Gardoki et al., 2018; Arto Olaizola et al., 2016; Owen et al., 2017). The analysis has been made for the year 2011 as different Input-Output databases have been used: Eora (Lenzen et al., 2013), EXIOBASE (Steinmann et al., 2018), WIOD (Chen et al., 2019), GTAP (Peters et al., 2011) and OECD (OECD, 2016); and 2011 is the most recent year for which there is information on all of them, particularly EXIOBASE, which has the most up-to-date data for that year. Finally, after comparing the results from all five databases, only the results from WIOD database are presented here, since we consider these to be representative of the group.

The GMRIO methodology developed in this research has been built on top of the algorithms developed by the authors in previous research (Akizu-Gardoki et al., 2021). Based on this prior work, a further development of the code has been carried out in this study for the HEC and JIEC calculations of 43 countries plus the Rest of the World.

- From Total Primary Electric Supply (TPELS) (see Fig. 1), which has been extracted from the Total Primary Energy Supply (TPES) from the database of International Energy Agency (IEA) data, the Total Primary Electric Footprint (TPELF) has been calculated. To make this calculation, the Leontief Input-Output (IO) equation has been used (Akizu-Gardoki et al., 2021), which is the keystone in the input-output model.
- The fundamental architecture of the Leontief IO model (Owen, 2017; Raa, 2006) is shown in Fig. 2, where Z is the transaction matrix, the rows of matrix Z indicate what an industrial sector sells to other industrial sectors, and the columns indicate what an industrial sector buys from each industrial sector in order to produce its product. Y represents the sales to final demand, thus, each element of Y indicates the demand for this specific sector product. X represents the total output obtained from Z and Y. Similarly, total input X can be obtained from Z and h.
- Data included in the red square of Fig. 2 is obtained from the World Input-Output Database (WIOD) (Timmer et al., 2015), whereas the electric extension vector is formed from IEA data. The WIOD IO database includes information about 57 sectors while IEA provides information for 108 categories. Thus, concordance matrixes have been used in order to unify the WIOD database and IEA electricity data for the 17 industrial sectors (Supplementary Table S1) analysed in this article.
- Once TPELS is obtained from IEA, TPELF is calculated using the Leontief equation. Technical coefficients matrix A is obtained by dividing corresponding column Z by output x. Substituting Z with Ax and reorganising the equation:

$$\mathbf{x} = (\mathbf{I}\text{-}\mathbf{A})^{-1}\,\mathbf{y} \quad \text{(eq. 1)}$$

$$(\mathbf{I}\text{-}\mathbf{A})^{-1} \text{ being the Leontief inverse } (\mathbf{L}) \quad \text{(eq. 2)}$$

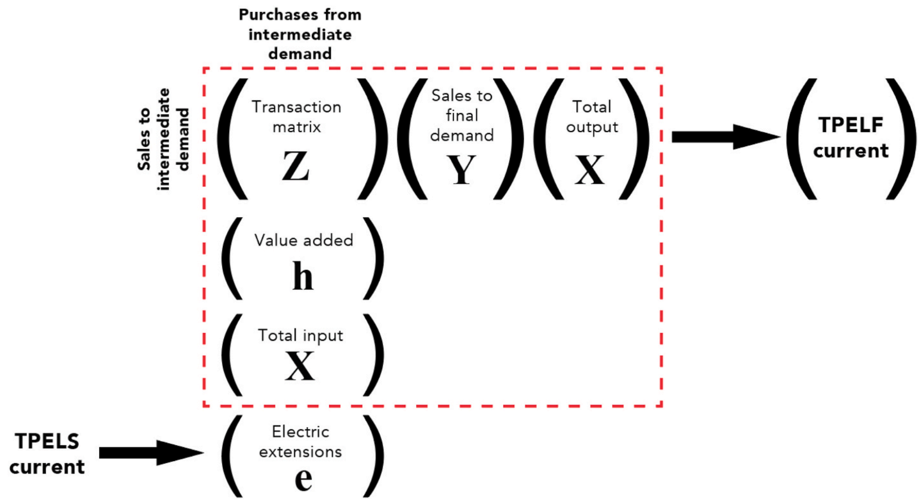

Fig. 2. Structure of the Input-Output system, where the Leontief inverse has been used.

Leontief's inverse shows that when the final demand for a product rises, the production of related industrial sectors also increases, not only the specific industrial sector that produces that good (Cerina et al., 2015).

- After defining TPELS (PBA) and TPELF (CBA), the corresponding cost for each has been calculated. In order to calculate the amount spent by a country on PBA electricity, industrial electric consumption and residential electric consumption has been multiplied by the national electricity prices, differentiating the industrial and household prices (IEA, 2011a). Regarding a country's electric cost according to CBA, all the industrial and residential electricity outsourced from other countries has been taken into account and included when multiplying electricity consumption by the corresponding industrial and residential prices for exporter countries. Thus, the difference between economic costs of electricity within a country (PBA) and costs taking outsourced goods and services into account (CBA) has been defined.
- Finally, in order to know how much it would cost a country to achieve electric sovereignty, the cost of producing the total TPELF has been calculated using national electric prices. This value gives us a reference by which to calculate the economic savings of externalising electricity production, in the case of developed countries. In the case of net embodied electricity exporter countries (most of which are non-developed), we have calculated the electricity cost reductions that would ensue if only national consumption needs were covered.

2.2. Hidden Electric Cost (HEC) and Justice in Electricity Costs (JIEC) calculations

Once national TPELFs were calculated using the GMRIO methodology, the target indicators of this research were obtained. These indicators have been conceived and defined by the authors in order to quantify for the first time the justice in payments in energy transactions between countries.

- The Hidden Electric Cost (HEC) indicator is defined as the difference between payment according to $TPELF_{CURRENT}$ and $TPELS_{CURRENT}$, that is, the difference in a country's electric cost when the production of part of the goods or services consumed in other countries is taken into account, versus when it is not.

$$HEC = \left(\frac{TPELFcurrent\ cost}{TPELScurrent\ cost} - 1\right) \tag{3}$$

- Justice in Electricity Costs (JIEC) indicator (or, alternatively, Injustice in Electricity Costs) shows the difference between the electric cost that a country would have to incur if it were to produce all the goods it consumes within its own borders $TPELS_{SOVEREIGNTY}$) and the current cost of electric consumption according to consumed goods: ($TPELF_{CURRENT}$).

$$JIEC = \left(1 - \frac{TPELSsovereignty\ cost}{TPELFcurrent\ cost}\right) \tag{4}$$

2.3. Data

The research has been carried out for the year 2011, so the data collected or estimated corresponds to that year. In any case, all calculations would be suitable for analysis of another year solely by changing the input data, if available.

- Electricity Data

TPELS—in other words, electricity consumed according to PBA accounting—has been calculated from International Energy Agency (2011) data (IEA, 2011b). TPELS has been obtained under two assumptions: in the first scenario, the transformation and distribution losses of producing the national electricity from primary sources have been included (see Fig. 1 and Supplementary Fig. S2) (such as the transformation losses in electric power plants or that consumed by the electric industry as a whole. A concordance matrix has been used in order to convert the 108 lines of IEA data to the 17 industrial sector electricity data vector (Supplementary Table S2). In the second scenario, the TPELS has been calculated without including the transformation and distribution losses, thus, the electricity consumption provided by the IEA for the different categories has been included, but for the electric sector, electric consumption has been measured as zero. This second scenario gives us a reference for the necessary electric consumption of a country if transformation losses where zero (as is the case of renewable electric sources) and an 100% efficient energy distribution grid (which is almost the case with distributed smart microgrids).

- IO Data

Global Multi-Regional Input-Output (GMRIO) data have been obtained from the World Input-Output Database (WIOD) (Timmer et al., 2015). A concordance matrix has been used in order to convert the original WIOD database with data for 57 industrial sectors to the 17 sectors analysed in this research (Supplementary Table S1). The number of countries has been maintained within the WIOD structure with 43 regions plus RoW.

- *Price* Data

In order to obtain the results of the national electric expenses, industrial and residential prices for electricity paid in each of the 43 regions plus RoW were needed. Two prices have been obtained from international databases: electricity prices for household consumers (residential sector) and electricity prices for non-household consumers (industrial sector). In the case of European Union (EU) countries, the Eurostat database has been used (Eurostat, 2011a). For non-EU countries, price data has been obtained from the IEA database (IEA, 2011a). Taxes have been included in price data.

Due to the lack of data for some countries for 2011, the following assumptions have been made:

- The price of electricity in Australian industrial sectors has been estimated from the household consumer electricity price, based on the average proportionate increase between household and non-household in the rest of the countries.
- Prices available for China were for 2015, so those for 2011 have been estimated based on the average evolution in prices that has occurred from 2011 to 2015 in the rest of the countries analysed.
- For France and Hungary, 2012 prices were available, and since severe variations have not been observed from 2011 to 2012, these 2012 data have been used for both.
- The residential electric price for RoW has been calculated from the average of the following countries: Albania, Algeria, Armenia, Belarus, Benin, Botswana, Chile, Ecuador, Egypt, Georgia, Iceland, Iran, Israel, Kazakhstan, Kenya, Kyrgyzstan, Laos, Malaysia, Mauritania, Mauritius, Mongolia, Montenegro, Morocco, New Zealand, Paraguay, Philippines, Saudi Arabia, Singapore, South Africa, Tajikistan, Thailand, Tunisia, Turkmenistan and Uruguay.
- The price for industrial sector electricity for RoW has been calculated from the average of the following countries: Algeria, Argentina, Armenia, Benin, Botswana, Chile, Ecuador, Islamic Republic of Iran, Israel, Kazakhstan, Kenya, Laos, Malaysia, Mauritius, Montenegro, New Zealand, Paraguay, Saudi Arabia, South Africa, Thailand and Uruguay.

Prices from the Eurostat database were provided in "€·MWh^{-1}", whereas the IEA price unit was "USD$·MWh^{-1}", thus, the exchange rate between € and USD$ obtained from Eurostat (2011b) for year 2011 has been used to convert all prices to "€·MWh^{-1}" units.

- *Other Data*

Population data for the analysed countries used for calculations have been obtained from the World Bank database for year 2011 (WorldBank, 2011). Human Development Index data have been obtained from the UNDP database for year 2011 (UNDP, 2011).

3. Results and discussion

Fig. 3 compares the electric cost per country according to PBA accounting ($TPELS_{CURRENT}$) with that according to CBA ($TPELF_{CURRENT}$) and the electric cost that each of these countries would incur if their entire production took place in their own country, the cost of Total Primary Electric Supply for Sovereignty ($TPELS_{SOVEREIGNTY}$) (see Supplementary Table S3).

3.1. *Comparison between $TPELS_{CURRENT}$ expense and $TPELF_{CURRENT}$ expense*

As can be seen in the graph, 34 of the 43 countries plus RoW analysed have a higher expense in TPELF than in TPELS. This means that if we compare the payment of each of these countries for electricity consumption measured according to PBA accounts with that for electricity consumption measured according to CBA accounts, the second is significantly higher for 34 of the regions analysed.

Conversely, for the remaining 10 countries, the payment for TPELS is higher than that for TPELF, which means that the electric cost in PBA accounts is higher than that calculated with CBA accounts, so the former includes the cost of electricity used in the production of goods that will eventually be exported and not consumed in the country.

This classification shows for which countries it is advantageous from the point of view of electricity consumption to base their declared expenses on data from PBA accounts, since they suggest less expenditure than CBA accounting would. Similarly, the rest of the countries under PBA accounting are presented as having a higher expenditure on

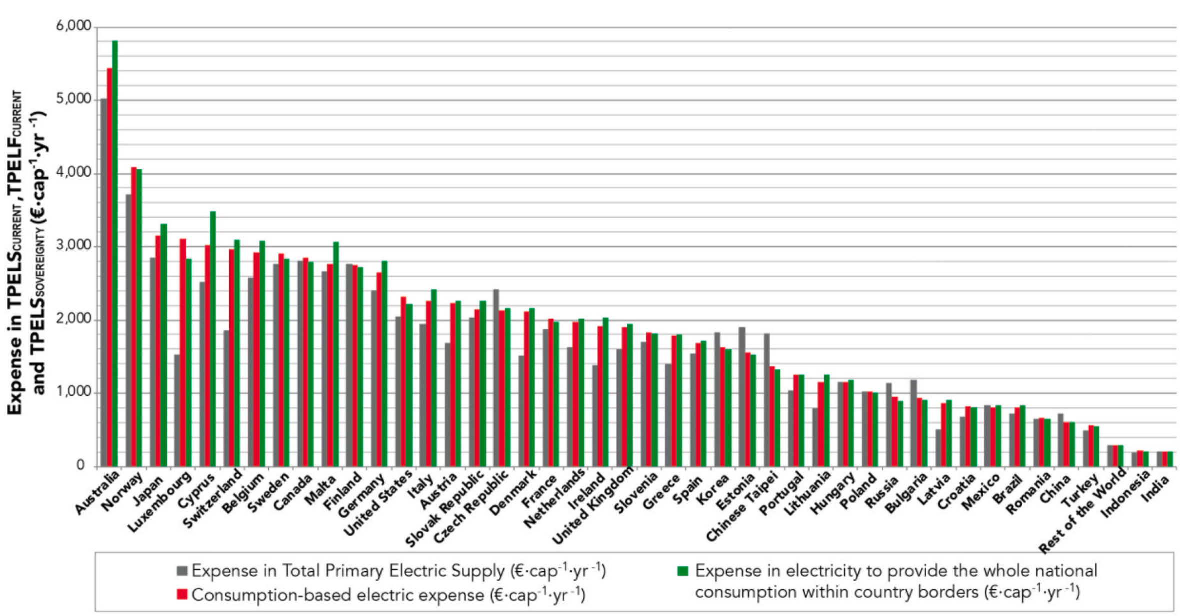

Fig. 3. Comparison among the expense in Total Primary Electric Supply, Total Primary Electric Footprint and Total Primary Electric Supply for Sovereignty (€·cap^{-1}·yr^{-1}), ordered according to current TPEF expense.

electricity than that which can actually be imputed to them based on their consumption.

3.1.1. Hidden Electric Cost (HEC)

Fig. 4A and 4.B show the share of Hidden Electric Cost for the countries analysed, including their level of development, measured through the HDI indicator of the UNDP.

When organising countries from higher to lower HEC value, in Fig. 4A, it can be seen that the most extreme case is that of Luxembourg, a country whose payment for $TPELF_{CURRENT}$ is 103.97% higher than that for $TPELS_{CURRENT}$. The opposite occurs in the case of Chinese Taipei (Taiwan), for which the payment for $TPELF_{CURRENT}$ represents savings of 24.14% in relation to the payment for $TPELS_{CURRENT}$ (see Supplementary Table S3).

For countries that result in a positive HEC value, which are 34 of the 44 analysed, it is more advantageous to report their expenses under PBA accounts, insofar as it implies fewer expenses than CBA accounting would in energy consumption and payments. The reason for this result is that in these countries, the cost of electricity for what is consumed in the country is significantly higher than the cost of electricity for what is produced by the country. The traditional Production-Based Accounts makes these countries appear more efficient and less energy dependent.

The ten countries with the highest HDI among those analysed have a Hidden Electric Cost of 14.36% compared with the traditional PBA accounts, an average payment of €306.7 more per person per year on electricity (being the average global payment measured in TPELF 1858.3 €·cap^{-1}·yr^{-1}, and variating from 204.3 in India to 5443.8 in Australia, see Supplementary Table S3). Meanwhile, the 24 intermediate countries are spending an average of €239.60 more per person per year, or 18.15% more than the current measured expense inside national borders. Meanwhile, the ten regions with the lowest HDI spend, for their own use, an average of €37.71 less per person per year, which is a decrease of 1.35% from PBA measurements (see Table 2).

3.2. Comparison between $TPELF_{CURRENT}$ expense and $TPELS_{SOVEREIGNTY}$ expense

As can also be seen in Fig. 3, there are a number of countries whose electric consumption would entail a greater cost than their current TPELF in the event of producing within the country itself everything they then consume (that is, achieving sovereignty). In other words, they would have to pay more for electricity than they currently do as measured in CBA accounts. This is the case for 24 of the 44 countries

Table 2
Average HEC values and corresponding yearly expense per capita in electricity.

	HEC		Average
	%	€·cap^{-1}·yr^{-1}	HDI
10 most developed analysed countries	14.36%	306.7	0.921
24 intermediate developed analysed countries	18.15%	239.6	0.864
10 least developed analysed countries	−1.35%	−37.7	0.722

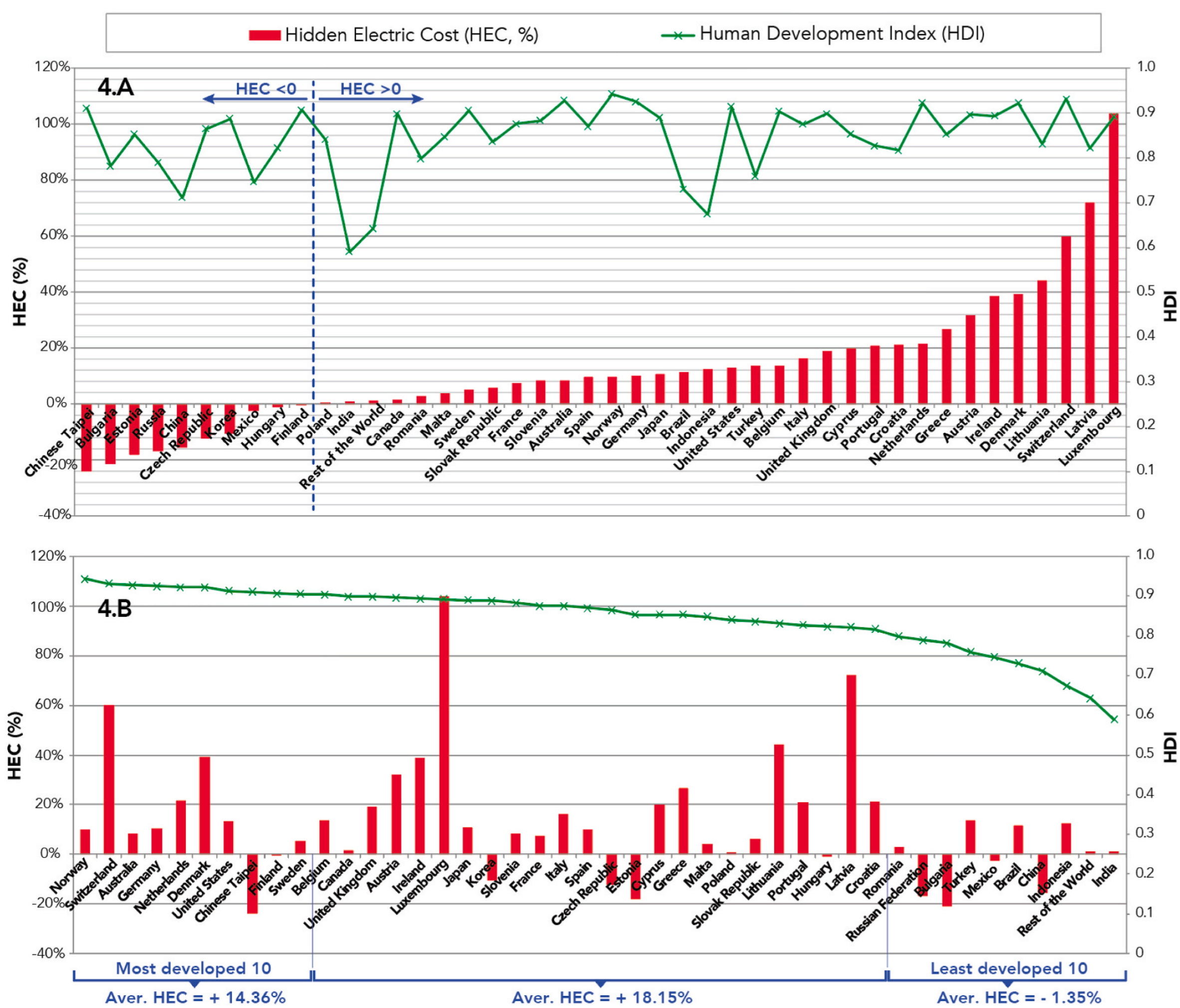

Fig. 4. Share of Hidden Electric Cost (HEC, %) compared to the national HDI.

analysed. Meanwhile, for the other 20 countries considered, the electric cost if sovereignty were achieved would be lower than that measured by CBA accounts.

This classification shows for which countries it is advantageous from the point of view of the cost of electricity to produce in other countries and then import the goods, instead of carrying out local production that would involve higher spending.

3.2.1. Justice in Electricity Costs (JIEC)

Fig. 5A and 5.B show the share of Justice in Electricity Costs for the countries analysed, including their level of development, measured through the HDI indicator of the UNDP.

According to the Justice in Electricity Costs (JIEC) indicator, which ultimately reflects the investment in electricity needed to achieve sovereignty, Cyprus would be the country farthest from achieving it, since the increase in cost would be by 15.63%, compared to the $TPELF_{CURRENT}$ payment. Luxembourg, on the other hand, would save 8.99% on the payment of $TPELF_{CURRENT}$ if all production took place within the country with current national electric prices.

The countries with a negative JIEC index are those that benefit the most from international trade, in terms of the cost of electricity. This is so, because if they were to aim to produce all the goods and services they consume in their own country, the cost of electricity would be considerably higher.

Table 3 shows that, the ten most developed countries analysed should be spending 0.86% more on average than their current electric

Table 3
Average JIEC values and corresponding yearly cost saving or increase per capita in electricity.

	JIEC		Average
	%	$€·cap^{-1}·yr^{-1}$	HDI
10 most developed analysed countries	−0.86%	−44.25	0.921
24 intermediate developed analysed countries	−2.45%	−54.9	0.864
10 least developed analysed countries	1.04%	6.6	0.722

Fig. 5. Share of Justice in Electricity Costs (JIEC, %) compared to the national HDI.

payment, which means €44.25 more per person per year. Similarly, the 24 intermediate countries should be spending €54.98 more per person per year, which is 2.45% more. On the other hand, the ten least developed countries should be spending €6.58 less than their current electric cost per person per year, which is 1.04%.

3.3. Textile sector

The same comparison among payments for $TPELS_{CURRENT}$, $TPELF_{CURRENT}$ and $TPELS_{SOVEREIGNTY}$ has been made specifically for the textile industry sector. The following figure (Fig. 6) shows the results:

Especially relevant for the textile sector is the analysis of the share of (In)Justice in Electricity Costs, which is the increase in spending or saving on electricity if everything were produced within the country ($TPELS_{SOVEREIGNTY}$) in comparison with payment for $TPELF_{CURRENT}$. Results are shown in Fig. 7.

Norway would require the largest investment, an increase in expenditure of 1247%, compared to their current electric cost based on CBA accounts ($TPELF_{CURRENT}$), whereas the People's Republic of China would have savings of 58.46%. As can be seen in the previous figure, the countries for which it would mean savings on electricity payments are: Mexico, Romania, India, Chinese Taipei, Turkey, Rest of the World, Czech Republic, Estonia, Indonesia, Bulgaria and People's Republic of China.

3.4. Agriculture sector

This comparison (among payment for $TPELS_{CURRENT}$, $TPELF_{CURRENT}$ and $TPELS_{SOVEREIGNTY}$) has also been made specifically for the agriculture sector. Results are shown in the following figure (Fig. 8):

Fig. 9 shows the share of Justice in Payments for the agriculture sector, measured as increase in spending or saving for $TPELS_{SOVEREIGNTY}$ in comparison with payments for $TPELF_{CURRENT}$.

Luxembourg would require the largest investment; an increase in payment of 188.64%, compared to what they actually pay for electricity consumption based on CBA accounts (TPELF), whereas the Netherlands would have savings of 76.48%. As can be seen in the previous figure, the countries for which it would mean savings on electricity payments are: Hungary, India, People's Republic of China, Rest of the World, Greece, Bulgaria, Australia, Belgium, Ireland, Turkey, Canada, Denmark, Spain, Mexico and Netherlands.

Particularly for the textile sector, as shown in Table 4, the ten countries with the highest HDI among those analysed would need to spend 438.75% more on average to achieve electric sovereignty, the 24 intermediate countries would need to pay 227.94% more, and the ten regions with lowest HDI, 15.67%. This increase in all countries occurs due the electric exchanges not only among countries, but also between industrial sectors. For the agriculture sector, Table 4 shows that the ten least developed countries would have savings of 1.46% on average (compared to current payments) if electric sovereignty were achieved. On the other hand, the ten most developed countries analysed would have to pay 24.4% more than they currently do in order to achieve this goal, while intermediate countries would have to pay 19.69% more.

4. Conclusions

In this study two indexes have been developed: Hidden Electric Costs (HEC) and Justice in Electricity Cost (JIEC). Both indexes allow us to quantify the justice or fairness in international electric exchanges embodied in goods and services. These indexes have allowed us to assign a numeric value to electric justice, evidencing the need to recognise the situation of global energy injustice: the unfair circumstances generated by the CBA accounts officially used to measure countries' consumption and expenditure in the energy field in general, and in the electric field in particular. The two indexes allow us firstly to understand the difference between the real electric expenditure of a country and the current electric expenditure reference (HEC, in percentage), and secondly, to understand how unfair the payment of the imported electricity has been, using as a reference the national electric price (JIEC, in percentage). All data of this research are available in Supplementary Table S3 in order to make them reachable to policymakers and future scientific studies. The novel contribution of this research has been to relate the hidden electric exchanges between countries to the economic payment concept. Creating this numerical bridge has allowed the authors to cast light on electric dependencies existing among countries, and the resulting levels of justice (in terms of payment). The fact of having a HEC or JIEC indicator can allow the policymakers of a country to improve the international electric exchanges globally, while acting locally. In addition, an annual evaluation could be made of the policies adopted and their real effects outside national borders, and the impacts of said actions and their implications within these indicators could even be virtually modelled.

This research reinforces the statement that fair, responsible and sustainable national development implies the inclusion of a global view of the international use of resources (Zhang et al., 2019). It is essential

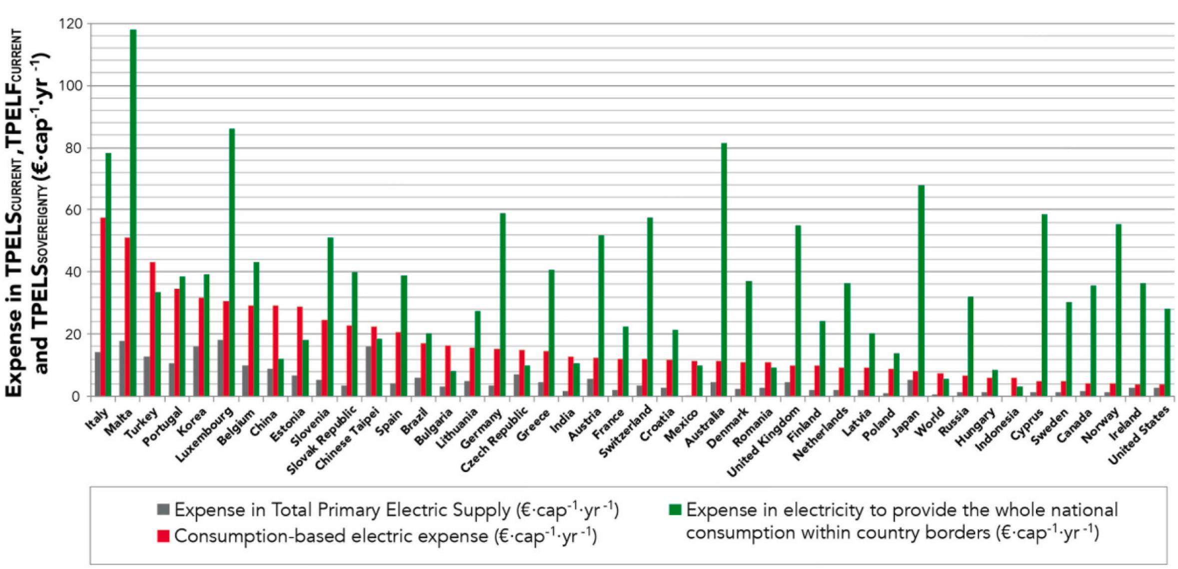

Fig. 6. Comparative for the textile sector among the expense in Total Primary Electric Supply, Total Primary Electric Footprint and Total Primary Electric Supply for Sovereignty (€·cap^{-1}·yr^{-1}).

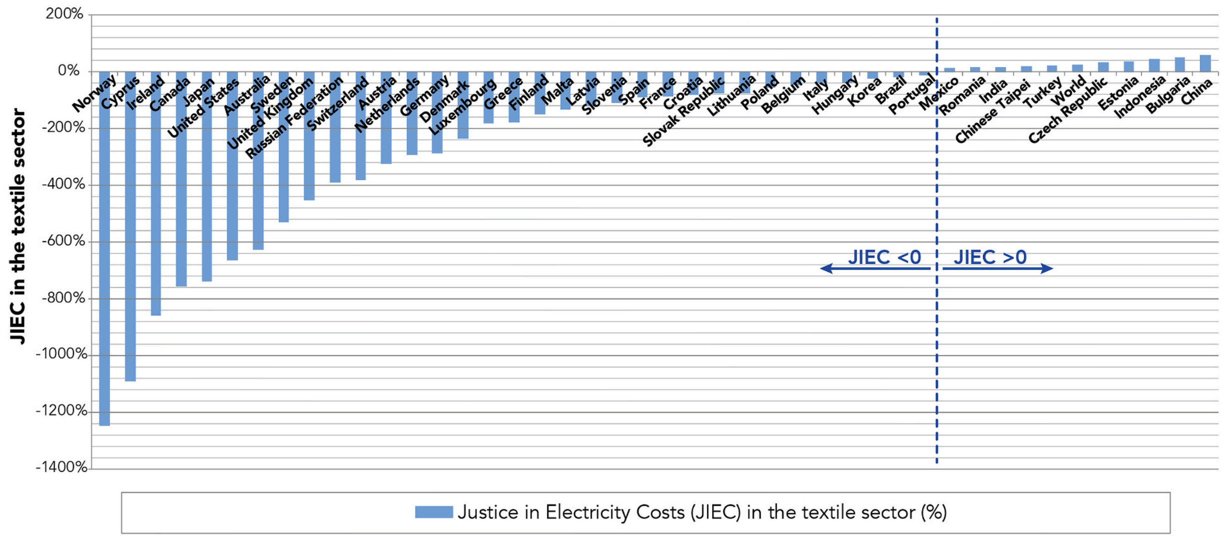

Fig. 7. Share of Justice in Electricity Costs (JIEC, %) in the textile sector.

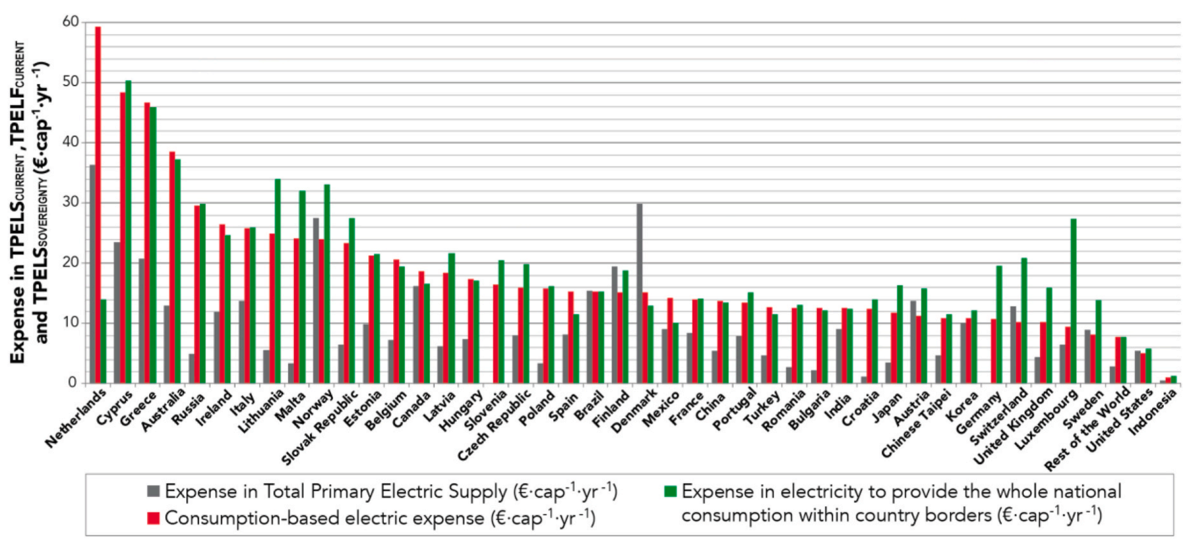

Fig. 8. Comparison for the agriculture sector among the expense in Total Primary Electric Supply, Total Primary Electric Footprint and Total Primary Electric Supply for Sovereignty (€·cap^{-1}·yr^{-1}).

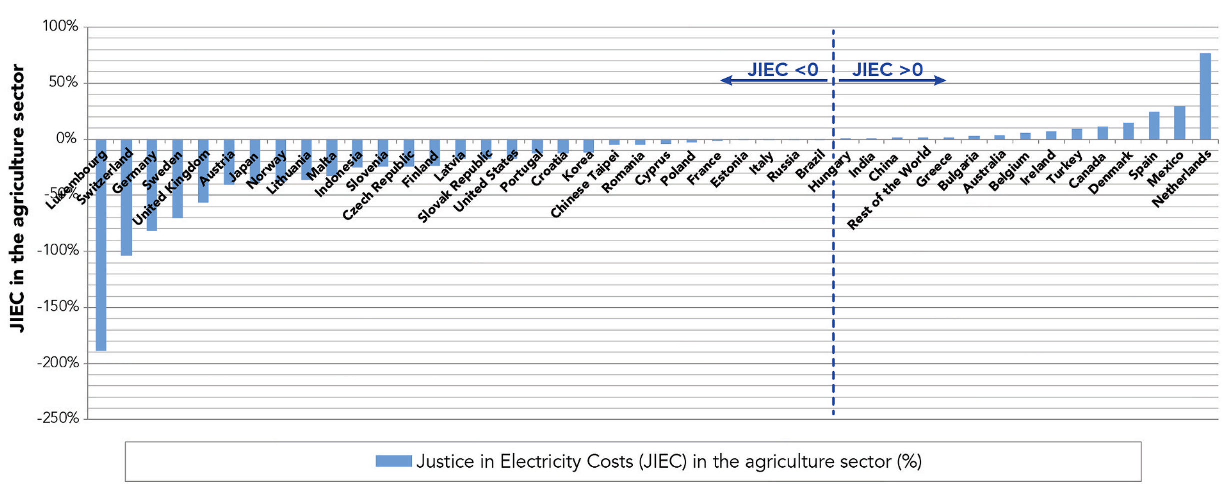

Fig. 9. Share of Justice in Electricity Costs in the agriculture sector.

Table 4
Average JIEC values in the textile and agriculture sector.

	JIEC Textile sector	JIEC Agriculture sector	Average
	%	%	HDI
10 most developed analysed countries	438.75%	24.44%	0.921
24 intermediate developed analysed countries	227.94%	19.69%	0.864
10 least developed analysed countries	15.67%	−1.46%	0.722

when we talk about development to consider the energy and electric resources that support this development by not only taking into account direct consumption within a country, but also considering the energy (in this particular research, electricity) embodied in imported goods and services. In this research, the electric footprint obtained for 43 countries and RoW reflects the general dependency trend between Global North countries and Global South countries observed in 2011. While it is not possible to say with certainty without performing the necessary calculations, indications would suggest that for more recent years these trends would at least continue, if not grow, since international trade and related global impacts has continued to grow in recent years (Wiedmann and Lenzen, 2018). This study shows that from the 44 countries analysed, the 10 most developed and intermediate 24 countries have 14.36% and 18.15% greater electric payments respectively if measured in CBA. Whereas, less developed ones have 1.35% lower expenses in electric cost.

Furthermore, from the point of view of fairness, and based on the costs that would be incurred if each country achieved electric sovereignty, the Justice in Electricity Costs indicator shows that most developed and intermediate countries would need to have greater electric payments in order to produce all consumed good nationally. Payments in electric cost would increase by 0.86% and 2.45% in the 10 most developed countries and intermediate ones, while the 10 least developed countries would be spending €6.58 less than their current electric cost per person. These differences are especially greater in the textile and agricultural sectors where most developed countries would face a 438.75% (textile sector) and 24.44% (agricultural sector) greater electric cost if those goods where nationally produced.

By paying insufficiently for imported products, the electricity consumed in other countries is not being "fairly" paid for. In other words, there is an unfair cost for the natural resources consumed in other countries. To take steps towards solving the environmental and social negative impacts that the current fossil fuel based electric system has generated globally, it would not be enough to improve the national electric system, but rather we need to address this international reality as a whole.

This research deals specifically with countries' payments for electricity, and so a future extension of the scope of the research to non-electric energy consumption would be appropriate. It would be appropriate, from the point of view of energy justice, for countries to recognise these variations in payments due to international trade and to take them into account in international relations. After all, some mainly importing countries are seeing their economies benefit from international trade at the expense of other mainly exporting countries. Moreover, the latter are those that face the social and environmental impacts. This research also provides insights towards a better understanding of what it would mean for countries to achieve energy sovereignty in monetary terms.

CRediT authorship contribution statement

María San Salvador del Valle: Data curation, Formal analysis, Investigation, Methodology, Validation, Software, Figures, Writing. **Ortzi Akizu-Gardoki:** Conceptualization and direction, Formal analysis, Investigation, Methodology, Validation, Software, Figures, Writing, Writing – review & editing. **Gorka Bueno:** Conceptualization, Formal analysis, Validation. **Roberto Bermejo:** Conceptualization, Formal analysis, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2022.130797.

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