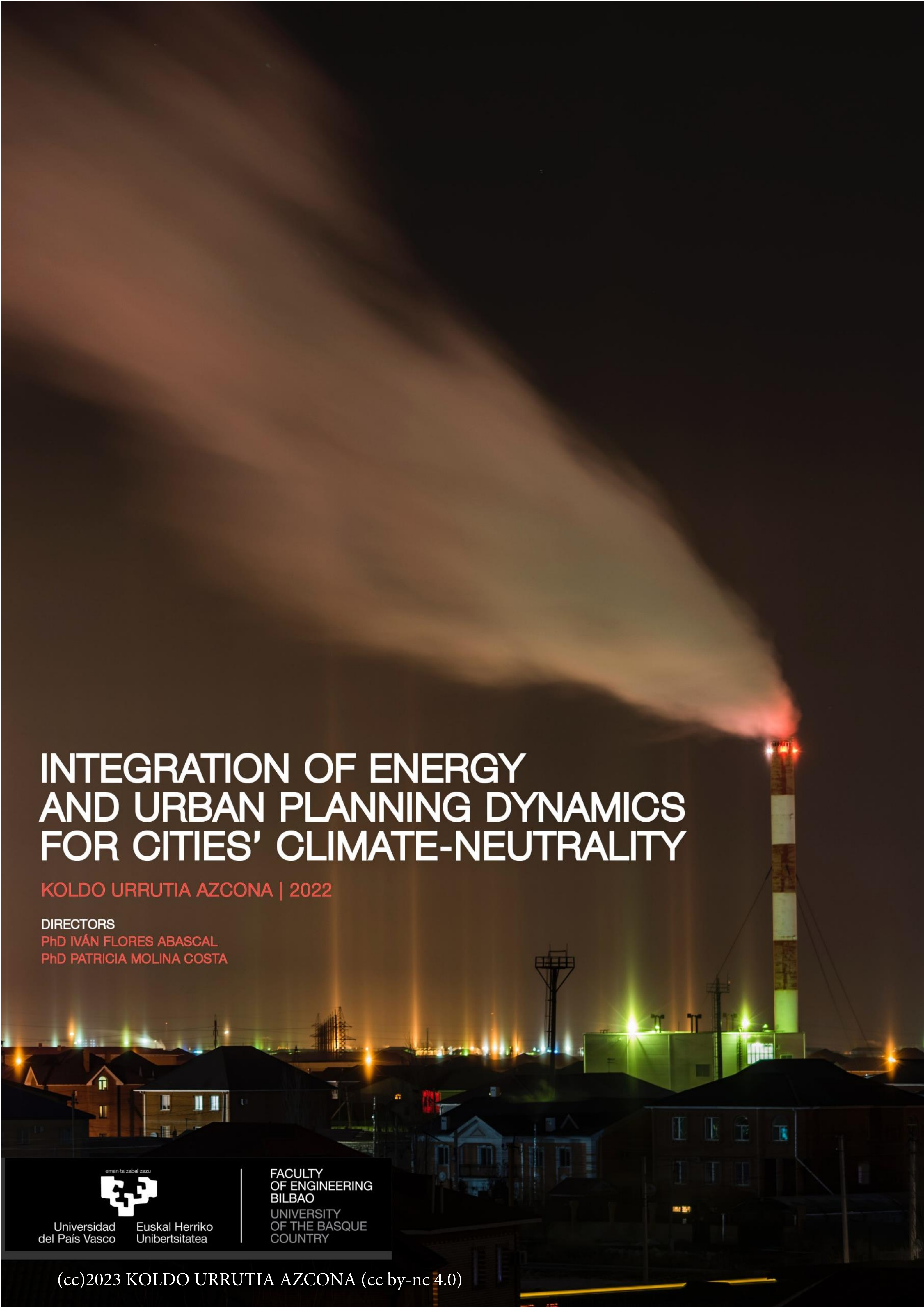

INTEGRATION OF ENERGY AND URBAN PLANNING DYNAMICS FOR CITIES' CLIMATE-NEUTRALITY

KOLDO URRUTIA AZCONA | 2022

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Title of the PhD Thesis

Integration of energy and urban planning dynamics for cities' climate-neutrality

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PhD

Preface

This research work intends to respond to the climate emergency the planet is suffering, focusing on the leading role of cities as the main nodes of attraction of activity, consumption, and consequently, generation of emissions. Therefore, this thesis is addressed to professionals and researchers in the field of urban planning, especially to those responsible for city management who can influence climate and energy transition, hoping that they can find support and inspiration in such a complex task.

My feeling is that a thesis must respond to personal motivation, as well as a professional one, both to find enjoyment along the way and to be able to bring it to fruition. In my case, I confess that both motivations are connected. On the one hand, ever since I became aware, I have felt a strong attraction to nature, for everything it offered and taught me as a child, even that unique sensation of simultaneous connection and disconnection that I value so much today. At different stages, Burguete pushed me to love her, Guatemala to respect her, and Visby to protect her, already aware that one must decisively protect what one loves.

And on the other hand, I am driven by my fascination for cities, for that vibrant space of human connection, where everything happens, everything connects. In each walk I am distracted by what I see, unconsciously, in rethinking its operation; from the curb of a sidewalk to the urban metabolism as a whole, always trying to find a model that is more consistent with the needs of its citizens and, at the same time, more balanced in that unequal relationship with its natural environment. If anyone was a teenager in the 90s, you can guess the influence that the *SimCity*[1] saga left in my subconscious. Fortunately, I am lucky enough to dedicate myself professionally to the different transformation processes of our cities and, although sometimes *Outlook*, *Teams*, or "*the client*" torment us, it is a luck that we cannot forget or miss out on.

As a result of these motivations, I decided to embark on this journey, we could say that it is one more milestone in life (in *Lean* vocabulary), which thanks to many I have been able to achieve.

First of all, I would like to thank my directors, Patricia and Iván, for their vision, experience, and support in a process that they suffered themselves. When jumping, I was not aware of where exactly I was going; a roller coaster with its achievements and its moments of disappointment, and they managed to guide me from beginning to end of the trip with success. Likewise, I would like to thank Tecnalia and the UPV-EHU for allowing me to defend this thesis, as well as to the team that has contributed to its development. To Fran and Patricia, as my professional mentors, and to Carolina, Elena, Pablo, Patxi, Iñigo, Mauri, Alessandra, Maider, Isabel, Olaia, Silvia, Antonio, Mikel, and Nacho, for your professional excellence and personal quality. Thank you very much, team!

On the other hand, my participation in the SmartEnCity, Atelier, and NetZeroCities projects has been decisive in having the necessary scientific support, both at a theoretical level and in terms of the applicability of the research activities. Thanks to the European Commission for financing and believing in this branch of knowledge as a vector that provides well-being and responds to the needs of our society; and to the consortiums of these projects, with an incomparable interdisciplinary scientific potential. I would like to mention Dave, Simon, Per Alex, and Peter, for the interesting and fruitful exchange of reflections on the subject, as well as the reviewers of our four articles, because they have undoubtedly contributed to the improvement of the final result.

[1] *SimCity* is a video game saga that enables the creation, management, and evolution of cities, developed by Maxis, currently Electronic Arts. The first game in the saga was released on the market in 1989, with a series of later versions going on until 2015.

I would also like to thank all the cities[2] that have shown interest in this work, and that allowed this research to evolve, be tested, and be validated. And especially to Vitoria-Gasteiz and Sonderborg, two flagship cities in terms of sustainability. Hopefully, we can continue collaborating in the implementation of the goals set.

And finally, I would like to show my most personal thanks.

To AAU Copenhagen, for educating me on the path of urban sustainability, for welcoming me in two very different stages, and for allowing me to teach what others instilled in me years ago.

To Robert, Ingrid, Joel, and especially Kalle, for forging sustainability and respect for nature in the depths of my character.

To Sidsel and Maider, for betting on me without hesitation.

To Jose Ignacio, for being an inexhaustible and always ready source of urban planning knowledge.

To my parents, Luz and Jose Luis, for their unconditional support and for giving me the tools to grow.

To Cristina, for being her as she is and for always being there.

To my host cities; to Copenhagen, for being a source of inspiration at all levels; to Bilbao, for teaching me that transition is possible; and to Pamplona, for that exceptional quality of life that I try to squeeze every day.

Finally, I would like to dedicate this work to Kris, my partner in a project that transcends this thesis; for being my soulmate, for your permanent smile and unconditional support, and for being my inspiration and reference in life. And to Cris, Amaia, and Martin, for being the light of all my days.

It has been a pleasure to develop and write this research. Hopefully, this small scientific contribution will be interesting and inspiring for the field dedicated to urban planning. I hope that other researchers can find support here to continue developing this line, which is so necessary for the quality of life in our cities and the balance of our planet as a whole.

[2] Vitoria-Gasteiz, Bilbao and Santurtzi (ES), Tartu (EE), Copenhagen (DK) and Sonderborg (DK), Lecce (IT), Asenovgrad (BG), Amsterdam (NL), Budapest (HU), Bratislava (SK), Krakow (PL), Riga (LV), Matosinhos (PT). SmartEnCity Network members, with currently 67 European cities.

PhD

Prefacio

Este trabajo de investigación trata de dar respuesta a la emergencia climática que sufre el planeta en su conjunto, poniendo el foco en el papel protagonista de las ciudades, como principales nodos de atracción de actividad, consumo y, en consecuencia, generación de emisiones nocivas. Por tanto, esta tesis está dirigida a profesionales e investigadores del ámbito de la planificación urbana y, especialmente, a aquellos responsables de la gestión de la ciudad que pueden incidir en su transición climática y energética, esperando que puedan encontrar soporte e inspiración en una tarea de tanta complejidad.

Mi sensación es que una tesis debe responder a una motivación personal, además de profesional, tanto para encontrar el disfrute en el camino como para poderla llevar a buen puerto. En mi caso, confieso que ambas motivaciones están conectadas. Por un lado, desde que tengo conciencia he sentido una atracción fuerte por la naturaleza, por todo lo que me ofreció y enseñó de pequeño, hasta esa sensación única de conexión y desconexión simultánea que tanto valoro hoy. En distintas etapas, Burguete me empujó a quererla, Guatemala a respetarla, y Visby a protegerla, ya consciente de que uno tiene que proteger con decisión aquello que ama.

Y por otro lado me impulsa mi fascinación por la ciudad, por ese espacio de conexión humana, vibrante, donde todo pasa, todo se conecta. En cada paseo me distraigo con lo que veo, de manera inconsciente, en repensar su funcionamiento; desde el bordillo de una acera hasta el metabolismo urbano en su conjunto, tratando de encontrar siempre un modelo más coherente con las necesidades de sus ciudadanos y, al mismo tiempo, más equilibrado en esa relación desigual con su entorno natural. Si alguien fue adolescente en los 90, podrá adivinar la mella que la saga *SimCity*[3] dejó en mi subconsciente. Afortunadamente, tengo la suerte de dedicarme profesionalmente a los distintos procesos de transformación de nuestras ciudades y, aunque a veces *Outlook*, *Teams* o "el cliente" nos atormenten, es una suerte que no podemos olvidar ni desaprovechar.

Fruto de estas motivaciones decidí embarcarme en este viaje, podríamos decir que un hito más en la vida (en vocabulario *Lean*), y que gracias a muchos y muchas he sido capaz de alcanzar.

En primer lugar, me gustaría agradecer a mis directores, Patricia e Iván, por su visión, experiencia y apoyo en un proceso que ellos mismos padecieron. Al saltar, uno no es consciente de dónde se mete; una montaña rusa con sus logros y sus momentos de desazón, y ellos han conseguido guiarme de principio a fin del viaje con acierto. De igual manera, quiero agradecer a Tecnalia y a la UPV-EHU por permitirme defender esta tesis, así como al equipo que ha contribuido a su desarrollo. A Fran y Patricia, como mis mentores profesionales, y a Carolina, Elena, Pablo, Patxi, Iñigo, Mauri, Alessandra, Maider, Isabel, Olaia, Silvia, Antonio, Mikel y Nacho, por vuestra excelencia profesional y calidad personal, ¡muchísimas gracias equipo!

Por otro lado, mi participación en los proyectos *SmartEnCity*, *Atelier*, y *NetZeroCities* ha sido decisiva para contar con el soporte científico necesario, tanto a nivel teórico como de aplicabilidad de las actividades de investigación. Gracias a la Comisión Europea por financiar y creer en esta rama de conocimiento como un vector que aporta bienestar y respuesta a las necesidades de nuestra sociedad; y a los consorcios de estos proyectos, con un potencial científico interdisciplinar incomparable. Me gustaría mencionar a Dave, Si-

[3] *SimCity* es una saga de videojuegos que permite la creación, gestión y evolución de ciudades, desarrollado por Maxis, actualmente Electronic Arts. El primer juego de la saga salió al mercado en 1989, con un recorrido de versiones posteriores que llega hasta 2015.

mon, Per Alex y Peter, por el interesante y fructífero intercambio de reflexiones en la temática, así como a los revisores de nuestros cuatro artículos, porque indudablemente han contribuido a la mejora del resultado final.

También me gustaría agradecer a todas las ciudades que han mostrado interés en este trabajo[4], y que han permitido evolucionar, testar y validar esta investigación. Y de manera especial a Vitoria-Gasteiz y Sonderborg, dos ciudades ejemplo y bandera en materia de sostenibilidad. Ojalá podamos seguir colaborando en la implementación de las metas fijadas.

Y para finalizar, me gustaría mostrar mi agradecimiento más personal.

A AAU Copenhagen, por educarme en el camino de la sostenibilidad urbana, por acogerme en dos etapas tan distintas, y por darme la oportunidad de enseñar lo que otros en su día me inculcaron.

A Robert, Ingrid, Joel, y especialmente a Kalle, por inculcarme la sostenibilidad y el respeto a la naturaleza en lo más profundo de mi carácter.

A Sidsel y Maider, por apostar por mí sin dudar.

A Jose Ignacio, por ser una fuente inagotable y siempre dispuesta de saber urbanístico.

A mis padres, Luz y Jose Luis, por su apoyo sin condiciones, y por darme las herramientas para crecer.

A Cristina, por ser como es y por estar siempre ahí.

A mis ciudades de acogida; a Copenhague, por ser fuente de inspiración a todos los niveles; a Bilbao, por enseñarme que la transición es posible; y a Pamplona, por esa calidad de vida excepcional que trato de exprimir cada día.

Por último, me gustaría dedicar este trabajo a Kris, acompañante en un proyecto que trasciende esta tesis; por ser mi alma gemela, por tu sonrisa permanente y apoyo incondicional, por ser mi inspiración y referente en la vida. Y a Cris, Amaia y Martín, por ser la luz de todos mis días.

Ha sido un gusto desarrollar y redactar esta investigación. Ojalá que este pequeño aporte científico resulte interesante e inspirador para el campo dedicado a la planificación urbana. Tengo la esperanza de que otros investigadores puedan apoyarse aquí para continuar con el desarrollo de esta línea, tan necesaria para la calidad de vida de nuestras ciudades y el equilibrio de nuestro planeta en su conjunto.

[4] Vitoria-Gasteiz, Bilbao y Santurtzi (ES), Tartu (EE), Copenhagen y Sonderborg (DK), Lecce (IT), Asenovgrad (BG), Amsterdam (NL), Budapest (HU), Bratislava (SK), Krakow (PL), Riga (LV), Matosinhos (PT). Ciudades de la SmartEnCity Network; 67 ciuades europeas a septiembre de 2022.

PhD

Abstract

Society is facing the climate change emergency, and cities play a crucial role as population concentrators, GDP producers, energy consumers, waste generators, and GHG emitters. Intending to improve an effective response by local authorities to this crisis, this PhD is focused on cities that are willing to start their journey towards climate-neutrality (net-zero CO_2 emissions) and how to orchestrate this transition from a local approach. Regarding the planning perspective of such an ambitious goal, this research has identified a lack of integration among energy and urban planning dynamics as a key barrier in this transition. Accordingly, this research aims to upgrade that level of integration by different means. First, through an integrated lead of strategic municipal processes; secondly, by using appropriate tools and data management procedures that enable the integration of energy and spatial elements in the decision-making process; and finally, by an effective engagement of local stakeholders in the climate-neutrality process. All these hypothetical statements are analysed by 4 interconnected research studies and later validated through their application in the coordination process of the climate-neutrality plan of Vitoria-Gasteiz.

Keywords: climate-neutrality, cities, urban decarbonisation, urban transition, local energy planning, strategic processes, integrated planning.

PhD

Resumen

Spanish / Español

La sociedad se enfrenta a la emergencia climática, donde las ciudades juegan un papel crucial como concentradoras de población, productoras de PIB, consumidoras de energía, generadoras de residuos y emisoras de GEI. Con la premisa de mejorar una respuesta eficaz de las administraciones locales a esta crisis, este doctorado se centra en dar soporte a aquellas ciudades que están dispuestas a iniciar su viaje hacia la neutralidad climática (cero emisiones netas de CO_2) y en cómo orquestar esta transición desde un enfoque local. En términos de planificación del proceso hacia una meta tan ambiciosa, esta investigación ha identificado la falta de integración entre las dinámicas de planificación energética y urbana como una barrera clave en esta transición. En consecuencia, el objetivo de esta investigación es mejorar ese nivel de integración por diferentes medios. Primero, a través de un liderazgo integrado de procesos estratégicos municipales; en segundo lugar, mediante el uso de herramientas y procedimientos de gestión de datos adecuados que permitan la integración de elementos energéticos y espaciales en la toma de decisiones; y finalmente, a través de una involucración adecuada de los agentes locales en el proceso de planificación hacia la neutralidad climática. Todas estas hipótesis son analizadas por 4 estudios de investigación conectados entre sí, y validados posteriormente a través de su aplicación en el proceso de coordinación del plan de neutralidad climática de Vitoria-Gasteiz.

Palabras clave: neutralidad climática, ciudades, descarbonización urbana, transición urbana, planificación energética local, procesos estratégicos, planificación integrada.

PhD

Scientific contributions of this PhD

Literature, lectures, events, projects, benefited cities, and awards

Primary literature

- RESEARCH STUDY 1 – Q3 - https://doi.org/10.6036/9273
  K. Urrutia-Azcona, S. Sorensen, P. Molina-Costa, and I. Flores-Abascal, "Smart Zero Carbon City: Key Factors Towards Smart Urban Decarbonisation," *DYNA Ing. e Ind.*, no. Climate Change Challenges for Engineering, 2019.

- RESEARCH STUDY 2 – Q1 - https://doi.org/10.3390/su12093590
  K. Urrutia-Azcona, M. Tatar, P. Molina-Costa, and I. Flores-Abascal, "Cities4ZERO: Overcoming Carbon Lock-in in Municipalities through Smart Urban Transformation Processes," *Sustainability*, vol. 12, no. 9, p. 3590, 2020.

- RESEARCH STUDY 3 – Q1 - https://doi.org/10.3390/su13010383
  K. Urrutia-Azcona, E. Usobiaga-Ferrer, P. De Agustin-Camacho, P. Molina-Costa, M. Benedito-Bordanau, and I. Flores-Abascal, "ENER-BI: Integrating Energy and Spatial Data for Cities' Decarbonisation Planning," *Sustainability*, vol. 13, no. 383, pp. 1–15, 2021.

- RESEARCH STUDY 4 – Q1 - https://doi.org/10.3390/su13168836
  K. Urrutia-Azcona, P. Molina-Costa, I. Muñoz, D. Maya-Drysdale, C. Garcia-Madruga, and I. Flores-Abascal, "Towards an Integrated Approach to Urban Decarbonisation in Practice: The Case of Vitoria-Gasteiz," *Sustainability*, vol. 13, no. 8836, pp. 1–20, 2021.

Additional published literature

- *Action Plan for an Integrated Energy Transition of Vitoria-Gasteiz 2030*
  Municipality of Vitoria-Gasteiz, 2021, 1st author.
- *District Heating & Cooling Solution Booklet*
  European Commission, 2021, 1st author.
- *Urban Freight Logistics Solution Booklet*
  European Commission, 2021, 1st author.
- *Smart Solutions for CO_2 Reduction – City Practitioner's Summary Guide*
  European Commission, 2020, 1st author.
- *Integrated and Systemic SmartEnCity Urban Regeneration Strategy*
  SmartEnCity project, 2019, 1st author
- *Sustainable Energy and Climate Action Plan of Vitoria-Gasteiz 2030*
  Municipality of Vitoria-Gasteiz, 2022, co-author
- *The Journey towards Zero Carbon Emissions – A Travel Guide for Cities*
  SmartEnCity project, 2021, co-author

University lectures

- MSc Engineering in Sustainable Cities, AAU Aalborg University Copenhagen.
  1. *Urban Synergies* course. *Integrated Planning, a practical approach to Smart Sustainable Cities' planning*. March 15th, 2021. Copenhagen, Denmark.
  2. *Sustainable Transport and Mobility* course. *Sustainable Urban Mobility Plans and the case of Vitoria-Gasteiz*. March 16th, 2021. Copenhagen, Denmark.

- MSc in Building Renovation and Urban Regeneration, Universitat Politècnica de València. *Urban policies and smart urbanization* course. *Smart and Sustainable Cities, a practical approach to integrated planning*. October 11th, 2021.

Conferences & events

- Speaker at *Sustainable Places Conference* – June 5-7, 2019. Cagliari, Italy. *Urban transformation process supporting the energy transition of European cities*
- Speaker at *100% Climate-neutrality Conference* – September 28th, 2021. Sonderborg, Denmark. *The Cities4ZERO methodology*
- Speaker at *CITYxCITY Conference. Connecting Cities, Empowering Communities*. February 10th, 2022. *Supporting cities' journey towards climate-neutrality through the Cities Mission Platform*
- Speaker at *STARDUST on a mission* webinar – March 23rd, 2022. *Expression of Interest submissions for 100 Climate-Neutral and Smart Cities by 2030*
- Speaker at *SmartEnCity Academy* webinars for planners & city representatives.
  1. *Lesson 1: The Cities4ZERO strategy for Integrated Energy Planning*. February 20th, 2020.
  2. *Lesson 4: Envision and Planning: The SmartEnCity planning process*. September 23rd, 2020.
- Coordinator and moderator of Vitoria-Gasteiz 2030 co-visioning workshops, part of the *Action Plan for an Integrated Energy Transition Vitoria-Gasteiz 2030* – January 29th / February 12th, 2020. Vitoria-Gasteiz, Spain.
- Coordinator and speaker at *Towards Climate-neutrality* event, assessing 9 Spanish cities on how to start their transition - May 5th, 2022. Vitoria-Gasteiz, Spain.
- Moderator of the high-level panel at *SmartEnCity – towards Smart Zero CO_2 Cities across Europe* Final Conference – June 14th, 2022. Vitoria-Gasteiz, Spain.

Cities supported by this research so far

- Vitoria-Gasteiz, Bilbao and Santurtzi (ES), Tartu (EE), Sonderborg (DK), Lecce (IT), Asenovgrad (BG), Amsterdam (NL), Copenhagen (DK), Budapest (HU), Bratislava (SK), Krakow (PL), Riga (LV), Matosinhos (PT).
- SmartEnCity Network members, with currently 67 European cities.

Projects supported by this research (and vice versa)

- SmartEnCity – Towards Smart Zero CO_2 Cities across Europe
  European Commission, 2016-2022 (Grant agreement ID: 691883)
- ATELIER – Amsterdam/ Bilbao Citizen-Driven Smart Cities
  European Commission, 2019-2024 (Grant agreement ID: 864374)
- Net Zero Cities – Towards climate-neutral European cities by 2030
  European Commission, 2021-2024
- Smart Cities Information System (before the current Smart Cities Marketplace)
  European Commission, 2018-2020

Awards

- Cities4ZERO methodology was appointed as a "*Key Innovation*" by the European Commission's Innovation Radar platform, with a market maturity of "business ready" and a "market creation potential".

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Table of Contents

PhD

SECTION I.

Summary report

A. Introduction & Background
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D. Results & Discussion
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Citation:

K. Urrutia-Azcona, *Integration of energy and urban planning dynamics for cities' climate-neutrality*. Bilbao: University of the Basque Country, 2022.

Directors:

PhD Molina-Costa, Patricia
PhD Flores-Abascal, Iván

Institutions:

TECNALIA, Basque Research and Technology Alliance (BRTA), Parque Tecnológico de Vizcaya, Geldo street, Edif.700, 48160 Derio, Spain.

University of the Basque Country, ENEDI Research Group, Alda. Urquijo s/n, 48013 Bilbao, Spain.

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PhD
A. Introduction & Background

A1. Introduction to the thesis

This PhD is focused on cities that are willing to start their journey towards climate neutrality and need guidance on how to orchestrate this transition from a local perspective. Specifically, the research has identified a lack of integration between energy and urban planning dynamics as a barrier to this transition. In this sense, it is relevant to highlight the importance of a systems thinking approach in this climate transition, where all urban systems are highly interconnected, and where the energy system of a city is highly transversal and a key one in this transition; it cannot be approached as an isolated system as it affects various urban systems as well as the whole urban planning practice.

Accordingly, this research aims to enhance that level of integration by different means. First, through an integrated lead of strategic municipal processes; secondly, by using appropriate tools and data management procedures that enable the integration of energy and spatial elements; and finally, by an effective engagement of local stakeholders in the climate-neutrality process. All these elements are summarised in the following *research question*:

How can local authorities integrate energy and urban planning processes, stakeholders, and tools to effectively address the climate-neutrality goal in cities?

To appropriately answer this question, the research framework includes some key elements structured and argued along the three main sections of this document, which are described below:

Section I

First, Part A provides an overview of the research background, delving into the concept of climate neutrality, the role of cities within the climate change emergency, and the existing initiatives towards climate neutrality in cities. Furthermore, this section argues the important role of integrated planning within cities' transformation processes and the existing lack of integration among urban and energy planning in climate-neutrality planning processes.

Secondly, Part B presents an in-short overall research framework description, formulating the research question, the hypothesis that will steer the process, and the objectives to be achieved by this research

Part C sets the theoretical and methodological framework of the PhD. Regarding theory, the author has chosen three pieces of literature to cope with the research question resolution. The theory of *understanding* and *escaping carbon lock-in* from Gregory C. Unruh (2000, 2002), combined with the *multi-level perspective* on socio-technical transitions from Frank W. Geels (2002, 2012, 2020), both provide a comprehensive mindset on how to understand and face climate-neutrality transitions in cities. Furthermore, and as local authorities are key facilitators of urban transitions, the theory of *institutional design* from E.R Alexander (2005) argues the institutional transformation need to better accommodate the flow of this climate transition. Regarding the methodological framework, this part also provides an overview of the overall research techniques used for data collection as well as the specific methods applied for this research.

The results of this PhD thesis are presented by a compendium of scientific articles, which are first summarised in Part D, and later attached in Section III:

- The first study, which works as the hypothesis of this PhD thesis, identifies the Key Factors that municipalities must incorporate as main levers that trigger their local processes towards climate neutrality, focusing on the case of Sonderborg municipality. The lack of integration between energy and urban planning is one of those factors, and the following studies provide methods and tools to improve that lack of integration.
  K. Urrutia-Azcona, S. Sorensen, P. Molina-Costa, and I. Flores-Abascal, "Smart Zero Carbon City: Key Factors Towards Smart Urban Decarbonisation," *DYNA Ing. e Ind.*, no. Climate Change Challenges for Engineering, 2019.

- The second study presents Cities4ZERO, a methodological approach for municipalities to plan strategic processes towards climate neutrality.
  K. Urrutia-Azcona, M. Tatar, P. Molina-Costa, and I. Flores-Abascal, "Cities4ZERO: Overcoming Carbon Lock-in in Municipalities through Smart Urban Transformation Processes," *Sustainability*, vol. 12, no. 9, p. 3590, 2020.

- The third study delves into the integration of energy and spatial data management for climate-neutrality decision-making (ENER-BI principles as so-called in the study).
  K. Urrutia-Azcona, E. Usobiaga-Ferrer, P. De Agustin-Camacho, P. Molina-Costa, M. Benedito-Bordanau, and I. Flores-Abascal, "ENER-BI: Integrating Energy and Spatial Data for Cities' Decarbonisation Planning," *Sustainability*, vol.13, no. 383, pp. 1–15, 2021.

- The last study applies the findings of the PhD thesis in the real planning environment of Vitoria-Gasteiz, whose climate-neutrality plan was coordinated by the author, obtaining interesting insights based on the contrast between theory and practice.
  K. Urrutia-Azcona, P. Molina-Costa, I. Muñoz, D. Maya-Drysdale, C. Garcia-Madruga, and I. Flores-Abascal, "Towards an Integrated Approach to Urban Decarbonisation in Practice: The Case of Vitoria-Gasteiz," *Sustainability*, vol. 13, no. 8836, pp. 1–20, 2021.

In addition to the summary of results of the PhD research, Part D also includes the discussion. This part presents a suitable current context for disruptive climate action but argues for the need for a comprehensive and common understanding of the climate-neutrality journey for cities. Furthermore, it stands for strategic municipal processes as the compass towards climate neutrality in cities, and for local stakeholders as the core of any transition. The complexity of urban planning processes and the role of urban-energy models and data management procedures in this transition are also discussed in this part.

Section II

This section presents, in a nutshell, the partial conclusions of the 4 research studies as well as additional concluding remarks from the whole PhD research. Section *II* also introduces the future lines of research this work has identified after analysing its results. Future research is structured on three main lines: 1) further scientific clarity on the climate-neutrality concept and journey for cities; 2) the potential evolution of the Cities4ZERO methodology; and 3) all gaps, and potential progress identified in urban-energy modelling and data management procedures within the climate-neutrality transition.

Section III

Finally, section *III* compiles the 4 published research studies, which are the core and thread of this PhD research.

These 4 published research articles are not isolated studies, but part of a research design structured from the start of the PhD research, which has been fulfilling successive planned milestones along its way. In this sense, Figure 1 provides a graphic overview of the PhD roadmap, including key concepts, scientific publications, and supporting events. The consistency of all its pieces has been a clear goal from the start of this long journey.

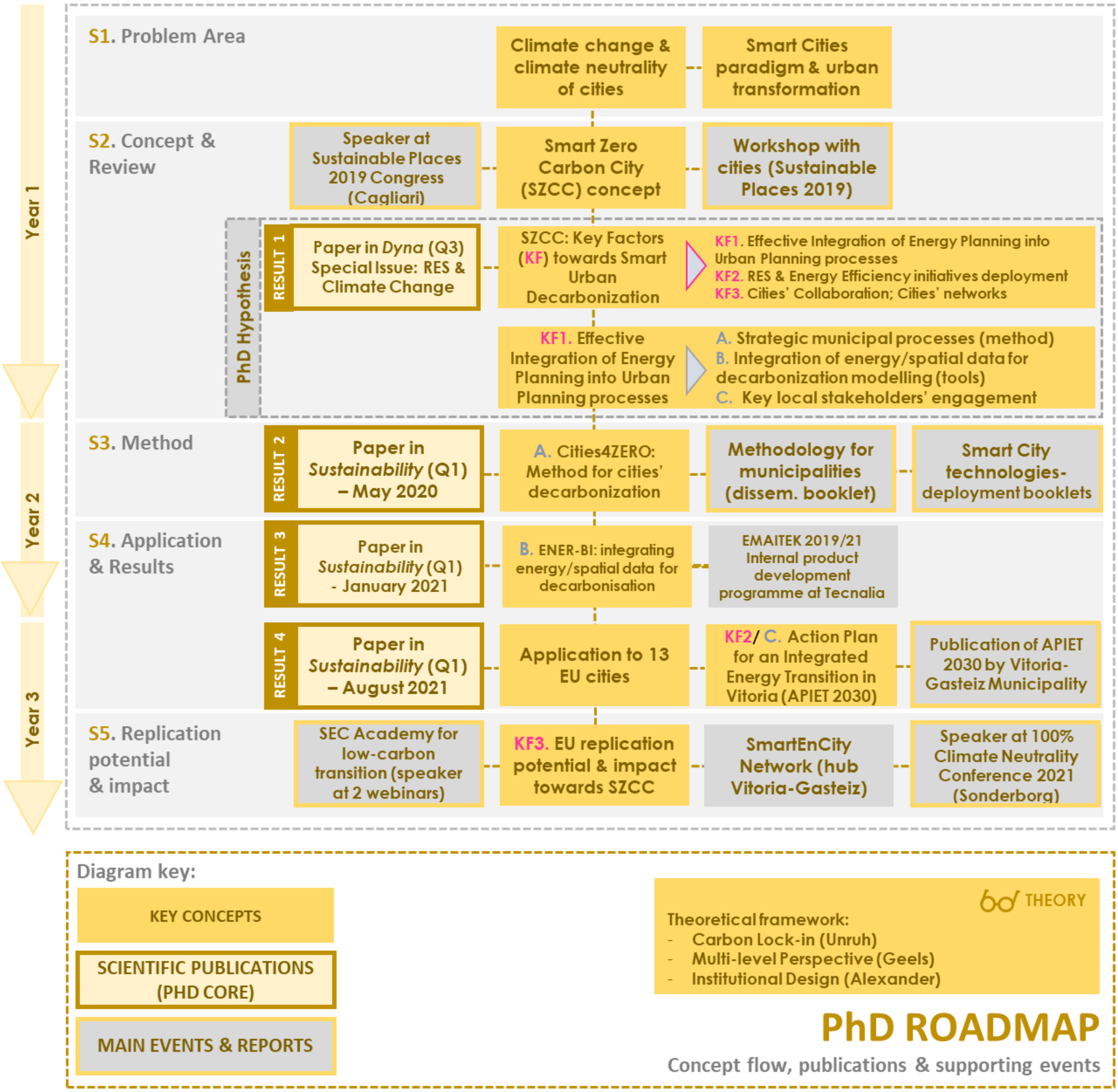

Figure 1. PhD thesis roadmap, including key concepts, publications, and supporting events.

A2. Research background

A2.1 Cities' climate-neutrality within the global Climate Change emergency

Why cities? The role of urban environments in this crisis

Society is nowadays facing one of the hardest challenges in history. Our progress has been highly dependent on burning fossil fuels since the industrial revolution in the 19th Century, obtaining energy at the lowest possible costs since then, while boosting Green House Gas (GHG) emissions. The result of this human activity over time has brought a destabilizing phenomenon to our time, Climate Change, which unforeseen consequences are already modifying global natural patterns. Focusing on GHG emissions and the impact this fossil-fuel dependency has on local environments, the World Health Organization (WHO) states that 92% of the global population lives in places where air quality levels exceed WHO limits [1]. Accordingly, cities are the most vulnerable environments, both eventually registering unacceptable pollution levels, while nowadays concentrating more than half of the global population, forecasting this rate to achieve a 68% by 2050 [2], provoking a huge impact on global public health. Indeed, this situation causes 800,000 extra premature deaths a year in Europe, and 8.8 million worldwide, according to the latest study by the European Society of Cardiology [3].

The migration associated with economic and social opportunities available in cities is forcing fast urbanisation. Currently accounting for 56% of the global population, urban environments are producing up to 70% of the global GDP [4]. This remarkable level of economic activity has also its consequence in terms of environmental impact; cities absorb about 70% of global resources and energy, generating about 70% of waste and 70% of GHG emissions worldwide [4]. All that impact by just occupying 2% of the global surface [5].

Besides this level of global incidence, cities offer a suitable environment to transform policies into specific projects. The Environment Programme from the UN states that local governments are uniquely positioned to advance in the implementation of climate action: "*as planners and regulators, as facilitators of finance, as role models and advocates, and as large consumers of energy and providers of infrastructure and services*" [6]. Accordingly, cities can play a major role in the fulfilment of Conference of Parties (COPs) agreements and the UN's 2030 Agenda for Sustainable Development, both as part of the problem and the solution, as two sides of the same coin.

The conceptual construction of climate-neutrality

The lines below describe how different interlinked concepts have led to the *climate-neutrality* concept, the focus of this thesis, evolving to a concept with high ambition and impact on current policies.

Back in the 1970s, the oil crisis affected the economy worldwide at the same time the cities were also suffering the decline of the industrialisation era. It was then than the concept of *sustainability* emerged under the *eco-development* term, exploring the need for an alternative growth model, where specific thresholds of degradation needed to be respected to avoid the collapse of urban areas. In 1987, the *Brundtland Report* introduced the concept of *sustainable development*, which was a turning point for the irruption of sustainable urban development action. In this sense, successive initiatives such as *Agenda 21*, the *Río Declaration* (1992), the *Aalborg Charter* (1994), and the *Lisbon Strategy* (2000), fostered the finetune and application of the term worldwide and specifically in European cities.

Since the beginning of the 21st century, the environmental, social, and economic conditions of cities have been a concern to improve the quality of life of their citizens. This trend has been supported by various urban development milestones (*Gothenburg Agenda*, *Leipzig Charter*, *European Urban Charters*, *Toledo Declaration*, *UN Habitat Conferences*, *Basque*

Declaration, etc.) and concepts that have guided policymakers, planners, and developers and, likewise, some of those concepts have also emerged in response to the climate change emergency [7].

The fight against climate change is built upon two main fields of action. Climate change *mitigation* refers to the reduction and prevention of GHG emissions, whilst climate change *adaptation* intends to prepare for the potential impacts of a warming world [8]. An alternative way of addressing climate mitigation term is through the *decarbonisation* term, which Oxford University defines as "*reducing the amount of gaseous carbon compounds released in or as a result of an environment or process*" [9]. Accordingly, both mitigation and decarbonisation terms coincide on the core of their elements: reducing carbon gas emissions from an environment; covering the aim of cities of reducing the emissions entailed to their urban metabolism process for a healthier urban environment, and the potential mitigation of Climate Change.

Intending to set a standard conceptual framework for the accountability and reporting of that urban decarbonisation process, the *Global Protocol for Community-Scale Greenhouse Gas Inventories* [10] provides standards and tools for measurable, comprehensive, and more efficient GHG emissions reduction strategies. This protocol acknowledges that urban activities can generate GHG emissions within the city boundary as well as beyond that boundary. Depending on where those emissions are generated, the Protocol sets three different scopes:

- Scope 1 (direct emissions), for GHG emissions coming from local sources within the city.
- Scope 2 (indirect emissions), for GHG emissions occurring outside the city, but because of the city activities within its boundary (grid-supplied energy).
- Scope 3 (out-of-boundary emissions), all other GHG emissions occurring outside the city boundary as a result of activities that take place within the city (life cycle of goods; out-of-boundary waste, water, and transportation; energy transmission and distribution) [10].

The definition of these three scopes is relevant for the climate-neutrality concept as it generates three different frameworks to become a climate-neutral city, each of those connected to a different degree of ambition in GHG emissions reduction.

In response to the climate change debate and underpinned by the GHG emissions Protocol, several terms have been generated, such as *low-carbon city*, *carbon-neutral city*, *zero-carbon city*, and *negative-carbon city*, developing similar definitions for those terms [7]. According to reviews, these are considered subsets of the *sustainable city* concept, with an emphasis on technical and energy issues [11]. In this regard, *climate-neutral city* and *carbon-neutral city* are interchangeable terms in academic research and policy discourse, both becoming the consolidated terms that are guiding all cities' efforts towards urban decarbonisation. Indeed, many cities have already published their climate-neutrality/ carbon-neutrality targets, taking the concept a central role in the policy discourse [7].

Despite this centrality in the political discourse, there is still no unique and clear definition of what a climate-neutral city is; it can be considered a relatively flexible term. Huovila et al [7] present a review of the approach to the concept by both "literature and policy documents" and "case cities", finding coincidences as well as slight differences among them. Both approaches agree on a climate-neutral city as an ambitious urban transitioning concept that sets a year for carbon neutrality as well as an emissions reduction target for that year. Regarding the emissions reduction percentage from the baseline year, "case cities" target a 60-80% reduction, whilst policy documents aim for an 80-100% reduction, both approaches considering carbon sequestration and offsetting emissions as complementary actions to achieve climate neutrality. Furthermore, both approaches identify cities' climate networks as key in co-defining ambition levels, accounting, the scope of emissions, providing a framework for action, etc. Finally, both approaches mainly target not just the energy sector, but also other areas related to climate neutrality, finding minor differences in the specific sectoral implications [7]. Overall,

Table **1** shows the main features and target areas of the climate-neutral city concept.

Table 1. Definition and content of a *climate-neutral city* from “literature” and “case cities” review [7].

	Literature and policy documents	**“Case cities”**
Features of a climate-neutral city	▪ The target for a certain period ending in a specific year when emissions will be balanced ▪ 80-100% GHG emissions reduction ▪ GHG residual emissions are balanced by sequestration and/or offsetting ▪ Definition of ambition level, accounting, and scope (1, 2, or 3), matters often addressed as part of local stakeholders’ dialogue	▪ Target set for a specific year ▪ 60-80% GHG emissions reduction ▪ GHG residual emissions are balanced by sequestration and offsetting (through local or global initiatives) ▪ The dimension of “climate-neutrality” is integrated into future cities’ decision-making.
Target categories/ action areas	Local level plans can include mitigation measures in: ▪ Energy use, energy efficiency, and saving, renewable energy ▪ Buildings ▪ Transport ▪ Waste ▪ Nature-based solutions, agriculture, and food ▪ Land-use ▪ Carbon sequestration ▪ Industry ▪ Consumption and behaviour, education, communication, and public relations ▪ Policy and research ▪ Other	▪ Energy production and consumption ▪ Transportation and mobility ▪ Built environment and community structure ▪ Carbon sinks, compensation, and biodiversity ▪ Waste management and circularity ▪ Water management and natural water areas ▪ Food production and consumption ▪ Procurement and private sector collaboration

Climate neutrality is currently becoming *the* term that brings all initiatives and actions around urban decarbonisation on board. In last years, while the climate neutrality term was gaining influence, the SmartEnCity project [12] worked on a similar concept to channel all urban climate mitigation actions: the *Smart Zero Carbon City* (SZCC) concept, which can be considered one of those subsets of the *sustainable city* concept [11], with a specific connection with the Smart Cities field:

“A Smart Zero Carbon City (SZCC) is a resource-efficient urban environment where carbon footprint is eliminated; energy demand is kept to a minimum through the use of demand control technologies that save energy and promote raised awareness; energy supply is entirely renewable and clean; and resources are intelligently managed by aware and efficient citizens, as well as both public and private stakeholders” (p.2) [13].

The SZCC concept is highly interlinked with the climate-neutral city concept, targeting urban decarbonisation through the main elements connected to cities’ energy systems: energy demand, energy supply, and energy management; all from a participatory, cross-cutting, and technology-supported perspective [13]. Within this thesis, the SZCC concept initially worked as a kick starter in the hypothesis and core scientific articles’ formulation, and it still stands fully aligned with the climate-neutral city concept. Overall, it is in the mitigation of climate change and the way municipalities face it where this thesis intends to provide support, both concepts being valid to articulate the path towards this mitigation goal.

Initiatives towards climate-neutral cities

The application of the climate-neutral city concept needs a framework that facilitates its deployment in practice. There currently are initiatives from global to local that intend to align efforts towards climate change mitigation, and those include of course the city scale.

Based on a global framework guided by two United Nations initiatives [the Sustainable Development Goals 2030 (SDGs) and the national agreements through the successive Conferences of the Parties (COPs)], cities' initiatives are mainly structured through collaborative approaches such as cities' networks and alliances. As Gordon and Johnson argue [14], city networks provide support through building capacity to measure, report, and verify GHG emissions reduction. Furthermore, and looking at the case of the cities of this thesis (i.e., City of Sonderborg), city networks can offer much more than that: inspiration from cities facing similar transitions, peer-to-peer discussions on how to address barriers and solutions, joint policymaking, procurement, and lobby for green purposes, as well as any other activity where an isolated city is more likely to fail. Accordingly, many cities have chosen a collaborative approach to address their climate transition, joining diverse city networks and joint policy frameworks such as the C40 Cities group [15] or the Carbon Neutral Cities Alliance [16]. Furthermore, over 400 cities and organisations have joined the Climate Ambition Alliance, which brings countries, businesses, investors, cities, and regions that work for the net-zero carbon goal by 2050 together [17].

In the international landscape, the European Union (EU) stands as the region with the most ambitious policies on climate neutrality, to be achieved by 2050. Before the start of the war in Ukraine in 2022, an event that will probably accelerate the urgency for climate neutrality in the region due to the strong dependency on Russian energy resources, the EU agreed on committing to a reduction of 55% of GHG emissions by 2030 compared to 1990 values [18]. Targeting this goal and supported by the European Commission (EC), the Covenant of Mayors for Energy & Climate (CoM) is the initiative that is gathering more members interested in advancing towards climate neutrality. With 10.898 signatories from 54 different countries and 6.221 submitted action plans, the CoM has become the mainstream initiative for cities' climate mitigation [19]. Furthermore, the EC orchestrates a set of programmes that provide support to the mitigation goal from different angles, such as the European Innovation Partnership on Smart Cities and Communities (EIP-SCC), the European Green Deal, and the Clean energy for all Europeans package, including comprehensive measures on the energy performance of buildings, renewable energy, energy efficiency, governance regulation, electricity market design, and both legal and non-legislative initiatives [20].

Within this favourable European context for climate policy, the EC adopted the EU Missions format, a new way of bringing more concrete solutions to the greatest challenges of the region, with an intent of delivering tangible results by 2030 within diverse fields of action. The climate neutrality of EU cities was appointed as one of those greatest challenges, hence the *100 Climate-Neutral and Smart Cities by 2030* Mission came to the stage in 2021. The so-called *Cities Mission*, anchored within the Green Deal programme, has the objective of a) delivering 100 climate-neutral cities by 2030, and b) ensuring that those 100 cities become experimentation and innovation hubs to enable all EU cities to follow them by 2050 [21]. In its first weeks of life, the Cities Mission achieved an outstanding impact on European municipalities as 377 cities submitted their Expression of Interest in this Mission, all of them ambitioning climate neutrality by 2030 if appropriately supported. According to the potential success of this rising programme, the 2020s decade will be the one seeing the first set of climate-neutral cities on Earth.

A2.2 Integrated planning for cities' climate-neutrality

Integrated planning within cities' transformation processes

Cities have been a subject of transformation processes since their inception, but it is by the end of the 19th century that urban planning conceptually becomes an acknowledged discipline. By that time, urban planning was very much focused on the spatial dimension of the city and the physical organisation of the urban fabric. Since then, urban planning has been incorporating other complementary urban disciplines into its practice, feeling the need for a coordinated overall planning perspective to appropriately address the evolving urban challenges. In this sense, over the past two decades, a highly interdisciplinary field has emerged focusing on cities and systemic change for sustainability [22] [23], and it is there where the *integrated planning* concept becomes crucial to fit the diverse views of that interdisciplinarity.

Within the current climate-neutrality transition, local authorities are experiencing increasing pressure to develop and implement innovative solutions responding to complex challenges, but their capacity to do so remains limited. To move towards the zero-carbon vision, it is not enough to implement individual solutions or single improvements without a wider vision. Success rather lies in an integrated planning approach, as a system of interlinked actions—profiting from modern ICT tools, massive data production, and analytical capacities, diversifying energy production with renewable energy systems, transforming the structure of energy production for enabling small-scale production, identifying the right business models, supporting changes with administrative and taxing practices, shaping user behaviours, etc. It's a fact that decarbonising cities involves numerous interrelated challenges and requires systemic and interconnected solutions. In this sense, the concept of *systemic planning* can be useful and also considered a potential evolution of the *integrated planning* concept; the main concern of *systemic planning* is to provide principles and methodology that can support a planning process characterised by complexity and uncertainty [24], a wider approach than traditional planning that fits better with current planning challenges such as climate-neutrality.

Although the concept of integrated planning is not new, *thinking in silos* is still common in too many municipal administrations. Often, individual sectorial strategies do not consider co-dependencies or interdependencies with other city systems. This not only leads to conflicts of interest but also falls short of addressing cross-sectoral challenges [25]. Consequently, to address these challenges, a holistic strategic approach is vital. This can address each challenge individually and systematically. Such a strategic approach would need the approval of the relevant city systems, actors, governance levels, and territories, and would be jointly developed by these different actors. Making sure that everyone is on board it is important because integrated planning goes beyond merely coordinating sector policies and interest groups. It presumes a common understanding of the mid and long-term development goals, which should be jointly developed. Furthermore, local governments need to be provided with incentives that promote integrated approaches and strengthen their capacities, so they can deal with interdisciplinary tasks [25]. Such processes beyond administrative boundaries require political and institutional transformation as argued within the *Theoretical background* section of this thesis. Overall, Eisenbeiß [25] summarises the main benefits of an integrated planning approach in pragmatic terms for municipalities:

- It allows cities to formulate cross-sectoral goals and policies.
- It enables cities to develop strategies and projects involving knowledge and perspectives from diverse disciplines and stakeholders.
- It supports cities with limited capacities and budgets to implement goals more efficiently by joining forces and reducing trade-offs.

Within the SmartEnCity project, those potential benefits of an integrated planning approach have been leveraged, identifying three main channels to potentiate such an approach. First, through an important emphasis on key local stakeholders' engagement. Secondly, through a horizontal seamless collaboration among city systems and within city planning structures. And finally, through vertical cooperation with other government scales. Contributing to an integrated planning ecosystem can be challenging, but the benefits of such an approach well deserve taking care of this sensitive balance. For sure, *soft* skills are essential to make it work.

Energy planning in cities as a siloed discipline

Starting with a definition of the *energy planning* term, Thery and Zarate define it as "*determining the optimal mix of energy sources to satisfy a given energy demand*" [26]. And such a task, coinciding with one of the key urban systems to achieve climate neutrality, needs to be integrated within urban planning dynamics, but this integration is fragmented and inconsistent [27]. This is mainly due to the diverse stages entailed from the energy supply to meeting the final demand (supply, conversion, storage, and transportation, all through a wide range of technologies) [28]. Furthermore, the understanding of energy systems and planning of our cities is being currently readjusted to meet decentralised local energy production and renewables, with a shift in the responsibility of main stakeholders in the field (i.e.: the role of prosumers). Adding upon these facts, the energy planning of our cities has been historically a siloed discipline, with scarce contact with the planning department, and just relegated to taking care of energy networks and infrastructures [29]. However, as Cajot et al state, energy planning must be coordinated or even embedded in the "*spatial and strategic planning processes attributed to urban planners*" [27], complying with the integrated planning principles mentioned above.

Lack of integration between urban planning and energy planning

As a disturbing counterpart to this integration need, the lack of integration between urban planning and energy planning has been identified as a key barrier to be overcome when implementing concrete climate-neutrality initiatives in municipalities [30]. If a sufficient level of integration among both disciplines is not achieved, mainly regarding the co-development of strategic local processes that appropriately involve both key local stakeholders and urban-energy modelling tools, the climate-neutrality goal is likely to fail sooner than later.

This aspect, the core part of the thesis, is further broken down and discussed in the next sections of this document, mainly at *C1.2 Institutional transformation for a more integrated planning approach*, *B1. Research Question & Hypothesis*, and the first publication of this thesis *Smart Zero Carbon City: Key Factors Towards Smart Urban Decarbonisation* (Section III).

Initiatives to progress in the level of integration (2008-2022)

In Europe, during the last decade, several initiatives have focused on this topic, building upon the studies and growing interest in urban planning aspects of energy, derived from the energy crisis in the 1970s [22–25]. In 2012, the Energy Efficiency Directive (2012/27/EU) encouraged the adoption of integrated urban planning strategies to take advantage of all the energy savings potentially present in urban areas. Furthermore, the CONCERTO European Commission (EC) initiative delved into this strategic approach, bringing together all relevant stakeholders while integrating a variety of urban systems and technologies: "the CONCERTO initiative proves that if given the right planning and if all necessary stakeholders are included from the beginning until the end of the project, cities and communities can be transformed into sustainable energy pioneers" [35]. Putting this approach into practice, the STEP-UP (Strategies Towards Energy Performance and Urban Planning), PLEEC (Planning for Energy Efficient Cities) and InSMART (Integrative

Smart City Planning) projects (FP7-ENERGY-SMARTCITIES-2012 EC call) examined an integrated approach to urban energy planning, testing diverse tools, methods, and levels of engagement, again with the focus on energy savings [27–29].

Since 2012, the EC has fostered the interaction of cities, industries, small and medium-sized enterprises (SMEs), investors, and researchers, through the *European Innovation Partnership on Smart Cities and Communities* platform, bringing them all together to design and deliver smart-sustainable solutions and projects. In this case, the projects anchored in this platform targeted the decarbonisation of cities through the formulation of integrated urban plans, and more recently through the concept of positive energy districts (PEDs), intending to tackle the integration of energy and urban planning at both city and district levels. This is the case for the SmartEnCity project—*Towards Smart Zero CO_2 Cities across Europe*, to which this thesis has contributed through the development of the Cities4ZERO urban decarbonisation methodology (2020), intending to upgrade the urban-energy planning integration to a higher level. The Cities4ZERO methodology is presented in the second scientific article of this thesis [39], and it is tested in the city of Vitoria-Gasteiz's climate-neutrality planning process in the fourth scientific article of this thesis [40](2021).

As of 2008, running in parallel to those initiatives, the EC launched the CoM, which has engaged up to 10.898 municipalities in the reduction of CO_2 emissions [19], fostering local strategic processes through the development of Sustainable Energy Action Plans (SEAPs) and Sustainable Energy and Climate Action Plans (SECAPs, introducing the climate adaptation dimension in 2016). Over the last decade, SEAPs and SECAPs have been *"considered the unique tool to manage and act on the urban-energy field"* regarding mainstream strategic methods for urban decarbonisation [41], in many cases replacing national initiatives thanks to the European funds connected to the signature of the CoM.

However, municipalities present issues when facing these strategic processes of integration; issues that SEAPs/SECAPs are not able to solve in general terms. First, most municipalities present an absence of the strategic dimension in the urban planning system, opting for short-term sectorial actions oriented towards fast results [41]. Secondly, there is currently a wide gap between theoretical efforts and practical implementation, suffering in some local cases from lack of political commitment, coordination, and funding; all of this is worsened by the perverse effects of the marketing use of the SEAP brand [41]. And besides all this, general urban plans do not yet include energy as a dimension to consider, hence not appropriately adapting urban limitations to a favourable context for the deployment of decarbonisation initiatives.

In the meantime, the reality is stubborn, and climate action is urgent. In 2015, the Conference of Parties of Paris (COP21) achieved a binding agreement among all signatory countries, which did not include cities, although it encouraged them to cooperate and support emission reduction efforts [42]. The subsequent COPs (most recently COP26 in Glasgow, 2021), as well as the Intergovernmental Panel on Climate Change (IPCC) reports, both have stressed the crucial importance of cities in this task, inviting them to take urgent climate action.

To cope with the Climate Change mitigation task, cities need a strategic framework able to bundle different elements into a concise, pragmatic, project-oriented approach, based on a long-term strategic vision with a stable-in-time and committed institutional structure, able to integrate disciplines and stakeholders into one single sequence that fits in with the urban planning procedures of each local context. There was still no strategic method that allowed cities to cope efficiently with this challenge, and it is there that this thesis intends to contribute. Furthermore, and intending to again support the needs of cities, this PhD is focused on the urban energy system as a whole, but it also punctually refers to the local authority jurisdiction and the authority-owned infrastructure, as is the case of the ENER-BI approach (third article of the PhD thesis).

After the first article of the PhD thesis that provides the hypothetical approach, the second article presents a strategic approach for municipalities to plan their journey towards climate neutrality through the Cities4ZERO methodology. Anchored in this methodology, the third article delves into the integration of both energy and spatial data for climate-neutrality decision-making. And finally, the last article tests all of it within the real environment of Vitoria-Gasteiz's climate-neutrality journey, which mitigation plan was coordinated by the author, also including the transversal engagement of the local stakeholders in the plan as a challenging but also rewarding planning-wise task. Overall, these research modules intend to upgrade the integration of urban and energy planning disciplines for the climate neutrality of cities, tackling the weakest points of that challenging integration to be practically overcome by municipalities. More details about this Research Framework are provided in section *B*.

PhD

B. Research Framework

B1. Research Question & Hypothesis

After the description of the research background in section *A2*, this section provides an in-short overall research framework description (at the end of this section, Figure 2 shows a graphic overview), presenting the research question, the hypothesis that will steer the process, and the subsequent general and specific objectives to be achieved by this research. Furthermore, this research framework is complemented by the following section (*C*), which provides the theoretical (*C1*) and methodological (*C2*) fundaments supporting the results of this thesis.

As presented in the research background, this thesis is focused on transitioning towards climate-neutral cities and how to orchestrate a more effective integration between energy and urban planning dynamics to achieve that goal. The start of the research studied the main lessons learned on planning, implementation, monitoring, and replication stages of climate-neutrality planning processes in the cities of Vitoria-Gasteiz (ES), Sonderborg (DK), and Tartu (EE). This study is the ground for the opening article of the thesis, which points to the *Key Factors towards Smart Urban Decarbonisation* [43].

One of these Key Factors for a successful climate-neutrality transition in cities requests an "effective integration of energy planning into urban planning processes", identified as a barrier when implementing concrete energy-related initiatives in municipalities. In this sense, delving into the way that "integration" could be achieved or improved within municipalities, three fields of action were identified as potential enablers: processes, tools, and people. Accordingly, the Research Question of this thesis stands as follows:

How can local authorities integrate energy and urban planning processes, stakeholders, and tools to effectively address the climate-neutrality goal in cities?

This Research Question can be disaggregated into several elements. First, the (pro)active subject is connected to its ultimate goal; municipalities as leaders in charge of steering their local communities towards climate neutrality. Secondly, the object of change; how to integrate both disciplines? But more specifically, how to readjust planning processes, tools, and stakeholders' engagement to ensure the level of integration among both disciplines is maximised? Here is where the research gap has been detected, and where this thesis is focused on.

As argued in section *A2.2*, there is an evident lack of integration among urban and energy planning disciplines when it comes to municipal management towards climate neutrality. In this sense, and again based on the research described in *Key Factors towards Smart Urban Decarbonisation* [43], the article formulates the thesis hypothesis, which consists of the three main statements to maximise the level of integration among disciplines.

Hypothesis formulation

Local authorities can enhance energy and urban planning integration for better addressing the climate-neutrality goal in cities by:

- *Strategic municipal processes towards climate neutrality in the mid-long term, all steered by a local climate action planning authority, avoiding the inertia of short-term decision-making usually limited to political cycles.*
- *Tools for effective urban decarbonisation, enabling the generation of alternative future scenarios as well as impact forecasting and monitoring of climate-neutrality plans; all including the geospatial variable. In this sense, tools are inherently linked to reliable and meaningful data availability as well as to all that this challenging collection and integration process entails for municipalities.*
- *Key local stakeholders' engagement in integrated urban-energy planning processes, including interdepartmental collaboration as well as representatives from the quadruple helix (public administration, private sector, academia, and citizenship). The local community will decide either to block or embrace and develop the initiatives towards climate neutrality, hence they must be on board from the planning stage.*

The development of the PhD thesis delves into this hypothesis, exploring the three identified branches where the integration among urban and energy planning disciplines can be improved.

B2. Objectives of the thesis

The General Objective of this thesis is *to provide a robust and comprehensive framework for local authorities to integrate urban and energy planning dynamics to effectively address the climate-neutrality challenge in their cities*. The formulation of this General Objective is thoroughly framed under the opening publication of the thesis [43], deepening the research question to present the three main fields of action to be explored.

- Publication no.1:
  K. Urrutia-Azcona, S. Sorensen, P. Molina-Costa, and I. Flores-Abascal, "**Smart Zero Carbon City: Key Factors Towards Smart Urban Decarbonisation**", *DYNA Ing. e Ind.*, no. Climate Change Challenges for Engineering, 2019. [43]

Once the overall research framework is set, each of the following articles tackles specific parts of the PhD hypothesis, addressing the Specific Objectives in which the General Objective is broken down. Accordingly, the research targets four Specific Objectives (SOs) to provide a comprehensive answer to the General Objective.

SO1. Strategic municipal processes towards climate-neutrality

The Specific Objective 1 (SO1) is *to provide a methodology able to support local authorities in steering strategic municipal processes towards climate neutrality in the mid-long term*.

The SO1 is addressed by the second publication of this thesis, presenting Cities4ZERO, a step-by-step methodology for integrated strategic municipal processes towards climate neutrality, which provides guidance for both short and long-term iterative climate action.

- Publication no.2:
  K. Urrutia-Azcona, M. Tatar, P. Molina-Costa, and I. Flores-Abascal, "**Cities4ZERO: Overcoming Carbon Lock-in in Municipalities through Smart Urban Transformation Processes**", *Sustainability*, vol. 12, no. 9, p. 3590, 2020. [39]

SO2. Tools to support urban climate-neutrality

The Specific Objective 2 (SO2) is *to explore how to better incorporate the geospatial dimension into urban-energy planning processes*.

The SO2 is addressed by the third publication of the PhD thesis, which identifies the main requisites and functionalities that Decision Support Systems must fulfil to effectively incorporate geospatial data to support city managers in climate-neutrality processes.

- Publication no.3:
  K. Urrutia-Azcona, E. Usobiaga-Ferrer, P. De Agustin-Camacho, P. Molina-Costa, M. Benedito-Bordanau, and I. Flores-Abascal, "ENER-BI: Integrating Energy and Spatial Data for Cities' Decarbonisation Planning", *Sustainability*, vol. 13, no. 383, pp. 1–15, 2021. [44]

SO3. Local stakeholders' engagement for climate neutrality; and SO4. Validation of SOs 1, 2, & 3 through the Vitoria-Gasteiz case study

The Specific Objectives 3 (SO3) and 4 (SO4) are both addressed by the fourth publication of the PhD thesis. In particular, the SO3 is *to achieve better integration of key local stakeholders into urban-energy planning processes*, and the SO4 is *to validate the whole hypothesis (SO1, SO2, SO3) through the application of the research to a real case study*.

In this sense, the author had the opportunity to coordinate the *Action Plan for an Integrated Energy Transition in Vitoria-Gasteiz 2030* (APIET 2030) along 2020 and 2021, which currently stands as the climate-neutrality plan of the city. Through APIET 2030 development, the PhD hypothesis and their linked partial research ([39],[44],[40]) were applied and contrasted in a real municipal environment, shedding light on the developed research applicability, robustness, and effectiveness. Furthermore, this application in a real environment allowed to understand and enhance the engagement process and the governance model of the Vitoria-Gasteiz climate action framework, placing local stakeholders at the core of it.

- Publication no.4:
  K. Urrutia-Azcona, P. Molina-Costa, I. Muñoz, D. Maya-Drysdale, C. Garcia-Madruga, and I. Flores-Abascal, "**Towards an Integrated Approach to Urban Decarbonisation in Practice: The Case of Vitoria-Gasteiz**", *Sustainability*, vol. 13, no. 8836, pp. 1–20, 2021. [40]

The scientific publications, which respectively address the SOs of this research, are included in Section III of this document, as well as briefly summarised and discussed in *D. Results and Discussion*.

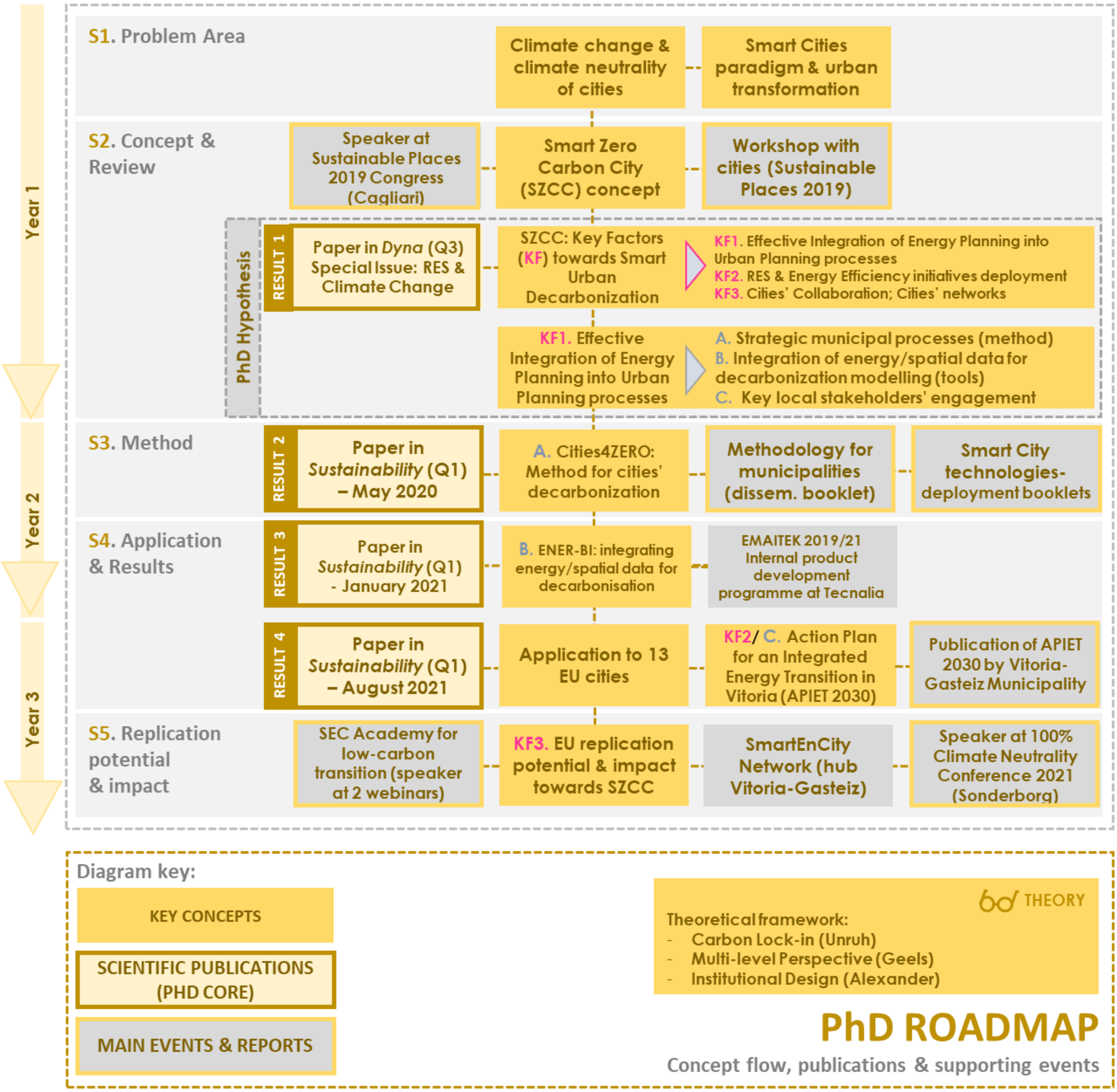

Figure 2. Overall PhD roadmap, including key concepts, publications, and supporting events.

PhD

C. Theoretical and Methodological Frameworks

C1. Theoretical framework

This section provides the theoretical background that enables a suitable approach to face the research question of this PhD thesis. The lines below bring elements from three main pieces of literature to understand how to approach transitions from different angles. The theory of *understanding* and *escaping carbon lock-in* from Gregory C. Unruh, combined with the *multi-level perspective* on socio-technical transitions from Frank W. Geels, both provide a comprehensive mindset on how to understand and face climate-neutrality transitions in cities. Furthermore, as local authorities are key facilitators of urban transitions and must foster the integration among energy and urban planning to that end, the theory of *institutional design* from E.R Alexander argues the institutional transformation needed to generate a suitable local ecosystem for this climate transition.

C1.1 Towards climate-neutrality: escaping carbon lock-in and the multi-level perspective

Climate-neutrality transitions in cities require a drastic cut in CO_2 emissions, forcing a change in last decades' trends. Even if there is wide scientific consensus and social awareness on climate change, its causes, and potential unprecedented impacts, the resistance to overcome the global emissions reduction turning point seems still far. Why is it so hard for our societies to adapt to this climate emergency context?

To address transitions and the extreme resistance of our societies to turn the tide, it's important to understand the evolution of technological systems and their close interdependency with public-private institutions, feeding and reinforcing each other at a macroeconomic scale. This is what Gregory C. Unruh calls a *techno-institutional complex* (TIC), a "*synergistic co-evolution between the technological increasing returns and the public and private institutions that govern their diffusion and use*" [45]. These TICs generate strong and permanent incentive structures which significantly influence the evolution (or not) of those technological systems, making them reliable and stable in time. In this sense, some quick TIC examples can orientate the reader on these virtuous cycles, such as electrical power networks (more appliances leading to more electricity use, new regulations, companies' investments and returns, expansion of grid networks, socio-cultural change of behaviour on electricity use, etc.) or automobile-based mobility (more roads lead to more drives, companies investments on better technological cars and economic returns, an increased tax collection by institutions, an acculturation of transport freedom, less compact urban designs, etc.). TICs can be of great value when expanding technologies in their first steps, if not competing with other already accommodated technologies, but they can generate lock-in situations in advanced stages, conditioning the emergence of alternative technological solutions; this is the so-called *techno-institutional lock-in* [45].

The idea of techno-institutional lock-in can clarify socio-technical processes and patterns leading to the climate change phenomenon. Unruh argues that "*industrial economies have been locked into fossil fuel-based energy systems through a process of technological and institutional co-evolution driven by path-dependent increasing returns to scale*" [45], presenting this statement as the *carbon lock-in* concept where society has been trapped since the industrial revolution. This techno-institutional lock-in attached to fossil fuel-based energy systems has developed such a level of stability over decades that market and policy errors have systematically been overlooked by institutions, even if the evidence of potential environmental risks is solid. This situation has delayed the irruption and consolidation of renewable energy technologies and climate mitigation policies for decades, with still outdated or even counterproductive subsidy programmes. Each year, worldwide public administrations are subsidising fossil fuels by *half a trillion dollars* (half a billion in Spanish terminology) to artificially reduce their price and make them more competitive [46].

However, TICs are beatable. History shows that despite fossil fuels-based TIC can generate barriers to renewable energy technologies and mitigation policies, the TIC is just postponing the moment when fossil-fuelled technologies will be replaced by a new regime of technological solutions that will solve the existing environmental contradictions [45]. In this sense, the multi-level perspective theory presented by Frank W. Geels provides a conceptual framework for this socio-technical replacement [47]. Taking Geels terminology, the climate change paradigm (*landscape*) would put pressure on the existing fossil-fuels dominant *regime*, altering mainstream forces of change to allow renewable energies (*niche*) to become aligned and stabilised into a dominant regime, taking advantage of the *window of opportunity* to readjust a new socio-technical regime (*market, user preferences, science, industry, culture, policy, technology*).

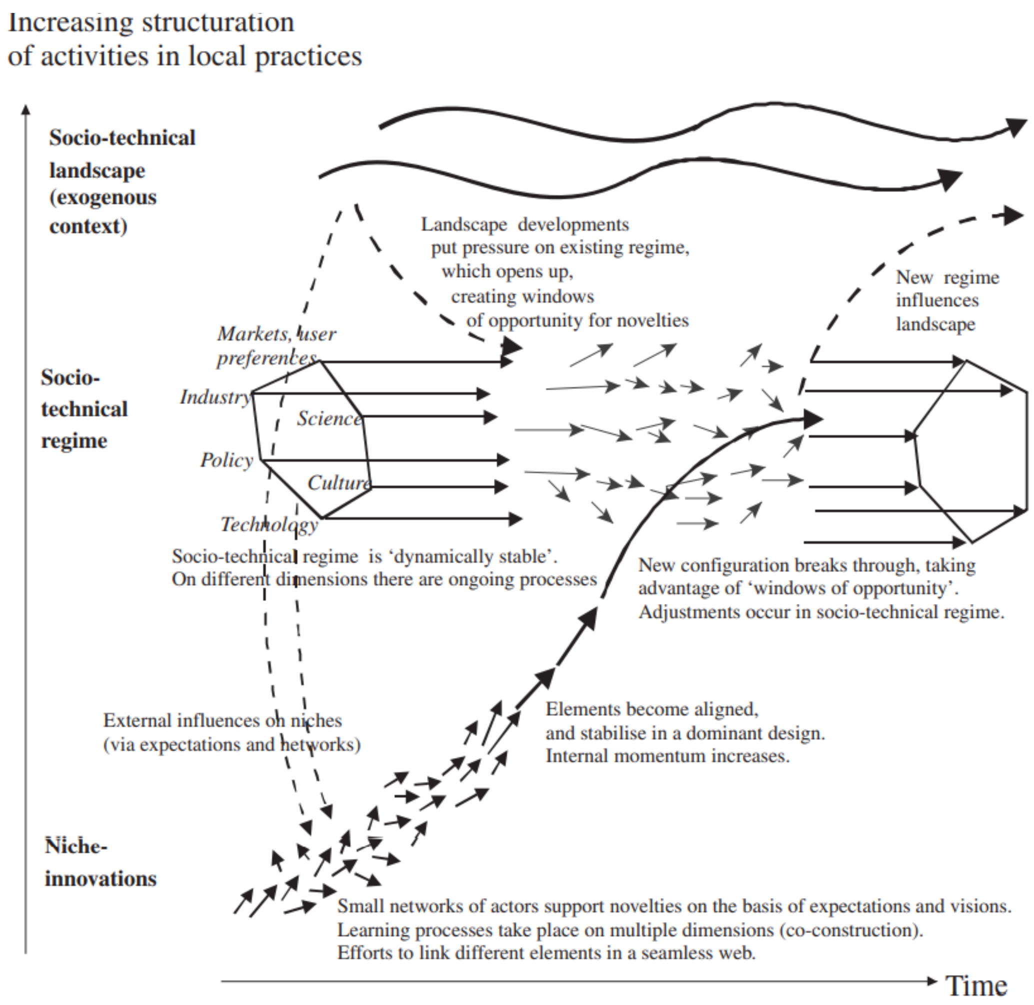

Figure 3. The multi-level perspective on transitions by Frank W. Geels [47], adapted from [48].

Looking at the initiatives described in section *A2.1*, it can be affirmed that there is a clear intent of part of our society of escaping from carbon lock-in. Continuing with TIC theory, there are two potential sources of change to occur, both at the core of the TIC concept: technological, and institutional [49]. In terms of technology, it is already proven that current renewable energy technologies can solve the economic and environmental contradictions entailed in the use of fossil fuels for energy generation. Furthermore, and touching now the private institutional side, traditional energy companies have shifted their focus towards renewables, starting to assume that escaping carbon lock-in is a major trend and renewable technologies are mature enough to channel that transition in economic terms.

Regarding institutions, and local authorities as the main focus of this thesis, they can play a determining role in escaping carbon lock-in. For this transition to occur, society needs to achieve a point where social priorities are reoriented, when a significant number of influential institutions and individuals recognise and claim that fossil-fuel path dependency is not tolerable anymore [49]. In this sense, local authorities are the closest public institutions to citizens, urban policies, and interventions, hence having a crucial role in the recognition and reorientation of social priorities into concrete climate action.

However, escaping carbon lock-in "*should not be seen as the result of a single change, but rather a series of complex, interconnected changes in multiple variables*" [49]. That social and institutional recognition of unacceptable environmental harm may be necessary but not sufficient to overcome carbon lock-in at a suitable speed. Looking at previous or ongoing transitions (i.e., acid rain, use of pesticides, ozone-hole), an external event may be required to put all societal engines at work. Can the COVID-19 outbreak be that triggering force? It does not seem so, as consumption patterns are rapidly coming back to 2019 figures, accompanied by relatively slow renewables penetration on the energy mix. "*Is a major catastrophe required?*" Unfortunately, history shows that a major natural event -or an interconnection of events- will probably have to provide an alarming shock that urges accelerated and disruptive climate action [49]. In this sense, Unruh suggests that future TICs must allow technological and institutional evolutions, be more flexible, and understand policy regimes not as *the-one* solution to our climate emergency, but as a step closer to its resolution [49].

C1.2 Institutional transformation for a more integrated planning approach

Intending to overcome carbon lock-in, and assuming a certain degree of renewable energy technological readiness, this thesis focuses on the institutional side; more specifically on cities and local authorities; and even more specifically on planning processes towards the climate-neutrality goal.

Local authorities are currently leveraging the *window of opportunity* opened by the European Commission for climate-neutrality policies and interventions, mainly through the Green Deal programme and the *100 Climate-Neutral and Smart Cities by 2030* Mission. However, in most cases, local institutions are not ready to lead and technically support this ambitious goal. The main focus of this thesis stands as a clear example; as described in section *A2*, there is a lack of integration among energy planning and urban planning processes at a municipal level, running both in parallel lanes that eventually touch each other to evidence their distance.

Considering climate neutrality a relatively new priority elevated over the last decade by municipalities, one question comes to the stage: how municipalities will organise and implement action to effectively address such a new, ambitious, and challenging programme and all projects entailed to it? It seems reasonable to assume that new priorities and programmes will need a certain degree of institutional transformation to address those. If planning structures and institutions are perceived as inadequate for their purposes [50], their function and credibility would be compromised.

With that institutional transformation aim, E.R. Alexander introduces the concept of *institutional design*, showing the variety of fields and depth of institutional transformation to adequately address new ambitious challenges such as climate neutrality in cities:

"Institutional design means, designing institutions: the devising and realisation of rules, procedures, and organisational structures that will enable and constrain behaviour and action so as to accord with held values, achieve desired objectives, or execute given tasks. By this definition institutional design is pervasive at all levels of social deliberation and action, including legislation, policymaking, planning, and program design and implementation." [50]

According to this definition, climate-neutrality municipal planners will need to readjust their current governance structures, recruit, or reorientate capacities, amend or formulate new regulations, generate new financing schemes and partnerships, upgrade local stakeholders' and citizen engagement to a higher level, integrate key planning disciplines towards the new goal, etc. All this constitutes a challenging exercise of institutional design for municipal planners and politicians; and it is there were Cities4ZERO methodology, the second publication of this PhD thesis, intends to provide support for cities, identifying the key city needs in such a process to provide a sequential method that facilitates both the pathway towards climate neutrality and the institutional design exercise it entails. As Alexander argues, to be effective in their planning tasks towards this goal, planners need a parallel reflexive consciousness of institutional design [50]. Just if this is the case, planners will have the ability to adapt the contextual local institutional structures to be successful towards their climate-neutrality goal.

Overall, the institutional design mindset is present all along the four scientific articles of this thesis, presenting clear examples in Sonderborg and Vitoria-Gasteiz municipalities (*Section III, G1* [43], and *G4* [40]), as a key exercise to cope with climate-neutrality planning challenges. Furthermore, Cities4ZERO urban decarbonisation methodology (presented in *Section III*, *G2* [39]) suggests an adapted strategic planning procedure to better address climate-neutrality goals by municipalities. And finally, the ENER-BI approach provides insights on how to integrate energy and spatial data for climate-neutrality planning in cities. All these exercises are considered diverse manners of institutional design, as part of the intent of adapting local leading institutions to a suitable planning framework able to generate robust and stable-in-time initiatives, policies, and plans. This approach ensures municipalities a more consistent coordination and implementation of the local climate agenda.

C2. Methodological framework

In the initial stage of the PhD, the methodological approach was based on Problem Based Learning (PBL) [51], where the research faced the resolution of the problem through an open-ended learning process, without a predefined solution, developing an exploratory approach toward the definition of the research background, the research gap (and research question), and a hypothetical answer, hence supporting the research design finally adopted. After even structuring an initial draft of the research background, the research flow kept the exploratory approach until the release of the first scientific publication [43]. This publication identified the research gap and research question's key elements and formulated the hypothesis, setting the ground for comprehensive and structured research in the following studies [39][44][40], which tackle the different statements of the research hypothesis. Only after a more exhaustive process of exploring the state-of-the-art in the matter and the challenge to be solved it was possible to consolidate the research framework described in section *B* (research question, hypothesis, objectives, potential results).

C2.1 Overall research techniques for data collection

As described in the research background (section *A2*), this thesis navigates both on social and technical scopes. For socio-technical research, the study *Promoting novelty, rigor, and style in energy social science: Towards codes of practice for appropriate methods and research design* from Sovacool, Axsen, and Sorrel [52] sets a taxonomy of the dominant research methods within this field. According to this taxonomy, the following research techniques for data collection have been used by the author in the PhD process:

- *Literature reviews*. This has been a key method of research all along the thesis as it provided not only the theoretical background (*peer-reviewed*), but also an experimental overview of urban-energy diverse initiatives, as reviews included implemented policies, project reports, working papers, and cities' case studies (the so-called *grey literature*).
- *Qualitative research.* This PhD thesis is predominantly based on qualitative research, using a variety of techniques to obtain information, understandings, perception of individuals and groups, local contexts, etc.
- *Case studies*. This was the approach that enabled first the formulation of the hypothesis, and secondly, the validation of the research. For the hypothesis, the research focused on the SmartEnCity project case, whilst for the validation, the case study delved into the development of the APIET 2030 of Vitoria-Gasteiz. In both case studies, the process implied an in-depth examination of the case and the associated contextual conditions, relying on multiple sources of both quantitative and qualitative evidence.
- *Data analysis*. This cannot be strictly considered a data collection technique, but it helped in the ENER-BI paper to explore, test, and compare the different variables to be introduced as requisites in a Decision Support System (DSS) for climate-neutrality planners, also affecting the DSS functionalities.

The results presented in the scientific papers of this PhD are not individual, but part of a collaborative research group, as the authorship of those papers states. Despite all studies have been coordinated by the author, the specific expertise of the contributors from this group has enabled the incorporation of an additional research technique:

- *Quantitative energy modelling*. This approach covers a variety of mechanisms, using simplified mathematical models. It consists of an abstraction of the complexities of the real case, enabling a focus on key aspects and mechanisms by a combination of empirical data and theoretical assumptions. This technique was used during the development of the APIET 2030, setting the CO_2 emissions baseline of the city as well as supporting all the collaborative planning process, from diagnosis and future scenarios' co-generation to the identification and quantification of actions within the APIET 2030. The software tool that enabled this research technique is LEAP Low Emissions Analysis Platform [53].

C2.2 Research methods in the scientific articles

The research background presented in section *A2*, mainly addressing the conceptual construction of the *climate-neutral city* term, and the integrated planning dynamics within this field, both have been based on a literature review. This review entailed documents of diverse typologies, such as scientific articles, policies, regulations, project reports, case studies of cities, and ongoing initiatives at different levels.

Regarding the 4 studies leading to their respective scientific publications, each of those made use of different methods, which are all further described in their corresponding *Materials and Methods* section [43][39][44][40]:

- Study 1. *Smart Zero Carbon City: Key Factors towards Smart Urban Decarbonisation*. The method for this study describes the stages of the SmartEnCity project, taken as a case study, which were followed by the research team to extract those *Key Factors*. Those stages include a theoretical and framework analysis, implementation of pilots in cities, monitoring and assessment of those pilots, and a validation knowledge exchange with cities and sectoral experts.

- Study 2. *Cities4ZERO: Overcoming Carbon Lock-in in Municipalities through Smart Urban Transformation Processes*. The method for this second study built upon the method developed for *Study 1*, achieving successive fine-tunned versions of the Cities4ZERO methodology through different stages of development, namely: a) *SZCC: the Concept Underlying the Methodology*; b) *Cities4ZERO Beta_0 Version: a Methodology from the Lab*; c) *Contrast of Cities4ZERO Beta_0.1 - From the Lab to the Urban Lab*; d) *Contrast of Cities4ZERO beta_0.2—From the Urban Lab to the Real World*.

- Study 3. *ENER-BI: Integrating Energy and Spatial Data for Cities' Decarbonisation Planning*. This study required a specific method to identify the main requisites and functionalities of a Decision Support System (DSS) able to effectively integrate energy and spatial variables for cities' climate-neutrality planning. This process required a thorough literature review of the European energy regulation, the climate-neutrality planning framework, and the existing urban-energy planning tools, followed by the identification of the most CO_2-emitting urban sectors and their data entailed (data analysis). All of this allowed the research team to identify DSS's requisites, structure, and contents (including algorithms and processes), leading to real-data test developments and the main requirements of user-friendliness interfaces.

- Study 4. *Towards an Integrated Approach to Urban Decarbonisation in Practice: The Case of Vitoria-Gasteiz*. This case study proceeded to the validation of the previous studies through their application in a real planning environment. Accordingly, the method applied for the development of Vitoria-Gasteiz's *Action Plan for an Integrated Energy Transition 2030* was the Cities4ZERO methodology, presented in the second publication of this PhD thesis. The application of Cities4ZERO also entailed the celebration of workshops with local stakeholders to co-develop a city diagnosis, and generate the 2030 scenarios and city vision, mainly based on the *foresight* approach [54]. Furthermore, and regarding the urban-energy model that quantitatively supported the planning process, the study relied on the requisites presented by ENER-BI publication (study 3), supported by LEAP Low Emissions Analysis Platform software, a widely-used software tool for climate change mitigation assessment developed at the Stockholm Environment Institute [53].

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PhD

D. Results & Discussion

D1. Results of the research

This section presents an overview of the main results of the PhD, all structured according to the four studies developed. The complete version of these studies is attached in Section III (*Published research*). Furthermore, a wider summary of complementary scientific contributions to this primary literature is attached in the first pages of this document, including grey literature, university lectures, conferences, events, research & innovation projects, benefited cities, and awards.

D1.1 Study 1. Smart Zero Carbon City: Key Factors Towards Smart Urban Decarbonisation

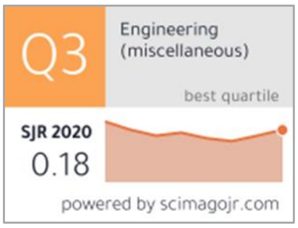
The result of this scientific article is the identification of the Key Factors that municipalities must incorporate as main levers that trigger their local processes towards climate neutrality. For that purpose, the article reflects on the climate-neutrality planning processes of the SmartEnCity project pilot cities (Vitoria-Gasteiz [ES], Tartu [EE], Sonderborg [DK], Lecce [IT], and Asenovgrad [BG]), with a specific focus on the Danish case to contextualise the results of the article. Complemented with local examples of the Sonderborg planning process, this paper presents the following Key Factors (KF):

- KF1. Effective integration of energy planning into urban planning processes
    - The strategic municipal process towards climate-neutrality in the mid-long term
    - Key local stakeholders' engagement in climate-neutrality planning processes
    - Tools for effective climate-neutrality modelling
- KF2. Climate-neutrality initiatives deployment (energy efficiency, clean supply, and raising awareness)
- KF3. Cities' collaboration; sharing knowledge & experiences through cities' networks

As described in previous sections of this PhD thesis, KF1 (*Effective integration of energy planning into urban planning processes*) is taken as the hypothetical statement that guides this research, providing potential solutions and more comprehensive answers to this KF1 along the following scientific papers.

Among the examples from the Sonderborg case that provide concretion to the Key Factors identified, the article provides further details about:

- The short and long-term strategic process towards climate neutrality started in 2007 and the public and private stable interest and cooperation over time.
- The key role of ProjectZero public-private partnership as the local leader and facilitator of climate transition in the municipality
- The pool of local stakeholders committed to the climate-neutrality process and the deployment of strategic projects aligned with their expertise and businesses.
- The engagement dynamics of those local stakeholders
- The role of urban-energy modelling in the process, supporting the co-development of the Roadmap 2025.
- An overview of Sonderborg's energy system and ambitions.
- An overview of the Sonderborg Roadmap 2025 and specific projects.
- The integration of the energy planning process into the municipal dynamics.
- The role of the Danish climate-neutrality network (Energibyerne) in sharing knowledge, experiences, common barriers, and potential solutions.



SMART ZERO CARBON CITY: KEY FACTORS TOWARDS SMART URBAN DECARBONISATION

K. Urrutia-Azcona, S. Sorensen, P. Molina-Costa, and I. Flores-Abascal, "**Smart Zero Carbon City: Key Factors Towards Smart Urban Decarbonisation**," *DYNA Ing. e Ind.*, no. Climate Change Challenges for Engineering, 2019.
https://doi.org/10.6036/9273

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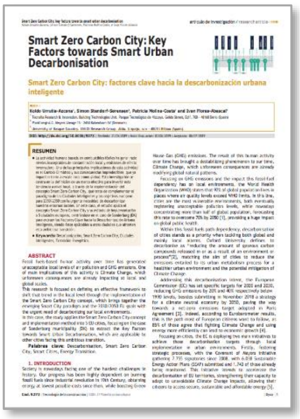
Smart Zero Carbon City: Key Factors towards Smart Urban Decarbonisation
Smart Zero Carbon City: factores clave hacia la descarbonización urbana inteligente

Received: 31 May 2019
Accepted: 26 July 2019
Published: 01 November 2019

ABSTRACT:
Fossil fuels-based human activity over time has generated unacceptable local levels of air pollution and GHG emissions. One of main implications of this activity is Climate Change, which unforeseen consequences are already impacting at local and global scales.
This research is focused on defining an effective framework to shift that trend at local level through the implementation of the Smart Zero Carbon City concept, which brings together the emerging Smart City paradigm and the 2030/2050 EU goals with the urgent need of decarbonising our local environments.
In this case, the study applies the Smart Zero Carbon City concept and implementation method into 5 EU cities, focusing on the case of Sonderborg municipality (DK) to extract the Key Factors towards Smart Urban Decarbonisation, which are applicable to other cities facing this ambitious transition.

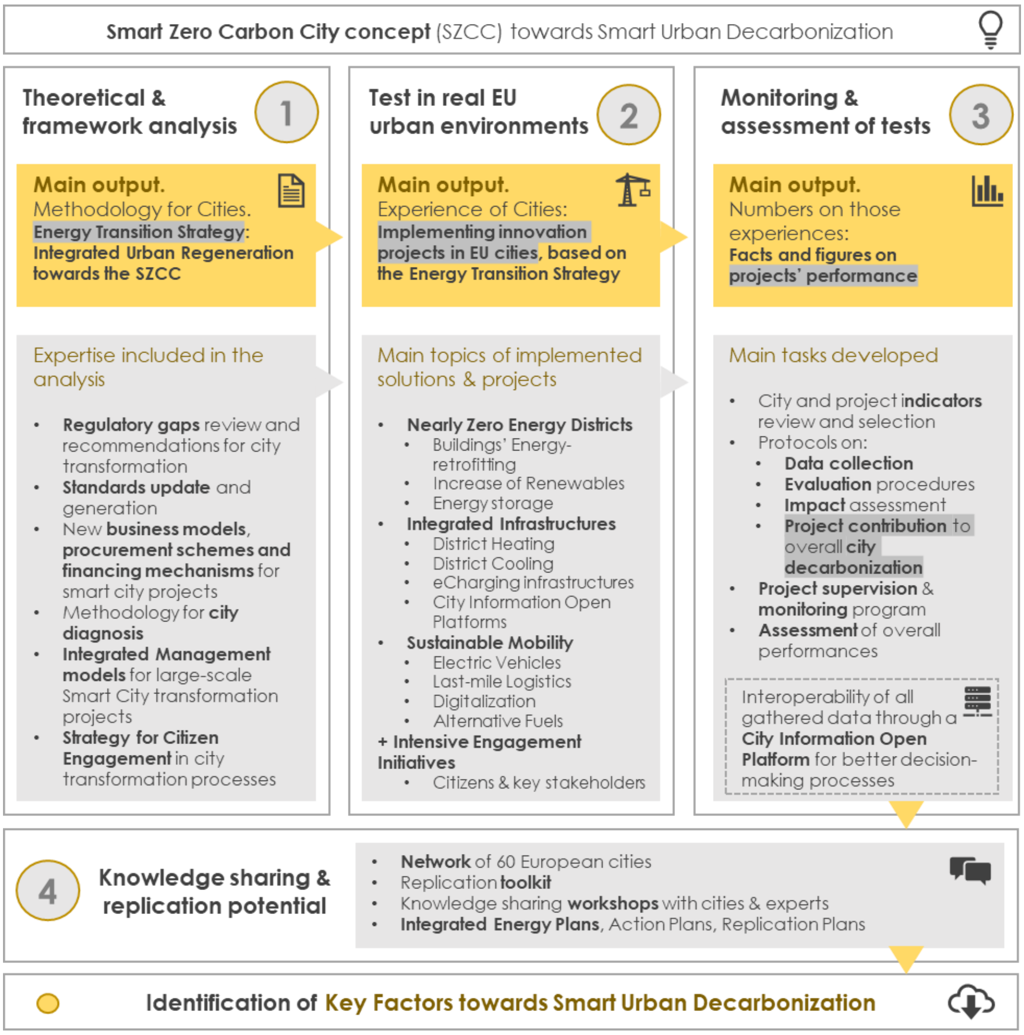

Figure 4. Methodology for Key Factors identification

D1.2 Study 2. Cities4ZERO: Overcoming Carbon Lock-in in Municipalities through Smart Urban Transformation Processes

This article presents a methodology for municipalities to structure their climate-neutrality transitioning planning processes, also supporting better integration of energy and urban planning processes. Overall, and while tackling the first element of the PhD hypothesis, this article presents the following results:

- Cities4ZERO, the urban transformation methodology for cities' climate-neutrality. This iterative methodology, consisting of 3 stages and 16 steps, is "a step-by-step methodology for a smart urban decarbonisation transition, guiding cities through the process of developing the most appropriate strategies, plans, and projects, as well as looking for the commitment of key local stakeholders for an effective transition; all from an integrated and cross-cutting planning approach".

Beyond the methodology, the article also provides complementary materials to contextualise and foster a suitable application of Cities4ZERO by municipalities:

- The value proposition Cities4ZERO offers to local authorities.
- An overview of cities where Cities4ZERO was initially tested, including their city strategies, main interventions, and CO_2 emissions reduction goals.
- Graphic material including step-by-step, stage, and overall sequential diagrams.
- Taxonomy of potential solutions to inspire project identification within Stage A.
- The City Check-up Assessment; a kick-off questionnaire that evaluates municipalities' planning situation according to Cities4ZERO's Stage A steps.

This methodology, developed in collaboration with Vitoria-Gasteiz (ES), Tartu (EE), Sonderborg (DK), Lecce (IT), and Asenovgrad (BG) municipalities, has enabled them to collaboratively develop their climate mitigation local strategies. Furthermore, and once published, it has guided diverse elements of the strategic climate-neutrality processes of cities such as Amsterdam (NL), Copenhagen (DK), Budapest (HU), Bratislava (SK), Krakow (PL), Riga (LV), Matosinhos (PT), Bilbao and Santurtzi (ES), as well as many of the SmartEnCity Network members, with currently 67 European cities on board [55].

Finally, the Cities4ZERO methodology was appointed as a "Key Innovation" by the European Commission's Innovation Radar platform, with a market maturity of "business ready" and a "market creation potential" [56].

Cities4ZERO: Overcoming Carbon Lock-In In Municipalities Through Smart Urban Transformation Processes

K. Urrutia-Azcona, M. Tatar, P. Molina-Costa, and I. Flores-Abascal, "**Cities4ZERO: Overcoming Carbon Lock-in in Municipalities through Smart Urban Transformation Processes**," *Sustainability*, vol. 12, no. 9, p. 3590, 2020. https://doi.org/10.3390/su12093590

JOURNAL: **Sustainability**
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ABSTRACT:
How can local authorities effectively address the decarbonization of urban environments in the long run? How would their interests and expertise be aligned into an integrated approach towards decarbonization? This paper delves into how strategic processes can help to integrate diverse disciplines and stakeholders when facing urban decarbonization and presents Cities4ZERO, a step-by-step methodology for local authorities, able to guide them through the process of developing the most appropriate plans and projects for an effective urban transition; all from an integrated, participatory and cross-cutting planning approach. For the development of the Cities4ZERO methodology, plans, projects, and strategic processes from five European cities that are part of the Smart Cities and Communities European Commission program have been monitored for 4 years, in close collaboration with local authorities, analysing ad-hoc local strategic approaches to determine key success factors and barriers to be considered from their transitioning experiences. The study indicates that an iterative strategic approach and a project-oriented vision, combined with a stable institutional commitment, are opening a window of opportunity for cities to achieve effective decarbonization.

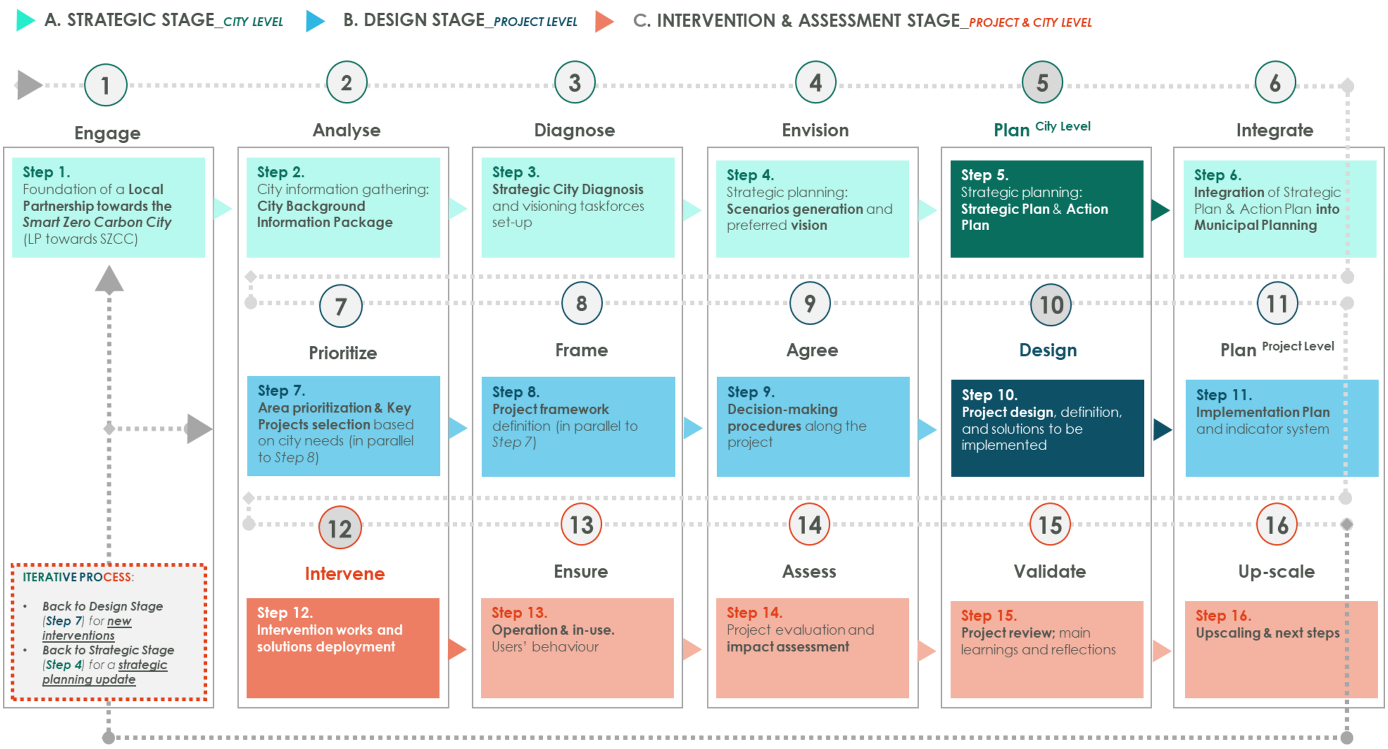

Figure 5. Cities4ZERO overview: 3 stages, 16 steps and iterative process

D1.3 Study 3. ENER-BI: Integrating Energy and Spatial Data for Cities' Decarbonisation Planning

This paper addresses the integration of the spatial dimension into the urban-energy planning process, setting the main requisites and functionalities that Decision Support Systems (DSSs) must fulfil to effectively support city managers in the overall climate-neutrality planning process.

Even if the hypothesis of the PhD was pointing at "modelling tools", the research identified a wider and more urgent gap. The way by which the urban-energy information is usually managed stands as a barrier to a suitable climate-neutrality planning process. Accordingly, climate-neutrality planers need technological support for a data-led decision-making approach, affecting the way information and data are collected, stored, integrated, aggregated, combined from diverse sources, potentially calculated, and visualised. After a thorough analysis of existing regulations, urban-energy software, and a data management test in PowerBI, the results of this article are the following:

- Identification of requisites and functionalities of a DSS able to support cities' climate-neutrality planning processes.
- Main requisites for a DSS (by data management stage):
  a. Information gathering (topic, information, disaggregation degree, format, periodicity): information by decarbonisation target (buildings, facilities, lighting, transport), and complementary information for a more integrated decision-making process by planners (i.e., socio-economic data)
  b. Information storage, depending on the format and kind of data (static, dynamic, georeferenced)
  c. Data integration, treatment, and KPIs calculations. The link between sensors' data and structural information within the 3DCity Model. Ad-hoc KPI calculation procedures, including specific steps and storage requirements.
  d. DSS outputs for decision-makers. Requisites for each energy field included in the Sustainable Energy Law 4/2019 from the Basque Country (i.e., building stock/ public lighting/ mobility).
  e. Visualisation. Intuitive, attractive, and user-friendly dashboard or software, combining 2D and 3D georeferenced information, including graphs and diagrams that enable to show and compare KPIs (aggregation of elements and temporal series) in a clear, concise, and understandable manner.

- Main functionalities for a DSS:
  - Regarding the potential reduction of CO_2 emissions and energy savings, three modules, according to the climate-neutrality planning process were identified and characterised:
    - Module 0. Inventory, characterisation, and monitoring
    - Module 1. Scenarios generation for climate-neutrality planning
    - Module 2. Climate-neutrality journey follow up

- Test with PowerBI software, including the connection to different databases; edition, and visualisation of static and dynamic data and KPIs; aggregation of elements; reception of temporal series when sources updated; all georeferenced when possible.

ENER-BI: Integrating Energy And Spatial Data For Cities' Decarbonisation Planning

K. Urrutia-Azcona, E. Usobiaga-Ferrer, P. De Agustin-Camacho, P. Molina-Costa, M. Benedito-Bordanau, and I. Flores-Abascal, "**ENER-BI: Integrating Energy and Spatial Data for Cities' Decarbonisation Planning**," *Sustainability*, vol. 13, no. 383, pp. 1–15, 2021.
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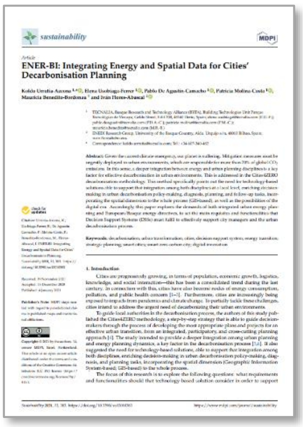

ABSTRACT:
Given the current climate emergency, our planet is suffering. Mitigation measures must be urgently deployed in urban environments, which are responsible for more than 70% of global CO2 emissions. In this sense, a deeper integration between energy and urban planning disciplines is a key factor for effective decarbonisation in urban environments. This is addressed in the Cities4ZERO decarbonisation methodology. This method specifically points out the need for technology-based solutions able to support that integration among both disciplines at a local level, enriching decision-making in urban decarbonisation policy-making, diagnosis, planning, and follow-up tasks, incorporating the spatial dimension to the whole process (GIS-based), as well as the possibilities of the digital era. Accordingly, this paper explores the demands of both integrated urban energy planning and European/Basque energy directives, to set the main requisites and functionalities that Decision Support Systems (DSSs) must fulfil to effectively support city managers and the urban decarbonisation process.

Figure 6. ENER-BI information flow: from data gathering at building and city level to a city dashboard

D1.4 Study 4. Towards an Integrated Approach to Urban Decarbonisation in Practice: The Case of Vitoria-Gasteiz

This paper analyses the application of the Cities4ZERO methodology's strategic stage and the ENER-BI principles to the development of Vitoria-Gasteiz's Action Plan for an Integrated Energy Transition 2030 (APIET 2030). This research study contributed to the validation of the previous studies through their application in a real planning environment, also working as an interesting contrast to the PhD hypothesis. These are the main results presented in the article:

- A new energy and climate action cross-cutting department in Vitoria-Gasteiz municipality, leading climate action, complying with sustainable energy regulation, coordinating cross-cutting collaboration, and managing the most relevant climate-related municipal areas (energy, environment, green infrastructure, waste management, and urban planning).
- A city background information package for local energy and climate action, including a repository of strategic documents, an urban-energy model, and a set of city indicators connected to the climate-neutrality journey.
- A working group of key local stakeholders engaged in energy and climate action strategic processes, fostering integrated planning governance principles, mainly involved in the tasks of validation of global city trends, city diagnosis, future scenarios' co-generation, city vision development, and identification and description of key projects of APIET 2030.
- The co-development of a city diagnosis on energy and climate action with local stakeholders, including the analysis and potential affection of global city trends, a qualitative sectoral SWOT analysis, and the quantitative support of the urban-energy model setting the CO_2 emissions baseline.
- The co-generation of future scenarios and a city vision for Vitoria-Gasteiz 2030. By following the foresight methodology (within Step 4 of Cities4ZERO), key local stakeholders generated 4 different 2030 scenarios that converged, through intense discussions, into the master scenario for Vitoria-Gasteiz 2030. Each scenario consisted of specific elements structured according to the most CO_2-emitting urban sectors. This process was assessed by the urban-energy model, simulating the potential impacts of stakeholders' choices. Taking the main elements of the master scenario 2030, the stakeholders formulated the city vision for Vitoria-Gasteiz 2030; both were the main drivers for the development of the APIET 2030.
- The APIET 2030, with an unprecedented level of agreement among the local community. The plan presents the city diagnosis, the master scenario, and the city vision 2030, leading to the final action plan 2030, consisting of strategic objectives (2 general; 7 specific), strategic areas (6), strategic lines (10), and key actions (40). The potential impact of each action was introduced into the urban-energy model to simulate the potential impact, enabling the possibility of readjusting the ambitions. Each action was defined according to a systematised layout, including a list of key fields. Overall, the city commits to reducing its CO_2 emissions by 61,5% and its energy consumption by 29,6% by 2030.
- The APIET 2030 integration into the municipal planning dynamics for its correct and efficient implementation in terms of:
    a. Coordination. The new energy and climate department will be the interdepartmental facilitator
    b. Strategic climate mitigation documents. The APIET 2030 is the update of SEAP 2020 (former strategy) and an intermediate milestone for Vitoria-Gasteiz climate neutrality by 2050 (former vision).

c. Commitments. APIET 2030 (climate mitigation plan) and APCCA 2030 (climate adaptation plan) work as background for the SECAP 2030, committing to comply with the Covenant of Mayors initiative.
d. Urban planning instruments. The outcomes of the APIET 2030 are included in the ongoing review of the Vitoria-Gasteiz land-use plan (PGOU). Furthermore, local regulations (*ordenanzas*) will incorporate specific modifications for a suitable APIET 2030 implementation.

TOWARDS AN INTEGRATED APPROACH TO URBAN DECARBONISATION IN PRACTICE: THE CASE OF VITORIA-GASTEIZ

K. Urrutia-Azcona, P. Molina-Costa, I. Muñoz, D. Maya-Drysdale, C. Garcia-Madruga, and I. Flores-Abascal, "**Towards an Integrated Approach to Urban Decarbonisation in Practice: The Case of Vitoria-Gasteiz**," *Sustainability*, vol. 13, no. 8836, pp. 1–20, 2021.
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ABSTRACT:
How can local authorities effectively approach the decarbonisation of urban environments? Recent efforts to redirect cities into a less energy-intensive model have been mostly approached from a sectoral perspective, with specific energy policies and plans being issued without deeply considering their ties with other urban aspects. In this sense, well-established urban planning procedures have not been part of those, with the consequence of barriers in the implementation phase of those energy plans. The Cities4ZERO methodology was developed to guide effective integration between urban planning and energy policies, plans, and practices. It provides a holistic approach to strategic municipal processes for urban decarbonisation in the mid-long term, which includes key local stakeholders' engagement into integrated energy planning processes, as well as tools for effective energy decarbonisation modelling. This paper analyses the application of the Cities4ZERO decarbonisation methodology on its strategic stage in the development of Vitoria-Gasteiz's Action Plan for an Integrated Energy Transition 2030 (APIET 2030). It suggests that in order to accelerate urban decarbonisation, it is critical to: (a) foster interdepartmental collaboration; (b) allow for flexibility on the land-use planning regulations; (c) back decisions with detailed urban-energy models; and (d) truly engage key local stakeholders in the planning and implementation processes.

Figure 7. Synthetic diagrams of the four 2030 scenarios developed by local stakeholders within APIET 2030 planning process.

D2. Discussion

Once the articles of this PhD research have been published, it is time to come back to the research question and hypothesis formulated at the beginning of the thesis and have a critical look at it (part *B1* of this document). Let's start with a brief recap.

Regarding the research question formulated, -*How can local authorities integrate energy and urban planning processes, stakeholders, and tools to effectively address the climate-neutrality goal in cities?*-, has the research provided an answer? The main contribution of this PhD thesis is a small step forward on that level of integration among disciplines towards climate neutrality. This small upgrade in the potential level of integration stands on a systemic approach to planning and managing the city, providing principles and methodology that can support a planning process characterised by complexity and uncertainty [24], such as the climate neutrality one. And even the PhD has intended to provide an overall upgrade of integration among urban and energy planning disciplines, there is a specific focus on supporting local authorities as key organisations in this urban transition. So, in overall terms, the research has provided an answer to the research question.

However, the next question is to what extent the research question has provided an answer. And for that, it is necessary to discuss each of the points considered in the hypothesis. In general terms, this thesis has its strength in the applicability of the results, with a close connection with ongoing projects, planning processes, and city administrations. Accordingly, the PhD thesis provides a quite thorough answer to the research question from the city planners' applicability point of view. However, from a more theoretical perspective, the PhD contribution is not as elaborated and funded as it is for the daily management of that integration; this PhD thesis is eminently focused on its applicability towards climate neutrality processes in cities.

Moving on to the hypothesis, it stated that climate-neutrality transition in cities would be significantly benefited from the effective integration of energy planning into urban planning dynamics. This fact was considered a key barrier when implementing climate action in cities, and three fields of action were identified as potential enablers to overcome it:

a. Strategic municipal planning processes towards climate-neutrality
b. Including the use of tools for climate-neutrality planning that integrate the geospatial variable as well as reliable and meaningful urban-energy data.
c. Engaging key local stakeholders in climate-neutrality-planning processes

In this sense, the lines below discuss to what extent the scientific studies of this research have contributed to potentially increasing that level of integration among both disciplines, always bearing in mind the local authorities' perspective.

D2.1 Strategic municipal processes: the compass towards climate-neutrality

The first hypothesis statement was claiming the importance of strategic municipal processes as integrators along the climate-neutrality journey.

Why *municipal*? The research has strengthened the idea of local authorities as the key institutions for climate neutrality, due to their unique and various capacities to boost transition at a local level. And why *strategic processes towards climate neutrality*? Because municipalities need a compass in this journey. As argued in the research, the current strategic framework provided by the Covenant of Mayors initiative presents clear deficiencies, and there is a need for methods that are flexible enough to consider both local conditions and the broader system transition [7].

Cities4ZERO; a suitable framework…

Intending to provide a compass for those strategic municipal processes, this PhD research developed the Cities4ZERO methodology. The Stage A of this method has been partially or completely applied in 14 cities by the author [Vitoria-Gasteiz (ES), Tartu (EE), Sonderborg (DK), Lecce (IT), Asenovgrad (BG), Amsterdam (NL), Copenhagen (DK), Budapest (HU), Bratislava (SK), Krakow (PL), Riga (LV), Matosinhos (PT), Bilbao, and Santurtzi (ES)], allowing to collect some feedback and reflections. First, Cities4ZERO has proven to be a practical facilitator for local climate-neutrality planning, being understandable and applicable by the stakeholders. Furthermore, as studies 2 (Cities4ZERO methodology [39]) and 4 (application to Vitoria-Gasteiz case [40]) present, Cities4ZERO helps to achieve better urban and energy planning integration; mainly through 1) stakeholder engagement; 2) among city systems and within planning structures; and 3) with other government scales. For example, the Vitoria-Gasteiz case shows that Cities4ZERO works as a flexible approach to local processes. The way in which the diverse ongoing sectoral strategies were coordinated to be integrated and accommodated to each other in terms of contents and time is a good example of such an integration planning upgrade. This allowed not just the integration of energy and urban planning disciplines, the core topic of this PhD research, but also the incorporation of mobility, urban regeneration, building renovation, and water management sectors. If minds are open to integrating once, they will probably be open to do the same with other sectors as well. This is also a clear example of *Institutional Transformation*, as argued in the *Theoretical Framework* section.

…but there is still room for improvement

However, the wide and quick spread of Cities4ZERO methodology to multiple cases has opened some room for necessary further development as well as identifying some gaps. In the cities of Bilbao and Riga, the framework provided to conform the coordination group able to lead the local transition (Step 1 within Stage A of Cities4ZERO) was insufficient, bearing in mind the complexity of such a governance model. The description of Step 1 was too generic and didn't provide clear guidance, hence further specifications were needed, mainly in terms of key groups engagement, climate-related data accessibility, and overall integration flow at a local level.

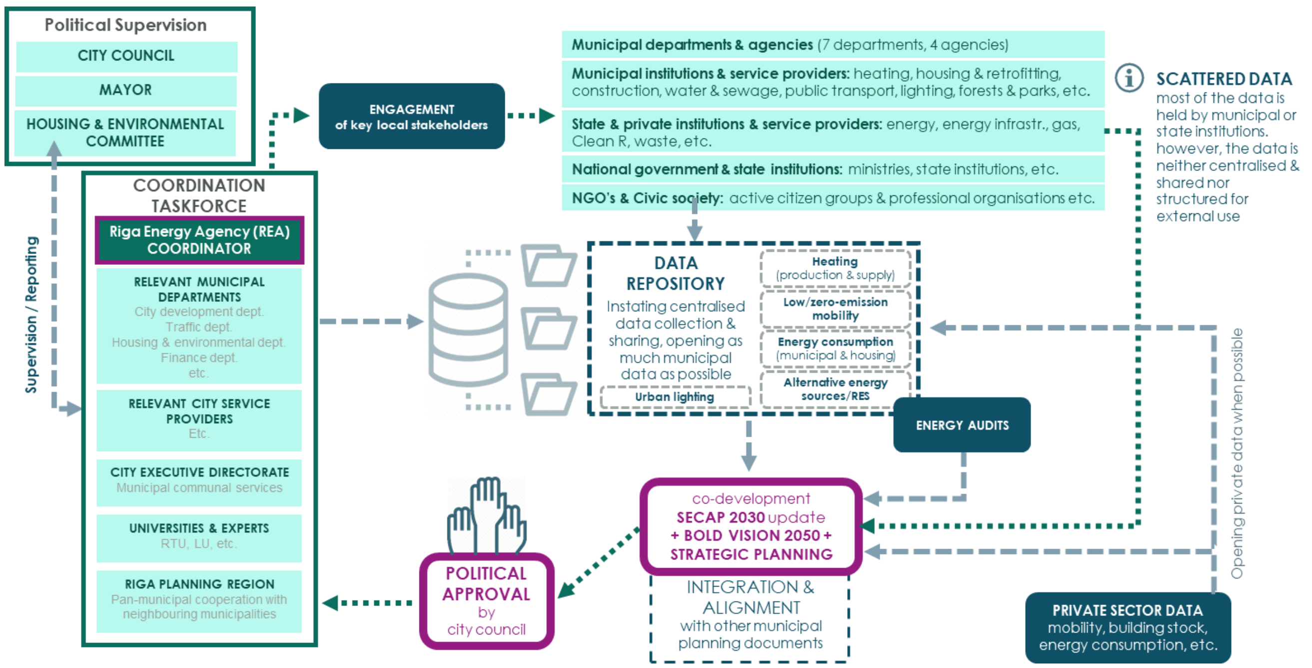

Figure 8. Riga's governance structure to coordinate local climate-neutrality planning (developed by the author)

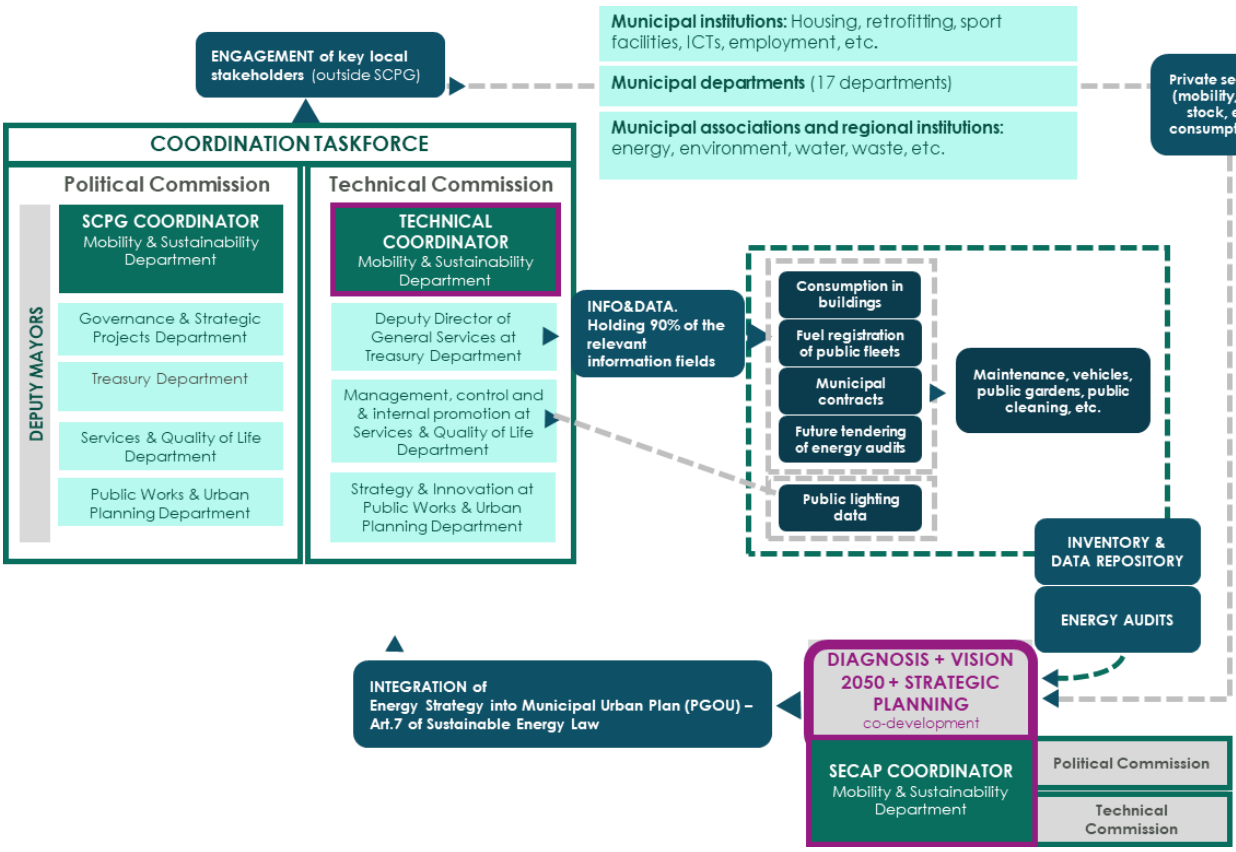

Figure 9. Bilbao's governance structure to coordinate local climate-neutrality planning (developed by the author)

Connected also to these governance structures, diverse models of coordination leading groups can be set. For example, in some cases, this group can be anchored within the municipality (most cases), whereas in others, it can be hosted in a separated third-party organisation, though in close partnership with the municipality (Sonderborg, Leuven 2030), or even in a third-party organisation that works as a member-based network (Deep Demonstration in Madrid). This increases the complexity of including all under the same methodology, but for sure different models will adapt better to different local contexts, hence characteristics, capabilities, and skills of those groups will have to be different to effectively set the transition process up. As stated by Hodson et al [57], there is often a significant gap between climate neutrality visions and the materialisation of those in projects and infrastructures, and it is there where the role of *urban intermediary governance* can strengthen and complement municipalities' capacities and competencies.

An additional concern of the current methodology is the difficulty of finding the right balance between engagement activities and the quantitative support of the urban energy models in those activities. To what extent the excess of quantitative data can make the engagement activities too complicated for overall stakeholders to contribute? But what happens if numbers are so superficial that those stakeholders don't have enough information to contribute meaningfully? This discussion is formulated here in very simplistic terms, but it is a balance extremely difficult to keep as the practice has revealed. Data must be well communicated, processed, and understood by the audience, and then kept as background for meaningful contributions. What it's clear is that Cities4ZERO and the foresight approach provide a very suitable process for a qualitative discussion, finding difficulties in effectively incorporating quantitative data into the communication flow within the engagement activities, in terms of meaningfully contributing that kind of data to the debate and the collaborative decision-making process.

In the case of Amsterdam and Copenhagen, they both had released their climate strategies when the work with them started, and Cities4ZERO was seen more as an interesting tool to contrast their recent planning processes, identifying potential gaps to be filled out. In these cases, it doesn't feel right to break up the pace already taken, but more to complement where possible the existing path.

Overall, even if Cities4ZERO has been proven as a useful and supporting methodology for transitioning cities, the wide range of topics addressed and the complexity and multiple connections of each of those topics make necessary a further evolution of the framework to provide an even more comprehensive toolkit for cities. A combined evolution of Cities4ZERO and a clearer and more comprehensive cities' climate-neutrality framework, as requested in the introduction of this section, seems an interesting future path of research.

Integration of strategic requirements into the land-use planning cascade

Focusing on one of the key steps of Cities4ZERO (Step 6. INTEGRATE), there are additional concerns in the strategic planning process. One of those affects the core of this PhD research, which is the integration of the climate-neutrality plan outcomes, such as the ones of the APIET 2030, into the land-use planning cascade. The great importance of such integration is stated by an energy manager in the city of Bilbao, who conditions the feasibility of any strategic action to the existing urban planning regulation: "*urban planning limitations have great weight when analysing and defining the areas in which to intervene. The prepared GIS maps and hotspots for each strategy must be taken into account as a first indication*" (personal communication).

There is a hierarchy and sequential conception of planning instruments, from the EU Territorial Agenda 2030 (not legally binding) to the municipal masterplans, detailing the land use of the territory and the city, both in graphic and text-regulatory terms. However, strategic plans, such as APIET 2030 do not belong to that operative and regulatory urban planning cascade. Is this a barrier when implementing APIET 2030 key actions? For some climate-neutrality initiatives, it seems clear the need to delve into that operative level (land ownership, rights and obligations, municipal regulation, land-use incompatibilities, etc.) if they are meant to be implemented. The multiple potential affections to land-use rights and incompatibilities compromise the process unless there is a deep reflection on the operative urban planning dimension. Furthermore, which kind of document shall reflect that integration? City masterplans seem very stable in legal terms, but they may not be agile enough for such a purpose, while urban agendas may lack the operational aspect. Probably, the local context of each city, bound to its national and regional regulations, will determine the best solution for each case; what seems clear is that these potential barriers must be addressed, and urban planning stakeholders must be engaged.

In the case of the APIET 2030, the involvement of the urban planning department was scarce, mainly due to the extremely slow updating process of the city masterplan, which takes several years of rigid bureaucracy, making the integration of APIET 2030 outputs in such a document a significant challenge. However, there was a specific and significant action within APIET 2030 called "*Analysis and adaptation of regulatory and urban planning instruments*", pushing the municipality to promote the necessary changes for the effective deployment of APIET 2030 actions. Furthermore, another action intends the modification of taxation to benefit decarbonisation actions in the fields of renewable energy, energy-efficient renovation, green mobility, and high-efficiency equipment acquisition, a fact that shows that regulation can also be an enabler for climate transition. Overall, a determined political will and technical dedication are both needed for local regulation not to block the transition but to transform it into an ally.

D2.2 Local stakeholders are the core of any city transition

The second hypothesis statement pointed to the engagement of local stakeholders to improve energy and urban planning integration within climate-neutrality processes. This statement seemed obvious at the start of the PhD research process, but after this research, the author has a much deeper understanding of all nuances this engagement entails for the climate-neutrality goal.

In this sense, municipalities must focus on proper engagement activities for creating a sense of joint ownership of the whole transition process. This exactly addresses the weaknesses that have been identified in numerous SEAPs and SECAPs [58], hence a core concern of Cities4ZERO development. In the case of Tartu municipality, they stated that the fact of creating a community of similarly motivated stakeholders in this transition was the main value of the planning process. This level of engagement demands a lot of effort and communication and may prolong the planning process. But at the same time, it creates an emotionally and intellectually invested group of stakeholders. It will eventually give a planning document the stakeholder support it needs to succeed.

In APIET 2030 development, key local stakeholders have been at the core of the planning process since the beginning, contributing to the diagnosis, envisioning, and action planning phases. This fact has been, for sure, a significant effort for the management team, which sometimes can be perceived as a toll on an agile planning process. However, in the eyes of APIET 2030 planners, this intensive engagement has reinforced the quality of the final output, and it has improved the alignment with other departmental strategies and other local public-private initiatives. Furthermore, it seems reasonable to think that the potential barriers at the implementation stage may be reduced due to this early engagement, and probably more synergies will be found at that stage due to the exchange of views during the planning process. In APIET 2030 case, a more intensive engagement of the local industry and some economic sectors would have been preferable (i.e., Mercedes, Michelin); hence the management team must reflect on how to present attractive processes for such stakeholders to participate. Local authorities must design participatory processes where every relevant local stakeholder finds an interest, branding their participation and climate action efforts as support to the local community development.

This scarce involvement of the private sector in the case of APIET 2030 can be considered a limitation of the Cities4ZERO methodology. However, when applying the methodology to the case of Sonderborg's climate-neutrality Roadmap 2025 [59], the private sector took a key role in the process. Anyhow, this is an aspect to take care of; otherwise, the final plan will find difficulties in the implementation phase as well as in becoming transversal among the local community.

D2.3 A bit more than just urban-energy modelling

The third and final hypothesis statement suggested the use of tools for urban-energy modelling in this transition, and indeed it's been proved to be one of the main ways of integrating both disciplines in practice. However, that integration must happen also during the data management process, so the pure modelling activity is first appropriately data-fed, and then well connected to the decision-making chain.

The role of urban-energy models in climate-neutrality planning

Looking at current cities' climate-neutrality planning processes, there is scientific consensus on the crucial importance of urban-energy models and their quantitative support to set goals and define actions. However, one should not lose sight of the main purpose of the urban-energy model, i.e., the prospective analysis. The defined urban-energy model does not aim to translate already decided actions or objectives, although it can be used for that end, but to generate different alternative pathways that may support the definition of these measures and targets. In this sense, APIET 2030 can be considered as a forecasting approach, where urban-energy modelled scenarios were used to analyse the potential impact of diverse actions in the city, hence setting CO_2 reduction targets; it is an explorative vision in line with the city's potential. In the coming years, when following up on APIET 2030 and generating the updated scenarios in the future, the method could link forecasting and backcasting (just objectives are defined; not actions) approaches. The urban-energy model should be used to feed the discussion and support the decision-making, rather than to justify already defined strategies, forming so-called socio-technical scenarios [60]. In the same line of inconsistency, there is no point in refreshing the base year of the model from year to year without generating updated scenarios to refine the mid/long-term visions, as that approach implies updates neither on actions nor on targets. Regarding that follow-up process, urban-energy modelling should be combined with assessment methodologies to evaluate results based on diverse criteria.

Furthermore, looking for future updates, it would be interesting to link Vitoria-Gasteiz modelling to what the rest of the Basque region and Spain are planning, which also has significant effects on the energy balance and carbon outcomes of the city and vice versa [61]; the city is likely not going to be a disconnected energy island in the future. This way, the energy and spatial integration would be extended to the territory, which makes sense for a comprehensive perspective of the energy system, while incorporating potential synergies of combined uses of renewable energy and rural activities, or within the emissions offsetting field, for example.

ENER-BI principles, step-by-step

One of the main takeaways of this PhD research is that before and beyond the pure urban-energy modelling activity, there is a huge challenge in the way data must be gathered, stored, treated, aggregated, calculated, and visualised, so the urban-energy model can appropriately fulfil its purpose and this whole package can consistently support and accompany the decision-making process towards climate-neutrality.

As broadly discussed within the ENER-BI scientific publication, the update of all necessary data can be a challenge for most municipalities, still a significant problem even in the planning phase, where the effort to provide enough detailed information to the urban-energy model is an issue. In addition, the depth of the analysis must determine some characteristics of the data to be gathered and the urban-energy model structure. The level of detail will not be the same if planners just want some rough numbers to orientate their decisions, or if they really want to check the exact potential impact of each proposed action; in this sense, both data and model characteristics must be considered.

In the case of Vitoria-Gasteiz, the ENER-BI data management principles faced the reality where most municipalities are currently standing in this field. For the data gathering process, the amount and quality of data were sufficient (except for the private mobility sector), but hard to retrieve, from different sources and stakeholders, standing far from being an automatism. The data was always static and stored in Excel files, still pending the incorporation of dynamic information into the process. Furthermore, information was neither automatically updated nor aggregated. However, two ENER-BI principles were included in the process, disrupting previous planning processes. First is the incorporation of geospatial data, hence welcoming the spatial variable in the energy analysis. Secondly, the visualisation and management of data into a dashboard, which objectively allowed an enhanced decision-making process. Even if still many things can be improved, those two principles made the difference for energy and urban planning integration within the APIET 2030 development, breaking the habit of siloed approaches based on non-georeferenced data. In this sense, Vitoria-Gasteiz is starting to better bridge the gap between project-oriented tools, such as a standard energy model, and what it was the traditional urban planning paradigm, based on non-georeferenced and static information. Finally, and this is something that didn't happen in APIET 2030, it would have been great to include an extra GIS layer in the dashboard, including the analysis of the current urban planning regulation, showing the potential limitations for APIET 2030 actions implementation.

This field of research has still a long path, but APIET 2030 development has helped Vitoria-Gasteiz to take a step forward. Probably the coming iterative planning cycles will keep upgrading these processes if the municipality keeps pushing this way. A brilliant way to start doing so would consist of applying ENER-BI principles in the APIET 2030 implementation and follow-up stages. This is what we call in the ENER-BI article the "*Module 2 – decarbonisation follow-up*", supporting the follow-up by enabling a quantitative review of climate actions, incorporating KPIs that address each decarbonisation target, showing the evolution of those KPIs over time, proposing corrective mechanisms, and updating data repositories and GHG emissions automatically.

D2.4 The broader context: a suitable context for disruptive climate action

Now looking at a broader context of this research, the global situation has changed dramatically during the 4-year development period of this PhD, also affecting the climate-neutrality context. The *Theoretical Framework* section argued that the occurrence of "extraordinary events" were required to overcome the existing socio-technical carbon lock-in presented by Unruh [49]. According to him, two potential sources can influence escaping carbon lock-in: technological and social/institutional. By mid-2022, we can argue that the current period has both; the convergence between the clean-tech overtake hand-in-hand with EU pushing commitments, and the latest "extraordinary events" that led to a deep socio-institutional reconsideration (2020-2022), they all have opened a window of opportunity for escaping carbon lock-in within the EU. At least it's the biggest window seen so far.

By 2018, the use of renewable energy was already accounting for stable growth while GHG emissions were being reduced, and numbers suggested that probably the European Union's 20/20/20 climate targets were to be achieved. By the end of 2019, the COVID19 outbreak came into our lives and it affected GHG emissions as well; if those were reduced by 4% in 2019, that number escalated up to 10% during 2020. Even if this figure entails projection uncertainties due to the exceptional health, social, and economic situation during the pandemic, the EU-27 GHG emissions were 31% lower compared to the 1990s, widely overcoming the 20% reduction target [62]. Accordingly, in 2021 it seemed reasonable to increase the ambition of 2030 emissions reduction targets from 40% (set in 2014) to 55% (within the "fit for 55" climate package), a figure captured in the European Climate Law [63].

The last episode of this incremental ambition has been forced by the unfortunate geopolitical situation resulting from Russia's invasion of Ukrainian territory. In 2021, the EU imported 27% of its oil, 43% of gas, and 46% of coal needs from Russia at a cost of 99 billion €. Even these shares have significantly dropped since 2011 when imports from Russia represented a 77% of the total EU energy needs (148 billion €/yr.), the EU intends to drastically reduce its Russian energy dependency to stop financing the ongoing war. Through the REPowerEU plan, the aim is to reduce gas imports by 155 billion cubic meters (bcm) by the end of 2022 and be completely independent of Russian fossil fuels by the end of the decade [64]. In this context, diversifying supplies is key, but there is also a clear opportunity to invest in reducing energy demand and producing green energy within the EU territory.

Result of diverse reasons, unprecedented ambitions and decisions are generating an appropriate context for climate-neutrality plans and the necessary disruption entailed to it. This is what Frank Geels calls "a window of opportunity" to readjust the socio-technical regime around the carbon lock-in [48]. However, taking advantage of this window implies a socio-technical challenge; the greater the change, the greater the resistance. According to Unruh, policymakers prefer *continuity* approaches to avoid that resistance when facing transitions. However, the distinction between *continuity* and *discontinuity* (or disruption) doesn't have to be rigid, but sometimes it can be both and just a matter of scale. Let's say that renewables can be part of a *continuity* approach by connecting them to existing electricity distribution grids, but they are also key in the overarching *discontinuity* strategy that aims to replace fossil fuels or centralised generation systems with renewable distributed generation systems. A similar case can be argued by replacing fossil-fuelled cars with electric vehicles, fostering *discontinuity* in power but a certain degree of *continuity* in vehicles' manufacturers and infrastructures. If policymakers want to leverage this window of opportunity, they will have to balance whether the resistance generated by the *discontinuity* shifts can hinder policy action. These examples can be also applied to climate-neutrality policies and ambitions in cities and nations, including the actions to be implemented for this purpose and the delicate balance to be kept in this race. Cases like the "yellow jackets" in France (since 2018), the logistics strikes in Spain (2022), the raising prices of energy for citizens and companies resulting from the Ukrainian war, or the manoeuvres of energy companies to pay back their investments. Even internally at a local level, within municipal structures, this tension shows up when an institutional transformation is needed for this shift, or when local jobs are compromised by this transition. There is a lot to navigate in this journey, and significant resistances are still to be overcome to leverage this "window".

D2.5 A comprehensive and common understanding of climate-neutral cities' journey

In parallel to this evolving context, it is crucial to bring further clarity and standardisation to the climate-neutral city concept and the context in which cities manage their journey towards this goal. There is a great number of cities that are setting ambitious plans and goals towards climate neutrality [21], and they need more systematic support to generate the right ecosystem to face this transition.

First, there is a need for harmonisation and guidance on common assessment methods [7]. The lack of consistency in the way cities account their emissions is evident, existing multiple frameworks, in some cases even self-made by municipalities. Furthermore, the lack of consistency in GHG emissions' scopes makes it very difficult to compare ambitions and facts among cities. Some framework elements must be robust and consistent for all cities. And secondly, the role of offsetting the emissions. To what extent cities can outsource them? Through which channels and through which not? How far in geographic terms? Which is the limit to be outsourced?

Overall, a systematisation of everything that surrounds the climate-neutrality city journey and final goal will be a great practical asset for cities and significant support for the legitimacy of the process and the cause. Furthermore, by providing a more solid and rigorous common framework for all cities, the potential temptation of some politicians to use climate transition as a greenwashing element will be limited.

PhD

E. Bibliography

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SECTION II

Concluding remarks

F. Conclusions

G. Future lines of research

Citation:

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F. Conclusions

This PhD thesis is focused on the effective integration of energy planning and urban planning dynamics to facilitate the transition of cities towards climate neutrality. Within this topic, and after 4 research studies, the contribution of this PhD thesis to the existing state of the art is an enhanced framework for local authorities in the way those can integrate both disciplines in practice when planning their climate-neutrality transition, tackling the identified lack of such integration in current planning processes. In this sense, it must be emphasised the importance of a systems thinking approach in this climate transition, where all urban systems are highly interconnected, and where the energy system of a city is highly transversal and a key one in this transition; it cannot be approached as an isolated system as it affects various urban systems as well as the whole urban planning practice.

However, this general achievement is constructed by small scientific steps within diverse topics that enable such integration. First, in methodological terms and as requested by scientific literature [32, 50, 54], the Cities4ZERO methodology provides a step-by-step framework for integrated strategic municipal processes towards climate neutrality. Secondly, based on climate transition planning needs, ENER-BI principles describe the main requisites and functionalities that a Decision Support System must fulfil to effectively integrate energy and spatial data, detailing how data must be gathered, stored, treated, aggregated, calculated, and visualised to support a data-led decision-making process. In this sense, it is important to stress the decisive introduction of georeferenced data into urban-energy planning procedures, and the step forward this means for municipalities' daily tasks. Finally, all this theoretical construct is applied to the extent a real planning case allows, consolidating Cities4ZERO as a suitable framework for transitioning cities, while showing the existing gap between theory and practice when contrasting ENER-BI principles. All this is seasoned by an intensive local stakeholders' engagement in the planning process, which stands as a demanding but smart investment for the potential success of the implementation of a climate-neutrality plan.

Connecting with the theoretical construct of this PhD thesis, each of these four studies has local authorities as the main target, intending to provide comprehensive support to facilitate the *institutional transformation* formulated by E.R Alexander, which is necessary to adapt structures in this transition towards climate neutrality. The reorientation in strategic, engagement, and data-modelling terms that occurred in Vitoria-Gasteiz and other cities shows an enhanced and more integrated capacity to collaboratively formulate achievable and ambitious plans and goals, effectively facing the uncertainty and complexity of contemporary planning demands.

Furthermore, the *integration* approach among urban and energy planning disciplines taken in this PhD thesis has been *socio-technical*, indeed dedicating a higher workload to *soft* aspects than to purely technical elements, reinforcing the idea of Frank W. Geels's *socio-technical transitions*. In this sense, climate neutrality's most significant both enablers and blockers are on that *soft* side, and it is there where the most substantial effort must be done. Only through this pathway cities will find the *window of opportunity* to *escape the carbon lock-in* in which they are all trapped.

Finally, and based on the *Discussion* section, an analysis of this whole PhD research brings the following concluding remarks.

Cities need support in this transition

There is currently a suitable context for disruptive climate action, which cities will not be able to leverage without specific technical, financial, legal, and political support. By listing the potential fields of support, it is evident that only if this transition is understood as socio-technical, cities will have the opportunity to succeed and overcome resistance. A clear field of support for cities consists of offering strategic guidance on municipal processes towards climate neutrality, where strategic methodological approaches that address the socio-technical nature of this transition have been proved useful facilitators, as is the case of Cities4ZERO. Furthermore, cities need clarity on the *climate-neutral city* concept and a systematisation of all that surrounds it, making the transition journey trackable, assessable, comparable, and hence reliable.

Planning considerations for an effective transition

Regarding climate-neutrality planning processes in cities, a few considerations can be emphasised. First, the uncertainty and changing complexity of this transition makes it hard to be tackled with a static method. Accordingly, those methods must be under constant evolution and contrast with real planning cases, as the Vitoria-Gasteiz case has shown. Secondly, and reflecting more on the operational perspective, climate-neutrality planning in cities needs both the agility of action plans (i.e., APIET 2030) and the competencies and legal stability of municipal urban plans. The integration and balance between those must be found for each specific local case, but their mutual coordination is key for this transition to happen. Also, regarding those competencies and legal constraints of urban plans and municipal structures, a determined political will and technical dedication are both needed for local regulation not to block the transition but to transform it into an ally.

Furthermore, and again thinking on the operational side, urban planning limitations have great weight when analysing and defining the areas in which to intervene. Accordingly, GIS maps and hotspots for each strategy must be born in mind as a first indication. For instance, including a GIS layer with the analysis of current urban planning regulations and limitations can be a great asset for early stages decisions.

And finally, as a concluding planning consideration, it would be appropriate to extend the energy and spatial planning integration to the territorial scale, which makes sense for a comprehensive perspective of the energy system, while incorporating potential synergies of combined uses of renewable energy and rural activities, or within the emissions offsetting field.

Local engagement as a facilitator

Within the whole climate transition process, municipalities must focus on well-designed engagement activities for creating a sense of joint ownership towards the final goal. This demands a lot of effort and communication may prolong the planning process, but it cultivates an invested group of local stakeholders, who will eventually provide the support the planning document needs to succeed. In this sense, the private sector can be a valid example, as this group won't always be involved in the process by inertia. This is an aspect to take care of; otherwise, the plan will find difficulties in the implementation phase as well as in becoming transversal among the local community.

Urban-energy data and modelling considerations for climate-neutrality planning

One of the first conclusions the author got when delving into the topic was that the integration of energy and urban georeferenced data must happen also during the data management process, so the pure modelling activity is first appropriately data-fed, and then well connected to the decision-making chain. The integration goes far beyond the modelling task. Accordingly, before and beyond the pure urban-energy modelling activity, there are very specific requirements on how climate-neutrality data must be gathered, stored, treated, aggregated, calculated, and visualised, as presented in the ENER-BI paper. Only by fulfilling those requirements, the urban-energy model can appropriately fulfil its purpose and this whole package can consistently support and accompany the decision-making process towards climate neutrality. Complementary to this package, the urban-energy modelling task can be also combined with assessment methodologies during follow-up stages to evaluate results based on specific criteria.

Regarding the choice of the right urban-energy modelling approach, data and model characteristics must be considered. For instance, the level of detail will not be the same if planners just want some rough numbers to orientate their decisions, or if they really want to check the exact potential impact of each proposed action.

Besides its characteristics, an appropriate choice of the urban-energy model aim is crucial. In this sense, the aim of the model shouldn't be to translate already decided actions or objectives, although it can be used for that end, but to generate different alternative pathways that may support the definition of these measures and targets. The urban-energy model should be used to feed the discussion and support the decision-making, rather than to justify already defined strategies, forming so-called socio-technical scenarios.

After collaborative work with various municipalities, most of them are still not ready to plan through a reliable, comprehensive, and automatised data set. However, as a first significant step, the incorporation of georeferenced data into the analysis and an appropriate visualisation for decision makers can make a difference in the level of integration of energy and urban planning disciplines.

Overall, this PhD has been an exciting journey that ends up formulating a lot of questions, as the next section shows, but just providing some answers. Let's hope future studies can shed some light on those open threads.

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G. Future Lines of Research

This PhD dissertation has delved into a specific issue, the integration between energy and urban planning processes, embedded in a much broader paradigm, which is the climate-neutrality transition in cities. In terms of future lines of research, this wide scope has favoured the opportunity to identify a variety of interesting paths, some of them already advanced in the previous sections.

About the climate-neutrality journey

First, and very much needed, science must provide further clarity on the *climate-neutral city* concept, as there are blurry elements to be defined if it intends to provide robust guidance in this transition.

- Is it still to be proposed as a concept strictly associated with the municipality boundaries? It seems more reasonable to focus on the specific characteristics of the city and its surrounding territory, and then apply climate-neutrality planning over that spatial aggregation, which fits better with the reality of cities' urban metabolism. For example, the current framework makes incomparable two neighbouring cities, with similar morphological and population characteristics, but very different city boundary structures and territorial sizes (Pamplona - 25,24km^2 vs. Vitoria-Gasteiz - 276,81km^2). With 10 times more unurbanized land than Pamplona, the CO_2 reduction accounting possibilities of Vitoria-Gasteiz through the introduction of renewables and carbon sinks are different, even if in reality they could both be implementing similar actions at a metropolitan level.

- How is the climate-neutral city concept going to be integrated with *the climate change adaptation* concept in cities? The current integration approach by the Covenant of Mayors is just limited to compiling both strategies under the same document (SECAPs). This is the first step, but this integration among both main action fields against climate change could be integrated into one overall single approach.

- How to integrate circularity within climate neutrality? Most cities are now focused on Scopes 1 and 2 of the GHG emissions protocol, but climate action pioneer cities such as Copenhagen are starting to plan the next steps (Scope 3). Accordingly, it is necessary to properly clarify the boundaries and scopes of circularity within that Scope 3 of climate neutrality. In this sense, a further description of all three *scopes* would provide consistency to the process.

- Cities would benefit from a systematisation of all that surrounds the climate-neutral city concept. This systematisation can be mainly focused on carbon accounting and assessment methods; this will help to make transition journeys trackable, assessable, comparable, and hence reliable.

About Cities4ZERO methodology

The application of the Cities4ZERO methodology to multiple cases after its publication has allowed the research team to identify further paths of development, which could generate an eventual updated Cities4ZERO 2.0 version:

- As stated in the Discussion section, cities need a taxonomy and more precise indications on possible governance models that can structure the local coordination groups towards climate neutrality. This means, independently of being a group within the municipality or a third-party organisation, information on how to ensure a suitable decision-making process, a high level of local engagement, good access and management of climate-related information, or the kind of expertise and competencies this coordination group needs.

- Once projects are identified within an action plan, a prioritisation framework based on CO_2 reduction criteria is needed, which must be aligned with the urban-energy model potential impacts of each action.

- The incorporation of digital tools to diverse steps of the methodology can provide a clear added value to the processes entailed, intending to automatise and speed up those. This digital upgrade can entail from specific tools for a specific purpose (i.e., a digital repository of information and data for Step 2) up to a digital twin for public authorities that provides overall support to the whole process.

- The integration need goes beyond climate neutrality, and Cities4ZERO methodological approach can be adapted to integrate the planning phase of other city systems with urban planning, such as mobility, waste and water management, green infrastructures, or building renovation.

- The Cities4ZERO methodology has been identified by a European group of experts in democratic renewables' deployment (Ad2WIND consortium), standing as the basis to develop an *Advanced democratic methodology for citizen participation and modelled-assessed wind power co-existence* (no reference as it has not been published yet). The innovative energy planning co-developed methodology, which intends to tackle the growing *not in my backyard* phenomenon against renewables, will be co-developed by municipalities, end-users, project developers, and researchers, including the use of combined GIS (spatial) and energy system models to embed data-led democracy in renewables' deployment planning processes.

About urban-energy modelling and ENER-BI principles

Regarding the ENER-BI principles identified in the third study of this research, a clear further line of study is to develop a Local Digital Twin for public authorities that integrates all functionalities of *Modules 0* (inventory, characterisation, and monitoring)*, 1* (KPIs calculation and scenarios' generation) and *2* (follow up) [44]. This would allow municipalities to perform accurate daily management, develop data-led strategies, simulate potential alternatives, and evaluate cities' performance in diverse fields. This means gathering all ENER-BI functionalities in that digital twin, mainly through:

- Assembling physical and technical infrastructure with urban planning tasks.
- Integrating spatial and non-spatial data (different layers; combined indicators)
- Exploiting open data principles, combining ground sources (i.e., sensors, open data repositories) with space data (i.e., Copernicus services)
- Combining virtual models with dynamic data through algorithms and simulation techniques.

Regarding urban-energy modelling, there is ongoing research to better support the 2030/ 2050 envisioning engagement processes with quantitative urban-energy modelled scenarios. There is a thin line between being too technical or too superficial regarding quantification in those engaging workshops, and this is a crucial part of a climate-neutrality plan. In this sense, a software tool or methodological procedure able to effectively incorporate data into the communication flow within the engagement activities would benefit the engagement process, as participants would understand better the context, and hence their contributions would probably be more meaningful. Overall, the urban-energy model should be a real supporter of collaborative decision-making.

Furthermore, it would be interesting to link urban-energy models to the regional and national scales, as cities are not isolated energy islands. This, besides providing a better planning overview, would match very well with the different scopes of the GHG emissions protocol, providing good insights on what happens inside or outside the city boundaries, and which would be the best resources and connections to be exploited as well as the territorial synergies to be leveraged.

Additionally, and already mentioned, it is crucial to start further research on how to incorporate circularity within Scope 3 of the GHG emissions protocol; in urban-energy modelling terms too. How to include emissions from activities that occur outside the city boundary as a result of activities taking place within the city boundary it is a challenge. Those activities entail supply chains beyond energy generation, such as food, water, building materials, clothing, products, etc. In this sense, LCA approaches, and extended input/output tables will be explored.

Finally, further research is needed to retrieve reliable data from those climate-neutrality planning sectors where data is not easily accessible (i.e., private mobility consumption and emissions, beyond estimations).

For sure, the author and Tecnalia's Urban Transformation Lab intend to explore some of these paths, which will hopefully provide a better framework for climate transition in cities, and a small in-time contribution to cope with the climate emergency we are facing as humanity.

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SECTION III.

Published Research

H. Smart Zero Carbon City: Key Factors towards Smart Urban Decarbonisation

I. Cities4ZERO: Overcoming Carbon Lock-in in Municipalities through Smart Urban Transformation Processes

J. ENER-BI: Integrating Energy and Spatial Data for Cities' Decarbonisation Planning

K. Towards an Integrated Approach to Urban Decarbonisation in Practice: The Case of Vitoria-Gasteiz

This section compiles the 4 research studies of the PhD.
Enjoy reading!

Citation:

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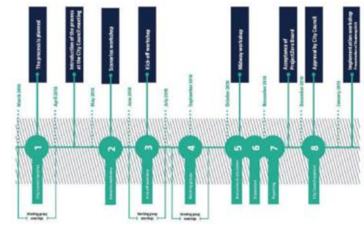
Published Research

K. Urrutia Azcona, S. Stendorf Sorensen, P. Molina Costa, and I. Flores Abascal, “Smart Zero Carbon City: Key Factors towards Smart Urban Decarbonisation,” *DYNA Ing. E Ind.*, vol. 94, no. 1, pp. 676–683, 2019.

Smart Zero Carbon City: Key Factors towards Smart Urban Decarbonisation



Smart Zero Carbon City: factores clave hacia la descarbonización urbana inteligente

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RESUMEN

- La actividad humana basada en combustibles fósiles ha gene- rado niveles inaceptables de contaminación local y emisiones de efecto invernadero. Una de las principales implicaciones de esta actividad es el Cambio Climático y sus consecuencias impredecibles, que ya impactan tanto a escala local como global. Esta investigación se centra en la definición de un marco efectivo para invertir esta tendencia a nivel local, a través de la implementación del concepto Smart Zero Carbon City, que trata de complementar el paradigma de las Ciudades Inteligentes y los objetivos europeos para 2030/2050 con la urgente necesidad de descarbonizar nuestros entornos locales. En este caso, el estudio aplica el concepto Smart Zero Carbon City y su método de implementación a 5 ciudades europeas, centrándose en el caso de Sonderborg (DK) para extraer los Factores Clave hacia la Descarbonización Urbana Inteligente, siendo éstos aplicables a otras ciudades que afronten esta ambiciosa transición.
- **Keywords:** Decarbonización, Smart Zero Carbon City, Ciudades Inteligentes, Transición Energética.

ABSTRACT

Fossil fuels-based human activity over time has generated unacceptable local levels of air pollution and GHG emissions. One of main implications of this activity is Climate Change, which unforeseen consequences are already impacting at local and global scales.

This research is focused on defining an effective framework to shift that trend in the local level through the implementation of the Smart Zero Carbon City concept, which brings together the emerging Smart City paradigm and the 2030/2050 EU goals with the urgent need of decarbonizing our local environments.

In this case, the study applies the Smart Zero Carbon City concept and implementation method into 5 EU cities, focusing on the case of Sonderborg municipality (DK) to extract the Key Factors towards Smart Urban Decarbonisation, which are applicable to other cities facing this ambitious transition.

Palabras clave: Descarbonisation, Smart Zero Carbon City, Smart Cities, Energy Transition.

1. INTRODUCTION

Society is nowadays facing one of the hardest challenges in history. Our progress has been highly dependent on burning fossil fuels since industrial revolution in 19th Century, obtaining energy at lowest possible costs since then, while boosting Green House Gas (GHG) emissions. The result of this human activity over time has brought a destabilizing phenomenon to our time, Climate Change, which unforeseen consequences are already modifying global natural patterns.

Focusing on GHG emissions and the impact this fossil-fuel dependency has on local environments, the World Health Organization (WHO) states that 92% of global population lives in places where air quality levels exceed WHO limits. In this line, cities are the most vulnerable environments, both eventually registering unacceptable pollution levels, while nowadays concentrating more than half of global population, forecasting this rate to overcome 70% by 2050 [1], provoking a huge impact on global public health.

Within this fossil fuels path dependency, decarbonisation of cities stands as a priority when tackling both global and mainly local alarms. Oxford University defines to decarbonise as "reducing the amount of gaseous carbon compounds released in or as a result of an environment or process"[2], matching the aim of cities to reduce the emissions entailed to its urban metabolism process for a healthier urban environment and the potential mitigation of Climate Change.

Addressing this decarbonisation intent, the European Commission (EC) has set specific targets for 2020 and 2030, reducing GHG emissions by 20% and 40% respectively below 1990 levels, besides submitting in November 2018 a strategy for a climate neutral economy by 2050, paving the way towards a net-zero emissions target adopted in Paris Agreement [3]. Indeed, according to Eurobarometer results, this is the path most of European citizens want to follow, as 85% of those agree that fighting Climate Change and using energy more efficiently can lead to economic growth [4].

Focusing on cities, the EC is deploying two main initiatives to achieve those decarbonisation targets through local implementation in urban environments. Firstly, fostering strategic processes, with the Covenant of Mayors initiative gathering 7.755 signatories since 2008, with 6.038 Sustainable Energy Action Plans (SEAP) submitted and 1.743 of those already being monitored. This initiative intends to accelerate the decarbonisation of EU territories, strengthening their capacity to adapt to unavoidable Climate Change impacts, allowing their citizens to access secure, sustainable and affordable energy [5].

In 2016, the initiative evolved to demand cities Sustainable Energy and Climate Action Plans (SECAP), based on a Baseline Emission Inventory and a Climate Risk & Vulnerability Assessment, as well as a report on progress every two years, committing cities to support GHG reduction EU targets by 2030.

Secondly, fostering real implementation in cities, the EC launched in 2012 the European Innovation Partnership on Smart Cities and Communities (EIP-SCC), a platform intending to engage cities, industries, SMEs, investors and researchers, bringing them all together to design and deliver smart-sustainable solutions and projects

This EIP-SCC initiative is supported by H2020 innovation programme and the Strategic Energy Technology Plan (SET Plan) [6], aligning all forces towards EU decarbonisation targets and the economic growth of the region.

In this context, the alignment among cities' decarbonisation and Smart City solutions implementation needs an overarching concept stating a vision and its goals, framing all plans and interventions this ambitious urban transition requires. In this line, theoretical and experimental research on SmartEnCity – Towards Smart Zero CO_2 across Europe (EIP-SCC project) has allowed to develop the Smart Zero Carbon City concept,

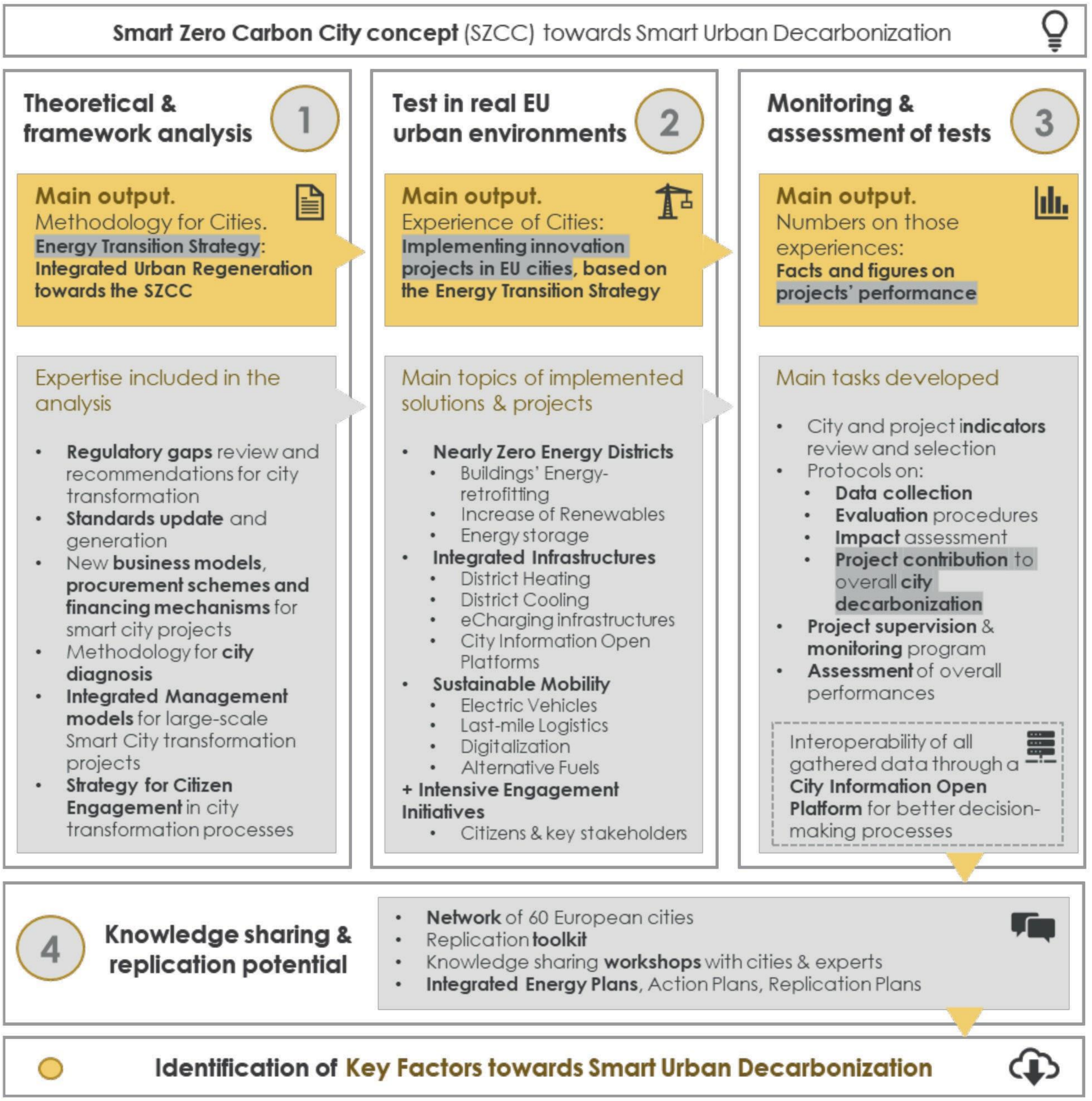

Fig. 1: Methodology for Key Factors identification (source: developed by the authors).

still missing on urban planning paradigm, setting a vision able to guide cities towards the smart urban decarbonisation:

"A Smart Zero Carbon City (SZCC) is a resource-efficient urban environment where carbon footprint is eliminated; energy demand is kept to a minimum through the use of demand control technologies that save energy and promote raised awareness; energy supply is entirely renewable and clean; and resources are intelligently managed by aware and efficient citizens, as well as both public and private stakeholders"[7] (p.2).

The concept is targeting main decarbonisation elements connected to cities' energy systems: energy demand, energy supply, and energy management; all from a participatory and technology-supported perspective. Here, energy elements are at the core, as almost total GHG emissions generated in urban environments come from activities entailed to cities' energy systems.

From this overarching concept, the problem is focused on how to deploy the SZCC; how this concept is effectively implemented in our cities? Intending to answer this question, SmartEnCity project is chosen as case-study, where the authors of this contribution and partners of the project explore planning, implementation, monitoring and replication works to identify the Key Factors towards Smart Urban Decarbonisation (SZCC concept), reviewing a still ongoing process of 3 years of coordinated initiatives in the cities of Vitoria-Gasteiz (ES), Tartu (EE), Sonderborg (DK), Lecce (IT) and Asenovgrad (BG). In this line, the methodological section of this contribution delves on how the analysis has been performed to extract those Key Factors towards Smart Urban Decarbonisation. Next, the Results section presents those Key Factors, examining Sonderborg initiatives as a real implementation case. Finally, the last section discusses further implications those Key Factors may have in this ambitious urban transition as well as potential research lines in the topic.

2. MATERIALS AND METHODS

SmartEnCity project has developed a program of coordinated actions to extract Key Factors towards Smart Urban Decarbonisation of cities. All these actions are happening within the boundaries of the existing city, therefore aligning the Smart Zero Carbon City concept with the Integrated Urban Regeneration one, which focuses on the built environment [8].

The Key Factors for Smart Urban Decarbonisation have been developed through desk research, real implementation and performance measurements, to be finally contrasted by the interaction with the cities, which are the final target group. Those Key Factors are presented in next section; Results.

2.1. THEORETICAL & FRAMEWORK ANALYSIS

Firstly, the analysis delves on a thorough review of Integrated Urban Planning processes in last decades, exploring the different urban systems and how those interact with each other, also addressing their scales of action -city/ district/ building-, the tools to be used in each planning stage, and the monitoring requirements to assess the final performance of interventions. The main urban systems analysed in this review apart from planning have been; energy, mobility, retrofitting, ICTs, and governance, as main sectors of interest in Smart Cities & Communities EC programme.

With this review as a background, the framework analysis has been supported by complementary analyses on key elements for urban transformation processes, such as: regulation and standards; business models, procurement schemes and financing mechanisms; a city diagnosis methodology; an integrated management model; and a Citizen Engagement strategy. All these inputs, as well as the Integrated Planning review are incorporated in a step-by-step methodology for Urban Transformation: the Urban Transformation Strategy for City Decarbonisation; a journey towards the Smart Zero Carbon City.

2.2. TESTS IN REAL EU URBAN ENVIRONMENTS – REAL IMPLEMENTATION

Once the Urban Transformation Strategy for City Decarbonisation is defined, it is time to turn plans into real projects, when strategies at city scale evolve into specific interventions at district scale. Grounded on the theoretical & framework analysis and the Urban Transformation Strategy for City Decarbonisation, interventions in real EU urban environments are planned and implemented in the cities of Vitoria-Gasteiz, Tartu, Sonderborg, Lecce and Asenovgrad, mainly at district or even building scale.

These interventions are focused on three main fields: Nearly Zero Energy Districts, Integrated Infrastructures and Sustainable Mobility; all of them facilitated by intensive Citizen & Stakeholders' Engagement activities. As a result, this study has been able to gather valuable implementation experiences, facing diverse EU urban contexts.

2.3. MONITORING AND ASSESSMENT

Aligned with the implementation in real urban environments, protocols on data collection, evaluation and impact assessment are designed, as well as a set of Key Performance Indicators (KPIs) both at project and city levels. This way, through monitoring and supervision of interventions at district scale, the project team has been able to obtain clear facts and figures on project's performance, identifying what works within this process and to what extent. Accordingly, these KPIs allow to measure the specific contribution of each intervention to the overall city decarbonisation target.

Furthermore, the interoperability of gathered data is structured through a City Information Open Platform, which enables access and exchange to diverse groups of stakeholders, besides public administration managers.

2.4. KNOWLEDGE SHARING & REPLICATION POTENTIAL – CONTRAST WITH CITIES

Finally, all the inputs gathered up to this point -2.1; 2.2; 2.3- are bundled into a replication toolkit, contrasting this knowledge within cities' networks, through knowledge-sharing workshops with cities and experts. Those interested cities attending the workshops are introduced to the materials included in the replication toolkit, where they identify which materials are of their interest depending on their local context. Furthermore, they can also check to what extent their current performance is effectively enabling a suitable city transition towards a Smart Urban Decarbonisation. Here, a comparative analysis on how cities are fulfilling their decarbonisation goals based on their monitoring results can foster a healthy competitiveness among transitioning cities [9].

In the section Results, Sonderborg planning (2.1), implementation (2.2), assessment (2.3) and national networking (2.4) case is taken as a reference to exemplify the identified Key Factors towards Smart Urban Decarbonisation

3. RESULTS

Sonderborg is one of SmartEnCity pilot cases, where the Urban Transformation Strategy for City Decarbonisation -in this case including an Integrated Energy Plan (IEP) [10]- was developed based on the SZCC framework. The project also deployed interventions in building retrofitting, mobility, and energy sectors, with high engagement standards, finally monitoring the performance of all those interventions. After this process was completed in Sonderborg, feedback allowed to refine the framework before being used again and further tested by Tartu, Vitoria-Gasteiz, Lecce and Asenovgrad.

The specific approach followed in Sonderborg was to develop an IEP process (Figure 2) where a pool of local stakeholders would commit to developing strategic projects, all aligned with the final goal of achieving the Smart Zero Carbon Sonderborg by 2029, based on sustainable growth and fostering green jobs creation as side-result. Through calculated scenarios, each of those strategic projects was introduced into the energy modelling software (section 3.1.3), quantifying the amount of CO2 emissions reduction and its overall contribution to the final decarbonisation target of the city.

The process was conducted and coordinated by a municipal and local-private structure. Based on this case and approach, the Key Factors (KF) towards Smart Urban Decarbonisation are presented below.

3.1. KF1. EFFECTIVE INTEGRATION OF ENERGY PLANNING INTO URBAN PLANNING PROCESSES

In the Sonderborg case, the IEP process was prepared and organized to fit into a much broader municipal process of updating the municipal plan for Sonderborg, which is developed every second year. In Sonderborg, the municipal plan is the formal steering document for politicians and municipal employees, and therefore there was a natural fit for the outcome of the IEP process – both in terms of diagnosing Sonderborg's energy system and envisioning realistic plans towards decarbonizing the energy system – to work as knowledge inputs for administration and politicians, becoming more integrated in the general urban planning process. The lack of this kind of integration has been identified as a key barrier to overcome when implementing concrete energy-related initiatives in municipalities.

The effective integration of energy planning into urban planning processes is mainly based on strategic municipal processes at municipal level (3.1.1), the engagement of key local stakeholders (3.1.2) and the integration of energy modeling tools into decision-making (3.1.3).

3.1.1. KF1.1. Strategic municipal processes towards Smart Urban Decarbonisation in the mid-long term

The Conference of COP24 Parties "reiterates its invitation to Parties to communicate, by 2020, mid-century, long-term low greenhouse gas emission development strategies in accordance (…) of the Paris Agreement" - COP24 [12]

Sonderborg intends to be a role model towards smart decarbonisation for small and mid-sized cities. The municipality started the journey in 2007 and its commitment towards decarbonisation has been growing since then, reducing CO2 emissions by 35% and energy consumption by 14%. Next steps are steered by Sonderborg's Roadmap 2025, when the city intends to attain a 75% carbon reduction, a key milestone before becoming carbon neutral in 2029 [11].

Since 2007, this strategic process has kept both public and private interest and cooperation over time, providing stability to the process in the long term. As an example, the co-development of Roadmap2025 has gathered more than 100 local stakeholders working in the proposals, inspiring business and citizens, spreading the feeling of belonging to a sustainable community, which works all together towards a common meaningful goal.

In this kind of long-term strategic processes, the creation of a local energy planning authority inside the municipality can provide the required support, being able to steer these processes and cross-work with other public departments and private stakeholders. In the case of Sonderborg, this strategic process was launched through a public-private partnership -ProjectZero-, even overcoming the public sector and spreading its roots in industry and academia. This inclusive partnership has been key in the acceptance and involvement of the local community in this initiative.

3.1.2. KF1.2. Key local stakeholders' engagement into Integrated Energy Planning processes

"*The new strategic discourse needs to emphasize the process than the content, the actors more than the structures separating of the planning and operational elements of the process*" – P. M. Williams [13].

The organization and servicing of stakeholders has been the single highest priority in Sonderborg's IEP process. This is based on the simple believe that, since stakeholders are the ones who are going to develop the initiatives, they need to be engaged from the beginning to achieve a successful implementation.

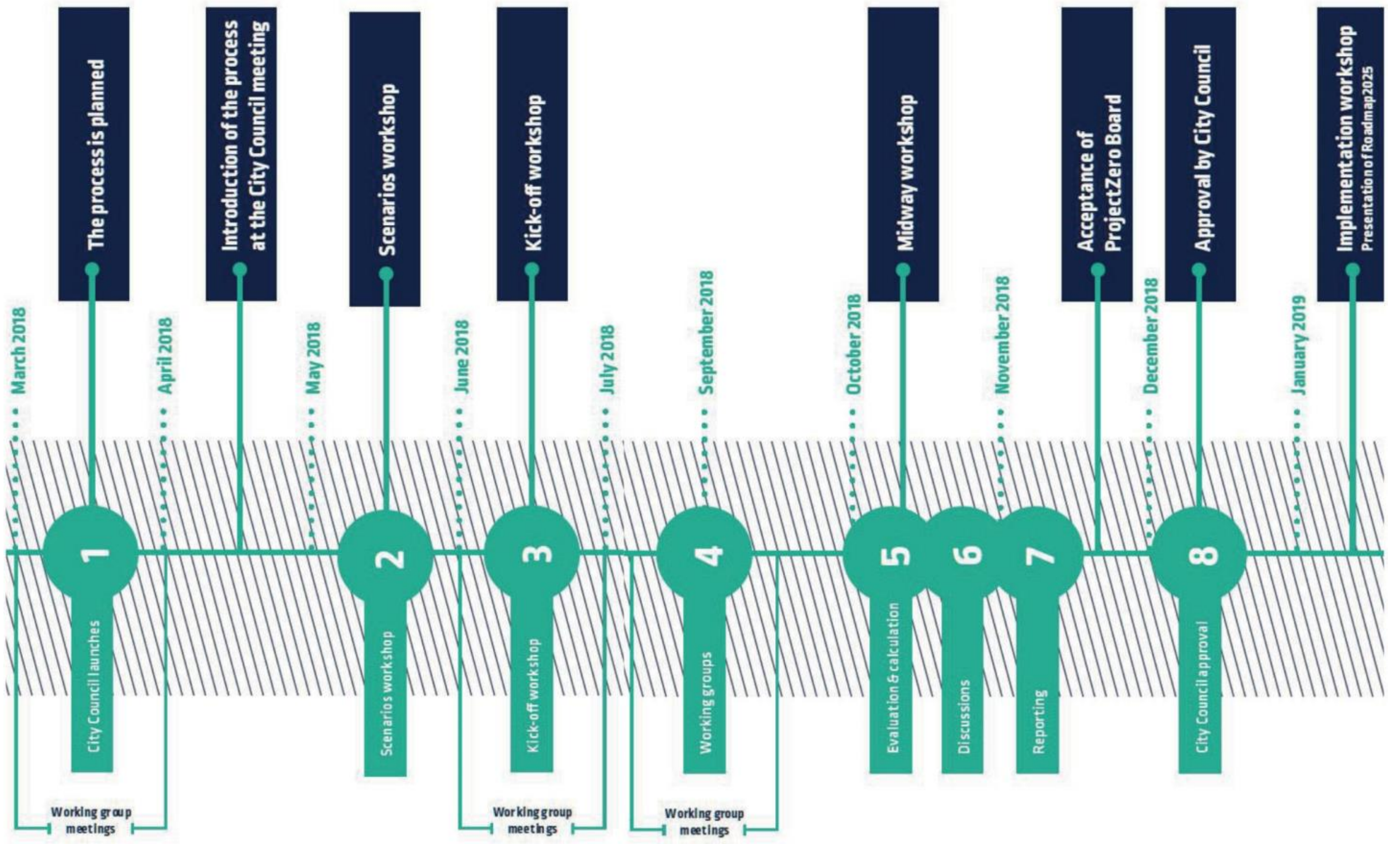

Figure 2: Sonderborg's Roadmap 2025 time-line as part of their Energy Transition Strategy for City Decabornisation and IEP Process [1]

Expertise from local stakeholders supports that the most cost-effective and understandable initiatives for them are brought forward, where only realistic and valuable actions are considered, reinforcing the implementation process.

During the IEP process in Sonderborg, local stakeholders were divided in 8 groups based on Sonderborg's primary focus areas in terms of CO2-reductions (Energy system, Agriculture, Housing associations, Private rentals, Owner-occupied housing, Passenger transport, Businesses and Heavy transport).

Each group had a work group leader (external stakeholder) and a secretary (internal stakeholder), and they had freedom to plan the most suitable working process for them, with the only requirement to be aligned with the IEP principles. The final project proposals were assessed by a steering group with involvement from the Energy system group to ensure the systemic approach.

Grouping stakeholders allowed them to apply their focus in the area each stakeholder had most commitment and expertise about. This also enhanced that the project proposals where developed efficiently and based on the available knowledge. In this line, some key stakeholders with decision-making authority were identified in Sonderborg, and were given special roles, acknowledging that changes in specific elements of Sonderborg's energy system have a larger impact (e.g. district heating production or fuel consumption in large industries/ sub-group for large industries having individual meetings with the steering group). The higher the impact, the more attention on steering their initiatives.

3.1.3. FC1.3. Tools for effective energy decarbonisation modelling

"*Tools can contribute to a broader scope, more comprehensive assessments, and better legitimacy of the energy planning*" – J. Ivner [14].

A clear picture of the local energy system is key to understand and plan a feasible path to follow towards decarbonisation, enabling the generation of alternative energy scenarios for the future. In Sonderborg case, two overall tools (energyPLAN [15], based on Aalborg University Smart Energy System model -Figure 3- and Energy Balance [16] -Figure 5-) have been used to calculate and visualise the current status of Sonderborg's energy system (Figure 4), as well as to forecast the potential effects from the projects proposed by the 8 stakeholder groups.

Using these modelling tools, Sonderborg's energy system was quantified at three different stages in the IEP process: the trend (2029 without new projects) – the midway (2029 with various types of projects) – and the ambitious (2029 with all projects finalized). Both tools provided the background knowledge for the work of all 8 groups, identifying which project proposals were most interesting for Sonderborg's decarbonisation target. In this regard, both tools were able to quantify the potential impact on overall CO2 emissions reduction of each project.

Furthermore, monitoring is considered key to maintain stakeholder motivation in Sonderborg during next years. A monitoring system has been therefore established, to enable progress follow-up for each of 8 stakeholder groups. The monitoring system is set up from an Excel-based Energy Balance Tool (which can be downloaded at SmartEnCity website [16]), where the energy flow is calculated according to guidelines established by the Danish Energy Agency.

The Energy Balance tool is further divided into subgroups, so the 8 activity groups can follow the development of each activity over time according to Figure 5.

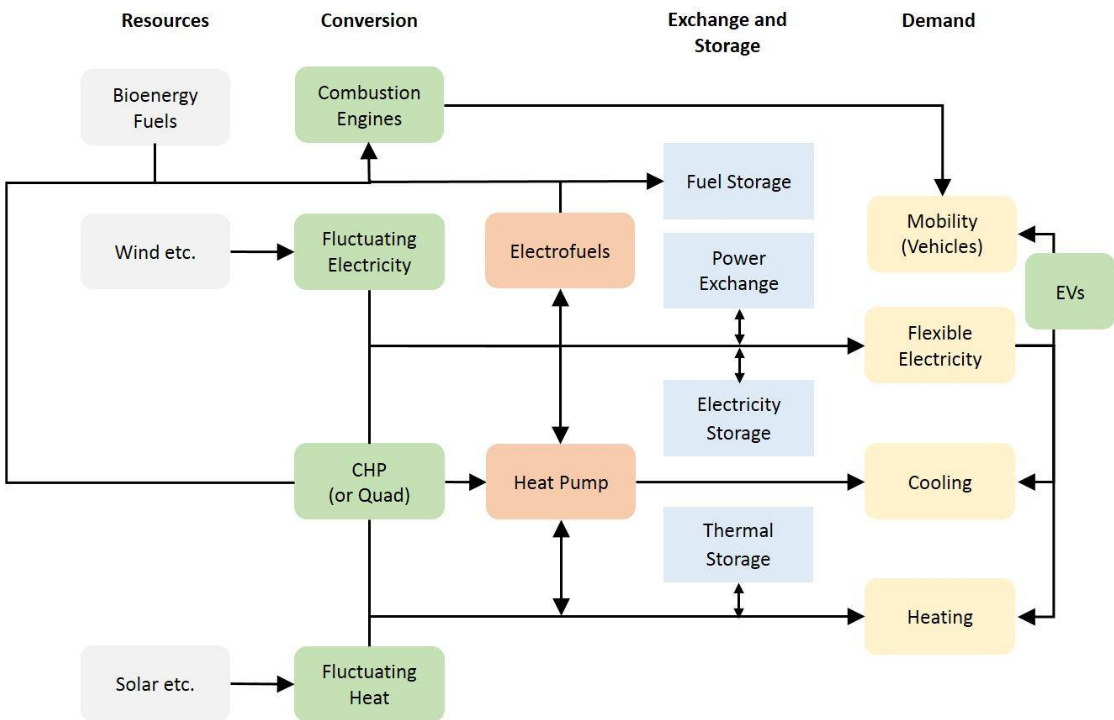

Figure 3: Smart Energy System model developed by Aalborg University [15]

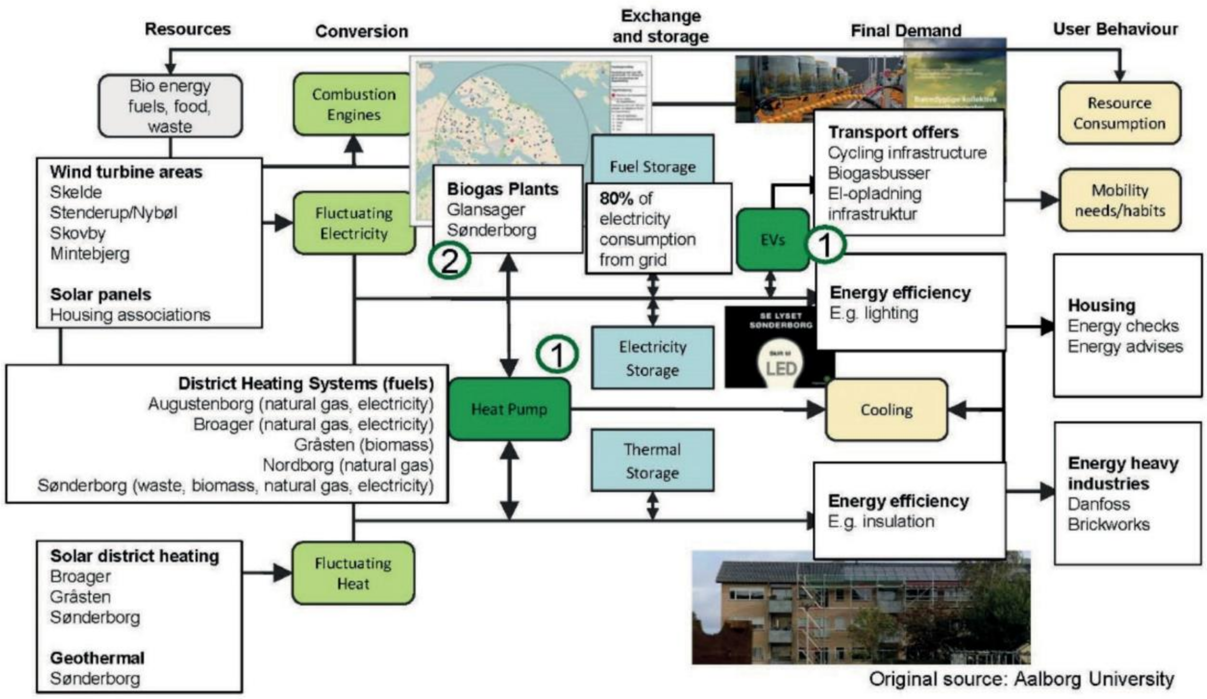

Figure 4: Smart Energy System model with local Sonderborg context used in Sonderborg's IEP process (PlanEnergi and Aalborg University in [11])

3.2. KF2. ENERGY EFFICIENCY, CLEAN SUPPLY AND RAISED AWARENESS INITIATIVES DEPLOYMENT

"It is important to propose initiatives without delay and in line with the Joint Declaration of the three institutions on the European Union (…), to allow for a swift energy transition on the ground. (…) the focus now turns to implementation" – European Commission [17].

The implementation of SZCC targeted initiatives is key to achieve Smart Urban Decarbonisation. In Sonderborg's IEP process (Figure 2), 56 project proposals were developed by local stakeholders, which were then processed and concentrated into 40 final project proposals, finding the agreement to include those in Sonderborg 2025 Roadmap.

Stakeholder Group	Main theme	Project Proposal	Project Description
Housing Association	Energy Efficiency	Advanced energy data collection	Real time energy data collection and digital heat control in Housing Associations buildings is implemented to enable quick response to energy waste by damage or improper use of installations. The project will generate documentation on energy retrofitting and management, making benefits visible for residents and Housing Associations, allowing residents to compare their energy consumption with the average in their block.
Agriculture	Energy Efficiency	Packaged solutions in ventilation systems	Aim to accelerate substitution of old ventilation systems in the farming industry with new more efficient ventilation systems through an approach where old ventilation systems are identified, and partners are grouped to offer more attractive packaged solutions.
Owner-Occupied House	Clean Supply	Oil and gas in district heating areas	The project aims to phase out individual oil and gas burners for heat supply within district heating areas in Sonderborg, connecting these buildings to the district heating system. Today there are approximately 400 oil burners and 3,700 gas burners located in areas where district heating is available. The Sonderborg area's district heating plant has phased out fossil fuels over the last few years, and the district heating supply is now based on sorted waste, biomass, large heat pumps, solar heat, and geothermal power.
Owner-Occupied House	Clean Supply	Oil and gas outside district heating areas	The goal is that all oil burners and 50% of gas burners outside district heating areas will be converted to heat pumps, while the remaining gas burners will use local biogas in 2029. The Sonderborg area has approximately 5,200 owner-occupied homes outside the district heating areas, besides the 2,500 summer houses on the east coast of Als and in Rendbjerg. Of all these, 1,850 have oil burners, 3,300 natural gas and an unknown number have biomass heating or electric heating.
Passenger Transport	Clean supply Awareness	Electric cars and plug-in hybrids	The project aims to increase the share of electrical cars and plug-in hybrids in Sonderborg by expanding public charging infrastructure and offering special privileges such as unlimited parking and free transport with the local ferry. This development is supported through active communication and behavioural efforts, dialogue with citizens and annual e-car events. In order to visualize technological developments and the increasing number of electric car models, green car events will be arranged where citizens can assess the offers, talk with local car dealers and test drive electric cars.
Heavy Transport	Clean Supply	Infrastructure and alternative fuels	In this project, local businesses with heavy transport needs are grouped and supported in a process for co-funding and investing in adequate strategically located infrastructure in Sonderborg, to make new fuels a realistic alternative to diesel.
Agriculture	Clean Supply	Test area - green tractors	The project aims to offer a group of local farmers the possibility to test tractor technologies that use biogas or electricity as fuel instead of diesel
Energy	Clean Supply	Photovoltaic field plants	A total of 100 MW installed photovoltaics by 2025 is the goal of this project. Local stakeholders, businesses and the municipality's proactive planning have ensured the rapid realisation of the project. At the same time, Sonderborg Municipality is in the process of drawing up a municipal plan, designating areas to be used for large solar cell
Energy	Clean Supply	Biogas plants in western Sonderborg and Glansager	Two large biogas plants will be built before 2025. The plants will process manure from local agriculture and produce up to 45 million m3 of biogas per year. The biogas is being upgraded to natural gas quality (biomethane) and is fed into the natural gas network. In the longer term, biogas should be further upgraded with hydrogen, allowing more flexible power consumption and enabling to double total production of biomethane at the plants.
Owner-Occupied House	Awareness	Customer journey	Sonderborg has already applied a customer journey approach to strengthen renovation efforts, in close collaboration among the municipality, financial institutions and craftsmen. Local stakeholders have developed ideas to strengthen the process: The municipal department will strengthen communication about the need to take energy and climate into account when considering either retrofitting a building or demolishing and rebuilding it. Communication is reinforced by targeted inspirational leaflets. • The primary schools’ green curriculum will develop a practice track, enabling students to apply their energy and climate skills at home and in their community. • All Sonderborg area banks and real estate agents take energy and climate into consideration, giving advice and paying special attention to the right timing of their customers’ housing market transactions, or roof/ heating replacements • EUC Syd will target new training programmes for the area's construction and installation companies. The nearly 80 companies that have previouslyeducated themselves as energy consultants form the basis for training, focusing on the strengthened efficiency and business potential through all the steps of the customer journey. • ProjectZero will develop badges/stickers for home-owners who have made a special effort.

Table 1: Examples of stakeholder developed projects from Sonderborg IEP process [11]

Each of those project proposals addresses either energy efficiency, clean supply or raised awareness – SZCC framework–, when not several of those themes at the same time. 10 of those 40 project proposals are briefly presented in Table 1.

3.3. KF3. CITIES' COLLABORATION; KNOWLEDGE & EXPERIENCES SHARING THORUGH CITIES' NETWORKS

"*Transnational city-networks are mobilizing cities in the global fight against climate change (…). City-networks help build capacity to measure, report, verify emissions reductions.*" – D. J. Gordon and C. A. Johnson [18].

The creation of a national Danish network of cities has been proven of great value when all members share the aim of achieving the Smart Urban Decarbonisation as top priority in their political agenda (Energibyerne, [19]). This network was created by an initiative from the SmartEnCity Network, offering various advantages for the cities involved such as inspiration from cities in a similar transitioning context, discussion of common barriers and solutions, common seminars on solutions (splitting expenses), common voice for addressing other actors (e.g. government or businesses), etc.

Feedback from Danish network cities states that network activities help to accelerate their process towards the Smart Zero Carbon City. In the Danish network, the cities agreed to set up a common stand at the yearly Danish conference "Folkemødet" for Danish people, politicians and businesses, where Energibyerne addresses their common agenda and tries to reach fruitful relations and agreements for their common Smart Urban Decarbonisation goal. This collaborative approach is also scaled up to the European level through the SmartEnCity Network, offering a learning and contrasting potential which would not be possible through an individualistic approach.

section intend to provide an alternative path to the way municipalities usually cope with those challenges, where different degrees of adaptation are required. Escaping this carbon lock-in towards cities' decarbonisation will not be the result of an isolated initiative, but rather "a series of complex, interconnected changes in multiple variables", as Unruh states in [21]. In this line, while technologies are continuously evolving to support this urban transition, most Key Factors identified are focused on the institutional and organizational structures, which are not just a current carbon lock-in source, but also a potential powerful tool to escape from it [21].

Considering cities' decarbonisation process as a socio-technical transition, from a dynamic multi-level perspective [22], the energy efficiency and renewable energy technological niches are currently breaking the fossil-fueled based socio-technical regime, slowly modifying the market, industrial, cultural, political and technological structures.

These already strong technological niches, altogether with the support of the growing interest of cities in this transition [5], are opening a window of opportunity to escape the carbon lock-in where society has been trapped since the end of 18th century. Nowadays cities can foster this transition through alternative management, strategic, and financial models and tools, engaging key stakeholders and frontrunner cities in this transition for a more effective integration of energy planning into urban planning processes as well as boosting the green economic local niches potential, as shows the case of Sonderborg municipality.

According to all tasks mentioned in this study and the Key Factors identified, the effective integration of energy planning into urban planning processes (KF1) is targeted as the task with a longer run, difficulty, and impact for local administrations, implying significant transformations in the municipal processes, commitments, staff and departmental silos, regulations, strategies and tools. This is a clear path for future research, which will be further elaborated by the authors in next studies. Additionally, an urban transformation digital tool able to gather all relevant data and key stakeholders' inputs to ease decision-making processes for cities in this integration process would be a great asset and a valuable research, to be also further explored by the authors.

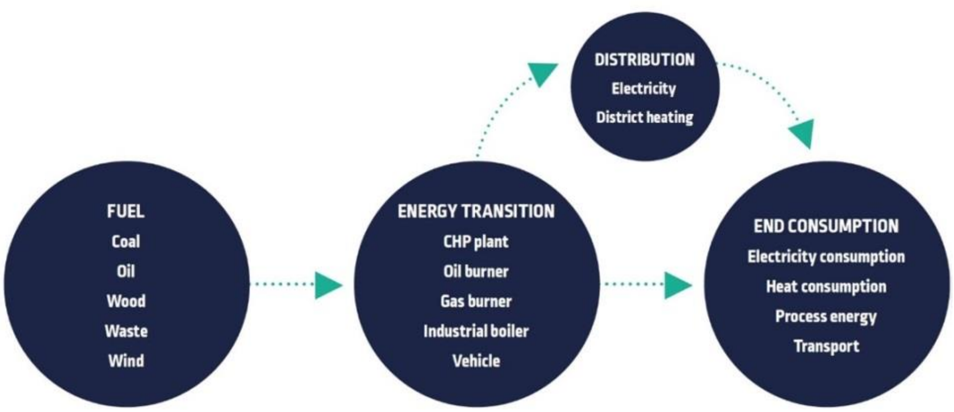

Figure 5: Energy Balance tool principle [11]

4. DISCUSSION

Transitioning towards a Smart Urban Decarbonisation requires a thorough analysis on the local context to propose the most suitable ad-hoc plans and interventions for each specific environment, as shown in the case of Sonderborg. However, all municipalities that were part of this research were facing common challenges in this urban transition. As cities are nowadays constrained by a techno-institutional carbon lock-in [20], Key Factors described in the previous

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Cities4ZERO: Overcoming Carbon Lock-in in Municipalities through Smart Urban Transformation Processes

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Abstract: How can local authorities effectively address the decarbonization of urban environments in the long run? How would their interests and expertise be aligned into an integrated approach towards decarbonization? This paper delves into how strategic processes can help to integrate diverse disciplines and stakeholders when facing urban decarbonization and presents Cities4ZERO, a step-by-step methodology for local authorities, able to guide them through the process of developing the most appropriate plans and projects for an effective urban transition; all from an integrated, participatory and cross-cutting planning approach. For the development of the Cities4ZERO methodology, plans, projects, and strategic processes from five European cities that are part of the Smart Cities and Communities European Commission program have been monitored for 4 years, in close collaboration with local authorities, analyzing ad-hoc local strategic approaches to determine key success factors and barriers to be considered from their transitioning experiences. The study indicates that an iterative strategic approach and a project-oriented vision, combined with a stable institutional commitment, are opening a window of opportunity for cities to achieve effective decarbonization.

Keywords: decarbonization; urban transformation; cities; energy transition; strategic planning; Smart cities; Smart zero carbon city

1. Introduction

Urban environments are suffering the increasing impact of climate change; thus, mitigation policies are becoming an urgent task for local authorities. By 2050, more than 70% of the global population will live in cities, a figure that shows the potential of municipalities for reducing greenhouse gas (GHG) emissions [1]. Furthermore, engaging cities in this fight can result in an even greater benefit to their citizens, such as reducing the unacceptable pollution at local levels: 9 out of 10 human beings live in places where air quality levels exceed the limits stated by the World Health Organization [2], causing 800,000 extra deaths a year in Europe, and 8.8 million worldwide, according to the latest study by the European Society of Cardiology [3].

Searching for the crucial elements to be addressed by cities to effectively transition towards urban decarbonization, a previous study by the authors points out a real integration of energy planning into urban planning processes as a key factor [4], suggesting the need for an innovative strategic municipal approach capable of integrating diverse disciplines and stakeholders, to identify and develop the most appropriate plans and projects for an effective urban transition.

In Europe, during the last decade, several initiatives have focused on this topic, building upon the studies and growing interest in urban planning aspects of energy, derived from the energy crisis in the 1970s [5–8]. In 2012, the Energy Efficiency Directive (2012/27/EU) encouraged the adoption of integrated urban planning strategies to take advantage of all the energy savings potentially present in urban areas. In line with this, the CONCERTO European Commission (EC) initiative delved into this strategic approach, bringing together all relevant stakeholders while integrating a variety of urban systems and technologies: "the CONCERTO initiative proves that if given the right planning and if all necessary stakeholders are included from the beginning until the end of the project, cities and communities can be transformed into sustainable energy pioneers" [9]. Putting this approach into practice, the STEP-UP (Strategies Towards Energy Performance and Urban Planning), PLEEC (Planning for Energy Efficient Cities) and InSMART (Integrative Smart City Planning) projects (FP7-ENERGY-SMARTCITIES-2012 EC call) examined an integrated approach to urban energy planning, testing diverse tools, methods, and levels of engagement, again, with the focus being on energy savings [10–12]. As a continuation of this evolution, since 2012 the EC has fostered the interaction of cities, industries, small and medium-sized enterprises (SMEs), investors and researchers, through the European Innovation Partnership on Smart Cities and Communities (EIP-SCC) platform, bringing them all together to design and deliver smart-sustainable solutions and projects [4]. In this case, the projects derived from this platform targeted the decarbonization of cities through the formulation of integrated urban plans, and more recently through the concept of positive energy districts (PEDs), intending to tackle the integration of energy and urban planning at both city and district levels. This is the case for the SmartEnCity project—Towards Smart Zero CO_2 Cities across Europe, where the authors have developed the decarbonization Cities4ZERO methodology, presented in this article.

As of 2008, running in parallel, the EC launched The Covenant of Mayors (CoM) initiative, which has engaged up to 10,075 European municipalities in the reduction of their CO_2 emissions [13], fostering local strategic processes through the development of Sustainable Energy Action Plans (SEAPs) and Sustainable Energy and Climate Action Plans (SECAPs, introducing the climate adaptation dimension in 2016). Over the last decade, SEAPs and SECAPs have been "considered the unique tool to manage and act on the Urban-Energy field" regarding mainstream strategic methods for urban decarbonization [14], in many cases replacing national initiatives, thanks to the European funds connected to the signature of the CoM.

However, municipalities present issues when facing these strategic processes of integration; issues that SEAPs/SECAPs are not able to solve in general terms. First, municipalities present, in general, the absence of a strategic dimension in the urban planning system, opting for short-term sectorial actions oriented towards fast results [14]. Second, there is currently a wide gap between theoretical efforts and practical implementation, suffering, in some local cases, from a lack of political commitment, coordination, and funding; all of this worsened by the perverse effects of a marketing use of the SEAP brand [14]. Besides all this, general urban plans do not yet include energy as a dimension to consider.

In the meantime, reality is stubborn, and climate action is urgent. In 2015, the Conference of Parties of Paris (COP21) achieved a binding agreement among all signatory countries, which did not include cities, although it encouraged them to cooperate and support emission reduction efforts [15]. The subsequent COPs (most recently COP25 in Madrid, 2019), as well as the Intergovernmental Panel on Climate Change (IPCC) reports, have stressed the crucial importance of cities in this task, inviting them to take urgent climate action.

To cope with this decarbonization task, cities need a strategic framework able to bundle different elements into a concise, pragmatic, project-oriented approach, based on a long-term strategic vision with a stable-in-time and committed institutional structure, able to integrate disciplines and stakeholders into one single sequence that fits in with the urban planning procedures of each local context. There is still no strategic method that allows cities to cope efficiently with this challenge. How can local authorities effectively address the decarbonization of urban environments in the long and short-run? How would their interests and expertise be aligned into an integrated approach towards decarbonization?

This question is what the Cities4ZERO theoretical approach addresses, based on the experience of a close collaboration with the local authorities of Vitoria-Gasteiz (ES), Tartu (EE), Sonderborg (DK), Asenovgrad (BG) and Lecce (IT), analyzing ad-hoc local strategic approaches, plans, and projects towards decarbonization. The methodology presented in this article is the result of a close analysis of the real planning dynamics in these cities; however, it has not yet been fully implemented, so it remains as a theoretical framework, while the real effects of its full implementation will take several years of monitoring progress towards effective decarbonization. Nevertheless, the application of this theoretical approach in these five cities has already been able to mobilize their local communities towards shared diagnosis, visioning, and planning processes; a cornerstone towards a promising urban transition.

In the rest of this research article, Section 2, the Materials and Methods section, presents the Smart Zero Carbon City guiding concept, while raising the question of how to implement this concept in real urban contexts. Section 2 also describes the method followed in this research, starting from a "beta" version of the strategic approach through to the final version of the Cities4ZERO methodology, which is presented step-by-step in Section 3, Results. Finally, the Discussion and Conclusions sections highlight the importance of supporting cities in this transition, fostering deeper horizontal and vertical integration, and sharing methodologies and tools for cities across a community of practice towards decarbonization.

2. Materials and Methods

2.1. Smart Zero Carbon City: the Concept Underlying the Methodology

Cities4ZERO methodology intends to align cities' decarbonization and Smart City solutions implementation, through a concept able to steer this urban transformation process: The Smart Zero Carbon City concept.

> A Smart Zero Carbon City (SZCC) is a resource-efficient urban environment where carbon footprint is nearly eliminated; energy demand is kept to a minimum through the use of demand control technologies that save energy and promote raised awareness; energy supply is entirely renewable and clean; and resources are intelligently managed by aware and efficient citizens, as well as both public and private stakeholders [4].

This concept targets the main decarbonization elements from a participatory and technology-supported approach, and works as the ultimate goal to be achieved by cities on board of this transitioning process. With this guiding concept as an overarching goal for cities, the following method was developed to enable effective action in municipalities, both in planning and implementation terms. This method builds upon the previous work of the authors on the article "Smart Zero Carbon City: Key Factors towards Smart Urban Decarbonization" [4], which is here briefly summarized, further developed and finalized, answering one of the key factors identified: "Strategic municipal processes towards Smart Urban Decarbonization in the mid-long term", asking for a strategic process able to guide the commitment of municipalities in the mitigation of GHG emissions through urban transformation processes in the mid-long term. This strategic process, Cities4ZERO, is presented in the Section 3, Results, and the method to obtain it, described in the following diagram and lines of this section (Figure 1).

2.2. Cities4ZERO Beta_0 Version: a Methodology from the Lab

Based on the SZCC concept (-0- in Figure 1), the research thoroughly reviewed urban transformation procedures, tools, and best practices in the last decades, delving on city systems and the way in which these interact with each other at the different urban scales [16]. This review was complemented by a framework on urban transformation processes, including studies on city diagnoses [17], regulation [18], financing, procurement schemes and business models [19], standards [20], an integrated management model [21] and a citizen engagement strategy [22].

This thorough theoretical and framework analysis in the lab (-1- in Figure 1) enabled the development of a beta_0 version of Cities4ZERO methodology, ready to be tested in real urban environments.

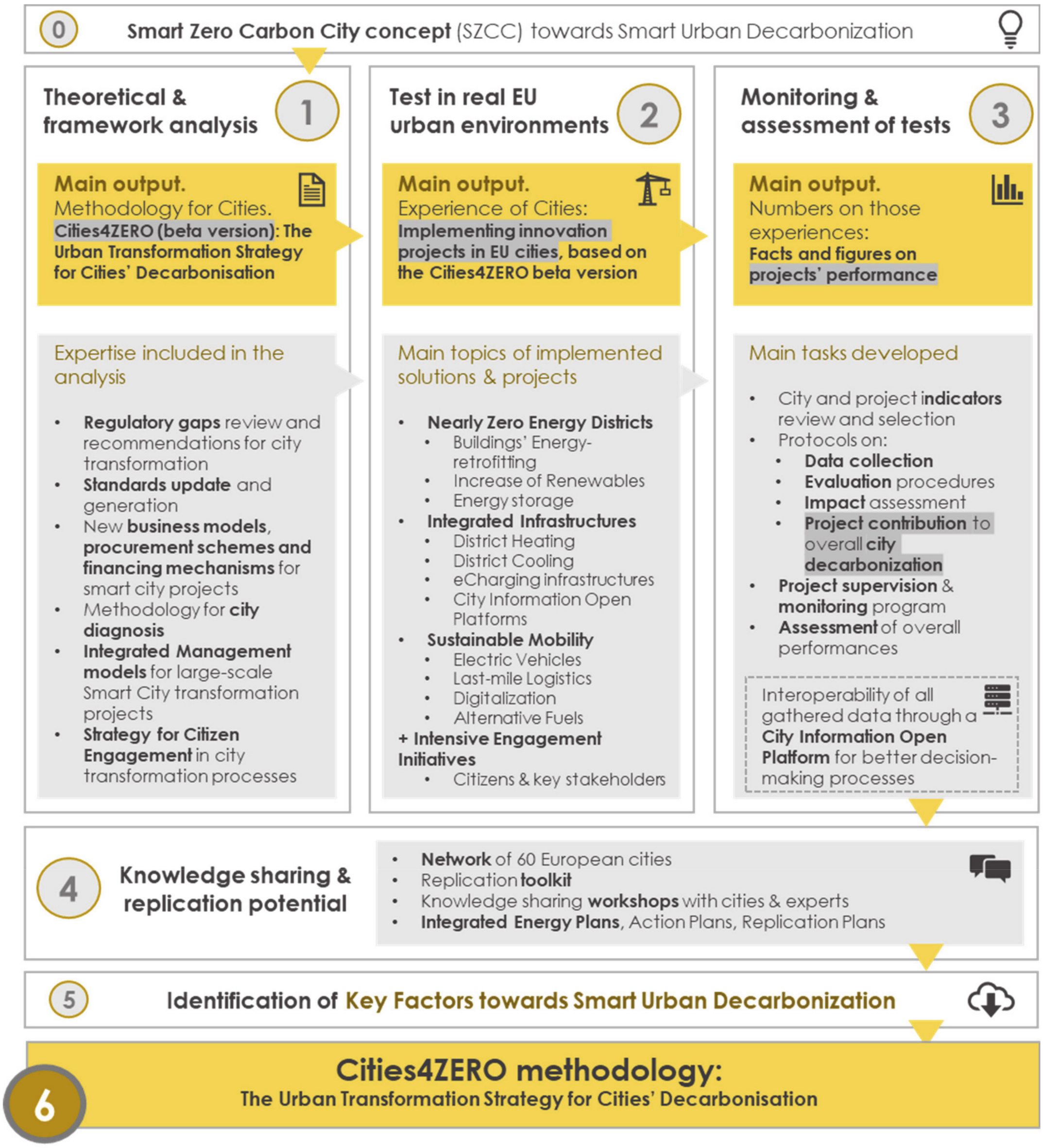

Figure 1. Wrap-up diagram presenting the method followed to develop Cities4ZERO methodology.

2.3. *Contrast of Cities4ZERO Beta_0.1 - From the Lab to the Urban Lab*

The Cities4ZERO beta_0 version was applied in five European cities with a formal commitment of reducing their GHG emissions, supported by an interdisciplinary consortium and the partial funding of the EC to develop strategies, plans, and interventions in their path towards carbon neutrality. Those cities were divided into two groups; the "lighthouse" ones were Vitoria-Gasteiz (ES), Tartu (EE), and Sonderborg (DK), willing to intervene through pilot projects in specific districts, as well as updating their city strategies; and the "follower" ones, Asenovgrad (BG) and Lecce (IT) [23], willing to learn from the experiences of lighthouse cities to update their city strategies, and start with specific district interventions in a later stage. The five cities were small and mid-sized, showing that this significant group of cities (83.43% of EU cities, according to Eurostat data [24]) can also move forward in this transition, far from big numbers and budgets of main European capitals. More specifically, the three leading cities were chosen as they were considered pioneers in different decarbonization fields (Vitoria-Gasteiz—sustainable mobility and green infrastructures; Tartu—ICTs deployment in the urban environment; Sonderborg—strategic roadmaps towards decarbonization), sharing a solid background and able to offer lessons to other cities from a collaborative approach (Table 1).

Table 1. Vitoria-Gasteiz, Tartu, and Sonderborg main features of value to Cities4ZERO research study.

Vitoria-Gasteiz	This administrative capital of the Basque Country, in northern Spain, has a population of 240,000 inhabitants, with an extension of 276.81km^2. A compact, moderately dense city, Vitoria-Gasteiz has an extensive background in the planning and implementation of environmental policies, being awarded the European Green Capital appointment in 2012. A flat and walkable city surrounded by a "green belt", and often regarded as a model in sustainable mobility planning, Vitoria-Gasteiz is committed to becoming a carbon-neutral city by 2050.
Tartu	Tartu is the second-largest city in Estonia, with a population of 100,000 inhabitants and a total area of 38.86km^2. The home of several knowledge-intensive organizations (University of Tartu, Estonian University of Life Sciences), it is better known for its extensive implementation of Smart technologies in the Urban Environment. Tartu implemented public Wi-Fi areas throughout the city and was the first city in the world to enable a mobile-payment system for street parking in 2000. Paperless government was implemented in 2003, e-elections in 2005 and 2011 (EU Parliament), and fully electric taxi service and charging grid were implemented in 2012.
Sonderborg	Sixteenth largest municipality in Denmark, with approximately 77,000 inhabitants, included in the Southern Denmark region. The municipality holds an extensive agriculture sector, some of Denmark's largest industrial companies (i.e., Danfoss), and some of the most beautiful natural resorts of the country, with a cost of approximately 200km (offshore wind potential) and vast forests (local biomass potential). The city of Sonderborg has been working with the "ProjectZero" roadmap since 2007, aiming to become carbon neutral by 2029; one of the worldwide pioneer cities in this regard.

Within this collaborative framework among municipalities, the pilot interventions in the lighthouse cities targeted three main interventions fields, closely connected to urban decarbonization: nearly zero energy districts; integrated infrastructures, and sustainable mobility; facilitated by citizen and stakeholders' engagement activities (-2- in Figure 1). These interventions were intended to trigger additional low-carbon investments in the cities, fostering local replication, as well as inspiration for other cities based on these best practices. Table 2 summarizes these interventions, where energy savings were calculated according to BEST (building energy specification table) and TEST (transport energy specification table) standards.

Aligned with all those strategies, plans, and interventions, a project supervision including a monitoring program and later performance measurements and assessment of interventions was developed (-3- in Figure 1). In line with this, key performance indicators let researchers know what was working and what was not as expected, and to what extent the interventions were contributing to decarbonization targets, besides other complementary measurements. Through this contrast in the five cities, Cities4ZERO methodology was fine-tuned to achieve its beta_0.1 version.

Table 2. Vitoria-Gasteiz, Tartu, and Sonderborg interventions during SmartEnCity project. Savings overview in pilot projects (2016–2021).

			Energy Savings (kWh/Year)	CO_2 Emission Reduction (Tn/Year)	
DISTRICT INTERVENTIONS	**Building Retrofitting**	• 450 dwellings/36,000m^2 • Envelope insulation (roof and façade) • Connection to district heating network	6,099,700	2149	**VITORIA-GASTEIZ**
	Integrated Infrastructures	• New biomass-powered district heating network • Integrated electrical and thermal network Energy Management Systems, at Home/Building/District levels (HEMS/BEMS/DEMS)			
	Sustainable Mobility	• Deployment of 100% electric bus line			
	ICTs	• Urban management systems (UMS)			
CITY STRATEGY		• *Integrated Energy Transition Action Plan 2030*	Baseline 2006: 841,068 CO_2 tn/yr 2020: 624,728 CO_2 tn/yr **Next target by 2030 (-40%): 504,640 CO_2 tn/yr**		
DISTRICT INTERVENTIONS	**Building Retrofitting**	• 900 dwellings/39,500m^2 • Envelope insulation (roof and façade) • New low-energy windows and doors • PV (Photovoltaic) panels in the south facades • Connection to the district heating and removing old electric boilers • Heat recovery ventilation system	16,080,829	12,244	**TARTU**
	Integrated Infrastructures	• Integrating heating and cooling in the current District Heating Through a new heat-pump • Smart public lighting			
	Sustainable Mobility	• Extending the recharging network for electric vehicles (EVs) • Bikeshare • Biogas buses • Reuse of EVs batteries as a storage system for PV panels			
	ICTs	• Urban management systems (UMS)			
CITY STRATEGY		• *Tartu 2030 Energy + Plan*	Baseline 2010: 540,794 CO_2 tn/yr 2020: 432,635 CO_2 tn/yr **Next target by 2030 (-40%): 324,477 tn/yr**		

Table 2. *Cont.*

			Energy Savings (kWh/Year)	CO_2 Emission Reduction (Tn/Year)	
DISTRICT INTERVENTIONS	**Building Retrofitting**	• 844 dwellings/66,181 m^2 • Envelope insulation (roof and façade) • New low-energy windows and doors • PV panels in roofs • LED outdoor lamps • Lighting control	16,080,829	12,244	**SONDERBORG**
	Integrated Infrastructures	• Residential electricity storage from local renewable energy (PV)			
	Sustainable Mobility	• 44 biogas buses fleet and biogas filling station • Extending the recharge network for EVs			
	ICTs	• Urban management systems (UMS)			
CITY STRATEGY		• *Roadmap2025—50 steps towards a carbon-neutral Sonderborg*	Baseline 2007: 701,044 CO_2 tn/yr 2018: 432,336 CO_2 tn/yr **Next target by 2025 (-75%): 175,261 tn/yr**		

2.4. Contrast of Cities4ZERO beta_0.2—From the urban lab to the real world

At this stage, Cities4ZERO beta_0.1 version and all the complementary materials and tools were packed into a replication toolkit, which was offered to municipalities with a decarbonization interest, within a pool of 60 cities from different countries that signed up as members of the SmartEnCity Network on their own will and interest [25], intending to learn about the experiences of the 5 pilot cities. Multiple workshops with municipalities and experts were organized in several European countries, where an intensive knowledge exchange allowed the testing of contents, interest, and replication potential of Cities4ZERO methodology, achieving the fine-tuned beta_0.2 version (-4- in Figure 1). Finally, the identification of the key factors towards smart urban decarbonization [4], based on the lessons learned along this process, and a final review by the authors allowed to achieve Cities4ZERO methodology, presented in the Section 3, Results (-5 and 6- in Figure 1).

3. Results

This section presents Cities4ZERO—the urban transformation methodology for cities' decarbonization—a step-by-step methodology for a smart urban decarbonization transition, guiding cities through the process of developing the most appropriate strategies, plans and projects, as well as looking for the commitment of key local stakeholders for an effective transition; all from an integrated planning approach.

Bearing in mind the critical situation regarding the need for mitigation actions, the important question is how to effectively deploy the SZCC concept in our cities. In line with this, Cities4ZERO suggests a pragmatic approach for municipalities structured on 3 stages and 16 steps. Stage A will deal with the development of the city strategy towards decarbonization, while stages B and C will develop the key projects identified in that city strategy (Table 3).

Table 3. Cities4ZERO value proposition for local authorities.

<table>
<tr><td>A. Strategic Stage ^{City Level}
STEPS 1–6. They provide a strategic planning framework which enables the city administration to perform an effective transition towards the Smart Zero Carbon City (SZCC), including:
• Key city stakeholders' engagement and institutional analysis
• Analysis and diagnosis of city strengths and opportunities
• Co-visioning process for urban transformation towards energy transition, including potential future scenarios
• Development of strategic plans to deploy that vision and identification of key projects, ensuring integration in local authorities' processes, commitment of engaged stakeholders and municipal support</td><td>CITY STRATEGY</td></tr>
<tr><td>B. Design Stage ^{Project Level}
STEPS 7–11. They guide municipalities through the development of key projects identified in Stage A, according to the strategic plans of the city, paving the way for tangible interventions towards the SZCC, including:
• Project prioritization and selection based on city needs
• City transformation framework with policies, plans, best practices, regulation, etc.
• Funding and financing mechanisms
• Citizen engagement strategies for project development
• Project design and tools
• Project implementation plan and indicator systems</td><td rowspan="2">DEVELOPMENT AND IMPLEMENTATION OF KEY PROJECTS</td></tr>
<tr><td>C. Intervention and Assessment Stage ^{Project and City Level}
STEPS 12–16. They structure the implementation and assessment of key projects identified in Stage A and designed in Stage B, finally transforming the urban environment; including:
• Intervention works, solutions deployment, and commissioning
• Monitoring, maintenance, and users training
• Interventions' performance and impact assessment
• Post management and communication through city information open platforms
• Project and strategy validation
• Up-scaling of successful experiences</td></tr>
</table>

This step-by-step methodology is not conceived as a linear process, but as a circular one. The whole process (Stages A, B, and C) cyclically iterates when felt partially obsolete to readjust the focus of strategies, plans, and key projects towards the final decarbonization goal, according to the co-formulated city vision (Figures 2 and 3).

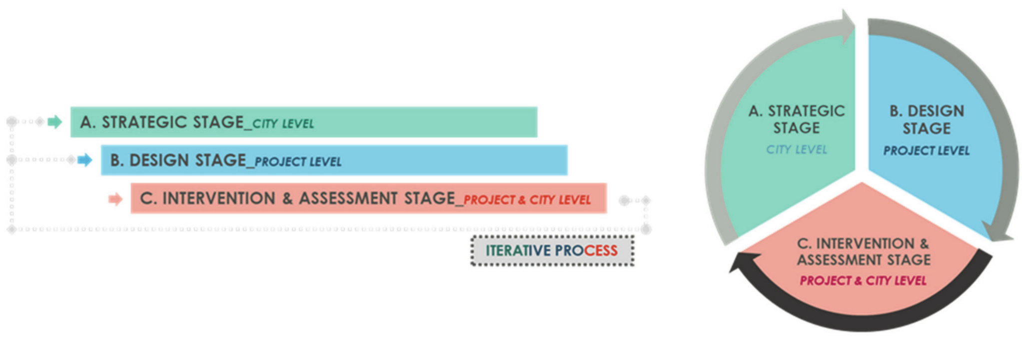

Figure 2. Stages from Cities4ZERO methodology and circularity of the process.

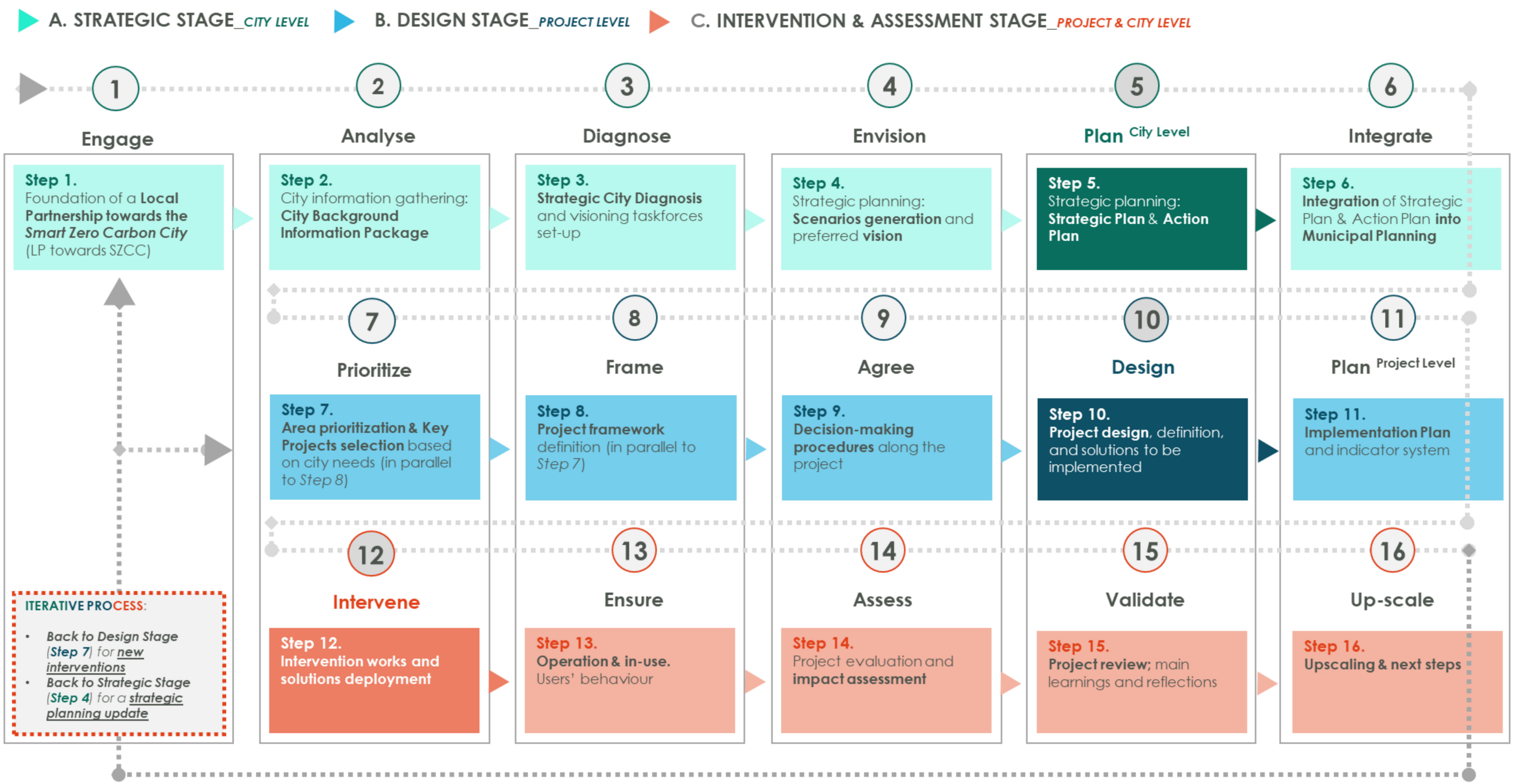

Figure 3. Wrap-up diagram from Cities4ZERO methodology.

Depending on the current status of each municipality, the point of departure can vary, as some methodological steps might be already fulfiled. The first exercise for cities consists of evaluating their situation regarding this process and which steps from Stage A will be a priority for them. As a starting point, the SmartEnCity team has developed the City Check-up Assessment tool [Supplementary Materials]. By filling a questionnaire, cities can self-assess regarding this urban transformation process.

Finally, step-by-step does not always mean that it must be a straight line; reality is usually more complex than plans. Either way, this methodology will work as a solid reference framework. The final aim of Cities4ZERO is to involve European cities on the path towards decarbonization, mainly targeting the wide range of small and mid-sized cities in the region (83.43% of cities) [26]. As the SmartEnCity project slogan states, "you don't have to be a capital city to make a major difference!".

3.1. A. Strategic Stage at City Level – CITY STRATEGY

The main objective of the strategic stage is to provide a framework that enables the city to perform an effective transition towards the SZCC (Figure 4). In later stages, the strategy delves into concrete projects' definition (B. Design Stage) and implementation (C. Intervention and Assessment Stage), landing on specific projects identified in this strategic stage at the city level.

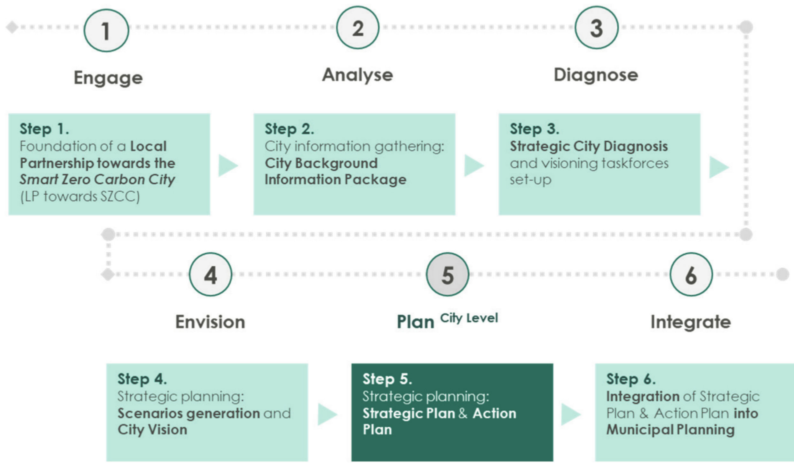

Figure 4. Steps of Cities4ZERO Strategic Stage.

The framework of this strategic stage consists of six steps, focusing on the main activities to be performed at the city-planning level. The first step (1. ENGAGE) describes the foundation of a permanent local steering group (local partnership towards the SZCC) lead by the local authority for this transition towards the SZCC, suggesting an alternative governance model with key local stakeholders on board. With this group in place, the city needs to perform a thorough city characterization (2. ANALYSE) and a strategic city diagnosis (3. DIAGNOSE), to understand what the point of departure for the city transition is. This comprehensive background analysis allows one to perform a strategic planning process, starting with the co-development of a city vision (4. ENVISION), based on potential decarbonization scenarios for the city. That resulting vision will provide an umbrella to develop a strategic plan, which will steer the city towards the achievement of that agreed vision, also defining an action plan to perform specific actions with that purpose (5. PLAN$^{\text{City level}}$— key step of Stage A). The last step of the strategic stage (6. INTEGRATE) fosters the integration of strategic plan contents into municipal planning instruments, ensuring the alignment and official approval of all processes to avoid legal, administrative and land-use barriers, while leveraging synergies among municipal departments and competences, all carefully steered by the local partnership towards the SZCC.

Before facing this strategic stage with Step 1, it is highly recommended for cities to use the City Check-up Assessment tool (Supplementary Materials), so that the reader has an overview of the process, contextualized to his/her specific local environment.

STEP 1. ENGAGE. Foundation of a local partnership towards the SZCC

The first cornerstone in this journey requires the foundation of a local group headed by the local authority (local partnership towards the SZCC), which will steer the urban transformation towards the SZCC, providing stability to the process in the mid-long term. This local steering group must map and engage key local stakeholders, including representatives from all quadruple helix branches (government, industry, academia, and citizenship), as well as defining the governance model for this urban transformation process. This local group can eventually be supported by external consultancy if some competences are missed within the municipality.

Before starting with the urban transformation strategy, preplanning tasks of this group must reflect on the overall strategy requirements and approvals such as timeline, coordination with other partners and municipal departments, potential institutional adaptations [27], budgetary needs, inventories and data repositories, (. . .); determining the needs for the shaping, regulating, stimulating and capacity building of potential projects or initiatives framed within this urban transformation process. A wide commitment of the local authority is key to a potential city decarbonization.

STEP 2. ANALYSE. City information gathering: the city background information package

When facing a strategic urban transformation process, a thorough analysis gathering comprehensive information on the current state of the city is crucial for successful regeneration.

A pre-analysis must perform a literature review at the city level, delving on existing policies, regulations, strategies, and plans, complemented by semi-structured interviews with experts and surveys on citizens' perception. On that basis, a city characterization provides a deeper understanding on the socioeconomic and sectorial features (energy, building stock, mobility, public space, ICTs—Information and Communication Technologies—engagement, waste, water, etc.) and the status of the city, where city indicators (SZCC readiness level in [26]) can provide a desirable quantitative approach to this characterization. Here, a carbon emissions baseline is key to perform further strategies and projects towards energy transition. In line with this, a comprehensive model of the local energy system is key to draw the carbon emissions baseline, to be performed by tools like EnergyPLAN [28] or Energy Balance [29].

All gathered information within this step can be bundled into a city background information package (CBIP), as a solid reference for further steps in this methodology (e.g.: Steps 3, 8).

STEP 3. DIAGNOSE. Strategic city diagnosis and visioning taskforces set-up

Once key stakeholders are initially engaged within the local partnership towards the SZCC (Step 1) and city information is gathered on the CBIP (Step 2), it is time to organize those stakeholders in working groups, to provide valuable input for the strategic planning tasks; namely: strategic city diagnosis (Step 3); scenarios and city vision generation (Step 4); strategic plan and action plan (Step 5). In the SmartEnCity project, the flow of these three strategic planning tasks has been supported by a participatory foresight exercise, which consists of gathering future insights and building common visions for making present-day decisions and mobilizing joint actions in the city.

This foresight exercise starts with the strategic city diagnosis (method in [17]), which consists of a thorough SWOT (strengths/weaknesses/opportunities/threats) analysis of the city, supported by CBIP (Step 2; internal drivers of SWOT including GIS data—geographic information systems), and a city-trends analysis (external drivers of SWOT), exploring relevant connections to regional/national/international targets, policies, and institutions in the field of SZCC. Within this SWOT, after identifying the main "external opportunities and threats", and "internal strengths and weaknesses" of the city, they can both be combined to assess the probability (likelihood to become a reality) and relevance of each element. The logic is that the "highly relevant, but uncertain drivers of change" should lead to defining the main strategic actions to be taken in the next steps (Step 4. ENVISION/ Step 5. PLAN). Furthermore, a PESTLE analysis (political, economic, social, technological, legal, environmental) can be useful for performing an in-depth analysis of external factors.

This strategic city diagnosis must be supported by the collaboration and contribution of local stakeholders organized in thematic working groups by the local partnership towards the SZCC, and it will provide critical topics and main input for scenarios and city vision generation (Step 4).

STEP 4. ENVISION. Scenarios generation and preferred vision

Building upon main outputs from the strategic city diagnosis (Step 3), local working groups will face a city visioning workshop with the assistance of a moderator expert in prospective, co-developing an agreed vision for the future of the city.

Assuming the role of city managers, the working groups will generate different future scenarios for the city based on the SWOT analysis of Step 3, while facing the formulated strategic question within the agreed timeframe; e.g.: How are we transforming our city to become carbon neutral by 2040? What can we do by 2030 as a mid-way milestone? The stakeholders will contrast the analysis on probability and relevance of the trends performed in the strategic city diagnosis, before generating the different future scenarios.

The local steering group must gather all those inputs and further develop each of the scenarios suggested by each of the working groups. Once all this input is structured, those final scenarios are presented to the local stakeholders, starting a discussion to select a preferred "master scenario", which can be one or a combination of those final scenarios. According to that master scenario, the group will develop a city vision, ideally as a result of reaching consensus among all stakes, being the basis of developing the strategic plan for the city (Step 5). After all these processes, the stakeholders in Vitoria-Gasteiz agreed on a master scenario for 2030, summarized in the following city vision, which guided the content of their strategic plan and action plan (Step 5):

> Vitoria-Gasteiz 2030; a resilient, safe, healthy, metabolic efficient, circular and high-quality environmental municipality; a benchmark for distributed energy production from renewable sources, for an effective energy-retrofitting model of the built environment, for its determined commitment to the active mobility modes, complemented by a high-quality electrified public transport system. A municipality with institutions that exercise powerful leadership and act in an exemplary way together with a co-responsible citizenship with a high level of awareness, reinforced by a model of community cooperation capable of facing the challenges of the energy transition at the local level. All this within a prosperous, innovative, and competitive economic environment, which ensures a collaborative social model in which no one is left behind.

STEP 5. PLAN $^{\text{CITY LEVEL}}$. Strategic plan and action plan

All materials and activities performed in Steps 1-4 provide a comprehensive background to develop a strategic plan and an action plan for the city, whose main goal is to pave the way, with specific actions towards the city vision achievement within the agreed timeframe.

The strategic plan of the city will transform the city vision (Step 4) into specific goals. From those goals, strategic axes and lines will structure the strategic plan, which will be further landed into an action plan. The action plan is the document in which specific actions and key projects are identified, appointing stakeholders, budget, impact indicators such as emissions reduction, and timeframe for their development. The desirable implementation timeframe of those key projects is less than five years, when the action plan must be updated, to readjust the focus to the evolving urban situation. Regarding the format of a strategic plan and action plan, the following summarized and generic example can be followed, based on the experiences of the SmartEnCity project [30]:

a) City vision: carbon neutrality for 2030, based on green economic growth
b) Strategic axis 1 (1 out of 3 axes): sustainable energy
c) Strategic line 1.3 (out of 5 lines): positive energy districts

d) Action 1.3.1 (out of 3 main actions): city diagnosis for vulnerable energy districts identification, promoting the "retrofitting pack" based on local businesses
e) Key project from action 1.3.1: Integrated retrofitting of 350 dwellings in old town district, including connections to district heating network, powered by local renewable energy sources

For the identification of key projects, it is recommended to involve the thematic working groups engaged in Steps 3 and 4, as those stakeholders, besides being experts in each field, will be more committed in the future implementation of those projects. In case there are conflicting interests, the local partnership towards SZCC will have to make decisions, which may imply a political component. In terms of the development of key projects within Cities4ZERO methodology, the DESIGN STAGE delves on them from Step 7 on.

Regarding the approach local authorities have to this kind of strategic actions, they usually tend to focus on isolated energy actions, whilst the complexity of urban decarbonization challenge requires an integrated and participatory approach, where urban planning and all city systems converge into one single path, and local stakeholders can influence the generation process, as they will later be protagonists in the implementation stage. In line with this, the integrated energy planning concept can be valuable to steer this process:

> Integrated energy planning (IEP) is an approach to find environmentally friendly, institutionally sound, socially acceptable, and cost-effective solutions of the best mix of energy supply and demand options for a defined area to support long-term regional sustainable development. It is a transparent and participatory planning process, an opportunity for planners to present complex, uncertain issues in structured, holistic, and transparent ways, for interested parties to review, understand and support the planning decisions. Furthermore, Integrated planning entails defining the goals and the problems to implement the appropriate solutions. [31]

Finally, it is strongly recommended to define an indicator system at the city level that monitors the progress towards the city vision and objectives fulfilment, trying to match the impact each of those key projects has on the overall city scale and decarbonization goals. Here, the model of the local energy system developed in Step 2 can show the potential carbon emissions reduction of each of those key projects, being able to quantify and prioritize each of those actions depending on their impact.

STEP 6. INTEGRATE. Integration of strategic plan and action plan into municipal planning and strategies

The local authority needs to guarantee the legal, administrative, and physical conditions to deploy the actions and key projects identified in the strategic plan and its action plan (Step 5), ensuring full integration in the municipal planning instruments. In the city of Sonderborg, the commitment of the local authority with the process allowed to review each of the 50 key projects identified in the action plan to analyze how to engage on them or support them from the public administration side to maximize their impact, releasing an internal steering booklet for politicians and municipal employees. Regardless of the internal steering booklet, this process should be a standard for any municipality producing a strategic document, but unfortunately, it is not.

In this regard, an update or modification of the land-use city masterplan it is essential, ensuring legal viability and land-use provision for identified actions. Furthermore, a review and acknowledgment of the strategic plan and action plan contents by local legislation and municipal competences is crucial, avoiding foreseen barriers. This acknowledgment by all municipal departments and strategies will enhance cross-cutting collaboration among disciplines, fostering synergies and breaking sectorial silos at the same time.

This integration process must be carefully steered by the local partnership towards the SZCC (Step 1), ensuring the alignment among existing and foreseen initiatives for a soft transition, as well as a more integrated approach to traditional land-use planning.

A wrap-up diagram of the Cities4ZERO strategic stage is presented in Figure 5.

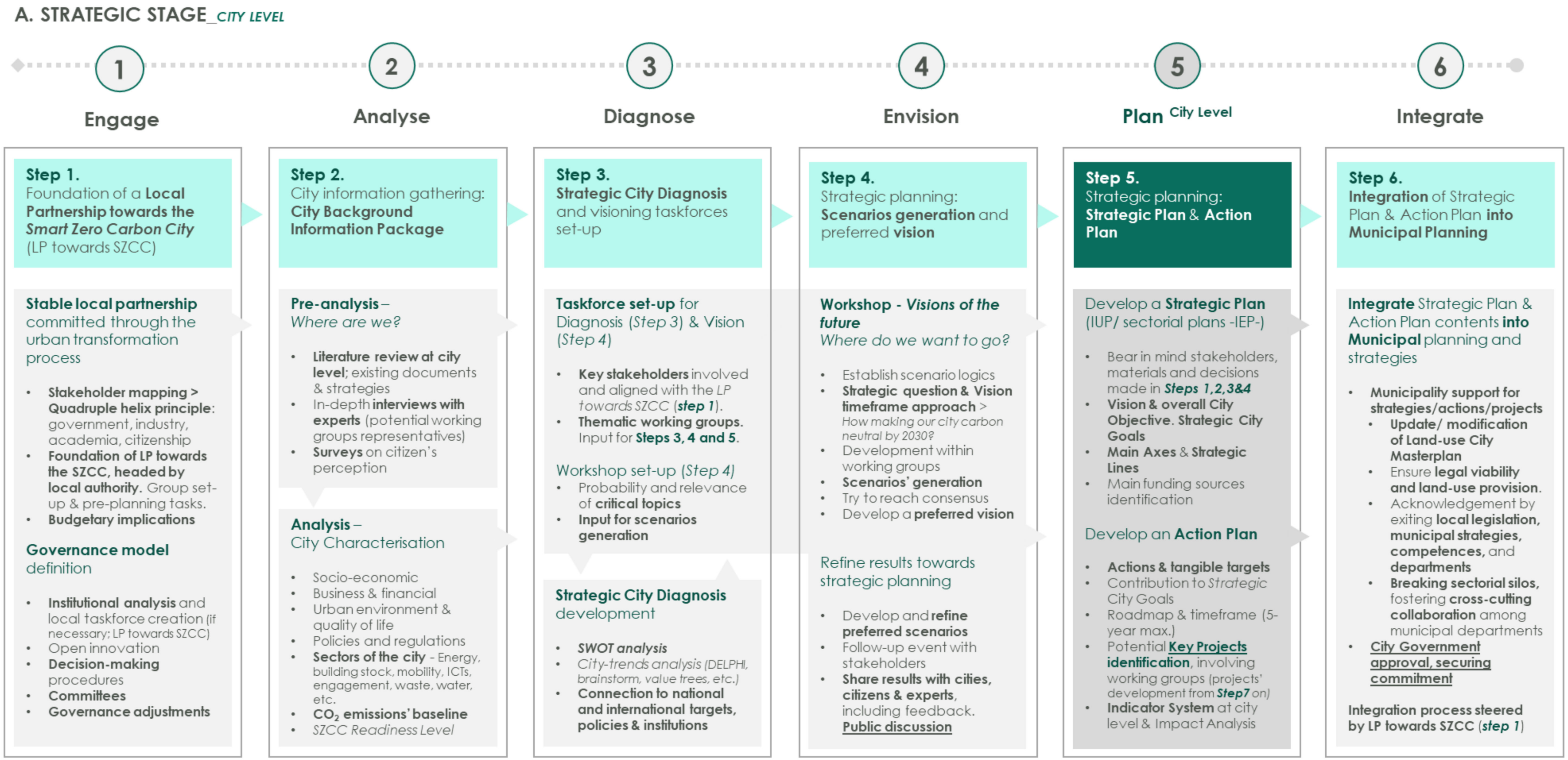

Figure 5. Wrap-up diagram from Cities4ZERO strategic stage.

3.2. Design Stage—DEVELOPMENT OF KEY PROJECTS

This stage aims to take a step beyond the strategic plans of the city (Step 5. PLAN CITY LEVEL; strategic plan and action plan), through the development of key projects identified as enablers for those strategic plans (Figure 6). This stage (B. Design Stage) will prioritize, frame, carefully co-design, and plan those projects, while the last stage (C. Intervention and Assessment Stage) will bring them to reality, monitoring and evaluating their performance and impact for further research and plans. Through the iterative development of all key projects identified, the transition towards the SZCC will become a closer reality.

Figure 6. Steps of Cities4ZERO Design Stage.

The framework of this Design Stage consists of five steps that fall into the specificities of the project level, always bearing in mind all main lines previously agreed upon at the city level (A. strategic stage). The stage will start with a prioritization based on city needs, choosing the most relevant projects and city areas (7. PRIORITIZE), defining the objectives and a rough draft for a district integrated intervention. In parallel to Step 7, it is crucial to build a city transformation framework (8. FRAME), analyzing the local context for implementation regarding the city-systems entailed in the intervention, including potential financing mechanisms and business models for all solutions. Once the project is framed, key agreements are needed (local partnership towards the SZCC, industry, academia, citizens), according to our governance model developed in Step 1 (9. AGREE), to hence carefully co-design and co-define the project and all solutions entailed, making use of a suitable design toolbox (10. DESIGN—key step of Stage B). Finally, in this stage (11. PLAN PROJECT LEVEL), the result will be transformed into an implementation plan, which, assisted by an indicator system, will ensure the effective deployment, quality, and evaluation of the project to be implemented in its final stage (C. Intervention and Assessment Stage).

STEP 7. PRIORITIZE. Area prioritization and key projects selection based on city needs

In this second stage, from those key projects identified in the strategic plan and action plan (Step 5), a project prioritization performed by the local authority (local partnership towards SZCC) will select and combine the most promising initiatives for the city, focusing on those city areas where the benefits of those initiatives will have the most impact for the citizens. This prioritization will build upon the strategic city diagnosis performed in Steps 2 and 3, using GIS tools for spatial analysis and reduction emissions potential, identifying priority areas and bottlenecks, as well as demarking the area of intervention of the project. In this process, the local partnership towards SZCC will work as a coordination node among municipal departments, agencies, and external stakeholders, to reach a wider consensus on the decisions to be made. In case conflicting interests do not allow one to reach a consensus, the local partnership will decide the most beneficial intervention for the municipality, according to the strategic and action plan developed in Step 5, considering all stakes in the table.

For this choice, it is recommended to focus on social, economic, or environmental vulnerable urban areas, those that experience a lower quality of life in comparison to other urban areas, with a specific look at emissions reduction potential. Both area and projects' selection would be ideally chosen in a parallel process, feeding one another. In the case of Vitoria-Gasteiz, the energy-efficiency, energy supply, age, and accessibility of the building stock, the socio-economic and demographic characteristics, and the quality of the public space connected to mobility and access to green areas were the key reasons to choose the Coronación district as the area of intervention with the highest potential of emissions reduction and upgrade of the quality of life standards.

Finally, a rough draft for a district integrated intervention project at this stage (pre-definition) will provide a good overview to enrich the following steps (8, 9 and 10), allowing more accurate analyses in this Design Stage (funding, regulation, standards, engagement, communication, etc.). In return, analyses on funding/ financing mechanisms and a city transformation framework (Step 8) will support this process.

STEP 8. FRAME. Project framework definition

The main objective of this step, together with step 7, is to ensure project viability in institutional, legal, and economic terms, leveraging potential opportunities, whilst tackling foreseen barriers in the development process.

In parallel to the pre-definition of the project in Step 7, Step 8 will support the process with the development of a city transformation framework, building upon city background information package developed in Step 2. This framework will consist of an analysis of local plans, policies, regulations, standards, barriers, good practices, and potential risks regarding city transformation processes and how they affect the city-systems entailed in the future intervention. This analysis will allow the identification of synergies, boundaries, and barriers for the selected interventions in the project.

As part of the city transformation framework, potential funding and financing mechanisms will explore how to cope with the required investments for the project. With that purpose, an overall budget will be estimated, fostering public-private partnerships and sources (European, national, regional, local, multilateral, NGOs, etc.). In line with this, business models will be drafted for each solution to be implemented, fostering the economic sustainability of the overall intervention.

STEP 9. AGREE. Decision-making procedures along the project

The success of planned interventions will depend very much on the level of agreement achieved among all parts at stake in the city (and district). That's why it is important to carefully engage all key stakeholders to ensure their alignment during and after the project.

The city governance model already defined in Step 1 will now be transferred into the project level, defining decision-making procedures along all steps of the project. An integrated management Plan will be accordingly defined, including decision-making roles for all stakeholders:

- Strategic, tactical: local partnership towards SZCC,
- Operational: technical committee (with main experts, including industry and academia),
- Collaborative: citizens committee, representing their interests and insights.

Special attention must be paid to an effective citizen engagement strategy, defining a model able to incorporate an interesting and well-communicated value proposition for the citizens, allowing social innovation practices and collaborative approaches. There is no unique recipe to develop a citizen engagement strategy; the design process must be adapted to each local reality. It is about developing proposals following the required project specifications, while creating tangible touchpoints that can be reshaped by the citizens.

STEP 10. DESIGN. Project design, definition and solutions to be implemented

Once the project and the city-area have been selected (Step 7), the contextual framework—including financial requirements—has been met (Step 8), and consensus about the integrated intervention is as wide as possible among all parts at stake (Step 9), it is time to carefully co-define and co-design project solutions to be finally implemented. This process will be built upon the pre-definition of the interventions developed in Step 7.

Firstly (A), the optimal solutions and technologies must be selected for each sector of the district integrated intervention. As an inspiration, EC funded projects (SCC-1 Smart Cities and Communities) have been developing more than 500 innovative city solutions in 93 European cities since 2014, all gathered and sustained in the EC Smart Cities Information System [32]. The main categories gathering these city solutions are (Table 4):

Table 4. Categorization of SCC1 solutions [32].

A. Energy	
• Building-integrated renewable energy sources • Building envelope retrofitting • Building services (Lighting and HVAC—Heating Ventilation Air Conditioning) • Heat pumps • Small energy storage	**Energy efficiency in buildings**
• District heating and cooling • Co-generation (CHP—combined heat and power) • Electrical energy storage • Thermal collectors • Biomass boiler • Photovoltaics • Waste heat recovery • Near-to-surface geothermal energy • Waste-to-energy • Large scale storage • Deep geothermal energy • Thermal storage	**Energy system integration**
B. Mobility and transport	
• Clean fuels and fuelling infrastructure • Electric, hybrid and clean vehicles • Bicycle infrastructure • Car-sharing • Intermodality • Urban freight logistics • Car-pooling	
C. ICTs	
• Building energy management systems • ICTs as planning support • Mobile applications for citizens • Smart district heating and cooling grids—demand • Smart electricity grid • Traffic control systems • Demand response • Neighbourhood energy management systems • Travel demand management	

Secondly (B), the intervention area will probably require a public space reconfiguration through a detailed project definition. A design team will include experts on the fields regarding solutions to be implemented, fostering collaborative design while defining the project. This project will fulfil all requirements of the integrated management plan developed in Step 9.

Both definition processes, (A) and (B), should be supported by the positive energy district's concept [33] and a comprehensive design toolbox able to integrate GIS, BIM (Building Information Modeling), system-illustrative tools and simulation models. These tools will significantly optimize the effectiveness of interventions as well as maintenance, operation, and monitoring of all solutions during their lifespan (e.g.,: models, building and city digital twins). Project design and solutions from this step will define key issues related to Step 11 (implementation plan) and Step 12 (intervention works and solutions deployment).

STEP 11. PLAN $^{\text{PROJECT LEVEL}}$. Implementation plan and indicator system

The project design developed in Step 10 will be included in an implementation plan, which will provide measures to control the outcome and development of interventions, such as a quality management plan, a risk management plan, a description of the sequence of activities, and an execution plan for all solutions.

Concerning procurement and contracting, both local and national contexts of each city will have specificities that need to be met. In some cases, public procurement for innovation (PPI) processes can be helpful, as some problems might need deeper reflections, avoiding straightforward market solutions that may not meet the expectations for the problem at focus.

As aforementioned in Step 5 for the city level, it is recommended to implement an indicator system at the project level, connected to an evaluation plan, a data collection plan and a monitoring Program (Step 13), defining a baseline for the interventions and the expected performance of those, hence, it is possible to assess the results and impacts towards decarbonization after processing all the data (Step 14). All that data will be also valuable in case the city develops a city information open platform (CIOP), to analyze and visualize all the data for better decision-making. This online platform can also improve transparency with citizens, setting different levels of access depending on the user (decision-maker/technician/citizen).

A wrap-up diagram of the Cities4ZERO Design Stage is presented in Figure 7.

Intervention and Assessment Stage—IMPLEMENTATION OF KEY PROJECTS

The last stage of Cities4ZERO methodology (C. Intervention and Assessment Stage, Figure 8) deploys the integrated intervention, through the implementation of key projects previously identified in the first stage (A. Strategic Stage) and designed in the second stage (B. Design Stage).

The Intervention and Assessment Stage consists of five final steps, focusing on implementing, assessing, and upscaling the solutions, all of them aligned with the strategic plans of the city (Step 5. PLAN). The first step of this stage implements all solutions (12. INTERVENE—key step of Stage C), including construction works. The intervention will leverage potential synergies among city systems and include strong engagement activities, while works are appropriately commissioned by experts. Step 13 will take care of the operation and in-use period (13. ENSURE), ensuring a healthy lifespan of interventions, mainly through on-going commissioning, monitoring, users' training, and community-based initiatives. Once all data and performance results have been collected and analysed, it is time to assess the project and its impacts (14. ASSESS), according to performance indicators generated in Step 11. All data generated during the project can feed the city information open platform mentioned in Step 11, where the city can perform analyses for better decision-making as well as visualize data to inform the citizens. Step 15 will perform a project review (15. VALIDATE), checking the fulfilment of the project objectives and asking for feedback to key stakeholders, including citizens and end-users, industry, and academia. Through this review and the assessment of Step 14, the steering group (local partnership towards the SZCC) will be able to check if the interventions were aligned with the strategic plan and action plan at the city level (Step 5), and to what extent they have been successful and replicable. The final step of this third stage explores the replication potential of the process and implemented SZCC solutions, through local up-scaling strategies for the city (16. UP-SCALE), considering urban labs for replication and exploitation paths for local partners. The connection to European sources such as the SCC-1 solutions portfolio and SCIS (Smart Cities Information System, mentioned in Step 10), or initiatives such as C40 Cities [34] will always be helpful for further inspiration.

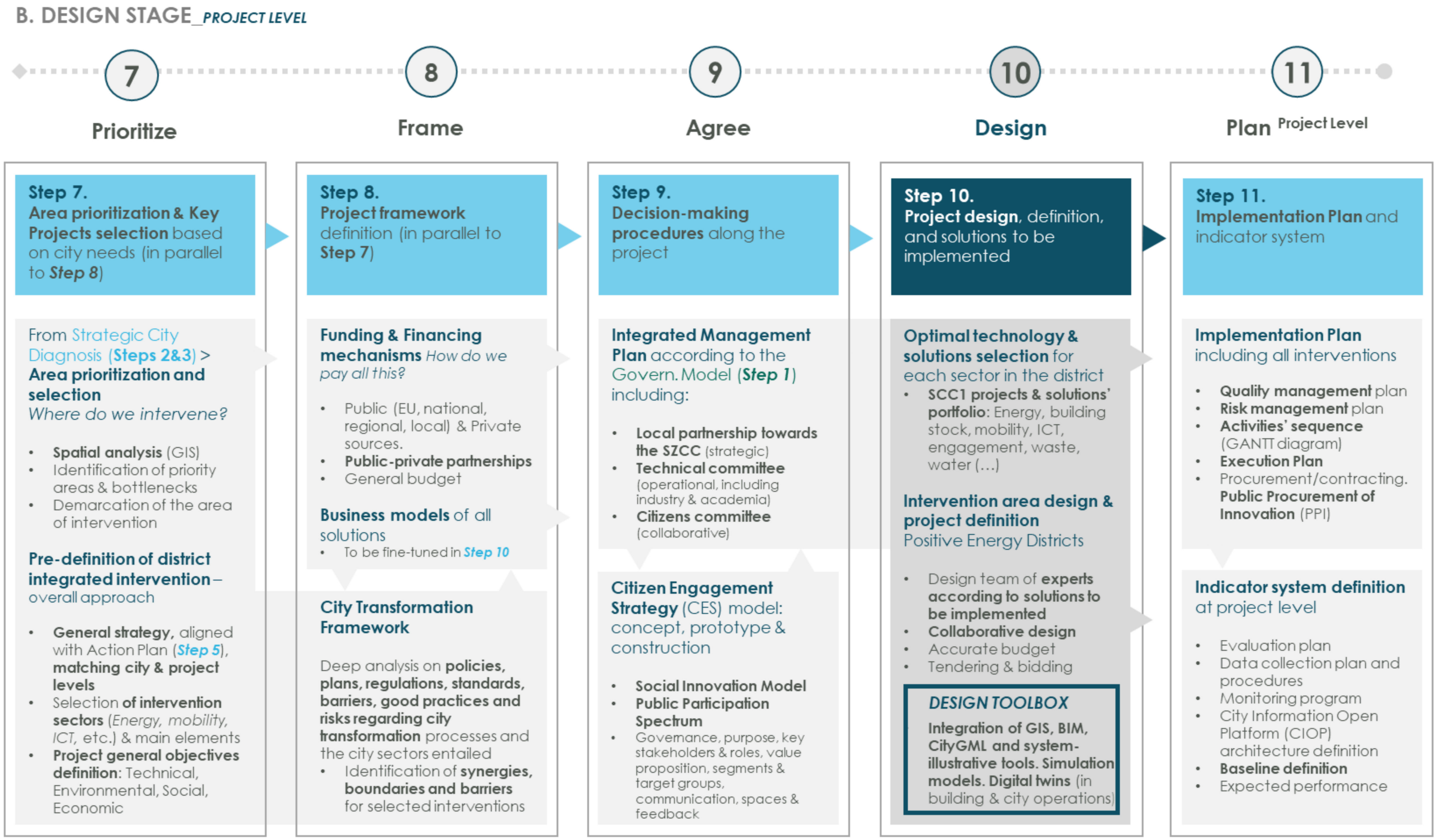

Figure 7. Wrap-up diagram from Cities4ZERO Design Stage.

Figure 8. Steps of Cities4ZERO Intervention and Assessment Stage.

This methodology will end with a final workshop steered by the local taskforce (LP towards the SZCC), reflecting on the next steps and future interventions. This workshop ensures the iteration of the whole process depending on city needs:

1. If the strategic plan and action plan are still considered valid after this process, and if an update is not yet necessary, the city can pick and develop new key projects coming back to Step 7 (7. PRIORITIZE), selected from the project list published in the action plan (Step 5).
2. In case the strategic plan and/or action plan are considered as partially obsolete, where an update is appropriate for a better project focus, the city can come back to Step 4 (4. ENVISION) and update its strategic planning process for a reconsidered planning umbrella (strategic plan and action plan).

This continuous iteration will readjust the focus of city projects and strategies towards the final SZCC goal.

STEP 12. INTERVENE. Intervention works and solutions deployment

After the strategic planning process and design of interventions, Stage 3 starts with the district integrated intervention, entailing execution works and the implementation of solutions according to planned schedules and requisites. Both for design, implementation, and assessment stages, BIM principles are highly recommended, fostering an integrated and effective deployment.

This intervention step, where the implementation plans become reality, involves a large variety of experts and technicians. Additionally, the coordination team at the city level will have to guard the correct deployment of the works and the overall economic control. At this stage, those experts appointed to follow-up the interventions will also take care of the adequate installation of the monitoring equipment and the data acquisition systems, to be able to measure performance and hence, appropriately assess interventions in the following steps. Regarding implementation expertise, the more prepared and skilled the workers and technicians taking the actions are, the bigger will be the guarantee of attaining the envisaged objectives. As in previous Step 11, suitable experts should be selected, internal or external, with the competences to address each action (energy, mobility, LCA—life cycle assessment, etc.).

Management aspects in this step are crucial. Works must be deployed on time and they need to comply with the requirements defined in previous steps to achieve the energy and emissions targets. Furthermore, the schedule and cost aspects must be guarded. Those are parallel aspects that have mutual implications, since delays on some works usually go hand in hand with cost increases. Delays in this step as well as in the tendering process are likely to happen—permits, potential industry/social resistance, saturation of the local market, etc., where predefined mitigation and contingency plans will be of considerable support.

In parallel to intervention works, intensive engagement and communication activities are highly recommended, according to the citizen engagement strategy developed in Step 9. This is identified as a key success factor, or even as an enabler, as in some cases, projects and solutions might not be feasible without the agreement of potentially affected citizens.

STEP 13. ENSURE. Operation and in-use; users' behaviour

Right after interventions are in place, the operation and in-use period starts. Here, ensuring a healthy lifespan of interventions is the main priority.

An ongoing commissioning will determine roles and responsibilities for each intervention. In this task, BIM models (digital twins) can significantly improve the operation and maintenance works, if we appropriately deploy sensors on buildings, infrastructures, vehicles, etc., as technicians will have a virtual update of all elements, simulating improvements or corrections, and finally implementing them in reality if considered beneficial. Furthermore, facilities management plans will provide protocols, key maintenance information, and end-user manuals, for an effective performance of all buildings and infrastructures deployed.

In line with this, the effectiveness of interventions may depend on end-user behaviour, which must be tackled by engaging them through training and communication activities. Here, community-based initiatives, economic incentives (or disincentives), and regulation modifications considering exemptions, agreements, pricing, etc., can be good tools for the correct use of interventions.

At this step, just right after the interventions, it is important to run performance tests and to start the monitoring period, which will allow data availability for assessment in Step 14. This will also allow one to certify the quality assurance of interventions.

STEP 14. ASSESS. Project evaluation and impact assessment

At this point, all interventions are finished and the data from each of them have been gathered for a significant period. Now it is time to find out if the actions have reached the expected results and the project goals in terms of energy performance or emissions savings; to calculate the LCA and the economic impacts; and to evaluate the social acceptance, among other parameters.

The process of assessing implemented actions needs the involvement of different experts on the different fields of evaluation for correct reporting and comparison. It is useful that, for some calculations, the experts are certified on an evaluation methodology (such as the International Performance Measurement and Verification Protocol—IPMVP, for example), to assure the quality of the work.

This assessment must go back to the set of key performance indicators (KPIs) already defined in Step 11, and using the data collected on the data-gathering period to calculate their values. These results can support an evaluation report, focusing on all key aspects, comparing the KPIs values before and after the intervention. At the city level, the obtained data can be contrasted with the indicators defined in Step 5. This comparison between before and after the interventions (PRE vs. POST interventions) will provide a good evaluation measure. It is important to stress that not all indicators are based on data gathered by technical equipment, but also from the citizens, tenants and the services' users. Data has been gathered, for example, through surveys, and needs to be analysed accordingly.

As a result of this process, a positive assessment supports the interventions developed, in case they have been correctly finished and good evaluation results obtained. But even if the results are not as expected, a correct assessment is still valuable, as it is the way to ensure better results in future interventions and corrective actions, if possible. The main challenge at this step is to have a complete and good quality set of data. This means a significant workload in previous stages.

All generated data in this step can feed the city information open platform (CIOP) described in Step 11. Through this new city tool, a CIOP catalogue of potential services can explore the applicability of the integrated data generated in the project.

STEP 15. VALIDATE. Project review; main learnings and reflections

Finally, after planning a healthy lifespan for interventions as well as assessing them, the project has come to its end. It is time to reflect and perform a project review. This review will check if the project objectives stated in Steps 7 and 10 have been fulfilled. For instance, the SmartEnCity project objectives were split into four main categories: technical, environmental, social, and economic objectives.

For a comprehensive review, general and specific feedback from key stakeholders can reveal critical factors; successful ones as well as barriers. The main groups to be asked are citizens and end-users; practitioners and experts; city administration; private sector; and academia.

With all this information, after assessment on Step 14 and project review, the local partnership towards SZCC will be able to check and validate if the interventions were aligned with the strategic plan and action plan at the city level (Step 5), and to what extent they are successful and replicable. What was successful? What might have been done better? From this reflection, key barriers, success factors, regulatory inputs, and potentially exploitable results can be extracted for future projects in the city.

STEP 16. SCALE-UP. Up-scaling in the city and next steps

The final step of this third stage and Cities4ZERO methodology explores the replication potential of the process and its implemented SZCC solutions. This is done through local up-scaling strategies for the city, considering urban labs for replication in other areas of the city (prioritization in Step 7/citizen engagement strategy in Step 9), and through exploitation paths for local partners (business models, incubators, accelerators, public-private partnerships, etc.).

As mentioned in the introduction of this third stage, Cities4ZERO methodology will end with a final workshop steered by the local partnership towards SZCC, reflecting on the next steps and future interventions. The thematic working groups set in Stage A for city diagnosis and envisioning processes (Steps 3 and 4) can provide valuable sectorial input. This workshop ensures the continuous iteration of the whole Cities4ZERO strategic process depending on city needs, readjusting the focus of city strategies and projects towards the final decarbonization goal and the evolving urban context:

1. If the strategic plan and action plan are still considered valid after this process, and if an update is not necessary, the city can pick and develop new key projects, coming back to Step 7 (7. PRIORITIZE), selected from the project list published in the action plan (Step 5).
2. In case the strategic plan and/or action plan are considered to be partially obsolete, where an update is appropriate for a project's improved focus, the city can come back to Step 4 (4. ENVISION) and update its strategic planning process for a reconsidered planning umbrella (strategic plan and action plan).

A wrap-up diagram of the Cities4ZERO Intervention and Assessment Stage is presented in Figure 9.

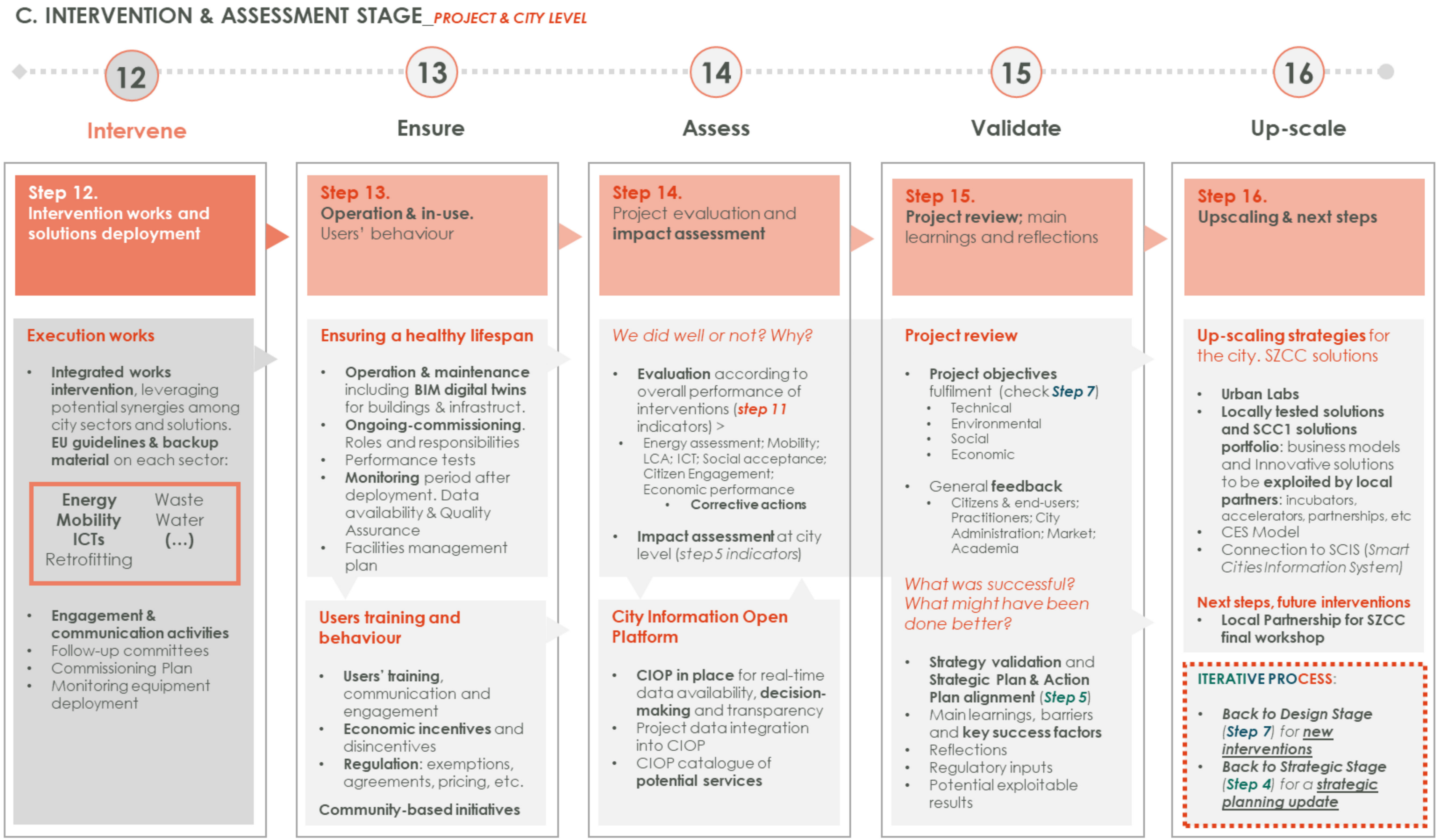

Figure 9. Wrap-up diagram from Cities4ZERO Intervention and Assessment Stage.

4. Discussion

4.1. Wider Support for Cities

In this environmental crisis, supporting cities is the priority, as local governments are uniquely positioned to enable urban decarbonization, according to their various capacities: as planners and regulators, as facilitators of finance, as role models and advocates, and as large consumers of energy and providers of infrastructure and services [35]. If they are stably committed, the rate of potential success is high for the following decades.

As mentioned above, the Covenant of Mayors being one of the most known initiatives to tackle climate change through reducing CO_2 levels in territories, brings together local and regional authorities across Europe, who give a voluntary commitment to implement energy, climate mitigation and sustainability policies on their territories, has already over 10,075 signatories, with over 6447 SEAPs/SECAPs submitted. Signatories already use the SEAP/SECAP, not only as an energy planning instrument, but also as the basis for an all-encompassing approach to urban planning, as highlighted in the Covenant of Mayors' evaluation report [36]. However, several evaluations of SEAPs and later SECAPs agree that more guidance could be provided to cities to help them address in a more effective way; all the key sectors of activity as the strategic dimension in the urban planning system is still often missing or weak [36–40]. Additionally, evaluations show that especially regarding aspects related to governance (e.g. the adaptation of administrative structures, the mobilization of civil society, or the SEAP monitoring process) and to the financing of actions, municipalities' plans generally show some weaknesses and are lacking tailor-made strategies to ensure citizens' and stakeholders' participation or assigning clear roles and responsibilities to municipal officers. Weaknesses also lay in how the plans are implemented and monitored and in the inconsistency of data [36]. There is room for supporting municipality representatives, planners or developers for a carbon-free urban transition and to provide them with the necessary tools to help cities and local governments reach their own goals of decarbonization in the near future.

Considering the challenges related to cities' high energy demand and carbon production, ways related to the development of energy-efficient urban areas are searched for everywhere; we need cities that are sustainable, smart and resource-efficient and, as argued in this article, who are willing to transform into Smart Zero Carbon Cities. Moreover, climate change is not only the issue for megacities and big urban centres; climate targets, and the need to implement sustainable development goals, are challenging each local government, despite their size [38]. As also admitted by an in-depth analysis of SEAP/SECAPs in the EU [36], smaller municipalities present a more accurate evaluation of the reality of the city and may therefore produce more efficient measures. Smaller municipalities may also benefit from more direct contact with the public and stakeholders and run more successful awareness-raising campaigns, which are an important part of every holistic approach to the city transformation process [36].

In particular, it is important for municipalities to focus on proper engagement activities for creating a sense of joint ownership of the whole transformation process. This exactly addresses the weaknesses that have been identified in numerous SEAPs and SECAPs [36]. As quoted by the representative of the city of Tartu, that is currently finalizing its integrated energy action plan following Cities4ZERO methodology:

> The main value for Tartu in this process has been in creating a community of similarly motivated stakeholders. The process demands a lot of effort and communication and may prolong the planning process. But at the same time, it creates an emotionally and intellectually invested group of stakeholders. It will eventually give a planning document the stakeholder support it needs to succeed.

By following Cities4ZERO, Vitoria-Gasteiz ended up with a very detailed baseline analysis and successful engagement of key stakeholders to jointly work towards the vision. Sonderborg involved almost 100 stakeholders from different sectors, who participated to create a concept that will drive the entire decarbonization process. All cities in the project are outstanding examples of how a local authority can take the lead in mobilizing different stakeholders to find mutually advantageous solutions for transformation. Cities4ZERO methodology also helps to address the need for coordination with other local strategies, initiatives, projects, and departments, to avoid foreseen barriers, as well as to leverage potential synergies in the local context.

All municipalities that were part of this research were facing common challenges and solutions in this urban transition and all concluded that integrated planning implies the commitment of different stakeholders, and the consideration of all dimensions of a problem (social, environmental, technological and economic parameters) is vital to determine the most appropriate solutions. In particular, it is critical to consider at all stages how different social profiles might be engaged in the process, concerning their socio-demographic, socio-economic, and cultural profiles. Some groups will be more difficult to engage than others, so messages and media will have to be tailored to different cultural standards, languages (i.e., for immigrants), formats (i.e., digital or analogical for the elderly), etc. Moreover, different interest groups will emerge (for example, those willing or not willing to retrofit their residential buildings, those willing to foster electric mobility infrastructure, etc.), and conflicting interests will have to be tackled and discussed. In terms of environmental parameters, not only energy will come into the equation, but also air quality and noise issues, ecology, and footprint of materials, as well as their contribution to higher resilience to climate change, for example.

At the time of revising this article, a global pandemic outbreak, namely COVID-19, has completely changed our perspective as a species. All aspects of our living will need revision, urban planning for energy transition certainly being one of them. In general, we are rapidly learning that qualitative analysis will need to be made quantitative, to provide a definitive assessment of the phenomena and their impacts, to be prepared in the future.

4.2. Towards Deeper Integration (Horizontal and Vertical)

Local authorities are experiencing increasing pressure to develop and implement innovative solutions to provide high-quality services and living environment with less resources, but their capacity to do so remains limited. In order to move towards the zero-carbon vision, it is not enough to implement individual solutions or single improvements without a wider vision. Success rather lies in an integrated approach as a system of interlinked actions—profiting from modern ICT tools, massive data production and analytical capacities, diversifying energy production with renewable energy systems, transforming the structure of energy production for enabling small-scale production, identifying the right business models, supporting changes with administrative and taxing practices, shaping user behaviours, etc. Decarbonizing cities involves numerous interrelated challenges and requires systemic and interconnected solutions.

Although the concept of integrated urban development is not new, "thinking in silos" is still common in too many municipal administrations. Often, individual sectorial strategies do not consider co-dependencies or interdependencies with other city systems. This not only leads to conflicts of interest, but also falls short of addressing cross-sectoral challenges [39]. Consequently, to address these challenges, a holistic strategic approach is vital. This can address each challenge individually and systematically. It could take the form of a city journey where a city would begin with basic steps, for example by defining a framework strategy, and advancing with time to address the more difficult challenges. "The city journey should preferably be underpinned by a long-term vision, designed as a shared roadmap to break through both time and human-related barriers." [40]. Such a strategy would need the approval of the relevant city systems, actors, governance levels, and territories, and would be jointly developed by these different actors. Making sure that everyone is on board is important, because integrated urban development goes beyond merely coordinating sector policies and interest groups. It presumes a common understanding of the mid- and long-term development goals, which should be jointly developed. Such processes beyond administrative boundaries require political and institutional changes. At the same time, local governments need to be provided with incentives that promote integrated approaches and strengthen their capacities, so that they can deal with interdisciplinary tasks [39].

As can be recalled from the name, Cities4ZERO proceeds from an integrated urban regeneration model that focuses on the concept of Smart zero carbon cities, i.e., cities that have zero carbon emissions on an annual basis. This article releases this novel, simple and iterative integrated approach for local governments, by explaining the essence of each step. Each step, as described in more detail in the Section 3 "Results", has its unique setting and elements which should be considered, but all are also very much interconnected. Moreover, experience among cities in the SmartEnCity project shows that this model effectively helps to achieve integration in urban planning, especially 1) through an important emphasis on stakeholder engagement; 2) among city systems and within planning structures; 3) with other government scales (Table 5).

Table 5. Cities4ZERO reinforcing energy planning and urban planning local integration for cities decarbonization.

INTEGRATION THROUGH LOCAL STAKEHOLDERS' ENGAGEMENT
STEP 1. Governance model definition and local taskforce foundation (institutional analysis) **STEPS 3–5.** Shared vision and strategic planning among key local stakeholders **STEP 9.** Decision-making procedures and agreements along each project (local community) **STEPS 12–13.** Engagement activities during implementation and end-users' training **STEP 16.** Shared reflection for next steps and future decarbonization interventions
HORIZONTAL INTEGRATION AMONG CITY SYSTEMS AND WITHIN CITY PLANNING STRUCTURES
STEP 1. Foundation of a local task force, stable in time engaging diverse expertise **STEPS 2–3.** Shared sectorial analysis and diagnosis from an integrated perspective **STEPS 4–5.** Strategic planning, integrating all sectorial perspectives from vision to action plan **STEP 6.** Integration of action plan outcomes into city planning procedures (integration booklet) **STEPS 7–11.** Design stage is conceived as an integrated process where all city systems and stakeholders converge once the project and the area of intervention are selected: general strategy (7), financing and overall framework (8), design and solutions (9) and implementation plan (10) **STEPS 12–14.** Interventions are planned and executed, considering potential synergies and barriers among sectorial projects (12); commissioning, and assessing the project as one package. **STEPS 15–16.** The integration becomes multi-scale, when project validation means a partial city strategy validation (15), and successful interventions can be applied transversally in the city, stimulating even different sectors of the city (16)
VERTICAL INTEGRATION AMONG PUBLIC AUTHORITIES FROM OTHER GOVERNMENT SCALES (REGIONAL, NATIONAL, EU)
STEP 1. Governance model definition, including multi-level governance mechanisms **STEPS 2–3.** Analysis of regional, national and European strategies, including the external global city trends that may affect the city in the coming years as part of the diagnosis **STEP 4.** Involve regional agencies' stakeholders in the visioning task **STEP 5.** Local planning considering regional, national and EU initiatives, looking for synergies that potentially enable a more straightforward implementation of the actions identified **STEP 6.** Municipal integration involving regional agencies when urban competences require this **STEPS 7–12.** Project collaboration of regional agencies when urban competences require this **STEPS 15–16.** Involvement of regional agencies in the upscaling task. Coordination with national and European best-practices repositories, facilitating the exchange of knowledge among cities. This contrast will enrich the iterative city strategic planning process

Moreover, while inevitably posing a considerable challenge for cities, successful integrated urban planning leads to many benefits [39]:

- It allows cities to formulate cross-sectoral goals and to develop monitoring systems for cross-cutting policy fields, such as how to efficiently use natural resources, or reduce socio-economic disparities;

- It enables cities to develop strategies and projects that involve the knowledge and perspectives of different disciplines and actors from the civil and private sector;
- It helps cities with limited budgets and capacities to implement their goals more efficiently by joining capacities and funds, and by reducing trade-offs between sectors and neighbouring municipalities.

5. Conclusions

Considering the importance of cross-sectoral solutions and coordination, the inclusion of relevant actors, coordination between different levels of government, and balanced territorial development, this article presented Cities4ZERO methodology—a theoretical framework for decarbonizing cities through a valuable holistic and system-thinking approach. Within the SmartEnCity project, five cities have worked closely towards developing and putting the approach into practice, and almost 60 cities through the SmartEnCity Network have already started implementing the approach in their local settings. The application of this theoretical framework is mobilizing all these cities towards their potential decarbonization in the coming years, allowing further studies from the diverse local degrees of application and results obtained. So far, Cities4ZERO has proved the ability to engage cities through this solid theoretical framework; a framework cities find understandable and applicable, as well as valuable for them, according to the number of cities already following its steps [25].

5.1. A Community of Practice with Shared Methodologies and Tools

As zero carbon transition should be on the agenda of almost every municipality in the world, there are many initiatives supporting this transition. Next to the mentioned Covenant of Mayors, the EU initiative EIP-SCC platform intends to engage cities, industries, SMEs, investors, and researchers, bringing them all together to design and deliver smart-sustainable solutions and projects. From a narrow techno-economic perspective, a smart city programme aims to encourage the replication of technological solutions, but

> smart city solutions are rarely a simple product or service. They often consist of complex urban interventions involving many different parties, each one with specific interests, agendas, and capacities. Everything must be there, at the right place, in the right moment: the technologies, the business models, the favourable legal context, the governance structure, social acceptance, user motivation, capacities and knowledge, budgets, aligned agendas, etc. [40]

This is exactly why the SmartEnCity project focused more on creating a comprehensive strategic toolbox for municipalities through examining planning, implementation, monitoring, and replication works, to identify the key factors playing a most important role towards smart urban decarbonization, reviewing an ongoing process of five years of coordinated initiatives in the cities of Vitoria-Gasteiz (ES), Tartu (EE), Sonderborg (DK), Lecce (IT) and Asenovgrad (BG) and ended up with Cities4ZERO. Applying a strategic and integrated urban planning approach in the city can be an efficient way to create a platform that supports increased connections and relations between the relevant stakeholders of the community and energy system, and to support the implementation of integrated solutions. As learned from the research, a key functionality of such a process is to activate and engage relevant stakeholders, to enhance cross-sectoral thinking among the stakeholders, and to expose varying interests and agendas. All of this has a central position in Cities4ZERO. Acceptance and support from the local stakeholders as well as generating a common reference point (i.e., energy plan and /or integrated urban plan agreed among stakeholders) for the transition of the city energy system are two of the main aims of the process, as this is necessary to form a basis or platform for increased co-operation in interconnected zero-carbon transformation processes.

5.2. The Way forward: Local Stakeholders Engagement and Digital Technologies for Improved Energy Planning

As already evident, the concept of Smart Zero Carbon Cities is a complex and multi-layered one, involving a lot of planning, risk analysis, public sector initiative, and stakeholder involvement to truly benefit the city. Transition in practice also requires large-scale investments for replacing the infrastructure and capital goods; all of these efforts are crucial as European cities are at the forefront in the shift to a low-carbon economy. Bulkeley et al. note the criticality of municipalities' actions to low-carbon transition, especially being dependent on some new starting points [41]:

1. We cannot invent our way towards a low carbon future without also engaging society—the sorts of changes that are required to urban infrastructure networks require not only new technologies, but also new forms of investment, new practices of energy use and new ways of working between the public and the private sector.
2. Responding to these challenges requires not only capacity at the urban level and a proactive political climate, but also a willingness to create new forms of knowledge about cities and to operate beyond established practices and ways of doing things.
3. Bringing transition to the city reminds us that what is at stake is not a simple choice between different paths to the future, but rather a complex and negotiated process—creating spaces in the city where diverse social interests can articulate and experiment with their visions for the future is a pressing policy challenge.

Regarding this engagement process, Steps 3 to 6 in Cities4ZERO are key (DIAGNOSE, ENVISION, PLAN $^{\text{CITY LEVEL}}$, INTEGRATE), as they steer the co-development of the long-term city strategy, identifying the key projects to be developed, involving key local stakeholders in the visioning and planning process, and ensuring their commitment in a potential implementation and its integration in the planning procedures of the city. An in-depth analysis and further development of these steps will allow one to reinforce the whole transition, spreading the shared commitment feeling among the local community.

Furthermore, focusing on city modelling for decision-making processes, municipalities would benefit from an ICT tool able to integrate energy and decarbonization mapping with spatial planning (GIS-based), helping to visualize the affection and spatial implications of decarbonization actions, so that they can be better integrated in future local policies, general/sectorial plans and projects. This is a future research line for the authors, as it would be of great support in the Cities4ZERO steps dealing with the diagnosis (2, 3), planning (5), integration (6), prioritization (7), design (10), assessment (14) and up-scaling of solutions (16), significantly supporting the decarbonization process of the city.

Finally, as participants in the SmartEnCity project, research will still gather valuable experience and new evidences of Cities4ZERO performance during the coming years, especially through Cities4ZERO Steps 7-16, an in-depth analysis of the whole methodology in practice will be considered. This theoretical framework developed over the years working with different cities will continue its implementation, monitoring, and evidence collection, which will enable its further refinement and consolidation.

Supplementary Materials: The City Check-up Assessment methodology for municipalities is available at http://www.mdpi.com/2071-1050/12/9/3590/s1, Figures S1–S9: Cities4ZERO final Diagrams.pdf, Tables S1–S5: Cities4ZERO final tables.pdf.

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ENER-BI: Integrating Energy and Spatial Data for Cities' Decarbonisation Planning

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Abstract: Given the current climate emergency, our planet is suffering. Mitigation measures must be urgently deployed in urban environments, which are responsible for more than 70% of global CO_2 emissions. In this sense, a deeper integration between energy and urban planning disciplines is a key factor for effective decarbonisation in urban environments. This is addressed in the Cities4ZERO decarbonisation methodology. This method specifically points out the need for technology-based solutions able to support that integration among both disciplines at a local level, enriching decision-making in urban decarbonisation policy-making, diagnosis, planning, and follow-up tasks, incorporating the spatial dimension to the whole process (GIS-based), as well as the possibilities of the digital era. Accordingly, this paper explores the demands of both integrated urban energy planning and European/Basque energy directives, to set the main requisites and functionalities that Decision Support Systems (DSSs) must fulfil to effectively support city managers and the urban decarbonisation process.

Keywords: decarbonisation; urban transformation; cities; decision support system; energy transition; strategic planning; smart cities; smart zero carbon city; digital innovation

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1. Introduction

Cities are progressively growing, in terms of population, economic growth, logistics, knowledge, and social interaction—this has been a consolidated trend during the last century. In connection with this, cities have also become nodes of energy consumption, pollution, and public health concern [1–3]. Furthermore, cities are increasingly being exposed to impacts from pandemics and climate change. To partially tackle these challenges, cities intend to address the urgent need of decarbonizing their urban environments.

To guide local authorities in the decarbonisation process, the authors of this study published the Cities4ZERO methodology, a step-by-step strategy that is able to guide decision-makers through the process of developing the most appropriate plans and projects for an effective urban transition, from an integrated, participatory, and cross-cutting planning approach [4]. The study intended to provide a deeper integration among urban planning and energy planning dynamics, a key factor in the decarbonisation process [5,6]. It also suggested the need for technology-based solutions, able to support that integration among both disciplines, enriching decision-making in urban decarbonisation policy-making, diagnosis, and planning tasks, incorporating the spatial dimension (Geographic Information System-based; GIS-based) to the whole process.

The focus of this research is to explore the following questions: what requirements and functionalities should that technology-based solution consider in order to support local authorities in effectively coping with the steps towards urban decarbonisation? What are the characteristics a Decision Support System (DSS) should have to help municipalities in the integration of energy and urban planning disciplines? Within municipalities, information for crosscutting tasks, such as decarbonisation planning, is often scattered and incomplete. Significant decisions are not made based on data—there is a general lack of integration. Relevant competences are fragmented; an intuitive and open-source software would be key to support this upgrade of crosscutting planning procedures.

Diverse urban energy planning tools have been developed. However, there is a gap in the decision-making chain between too technical, project-oriented engineering energy tools, and the discussions of urban planners around 2D city maps, which are not connected to databases. The current digital era offers the possibility of having access to automatic updatable real data from the urban environment (Internet of Things—IoT/sensors) as well as to automatize calculation processes connected to urban energy planning (algorithms); all of this presented (and able to be analysed) in a georeferenced manner (GIS-based). Therefore, this research aims to define the required main features to conform a data-based decision-support tool for integrated urban decarbonisation planning, which the authors have named ENER-BI. This acronym combines the urban energy analysis potential of the presented DSS with a Business Intelligence (BI) dashboard format, including the management, visualization, and data updateability possibilities of PowerBI software, which is also able to process and display georeferenced information, a crucial aspect in urban decarbonisation planning.

Regarding the content of the following sections: the Materials and Methods section delves on current sustainable energy directives of the European Union (EU) and the legal framework for the regional case of the Basque Country (Spain), extracting elements that ENER-BI DSS must provide from a legal perspective. Furthermore, this section presents the steps ENER-BI must cover in low-carbon city planning, as well as an analysis of the existing tools in the market. This section also describes the process followed by the research team, to identify the requirements and functionalities of ENER-BI from a DSS perspective, which are both presented in the Results section. Finally, the Discussion section argues for the adaptability of ENER-BI to municipal environments and the implications of such a DSS in the transition towards the decarbonisation of cities, presenting future lines of research in the field.

2. Materials and Methods

2.1. Identifying Requisites and Functionalities from a DSS Perspective

The process followed by the research team to identify the requirements and functionalities from a DSS perspective is structured in 5 tasks: (1) review of regulatory framework and tendencies in a European energy context; (2) selection and analysis of most CO_2-emitting city systems and the data entailed (building stock, transport, public lighting, etc.); (3) identification of ENER-BI DSS structure and contents (algorithms and processes); (4) identification of requisites for ENER-BI DSS; (5) real-data test development to deepen in requirements and a user-friendly interface.

The first task, framed in Section 2.2.1, begins with the analysis of current sustainable energy European Union (EU) directives and the regional case of the Basque Country, complemented with other regional regulations in Spain. This regulatory analysis pointed the most CO_2-emitting sources from public administration and the main city systems to be addressed by ENER-BI DSS from the collective perspective: public building stock and facilities, public lighting, and public transport and fleets. In addition, due to its significant impact on city energy consumption, private building stock was also born in mind. Regarding other CO_2-emitting private sectors, such as private mobility, real-data availability was an issue; hence, estimations were calculated according to other reference factors (traffic intensity, fuel imports, etc.).

According to regulation requirements (task 1) and the decarbonisation targets identified (task 2), a group of multidisciplinary experts in energy efficiency identified the structure and contents for ENER-BI DSS (task 3—urban planners, energy engineers, GIS experts, physicists, and sociologists). The resulting structure, explained in detail in Section 3.2, is composed by three modules: module (0) inventory, characterisation, and monitoring; module (1) scenario generation for decarbonisation planning; and module (2) decarbonisation follow-up. For these modules, the contents were defined (algorithms and processes), the main sources of information and its requisites were identified (disaggregation degree, georeferencing, periodicity, format, structure, etc.) as well as the storage procedures, treatment and representation/visualisation (task 4).

Delving in the requisites identified in task 4, the research team developed a set of tests including real data from different sources (municipal samples of public transport and public lighting data, dynamic energy consumption data from private buildings, a georeferenced inventory of buildings from a city, cadaster, and other public sources of data). These sources come from diverse cities/contexts and were used only as a test to face the different information treatment problems of each source. These information sources were processed with diverse software tools to identify the potential requisites and functionalities of ENER-BI DSS: QGIS and PowerBI to test data processing needs; Influxdb, PostgreSQL, and Postgis for database connections; EnergyPlus and EnergyPLAN for delivering energy and CO_2 hybrid data-model Key Performance Indicators (KPIs), and business intelligence and three-dimensional (3D) models for visualisation.

2.2. Literature Review for a Conceptual Framework

The requirements and functionalities of the targeted ENER-BI DSS are mainly conditioned by (a) existing energy regulation; and (b) strategic planning procedures connected to the decarbonisation of cities.

2.2.1. Regulatory Framework

Regarding the regulatory framework, the ENER-BI DSS must be able to provide a robust energy GIS-supported baseline for the city, as well as enable planning and monitoring of city strategies towards decarbonisation. Ambitious European directives and national/regional regulation demand specific decarbonisation targets and plans, as the main reference at an international level, which need the support of ENER-BI DSS to be quantitatively achieved.

The EU, in line with its commitment to fight against climate change and in search of a competitive and low-carbon economy, published the Climate and Energy Framework (with key target for 2030), which seeks to continue reducing greenhouse gas (GHG) emissions by at least 40% by 2030, compared to 1990. In September 2020, the European Commission (EC) proposed updating this target to 55% as part of the European Green Deal, increase the share of renewable energy consumed (by 32%), and improve energy efficiency (by 32.5%). Given that the building sector is the main energy consumer in the EU (where buildings are responsible for approximately 40% of energy consumption and 36% of CO_2 emissions, and where 75% of the building stock is considered energy inefficient), the European directives on the Energy Performance of Buildings (EPBD) and Energy Efficiency (EED) have recently been updated (EU Directives 2018/844 and 2018/2002, respectively) as part of the legislative package “Clean Energy for all Europeans”. Altogether, the directives promote policies that help to achieve a decarbonised and energy-efficient building stock by 2050, to create a stable environment that is conducive to investment, and to empower consumers and businesses to make informed decisions to save energy and money.

At a specific regional level, and aligned with these European directives, the Euskadi Energy Strategy 2030 (3E2030) establishes the intensification of energy efficiency actions in all consumer sectors, the penetration of alternative energy in transport, and the increasing use of renewable energy. For all of these reasons, the Basque Parliament approved, last year, Law 4/2019 on Energy Sustainability of the Basque Community [7], as an example of regional EU directives transposition, which seeks to establish the regulatory pillars of energy sustainability in the areas of Basque public administration and the private sector, aimed at promoting energy-saving and efficiency measures, and the promotion and implementation of renewable energies. This kind of regional regulation is crucial to understand ENER-BI DSS requirements, as it states a concrete case of energy requirements for municipalities within the EU, much more specific and closer to implementation than EU directives.

2.2.2. City Decarbonisation Planning Framework

Regarding urban energy planning procedures, the Energy in Buildings and Communities (EBC) Programme of the International Energy Agency (IEA) analyses, in Annex 63, the importance of optimising existing local instruments, processes, and frameworks to effectively support the implementation of energy and decarbonisation strategies in our communities [8].

In this sense, the Cities4ZERO methodology describes, sequentially, through 16 steps, the main elements to be covered by a decarbonisation process, both at city and project levels [4]. Within these steps, ENER-BI DSS can allow integrating energy and urban planning information to provide relevant data for decision-makers, mainly in the following tasks:

- Inventory and characterisation of the city (ANALYSE—Step 2 from [4]); mainly focusing on providing and integrating data of the most CO_2 contributing sectors (building stock, mobility, and public lighting).
- City diagnosis in decarbonisation terms (DIAGNOSE—Step 3 from [4]); identifying the key local strengths and weaknesses, as well as the main opportunities and threats, for the future, integrating spatial quantitative and qualitative data in the development of such city diagnosis.
- Generation of future scenarios and consensus on city visioning (ENVISION—Step 4 from [4]); generating urban energy models to study and discuss the future implications of present decisions.
- Strategic planning (PLAN $^{\text{CITY LEVEL}}$—Step 5 from [4]); enriching with spatial and quantitative data the impacts forecasted for the actions to be developed, described in the current plans.
- Follow-up, assessment, review, and potential up-scale of actions and plans developed in the city (ASSESS; VALIDATE; UP-SCALE—Steps 14, 15 and 16 from [4]); ensuring a close commissioning and post-intervention development, exploring potential replication of successful actions in other areas of the city.

2.2.3. Urban Energy Planning Tools

IEA-EBC's Annex 63 also claims for data certainty, which will reinforce improved decision-making, as well as the public acceptance of those urban energy planning decisions. In this sense, Planning and Decision Support Systems (PDSS) are encouraged to integrate spatial (GIS-based), technical, and local information to guide and support the decision-making process. Furthermore, these kinds of tools will be able to evaluate the performance of decarbonisation policies incorporating the spatial variable, following their effectiveness up at the city and regional levels [8].

In recent years, in parallel to the popularisation of energy efficiency and renewable technology integration concepts in the urban environment and the increase of distributed energy resources (DER), several software tools were developed for urban energy planning. Available review studies assess these tools [9–15], which present diverse approaches, functionalities, scales, and often focused on the DER aspects. In particular, Ferrari et al. [16] carried out a comprehensive review of 17 well-documented energy assessment tools at urban/district scale, classifying them according to their features (license type, user-interface, output time resolution, energy services, scale, analysis type). Among them, six tools with good usability level and user-friendly interface were identified as the most appropriate ones for energy planners: EnergyPLAN, energyPRO, HOMER, iHOGA, SIREN, WebOpt. Some of these tools, such as iHOGA and SIREN, are oriented to renewable electricity production, while other ones include also heating and cooling services, being Energy-

PLAN the one that covers the widest variety of energy supply technologies. On the other hand, spatial representation features are included in energyPRO, iHOGA, and SIREN, such as geographic localisation of the case study and relations to environmental conditions (i.e., solar resource estimation based on latitude), but do not address urban geography in detail, information such as the geometric distribution of buildings and urban elements, not tapping into the potential of georeferenced information. Finally, these tools enable various grades of complexity in modelling energy projects and results' assessment, but require gathering and manually introducing correct datasets from the case study, along with profiles selection, which is time-consuming, and, in case of wrong assumptions or poor inputs, leads to deviated energy analysis outputs and incorrect conclusions for the decision making.

After all, the digitalisation of the building sector and the spread of IoT connected devices are main attributes of smart buildings and smart cities, which lead to automatic data generation and gathering processes that energy planners should take advantage of. These urban asset data sources should be combined with complementary sources under Open Data initiatives for a holistic analysis (i.e., Copernicus [17]; governmental open data initiatives [18]).

Along with this, an urban decarbonisation tool should exploit real data from smart devices, which, combined with georeferenced information of the sources, loads and decarbonisation targets, and additional data sources should be processed for an integrated and georeferenced urban energy analysis, enriching an assessed decision-making.

3. Results

Following the workflow described in Section 2, Results presents the requisites and functionalities from a DSS perspective that must be regarded in the generation of a tool able to support strategic city decarbonisation processes.

3.1. ENER-BI DSS for Urban Decarbonisation Planning: Main Requisites

In terms of requisites for ENER-BI DSS, the aforementioned tests from different sources allow to distil those requisites according to the following sections:

3.1.1. Information-Gathering as Input for ENER-BI DSS

The information is divided into two subsections; information needed by the decarbonisation target (Table 1), and complementary information for urban analysis that can contribute to a more integrated decision-making process by planners (Table 2). In this information-gathering process, and depending on the topic, local authorities will have to retrieve and integrate data from both public sources, often more easily accessible [19]; and private sources, which can become challenging sometimes.

Table 1. Information needed by decarbonisation target.

Decarbonisation Target	Information	Disaggregation Degree	Format	Periodicity
Public buildings	Building characteristics (i.e., age, indoor area, typology, energy certification)	Building	Georeferenced database	Yearly, at least
	Electricity consumption	Electricity meter/supply point	.txt, .csv or database	Monthly/hourly [1]
	Gas consumption	Gas meter/supply point	.txt, .csv or database	Monthly
	Other energy carriers' consumption (i.e., District Heating)	Meter/supply point	.txt, .csv or database	Monthly
Public facilities	Electricity consumption	Electricity meter/supply point	.txt, .csv or database	Monthly/hourly [1]
Public lighting	Electricity consumption	Lamppost/ node of lampposts	.txt, .csv or database	Monthly
Public transport and fleets	Fuel consumption and Kms	Vehicle by type of fuel	.csv or database	Monthly
Private buildings	Geometry of buildings	Building	Georeferenced (.shp, .gml, etc.)	Yearly
	Characteristics: use, no. of floors and dwellings, effective m^2, year of construction, inhabitants	Building	Georeferenced database	Yearly, at least

[1] Increase of smart electricity meters allow to gather hourly data, which can be of interest for specific scenarios analysis (i.e., photovoltaic (PV) self-consumption promotion, demand aggregation).

Table 2. Complementary information for urban analysis.

Topic	Information	Disaggregation Degree	Format	Periodicity
Ageing population	% Population >79 years [20]	Census track	Georeferenced (.shp)	Annually
Socio-economic deprivation	% low-income population	Census track	Georeferenced (.shp)	Annually
Unemployment	Unemployment rate	Census track	Georeferenced (.shp)	Annually
Living conditions [21]	Average of occupants per dwelling	Census track	Georeferenced (.shp)	Annually
	% of rented dwellings	Census track	Georeferenced (.shp)	2, 5, or 10 years (depending on the availability)
	% of dwellings without heating system	Census track	Georeferenced (.shp)	
	% of dwellings with bad conservation status	Census track	Georeferenced (.shp)	

3.1.2. Information Storage

Regarding the information gathered, ENER-BI DSS combines different kinds of information; static, dynamic, and georeferenced; and consequently, diverse formats of information (.csv, .shp, .gml, etc.).

Static Information

It consists of information that is not going to change over time. It includes the georeferenced structural information, as well as the semantic one for characterisation. The elements that are going to be part of this set of information are public buildings and facilities, private buildings, and public lightning furniture. For instance, metadata for building characterisation includes cadastral data, typology, number of floors, area, use, height, number of dwellings, roof type, heating system, etc. For lightning, the metadata associated entails features, such as the type of lights, height, support, power, life expectancy or lumens.

The selected information allows creating a 3D City Model that will be stored following the Open Geospatial Consortium (OGC) CityGML standard data model [22]. Once created, these data model will then be included in a 3D City Database. A correctly georeferenced model is crucial, as many of the indicator results rely on the localisation of the assets on the field.

Finally, access to the city model can be enabled by publishing the data through a Degree Server. This server must implement the OGC Standards, such as Web Map Service (WMS), Web Feature Service (WFS), Catalogue Service (CSW), Web Coverage Service (WCS), Web Processing Service (WPS), and Web Map Tile Service (WMTS); these allow geoprocessing operations more efficiently. Furthermore, and for visualisation purposes, it is possible to directly convert the City Model (including semantic data) to KML or 3DTiles.

Dynamic Information

This information is changing over time, such as the large amount of data that will be generated by the IoT devices or sensors used to monitor the state of the area of interest at any given time, or to implement temporal series; e.g., building energy consumptions.

To store dynamic information, it is essential to use a database designed to handle this kind of data. In this case, InfluxDB would be appropriate as it is designed and optimized to store time series and manage them efficiently. The access and manipulation of these data can be done through the InfluxDB API (Application Programming Interface); InfluxDB can connect with sensors, through the API, and store their data. However, in most cases, a pre-processing task is needed to adapt raw data to final users' needs. Furthermore, a module for data treatment should be implemented in Influx to perform operations, such as applying filters, formatting, changing units or calculating data aggregations, before storing the data in the InfluxDB.

There is also some data that can be considered as semi-dynamic, such as some elements regarding the general context definition, or the generation of potential future scenarios. Those can be elements such as climatic zones, regional regulations, directives, energy prices, and any other associated information that would be valuable when assessing the state of an area or region, and that may change depending on the context. These data can be stored in a PostgreSQL relational database.

Furthermore, a PostgreSQL database can be deployed to store the results after the Key Performance Indicators (KPIs) calculation. That way, KPIs results would be saved into these database, avoiding the need for recalculating them during a project lifespan. In addition, a baseline can be calculated and compared with potential future scenarios, obtained as the result of applying different city solutions, which provides a significant asset for decision-makers. Another functionality could be to calculate and compare KPIs among the entire city and smaller areas, addressing different city scales.

3.1.3. Data Integration, Treatment and KPI Calculations

As presented above, there are diverse alternatives to store the information depending on its nature: structural, semantics, context-based data, and temporal data. However, all of that information must be connected and accessible by the different tools to be able to perform analyses, KPI calculations, and geoprocessing tasks. Sensor data must therefore be linked with structural information included in the 3DCity Model. This link can be established by two approaches:

- By sharing IDs between sensor and elements (i.e., building/public lamppost); hence, the sensor detects the element is connected to via ID and vice versa.
- By the location, the elements in the model are georeferenced, so they can be retrieved when selecting an area of interest.

All type of information stored (static and dynamic, gathered at building, and urban levels) are interpreted for the generation of meaningful KPIs (Figure 1). Some of these indicators derive directly from measured data (i.e., annual electrical consumption of a public building as the aggregation of hourly readings from a smart meter), whilst other have a hybrid measurement-model approach (i.e., CO_2 emissions related to the annual electrical consumption).

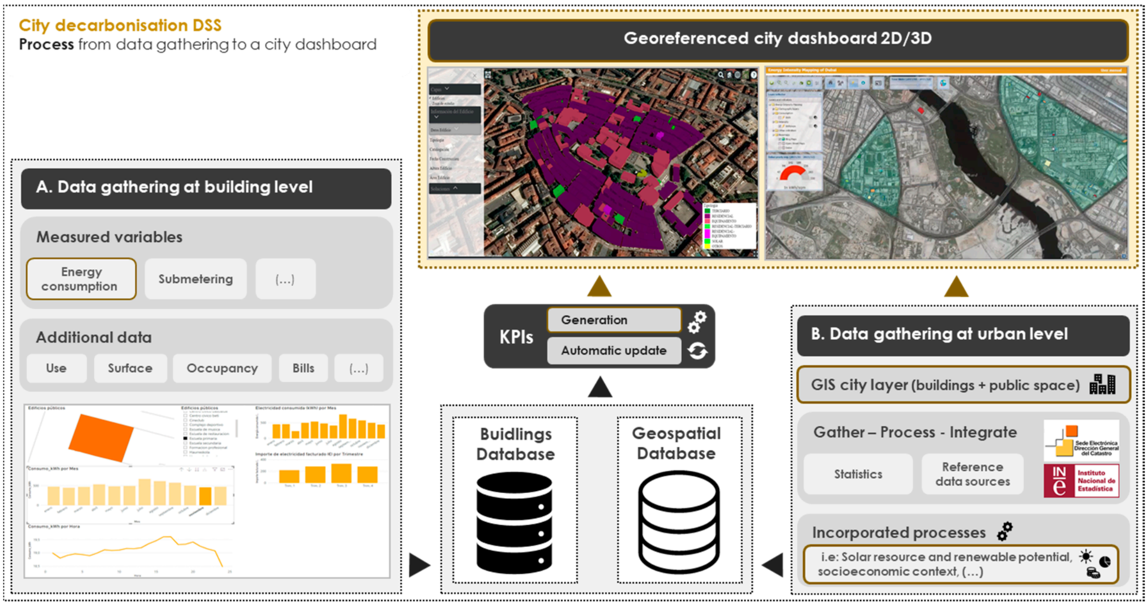

Figure 1. Information flow: from data gathering at building/city levels to a city dashboard.

Each variable and KPI requires a defined procedure on data integration and analysis across the diverse data stores and steps. In the following lines, as an additional example, how both types of KPIs can be derived from the same data source (an urban weather station) is described, in order to calculate annual solar irradiation (kWh/m^2·y, integrating measured data) and the renewable electricity potential of a group of roofs if photovoltaic (PV) modules are deployed (electrical kWh/m^2·y, hybrid KPI, combining measured solar resource and geospatial data with a mathematical model of a generic PV module). The steps would be:

- Define the area of interest.
- Set-up the scenario data.
- Select the structural elements inside the area of interest through the WFS 3D City Model published on degree and retrieve geometric information, as well as the useful metadata, such as rooftop area, building orientation, or shading grade.
- Get context data associated with the calculation scenario connecting to the PostgreSQL database (e.g., climatic zone, usage rate).
- Collect sensor data using the InfluxAPI to obtain solar irradiance.
- Process the data, with the defined procedures for each KPI, based on a service implemented specifically via REST API.
- Return the data via service, to be loaded on a map or dashboard.

3.1.4. DSS Outputs for Decision-Makers

The requisites of data gathering, storage, treatment, and KPI calculations pursue one main goal: providing city planners with key city data to inform, support, and enable traceability of their decisions. In this case, the research team has taken the Law 4/2019 on Energy Sustainability of the Basque Community, an example of regional EU directive transposition, as a reference to show which DSS outputs decision-makers need to plan and follow cities decarbonisations up.

Within this law, outputs are condensed in three main sectors regarding energy consumption and CO_2 emissions: building stock, public lighting and mobility. In the case of buildings, main outputs point at electric and thermal energy consumption (heating/cooling/domestic hot water (DHW)/lighting; preferably as a monthly aggregation) as well as its equivalence on CO_2 emissions; the costs associated to that consumption (by month), and the characteristics of buildings (age, indoor area, typology, energy certification, renovation date), and installations (type, year of installation, energy source, power, efficiency). Additionally, the research team has considered relevant, in terms of energy-retrofitting planning, outputs connected to the solar resource, leveraging the collector potential of buildings rooftops, such as rooftop useful surface, PV/Solar Thermal (ST) installable capacity, PV/ST annual generation, related economic savings and investments' payback period, and associated CO_2 emissions avoided.

Regarding public lighting, the output is simpler than in the case of the buildings, targeting aggregated monthly energy consumption and its equivalence on CO_2 emissions as the key output; the type of lighting spot and its efficiency are also interesting elements for planning potential renovations. Both in public lighting and buildings cases, the georeferentiation of each element is crucial for a 2D/3D analysis. Finally, in terms of mobility, the targeted output must be the overall fuel/ energy consumption of all vehicles and its equivalence on CO_2 emissions depending on the fuel of each vehicle. An inventory of all public fleets and public transport vehicles is relevant for planning fleet renovations within the public sector. The monitoring of all those collective vehicles should not be a problem for public administration, as they belong to the public sector. Hence, the targeted output for the DSS is feasible; however, the same level of monitoring would be desirable for private vehicles, which is a challenge at a city level, partially solved by estimations anchored on reference terms, such as vehicles excise duties, traffic intensity on certain streets, fuel imports, average km per type of vehicle (national sources), etc.

For a comprehensive city analysis, outputs regarding complementary decarbonisation city systems, such as green infrastructures (CO_2 sinks; i.e., green areas surface), waste management or water management are recommended to be included in the overall equation and the DSS outputs.

3.1.5. Representation/Visualisation

The target users of ENER-BI DSS are city managers, supporting their diagnosis, planning, and follow-up tasks within the city decarbonisation process. For this reason, it is essential to create an intuitive, attractive, simple, and user-friendly system, combining 2D and 3D georeferenced information and presenting data through interactive graphs and diagrams that can show KPIs, aggregation of elements or temporal series in a clear, concise, and understandable manner. Accordingly, a dashboard including combined functions could be the most suitable choice.

3.2. ENER-BI DSS for Urban Decarbonisation Planning: Functionalities

Once presented the leading requisites for ENER-BI DSS, this section describes the main functionalities of the tool to effectively support a city decarbonisation process.

Regarding the visualisation and use of the tool, the research team developed several tests with Power BI software (Figures 2 and 3), creating a dashboard that presents the foremost information of the city. Through this software, the city team can connect to the different databases, edit, and visualize both static and dynamic data/KPIs; it is possible to aggregate elements and update the information receiving temporal series when the source files are updated, following the requisites described in Section 3.1. This software can also process and present georeferenced data, allowing the user to crosscheck different sets of data within the map of the dashboard, facilitating an integrated analysis by city planners.

Figure 2. Example of PowerBI city dashboard; public buildings analysis in a Basque urban area (Spain).

Figure 3. Example of PowerBI city dashboard; summary of Vitoria-Gasteiz (Spain) public lighting inventory; years 2016–2018.

Regarding the quantification of CO_2 emissions reduction and energy savings, the functionalities of ENER-BI DSS have been split into three modules, according to the different needs of the city decarbonisation planning process, taking the steps of Cities4ZERO decarbonisation methodology as a reference.

3.2.1. Module 0—Inventory, Characterisation, and Monitoring

The main objective of this module is to gather and integrate all necessary information to provide planners with effective support in the city decarbonisation process. Firstly, Module 0 entails the information gathering mechanisms to provide a comprehensive inventory of all decarbonisation targets. This inventory includes monitoring those decarbonisation targets and their elements with the suitable periodicity each element requires. The monitoring task is different from element-to-element; some need to import data from existing sources (i.e., cadaster); others bring remote data from sensors; others retrieve information from electricity companies' devices; others need to be monitored by planners (i.e., audits and studies). Here the objective is to develop this inventory as automatically as possible; the research team explored ways to facilitate a regular automatic update of each element without the intervention of a practitioner, who would have to update it manually, so city planners can be as autonomous as possible in the use of ENER-BI DSS. Table 3 shows the main elements gathered, monitored, and integrated into the PowerBI dashboard.

Table 3. Elements monitored in Module 0 Inventory, characterisation, and monitoring.

Decarbonisation Target	Main Elements
Public buildings	Georeferenced inventory and characterisation (geometry and characteristics of public building stock) Energy consumption (monitoring) Energy audits (study results)
Private buildings	Georeferenced inventory and characterisation (geometry and characteristics of private building stock)
Public lighting	Georeferenced inventory Energy consumption (monitoring) Energy audits (study results)
Mobility	Public fuel consumption (monitoring of public transport and fleets) Private mobility (studies and estimations) Active mobility (study results)
Socio-economic/socio-demographic (urban analysis)	Vulnerability (index monitoring)

Through this inventory supported by ENER-BI DSS, planners will be able to perform a quantitative city characterisation regarding the main decarbonisation targets (Public Lighting example on Figure 3), corresponding to Step 2 (ANALYSE) of Cities4ZERO methodology. This city characterisation has to include the aforementioned inventory, which will be the base to create a CO_2 emissions baseline, and which can be complemented by a qualitative analysis, providing a more comprehensive understanding of the city status: a literature review on a city level (existing policies, regulations, strategies and plans), semi-structured interviews with sectorial experts (energy, building stock, mobility, public space, Information and Communication Technologies (ICTs), engagement, waste, water, etc.), and surveys on citizens perception.

3.2.2. Module 1—Scenarios Generation for Decarbonisation Planning

This module intends to support a diagnosis of the inventory developed in Module 0, both in technical and socioeconomic terms, before generating future potential decarbonisation scenarios. This module seeks to standardize and automatize the calculation processes of algorithms applied in urban energy-retrofitting, public lighting and mobility projects by the research team, now integrated as a part of ENER-BI DSS (Table 4). Through the embedded algorithms, the DSS can calculate CO_2 emissions reductions, as a result of implementing a set of projects and strategies in the city including, for instance, an increase on local renewable energy production.

Through the possibility of calculating the impact of potential future projects and strategies, ENER-BI DSS can support the generation of future scenarios. To determine the impact and progressive implementation of such initiatives, the DSS must estimate what the trends are and the quantitative references of each city system for the following years, so specific projections can be addressed to each initiative (i.e., electric vehicle penetration rate per year; public/private building stock retrofitting rate per year). In this line, city planners will have to set a level of ambition according to the city decarbonisation targets, being aware of what is doable, according to their baseline, context, and resources.

Table 4. Automatized/semi-automatized calculation processes embedded in Module 1.

Decarbonisation Target	Calculation Processes
Public buildings	• Solar potential on rooftops and Renewable Energy Sources (RES) penetration scenarios [23] • Viability of energy nodes (local renewable production feeding adjacent buildings) [24]
Private buildings	• Energy consumption and CO_2 emissions • Upgrade potential after energy-retrofitting • Solar potential in rooftops and RES penetration scenarios • Demand aggregation and synergies (depending on final energy use)
Public lighting	• Efficiency improvement of public lighting
Mobility	• Vehicle replacement (public fleets and public transport) • CO_2 reduction from private vehicles use decrease • Progressive increase of electric energy demand (e-charging points)
Socioeconomic	• Socioeconomic viability of generated scenarios

In this sense, Cities4ZERO methodology suggests the co-generation of future scenarios (in Step 4 of [4]; ENVISION), engaging key local stakeholders, specifically incorporating to the debate those with the key city competences, who will be potentially involved in the implementation of the actions of the decarbonisation plan. The support of ENER-BI DSS to complement the envisioning co-generation workshops with quantitative data will upgrade the debate, showing participants, which would be the potential future consequences of present decisions in each city system. Through this debate, local stakeholders will be able to reach consensus on a "master scenario" for 2030/2050 and will be able to participate in the design of the actions included in the roadmap 2030/2050 to achieve that scenario (Step 5 of [4]; PLAN$^{\text{City Level}}$), envisioning the city of the future and jointly planning the pathway towards it.

3.2.3. Module 2—Decarbonisation Follow Up

Once city planners achieve a "master scenario" and develop an Action Plan towards decarbonisation, ENER-BI DSS must support the fulfilment of that plan, setting a follow-up framework that enables the fulfilment of the actions in the coming years. Furthermore, that framework must allow the quantitative review of the actions, as well as for deciding corrective mechanisms, if necessary. Accordingly, this module must incorporate follow-up KPIs addressing each decarbonisation target, and even the specific initiatives of the Action Plan too. Once decided all KPIs to be included, ENER-BI DSS must allow studying that data over time, hence, showing the historical evolution of those KPIs over months/years (steps 12–16 within the Intervention and Assessment Stage of Cities 4ZERO methodology [4]).

In this sense, Module 2 is supported by Modules 0 and 1:

- The automatization of the updating process of the inventory of Module 0 is a significant asset within this follow-up process of Module 2, as it always provides city planners with updated information.
- If corrective mechanisms are needed over time, the calculation processes of Module 1 for generating scenarios are also valid in the follow-up process, recalculating the potential impact of those corrections.

An additional feature of this module can be the link between the DSS and the digitalization of some city procedures (e.g., building permits/licenses), which would provide the DSS with some valuable skills for city planners' daily tasks, becoming a transversal software within planning departments. However, the research team has not explored this possibility.

Overall, these three modules provide rigorous quantitative data within decarbonisation planning, which can additionally fulfil transparency requisites of public administrations, enabling fair and understandable sets of data, which can be publicly presented to the citizenship for an informative and engaging decarbonisation local process.

4. Discussion

Overall, ENER-BI DSS supports decarbonisation planning through an automatic update of real data collected by sensors; automatizes calculation processes connected to decarbonisation planning and urban analysis; and provides georeferenced data of elements to be decarbonised, a key aspect for an integrated urban energy analysis.

From a city planning perspective, ENER-BI fosters the practical integration of energy and urban planning processes as defined by the Cities4ZERO methodology, helping to overcome traditional siloed approaches to energy planning that have been applied in, for instance, Sustainable Energy Action Plans (SEAP)/ Sustainable Energy and Climate Action Plans (SECAP) processes in the framework of the Covenant of Mayors. In this sense, it provides a data-led approach to the complex process of decision-making for urban decarbonisation planning, where several competing interests exist, and where different stakeholders are engaged at different levels and moments of the process (politicians, civil servants with technical responsibilities, private energy companies, building owners, and the civil society at broad).

In addition, ENER-BI has a balanced level of detail on the energy assessing and modelling aspects that enable decision making at urban/district level. After that, dedicated energy project-oriented planning tools can be used for a detailed scenario or intervention design. Authors have followed a similar methodology on [24], where energy efficiency and socio-economic vulnerability in districts were assessed through GIS, building data and model-based KPIs, and once the retrofitting needs were identified and prioritized, the intervention in a selected neighbourhood was designed through EnergyPLAN; ENER-BI can therefore be complementary of project-oriented tools. Furthermore, ENER-BI fills the gap in the decision-making chain between those project-oriented tools, which go directly on the technical details of engineering preliminary projects that do not address the urban dimension, and the current urban planning paradigm, where decisions affecting energy planning are usually based on non-georeferenced static analysis.

ENER-BI is the result of the integration of several steps needed along the decarbonisation planning process at a local level: baseline definition, diagnosis, strategic planning, evaluation of the implementation, etc. Each of the modules can be adapted and refined separately and linked back to the DSS. This modular approach gives ENER-BI DSS the needed flexibility to be useful in different places since the planning process is very context-sensitive: it heavily relies on the local/regional regulation, competencies distribution, governance model, data gathering and availability, etc. Therefore, ENER-BI offers a systematic approach to the process, based on a sound planning methodology (Cities4ZERO) that can be tailored to the specific context.

However, in the process of developing the tool, several limitations have been detected. The main barrier regarding data gathering is the lack of information about one energy-intensive sector, such as private mobility. In terms of functionalities definition, the tool was designed to fulfil the specific requirements for municipalities of the Basque Region's Law on Energy Sustainability; this law aims to transpose the European Directives related to the "Clean Energy for all Europeans", and as such, it is conceptually aligned with it. However, it does not cover all of the aspects covered by such directives, being mainly focused on public action at a local level.

Once the conceptual design of the tool has been defined, future research should focus on testing it in a real-case environment, as a support tool for the implementation of the Cities4ZERO methodology in a city. In this process, it is to be expected that several barriers will be encountered when actually integrating information sources. Moreover, further research will be needed to gather essential information such as energy consumed by private vehicles, beyond the current consumption and emissions' estimates. In this sense, and after this first approach (buildings/mobility/public lighting), any additional urban information that can affect the development of a city decarbonisation plan must be incorporated (i.e., energy network's distribution typology; bike paths and pedestrian areas; waste-to-energy potential; etc.). Moreover, once the tool has been refined, further work will be needed in order to develop a commercial, user-friendly, and intuitive interface to facilitate its wider use.

Finally, and regarding the current EU Green Deal and COVID-19 recovery fund framework, municipalities expect significant resources to be allocated to climate mitigation and adaptation projects during next years. Accordingly, municipalities need georeferenced quantitative support on this, so they can effectively draft strategies, plan actions, prioritize their implementation and monitor their performance, in the most meaningful and rigorous manner, for the broader benefit of local communities. If these investments are not perceived by citizens and institutions as appropriately appointed and executed, the perception on society's capacity to cope with climate change will suffer a severe dent; this is a window of opportunity that Europe cannot squander.

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Towards an Integrated Approach to Urban Decarbonisation in Practice: The Case of Vitoria-Gasteiz

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Abstract: How can local authorities effectively approach the decarbonisation of urban environments? Recent efforts to redirect cities into a less energy-intensive model have been mostly approached from a sectoral perspective, with specific energy policies and plans being issued without deeply considering their ties with other urban aspects. In this sense, well-established urban planning procedures have not been part of those, with the consequence of barriers in the implementation phase of those energy plans. The Cities4ZERO methodology was developed to guide effective integration between urban planning and energy policies, plans, and practices. It provides a holistic approach to strategic municipal processes for urban decarbonisation in the mid-long term, which includes key local stakeholders' engagement into integrated energy planning processes, as well as tools for effective energy decarbonisation modelling. This paper analyses the application of the Cities4ZERO decarbonisation methodology on its strategic stage in the development of Vitoria-Gasteiz's Action Plan for an Integrated Energy Transition 2030 (APIET 2030). It suggests that in order to accelerate urban decarbonisation, it is critical to: (a) foster interdepartmental collaboration; (b) allow for flexibility on the land-use planning regulations; (c) back decisions with detailed urban-energy models; and (d) truly engage key local stakeholders in the planning and implementation processes.

Keywords: decarbonisation; urban transformation; energy transition; integrated planning; smart cities; smart zero-carbon city; foresight; climate change mitigation

1. Introduction

Scientific evidence confirms that climate change is increasingly affecting our planet, so it is essential to accelerate adaptation and mitigation actions. Cities are at the forefront of this battle, being part of both of the problem and the solution, as urbanisation is accelerating, and it is estimated that 70% of the world's population will live in cities by 2050 [1]. Local pollution is a clear example of this entrenched problem, as cities account for 70% of GHG emissions [2], and 92% of the world's population lives in polluted environments, with serious health consequences [3].

Mitigating climate change is key to avoid reaching a point of no return. Bold, transformative action is needed in our cities, both new and old, to transition towards a new urban model that is compatible with caring for life on the planet.

Goals seem to be clear, but the question of how to put them into practice remains unclear. How can local authorities effectively approach the decarbonisation of urban environments through pragmatic and concrete actions? Transforming complex urban ecosystems requires a systemic approach, cooperative leadership, and clear pathways for cities to follow [4]. Moreover, transformative action needs to be multi-dimensional, multi-scalar, and multi-stakeholder [5–7].

Recent efforts to redirect cities into a less energy-intensive model have been mostly approached from a sectoral perspective, with specific energy policies and plans being issued without deeply considering their ties with other aspects [8]. In particular, well-established, consistent urban planning procedures appear not to exist to aid these efforts [9], with the consequence of creating barriers in the implementation phase of those energy plans.

The Cities4ZERO methodology [10] was developed as a consistent guide to effectively integrate urban planning and energy policies, plans, and practices. It provides a holistic approach to strategic municipal processes for urban decarbonisation in the mid-long term, which includes key local stakeholders' engagement into integrated energy planning processes (for Vitoria's foresight case, see [11], as well as tools for effective energy decarbonisation modelling (such as ENER-BI; see [12]).

The strategic stage of this framework has been comprehensively applied for the first time in Vitoria-Gasteiz, focusing on the key factors towards a smart urban decarbonisation [13], and covering the main governance and planning milestones to accelerate urban decarbonisation from municipal action.

This paper delves into this approach through an in-depth analysis of the process of developing Vitoria-Gasteiz's Action Plan for an Integrated Energy Transition 2030 (APIET 2030) in order to determine if Cities4ZERO works as an effective and pragmatic framework for such strategic processes. Does it really provide a strategic framework able to accelerate Smart Urban Decarbonisation processes in the mid-long term?; Does Cities4ZERO effectively engage key local stakeholders while using energy and decarbonisation modelling tools in such a process?; Is it a useful governance mechanism to draft a decarbonisation strategy for the city, complemented by a set of key transitioning projects? The paper also reflects on the need for flexibility from municipal planning structures to adapt to evolving challenges, advocating for urban-energy models as a crucial element of decarbonisation planning.

In Section 2, the detailed process followed in Vitoria-Gasteiz for the development of the APIET 2030 is presented, following the main steps of the strategic stage of the Cities4ZERO methodology. Section 3 delves into the results of each step, raising important findings that are further discussed in Section 4, which finally outlines future lines of research.

2. Materials and Methods

2.1. Cities4ZERO for Vitoria-Gasteiz Planning Process

The development of the Action Plan for an Integrated Energy Transition 2030 (APIET 2030) in Vitoria-Gasteiz follows the Cities4ZERO urban decarbonisation methodology, "*a step-by-step methodology able to guide local authorities through the process of developing the most appropriate plans and projects for an effective urban transition; all from an integrated, participatory and cross-cutting planning approach*" [10]. This methodology builds upon the smart zero-carbon city (SZCC) concept, which defines a resource-efficient urban environment where the carbon footprint is nearly eliminated [14]. Both Cities4ZERO methodology and SZCC concepts are based on the theoretical and empirical analysis developed in research pilot projects in European cities within the smart cities and communities programme of the European Commission (EC); such an analysis resulted in the definition of the key factors towards smart urban decarbonisation, linking the smart cities and the climate mitigation action movements [13]. This methodological and conceptual framework was presented to Vitoria-Gasteiz representatives, meeting their expectations and the city transitioning needs, and it was therefore applied to the specific case of the APIET 2030, coordinated by the authors of this research.

The development of the APIET 2030 follows the strategic stage at the City Level (Stage A of Cities4ZERO, Figure 1), focused on providing the most suitable planning framework for effective urban decarbonisation. In particular, the strategic stage consists of 6 steps, all of which are applied to the Vitoria-Gasteiz case:

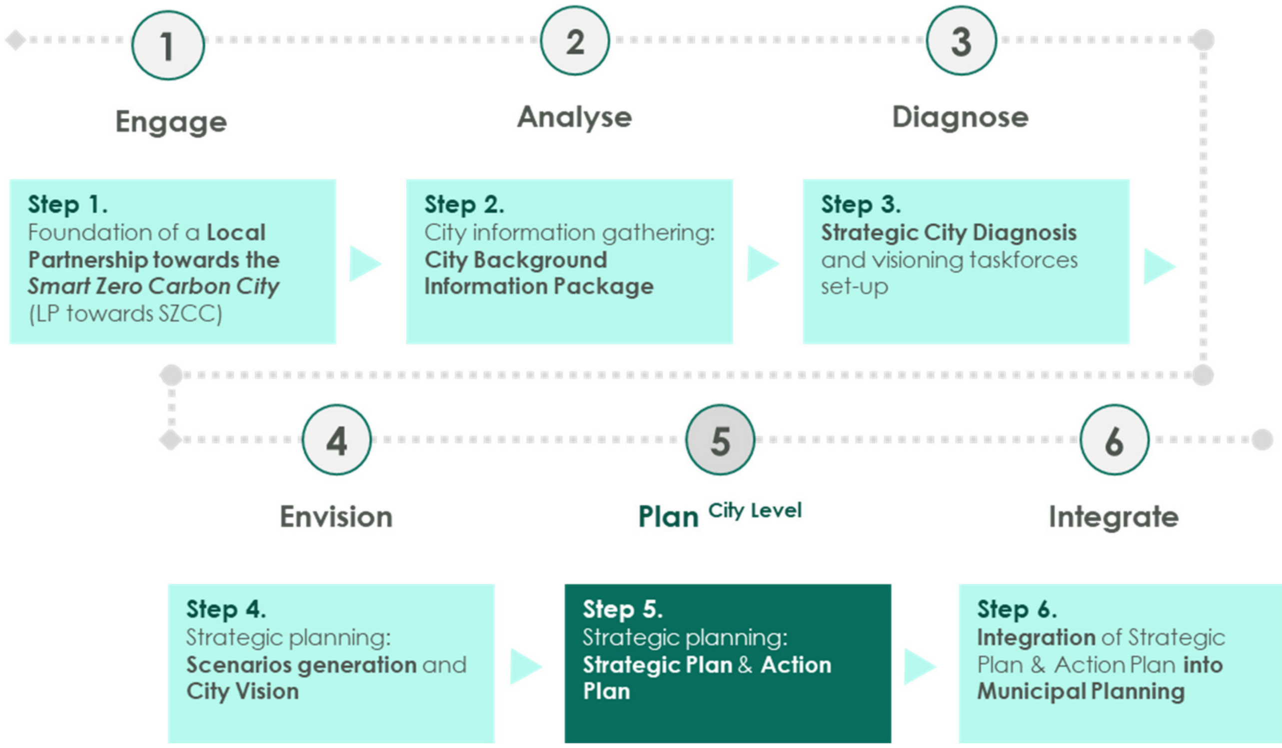

Figure 1. Strategic Stage (A) of Cities4ZERO urban decarbonisation methodology.

2.1.1. Step 1. ENGAGE. Foundation of a Local Partnership with the SZCC

In 2019, Vitoria-Gasteiz created the new transversal energy and climate municipal service, intending to lead and coordinate the climate action programme in the city. This internal reorganisation is a consequence of municipal elections and the structural update of the incoming administration, which can be considered as an exercise of *Institutional Transformation* [15], to more consistently steer the challenging climate action agenda. In the case of the APIET 2030, the incoming Energy and Climate Department has been supported by the external consultancy of research and technology organisations (RTOs), to which the authors of this study belong, to be able to develop this strategic planning process.

2.1.2. Step 2. ANALYSE. City Information Gathering; City Characterisation

Once the leading team is in place, the first task to develop the APIET 2030 consists of collecting all necessary data for an integrated planning process; building a city background information package (CBIP). This process required a literature review on the existing policies, regulations, strategies, and plans on the field, providing a deeper understanding of the socio-economic and sectorial characteristics of the city. Furthermore, this analysis was complemented by a set of city indicators, described on the SZCC readiness level framework [14], and an urban-energy model able to calculate a carbon emissions baseline (More information about the model is included in Section 2.2 Principles for urban-energy modelling).

2.1.3. Step 3. DIAGNOSE. Strategic City Diagnosis and Visioning Taskforces Set-Up

To extract some conclusions of the city analysis performed, the steering group firstly identified and later coordinated the key stakeholders of the city to develop a shared strategic city diagnosis. These stakeholders were summoned by personal email invitations to a first workshop on 29 January 2020, at Vitoria-Gasteiz's Europa Congress Hall, gathering more than 40 representatives coming from 4 main social groups: public practitioners, private businesses, civil associations, and research institutions. Through this event, the participants were able to discuss and identify the city's global trends that might externally affect the city in the coming years, as well as the internal characteristics of the city, finally co-developing the SWOT (strengths, weaknesses, opportunities, and threats) analysis of Vitoria-Gasteiz.

2.1.4. Step 4. ENVISION

Building upon the strategic city diagnosis co-developed during the first workshop, the same representatives of the main social groups gathered again at the same venue on 12 February 2020, this time with the aim of co-creating the future vision for Vitoria-Gasteiz by 2030, supported by the assistance of sectorial experts (energy, mobility, building renovation, public lighting, water and waste management, etc.) and a moderator expert in prospective exercises (detailed *foresight* method described in [11]). Divided into four groups, assuming the role of city planners, and based on the SWOT analysis, the participants generated four different scenarios by 2030, which was then converted into one "master scenario", taking diverse elements of each scenario. According to that "master scenario", the participants co-developed a city vision for Vitoria-Gasteiz 2030, which resulted from reaching consensus among all participants (see the development process in Figure 2).

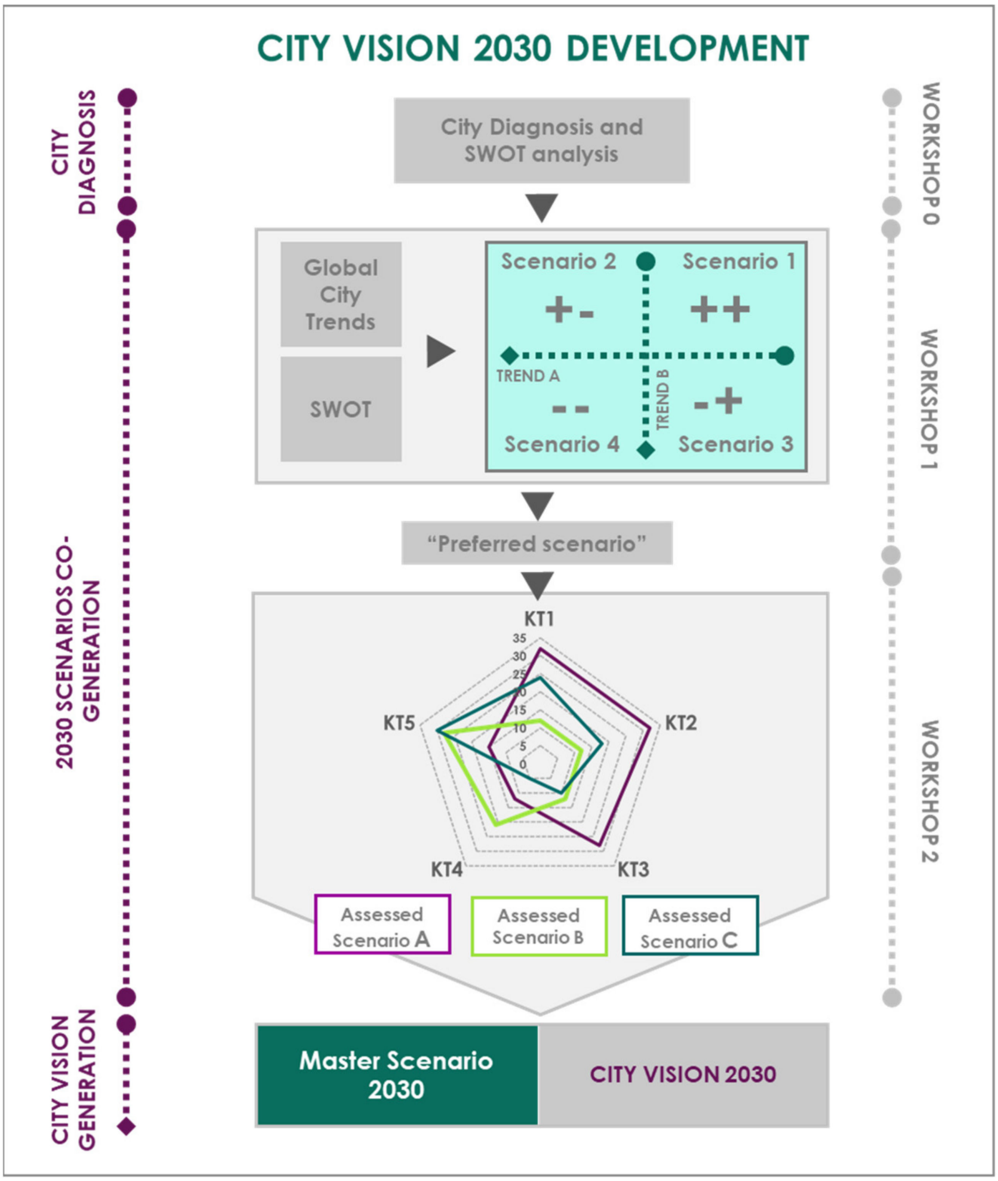

Figure 2. City Vision co-development process in APIET 2030.

2.1.5. Step 5. PLAN CITY LEVEL

Based on the City Vision 2030 and the co-generated master scenario, the leading energy and climate municipal service started the development of the APIET 2030 document. This process consisted of a thorough analysis of the input gathered in the workshops, identifying the objectives of the APIET 2030, as well as structuring all contents into a detailed breakdown of strategic areas, strategic lines, and key actions. This content was contrasted by local sectorial experts, supported and aligned with the urban-energy model, and presented in a final draft document, which was opened to the citizenship in a public participation process before its final publication.

2.1.6. Step 6. INTEGRATE

Once the APIET 2030 was published, the municipal service of energy and climate made a reflection on how to integrate the outcomes of the APIET 2030 into municipal planning dynamics and instruments. In this regard, integration was considered in terms of horizontal integration (cross-cutting collaboration among municipal departments and their sectorial strategies), looking more specifically to the ongoing update of Vitoria-Gasteiz urban plan; and vertical integration, looking for alignment with existing initiatives at regional, national, and European level.

2.2. Principles for Urban-Energy Modelling

According to the Cities4ZERO methodology, the decarbonisation planning process needs the support of an urban-energy model able to calculate the potential impact of the actions defined on the local energy system. With that purpose, the urban-energy model must set a baseline (2017 in the case of Vitoria-Gasteiz) upon which to introduce city actions, checking to what extent the objectives defined can be fulfilled and in what timeframe.

In this sense, the ENER-BI research project presented the desirable characteristics of an urban-energy decision support system (DSS) able to integrate energy and spatial data for cities' decarbonisation planning [12]. This research project set specific requisites on information gathering procedures, information storage (both static and dynamic data), data integration and treatment, key performance indicators' calculations, necessary outputs for decision-makers, and dashboard visualisation. All these requisites were oriented to enable the three main functionalities of an urban-energy DSS, also described in [12]:

- Module 0—Inventory, characterisation, and monitoring.
- Module 1—Scenarios generation for decarbonisation planning.
- Module 2—Decarbonisation follow up.

In the case of APIET 2030, the developed urban-energy model integrates these three items. Based on the gathered information at the city level (Section 2.1.2 *Step 2. ANALYSE*), the model can process the characterisation of the urban-energy system (Module 0). The end-use sectors of the city and the supply technologies are both portrayed in the LEAP modelling framework [16]. Demand-side sectors are detailed as much as possible (according to the available information) to accurately model the energy actions that will be enacted.

The characterisation of the baseline year serves as the starting point from which scenarios are created. Indeed, the main goal of the urban-energy model is to generate different future situations that the city could face in order to assist in the generation of the city vision (Module 1). Scenarios are modelled through the combination of global city trends, past and future socio-economic and demographic tendencies, as well as the impacts of implemented energy actions. The first business as usual scenario is created, serving as a benchmark for the generation of the alternative scenarios, to be discussed by local stakeholders (Section 2.1.4 Step 4. ENVISION). As a result of this exchange, a master scenario is modelled, representing the 2030 city vision.

The model can be updated, and new scenarios generated, allowing the follow-up of the city decarbonisation process, as well as the rework of the energy plans and targets (Module 2).

3. Results

Once the process has been described, this section presents the results of the application of the Cities4ZERO methodology to the case of Vitoria-Gasteiz's APIET 2030 development.

3.1. A New Energy and Climate Action Cross-Cutting Department

Ten years after starting the implementation of the first climate change adaptation and mitigation plan in Vitoria-Gasteiz [17], and once the new government municipal structure was defined as a consequence of the 2019 elections, the new political board decided to make a decision that had been under consideration for some years: the creation of the energy and climate department. At the end of 2019, with the APIET 2030 in its preparation phase, the municipality agreed on the need for an institutional analysis leading to an internal reorganisation of resources to better cope with the challenging complexity of implementing Vitoria-Gasteiz's climate action agenda.

Managed by the former environment department director, the role of the energy and climate department mainly consists of:

- Leading the climate action agenda from the municipality, complying with the covenant of mayors and sustainable development goals municipal commitments; strategic coordination, tendering processes, climate innovation fundraising, and strategic road-mapping and documents' development. Furthermore, the department must ensure the municipality complies with the sustainable energy regional regulations [18], in line with the energy performance of buildings (EPBD; 2018/844) and energy efficiency (EED; 2018/2002) EU Directives, and tightly linked to the decarbonisation of our energy systems.
- Coordinating a cross-cutting collaboration within the municipal departments and agencies (internal), as well as with external stakeholders that are engaged in specific climate action strategies or initiatives (private sector, academia, citizenship).
- Managing the competencies of some relevant climate-related municipal areas, absorbed from the former municipal structure: energy, environment, green infrastructure, waste management, and urban planning.

In order to fulfil the expectations of these competencies, the new department has needed a reallocation of former workers from other departments, as well as the recruitment of two new profiles for the staff.

3.2. A City Background Information Package for Energy and Climate Action

One of the first new department's tasks was performing a city characterisation in energy and decarbonisation terms, which can be an evolving repository that grounds any strategic work connected to this topic. This characterisation, appointed as Vitoria-Gasteiz background information package, consists of:

1. A repository of strategic documents of the municipality, both general and sectorial, that can affect the decarbonisation strategy; hence they can be more efficiently coordinated and aligned in the future. In this case, the documents reviewed were: former sustainable energy action plan (SEAP) 2010–2020 [17], former carbon neutrality strategy 2050 (Vitoria-Gasteiz's "Carbon Neutrality" understanding goes in line with Scope 2 of greenhouse gas protocol: *"GHG emissions occurring as a consequence of the use of grid-supplied electricity, heat, steam and/or cooling within the city boundary"*. In this sense, emissions offsetting by exporting renewable electricity is considered.), analysis of solar energy potential in rooftops, energy strategy for municipal buildings, agri-food municipal strategy 2025, Basque energy transition strategy, study for a municipal energy-marketer, a comparative study on cities energy transition 2030 including Vitoria-Gasteiz, sustainable urban mobility plan (SUMP), water management strategy, waste management strategy, green infrastructure strategy, sustainable energy regional regulation, national plan for energy and climate, and the diverse local ordinances on energy and urban planning.

2. An urban-energy model portraying the energy system of the city and its performance. The urban-energy model integrates both Vitoria-Gasteiz's end-use sectors and energy supply infrastructures, accounting for the energy consumption and related carbon emissions for the baseline year. The urban-energy model allows the simulating of future energy scenarios supporting further strategic planning and decision-making (Section 2.2 Principles for urban-energy modelling).
3. A set of city indicators related to decarbonisation, already published in [14], provides an overview of the key metrics to be monitored in a city decarbonisation process. In this sense, both the urban-energy model data and this set of city's decarbonisation indicators can be integrated into an urban management dashboard, altogether with multiple georeferenced data sets that allow an integrated analysis, as Figure 3 shows.

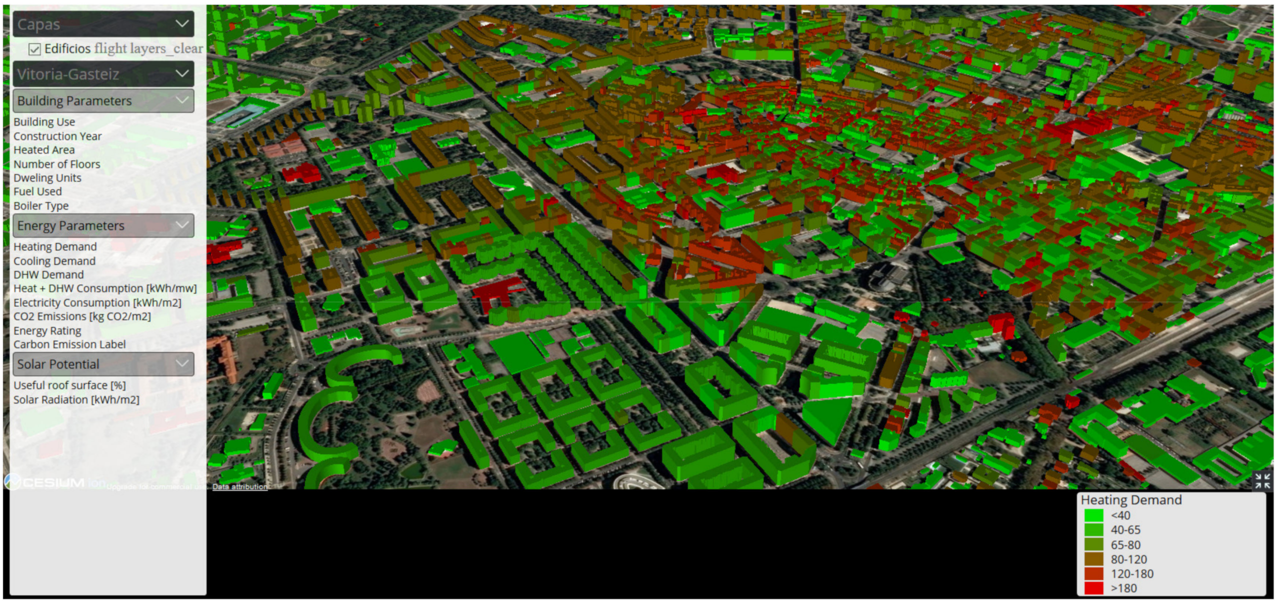

Figure 3. Vitoria-Gasteiz's management dashboard (i.e., overview on buildings' heating demand; kWh/m^2).

3.3. A Working Group of Key Local Stakeholders Engaged in Energy and Climate Action Strategic Processes

A core element in Cities4ZERO methodology is its alignment with integrated planning governance principles, namely, (a) integration through local stakeholders' engagement; (b) horizontal integration among city systems and within planning structures; and (c) vertical integration among public authorities from other government levels. A working group of local stakeholders engaged in energy and climate action strategic processes is, therefore, a cornerstone of the APIET 2030.

During the APIET 2030 development, working groups were constantly engaged (Table 1); with a twofold purpose. First, the intensive co-creation process significantly enriches the result of the final plan, thanks to the variety of knowledge brought by the diverse set of stakeholders. Secondly, most of the local stakeholders involved own the key competencies, resources, and knowledge relevant for implementing the APIET 2030 projects; bringing them on board since the beginning of the process increases their commitment in a future implementation, as well as in overcoming potential barriers.

Table 1. Involvement of working groups in APIET 2030.

		NOVEMBER 2019/ MARCH 2020 **Validation of Global City Trends, City Diagnosis, Scenarios' Generation, and City Vision Development**	**APRIL 2020/ FEBRUARY 2021** **Identification and Description of Key Projects for APIET 2030**
Public Administration	**Political**: deputy mayors **Technical**: municipal department directors, municipal agencies, regional agencies; city/regional managers and practitioners the on environment, energy, built environment, urban planning, active mobility, public transport, digital transition and administration, waste management, economic development	Co-leading the process (leading municipal department) Invited to two co-creation workshops, covering the whole process (rest of public administration staff)	Co-leading the process (leading municipal department) Coordination of APIET 2030 actions with each departmental strategy
Private companies	**Representatives** from companies and cooperatives with expertise in energy management, water management and solutions, construction, urban infrastructures, PVs, geothermal solutions, mobility, urban participatory processes, and district heating	Invited to two co-creation workshops, covering the whole process	Suggestion of key projects and contrast of APIET 2030 actions
Academia/RTOs	**Experts** on urban planning, construction, energy, and environment	Co-leading the process Involved in the design of the co-creation process, moderation of workshops, and background materials for participants. Invited to two co-creation workshops, covering the whole process	Co-leading the process. Coordinating actions' files and APIET 2030 document. Sectorial contrast in scientific and innovation terms
Civil associations	**Representatives** from neighbours' associations	Invited to two co-creation workshops, covering the whole process	Suggestion of key projects and contrast of APIET 2030 actions

3.4. A City Diagnosis on Energy and Climate Action

Based on the city background information package of Vitoria-Gasteiz (Section 3.2), and the working group of key local stakeholders engaged in energy and climate action strategic processes (Section 3.3), a city diagnosis on the topic was developed. As described in Section 2.1.3, this city diagnosis involved local stakeholders in the identification of global city trends for Vitoria-Gasteiz 2030, considering potential external affections (opportunities and threats), and performed a SWOT analysis to contrast those external affections with the internal characteristics of the city (strengths and weaknesses). First, regarding the global city trends identification, the stakeholders voted the "relevance" and "uncertainty" of each of those (Table 2, Figure 4); on the one hand, the potential impact of those trends by 2030 is what makes them relevant; on the other hand, the uncertainty of such impact is what generates different scenarios by 2030 depending on whether those trends follow one or another direction.

Table 2. Global city trends. Votes of Relevance and Uncertainty in APIET 2030 workshop 0 (process diagram on Figure 2).

	Global City Trend	Code	"Relevance" Votes	"Uncertainty" Votes
Building stock	Decarbonisation 2050	Ed1	2	2
	Building stock renovation	Ed2	13	10
	Smart Devices implementation	Ed3	0	0
	3D printing	Ed4	0	1
Sustainable mobility	E-mobility	Mo1	7	6
	Connectivity	Mo2	0	0
	Autonomous driving	Mo3	0	3
	Mobility as a service	Mo4	1	0
Governance	Long-term planning	Go1	2	2
	Co-design/co-creation processes	Go2	4	2
	Supra-municipal funding in climate action	Go3	1	5
	Institutional and citizenship awareness	Go4	16	20
Energy	Renewable energies	En1	11	2
	Local energy communities	En2	1	1
	Energy system's monitoring	En3	0	0
	EU Green Deal	En4	4	3
ICTs	Data access	TIC1	0	2
	Virtual reality, augmented reality, digital twins	TIC2	0	1
	Smart city apps and 5G	TIC3	0	0
	Increasing inequalities	TIC4	1	2
Social	Responsible consumption	So1	2	7
	Demographics and aging population	So2	2	0
	Individualism and consumerism	So3	10	8
Others	Telework and reduced commuting	Otro1	3	4
	Active mobility	Otro2	0	2
	Increasing legislation	Otro3	4	3
	Education and leading societal patterns	Otro4	1	1
	Impact of climate change	Otro5	2	0
	Industry 4.0	Otro6	2	0
	Globalisation and big capitals attraction	Otro7	3	1

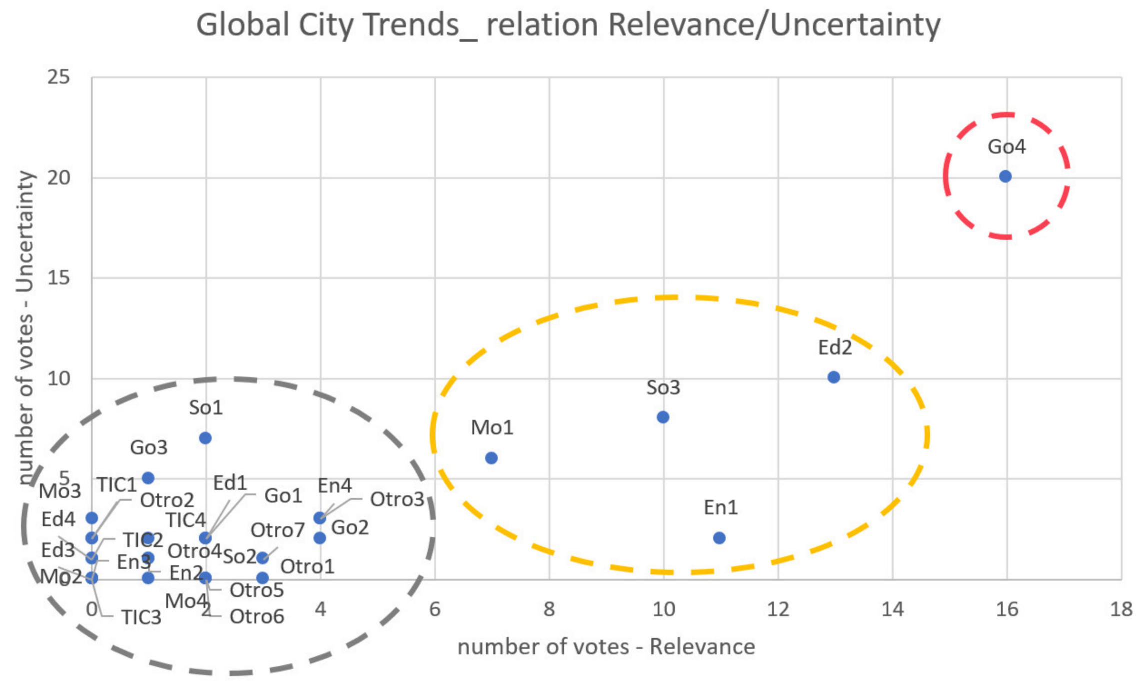

Figure 4. Scatterplot diagram showing the relation Relevance/Uncertainty of global city trends in APIET 2030 workshop 0 (process diagram on Figure 2/acronyms in Table 2).

Derived from the global city trends assessment, the stakeholders identified the main external opportunities and threats; derived from the CBIP (city characterisation; Section 3.2), the main internal strengths and weaknesses of Vitoria-Gasteiz in energy transition terms were identified, assembling a SWOT analysis focused on qualitative input. This SWOT exercise was supported by the urban-energy model, which provided a deeper quantitative input (Sankey diagram on Figure 5, summarising Vitoria-Gasteiz's energy system).

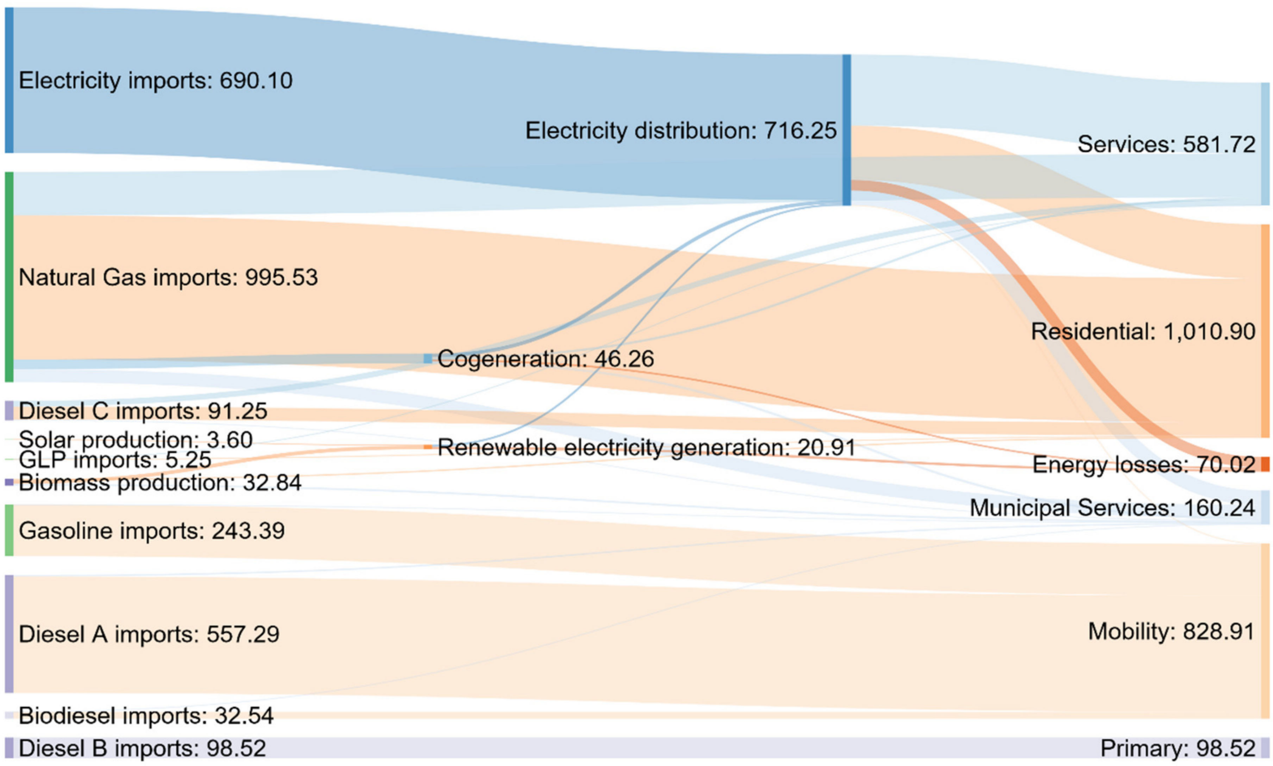

Figure 5. Sankey diagram of Vitoria-Gasteiz's energy balance, part of APIET 2030 city diagnosis (GWh).

Finally, the resulting SWOT was contrasted and complemented by the key local stakeholders' group (Section 3.3), finding in this city diagnosis a common ground to build the strategic planning process of Vitoria-Gasteiz (city vision 2030; Section 3.5 and action plan 2030; Section 3.6).

3.5. City Scenarios Generation and a City Vision for Vitoria-Gasteiz 2030

Once the city diagnosis development and global city trends identification processes were finalised, the ground for co-generating a city vision 2030 was ready (Figure 2). First, taking the CO_2 reduction and climate adaptation institutional goal, together with the most "relevant" but "uncertain" global city trend voted by local stakeholders ("Institutional and citizenship awareness"; Table 2), four different 2030 scenarios were co-generated by four stakeholders' groups (workshop 1 in Figure 2). Each of those scenarios was developed according to a prospective exercise performed by each group [11], where the stakeholders identified the main elements that would lead to such a situation in 2030, all categorised by city system (energy and renewables; built environment; mobility; governance; others). At this point, all SWOT elements and main global city trends identified were kept in mind for each scenario generation. Each of those four scenarios consisted of a prospective narrative and an urban-energy model, and they were complemented by a summarising diagram and a title proposed by the participants, aiming for a better common understanding for the whole stakeholders' group (Figure 6):

- "Haec est Victoria quae vincit", where institutional and citizenship awareness would be high, and CO_2 reduction targets would be achieved (+/+).
- "Vitoria-Gasteiz is frustrated", where institutional and citizenship awareness would be high, but CO_2 reduction targets would not be achieved (+/−).
- "ECO-nomic despotism", where institutional and citizenship awareness would be low, but CO_2 reduction targets would be achieved (−/+).
- Vitoria-Gasteiz Grey Capital, where institutional and citizenship awareness would be low, and CO_2 reduction targets would not be achieved (−/−).

Figure 6. Synthetic diagrams of the four scenarios in APIET 2030.

After an intense debate among local stakeholders, they tried to reach a consensus on the key elements for a "preferred scenario" (Table 3), which must be ambitious enough to reach CO_2 reduction 2030 goals and achievable to not generate wrong expectations among the local community. Furthermore, the key elements of that "preferred scenario" were introduced in the urban-energy model, generating slightly different technical proposals to achieve those 2030 goals. Finally, the members of the energy and climate department, with the support of the urban-energy modellers, were able to refine the outputs of the co-creation process to present the "master scenario 2030".

Table 3. Summary of key elements of Vitoria-Gasteiz's master scenario 2030.

Energy and Renewables	Building Stock	Mobility	Governance	Others
High renewables share	Increasing energy-renovation	Active mobility	CO_2 reduction and resilience targets achieved	Diversified economic drivers, with high added value and based on a circular economy
Local energy communities (residential and industrial)	Building stock adaptation to climate change impacts	Impact of "superblocks" concept and proximity services	High institutional awareness. Public administration as a role model	Services vs. production
Energy exchange (waste energy management	Renovation solutions with clear and shared financing models	New mobility services: micromobility, shared mobility	High citizenship's awareness; empowerment	Industrial regeneration
Distributed energy generation	Systemic renovation actions; no more pilot projects	Last-mile logistics revolution	Political multi-level alignment (local/regional/Europe)	High-quality employment
Energy self-sufficiency	Reduction of heating demand	Electrification of private vehicles and public transport	Flexible regulatory and taxation frameworks	Higher food and logistics self-sufficiency
Energy storage systems upgrade	Urban regeneration of vulnerable areas; "superblocks" concept	Integration of technology companies into urban areas, avoiding commuting to industrial areas	One-stop-shop for energy and renovation projects and local energy communities	New waste-management model

Furthermore, the essence of the master scenario 2030 was condensed into Vitoria-Gasteiz 2030 city vision, a statement with the main headlines the city intends to achieve after the implementation of the APIET 2030 plan, finding a consensus among the group of local stakeholders:

Vitoria-Gasteiz 2030; a resilient, safe, healthy, metabolic efficient, circular, and high-quality environmental municipality; a benchmark for distributed energy production from renewable sources, for an effective energy-renovation model of the built environment, for its determined commitment to the active mobility modes, complemented by a high-quality electrified public transport system. A municipality with institutions that exercise powerful leadership and act in an exemplary way together with a co-responsible citizenship with a high level of awareness, reinforced by a model of community cooperation capable of facing the challenges of the energy transition at the local level. All this is within a prosperous, innovative, and competitive economic environment, which ensures a collaborative social model in which no one is left behind [10].

3.6. APIET 2030—The Action Plan for an Integrated Energy Transition in Vitoria-Gasteiz

As a result of the co-development planning process, the APIET 2030 was finalised. The document describes the co-generation process at all stages, achieving an unprecedented level of agreement among the local community. Furthermore, it presents the city diagnosis, the master scenario, and the city vision 2030, leading to the final action plan 2030 (summary on Table 4), consisting of strategic objectives (2 general; 7 specific), strategic areas (5), strategic lines (10), and key actions (41).

Table 4. APIET summary; strategic objectives, areas, lines and key actions.

STRATEGIC OBJECTIVES (Overall - OSO/Specific - SSO)	
OSO1. Improvement of carbon footprint	**OSO2.** Local partnership for the energy transition
SSO1. Decentralised energy production and Local Energy Communities promotion	
SSO2. Social-fair energy-renovation of the building stock	**SSO3**. Sustainable Mobility
SSO4. Exemplary municipal leadership on energy transition	**SSO5**. Local community empowerment
SSO6. Industrial ecology and circular economy	**SSO7**. Digital transformation
STRATEGIC AREAS (SA), STRATEGIC LINES (SL), KEY ACTIONS (A)	
SA1. ENERGY GENERATION & RENEWABLES	
SL1. Implementation of distributed energy generation and electrification [19]	
A1.1.1 Renewable energy in public buildings/infrastructures	A1.1.2 Electrification of energy demand
A1.1.3 Waste and sustainable forestry maintenance as energy source	
SL2. Self-consumption potential management	
A1.2.1 Study on suitable urban locations	A1.2.2 Plan for self-consumption installations
A1.2.3 Fostering energy exchange among prosumers	A1.2.4 Energy Transition Plan for industry sector
A1.2.5 Partnership with energy and climate research/innovation institutions	
SA2. INDUSTRIAL, RESIDENTIAL, AND TERTIARY BUILDING STOCK	
SL3. Proactive management of renovation solutions; energy demand/consumption reduction in buildings	
A2.3.1 Creation of a municipal renovation institution	A2.3.3 Urban regeneration master plan
A2.3.3 Director Integrated Plan for housing renovation	A2.3.4 Reducing energy consum. in services sector
A2.3.5 Programme for energy meters deployment in buildings. Control of electric and thermal energy demand	
SA3. SUSTAINABLE MOBILITY	
SL4. 15 min mobility and shared mobility	
A3.4.1 "Superblocks" urban concept implementation	A3.4.2 Capacity building and promoting cycling
A3.4.3 Plan for school and work commuters	A3.4.4 Regulated parking plan
A3.4.5 Services of shared mobility	
SL5. Vehicles and infrastructures electrification	
A3.5.1 Electrification of public transport	A3.5.2 Last-mile logistics hubs
A3.5.3 Electrification of municipal fleets	A3.5.4 E-chargers deployment programme
SA4. GOVERNANCE	
SL6. Institutional leadership on energy transition	
A4.6.1 Transversal governance activities	A4.6.2 Adaptation of urbanistic instruments
A4.6.3 Public-private financing system	A4.6.4 Green taxation programme
A4.6.5 Participation in global city networks on energy and climate neutrality	
SL7. Fostering Local Energy Communities (LECs)	
A4.7.1 Fostering local stakeholders' interest/cooperation	A4.7.2 Open capacity building on energy transition
SA5. MUNICIPAL SERVICES AND FACILITIES	
SL8. Efficient municipal services	
A5.8.1 Creation of an energy transition one-stop-shop	A5.8.2 Energy efficiency on waste management
A5.8.3 Energy efficiency on the water cycle management	A5.8.4 Circular economy on municipal activity
A5.8.5 Environment criteria on municipal energy contracts	A5.8.6 Municipal website on energy & climate action
A5.8.7 Participatory budgeting for prioritisation of lines	
SL9. Exemplary and efficient municipal facilities	
A5.9.1 Energy-renovation plan for municipal buildings	A5.9.2 High-efficiency public lighting deployment
A5.9.3 Fostering low-carbon procurement	A5.9.4 Raise awareness of public admin. employees
SL10. Increase of CO_2 sinks. Green infrastructures and local food production	
A5.10.1 Increase of municipal CO_2 sinks capacity	A5.10.2 Emissions reduction on food production
A5.10.3 Implementation of food self-sufficiency plan 2025	A5.10.4 Municipal strategy on green-circ. economy

Regarding key actions, each of them was defined according to a systematised layout, enabling the potential of performing a joint analysis through a digital dashboard (Figure 3), visualising overall APIET 2030 figures and interconnections. Furthermore, the potential impact of each key action was introduced into the urban-energy model, quantifying the impacts of its implementation on a yearly basis, setting evolution rates, and calibrating overall consumption and emissions goals. All elements considered for the definition of each key action are presented in Table 5.

Table 5. Elements considered in the description of each APIET 2030 key action.

Description of the Key Action:
Title and description of the action—free text
Alignment with sustainable development goals (SDGs), APIET 2030 elements (strategic objectives, strategic area, strategic line, other key actions)—multiple choice, and connection to municipal/regional/national plans—free text
Specific objective of the action—free text
Implementation period and follow-up indicators—period choice, by year
Kind of action and potential barriers entailed—multiple-choice
Best practice on the field—fill out a systematised table, including an online link
Responsible department and position/competence owner/stakeholders involved—free text
Environmental, socio-economic, budget, and energy parameters:
Climate proofing description (analysis on the potential impact of climate change on the action)—free text + Other environmental elements—checklist
Socio-economic elements—checklist
Budget (total approximate budget, payback time, annual savings once payback is finalised, budget description)—free digits + free text
Energy savings/year, CO_2 savings/year, the evolution of CO_2 emissions' reduction—free digits

Depending on the key action, this level of information was not always possible to be provided, as was the case in most of the quantitative energy and emissions' impacts of the strategic governance area (SA4, Table 4). In terms of stakeholders' engagement, all actions were contrasted with local sectorial experts, which significantly enriched the outcome of the plan, as well as the alignment with ongoing initiatives in each field.

Based on the foreseen impact of APIET 2030 key actions, quantified by the urban-energy model, the following tables show the distribution of energy consumption and CO_2 emissions by energy source (Table 6) and city system (Table 7) by 2030.

Table 6. Energy consumption and emissions by energy source; 2030 scenario.

Energy Source	**2006**		**2030**		**Variation 2006/2030**	
	Consumption (GWh)	**Emissions ($ktCO_{2e}$)**	**Consumption (GWh)**	**Emissions ($ktCO_{2e}$)**	**Consumption (%)**	**Emissions (%)**
Electricity	686.2	306.3	683.7	41.4	17.6%	−86.5%
Electricity self-consumption (PVs)	-		123.4	0.0		
Natural gas	709.9	144.0	500.0	101.5	−29.6%	−29.5%
Fossil-fuels based	1253.9	388.1	461.3	172.4	−63.2%	−55.6%
Biofuels			42.2	7.4	-	-
Other (biomass/waste-heat)	0.0	0.0	54.9	0.0	-	-
TOTAL	**2650.0**	**838.3**	**1865.6**	**322.8**	**−29.6%**	**−61.5%**

Table 7. Energy consumption and emissions by city system; 2030 scenario.

City System	2030		Variation 2006/2030		Variation 2017/2030	
	Consumption (GWh)	Emissions ($ktCO_{2e}$)	Consumption (%)	Emissions (%)	Consumption (%)	Emissions (%)
Housing	775.4	99.6	−19.7%	−63.1%	−22.7%	−56.5%
Services	453.1	37.5	−17.6%	−81.5%	−20.8%	−74.3%
Mobility (internal)	453.0	106.7	−51.0%	−56.3%	−45.4%	−50.8%
Primary	81.2	72.9	−4.6%	−8.2%	−17.6%	−19.6%
Water cycle	9.8	0.0	−16.2%	−100.0%	0.0%	−100.0%
Municipal services	89.9	2.8	−23.8%	−92.6%	−36.3%	−83.7%
Waste management and street cleaning	20.4	3.3	90.7%	16.4%	0.0%	−31.2%
TOTAL	**1865.6**	**322.8**	**−29.6%**	**−61.5%**	**−29.7%**	**−54.0%**

The tables above refer to years: 2030, as the implementation timeframe of APIET 2030; 2006, as the baseline date for CO_2 reduction calculation; and 2017, as the last year with energy consolidated data introduced in the urban-energy model, indicating approximately the estimated impact of APIET 2030 implementation, from 2017 to 2030.

3.7. APIET 2030—A Plan Integrated into Municipal Planning Dynamics

The main risk of the APIET 2030 was not transcending to the right fields of action for its correct implementation. With that purpose, the energy and climate department promoted the following integration lines of APIET 2030 into municipal planning dynamics:

- At the coordination level of APIET 2030, the new energy and climate department will act as an interdepartmental facilitator, working as a municipal hub for APIET 2030 deployment, ensuring a suitable governance scheme.
- At the strategic level on energy and climate, the APIET 2030 is considered the evolution of SEAP 2020 [17] and an intermediate milestone of Vitoria-Gasteiz's strategy on carbon neutrality 2020–2050.
- Regarding municipal commitments, the APIET 2030 (complying with climate change *mitigation* requirements) in coordination with the action plan for climate change adaptation 2030 (APCCA 2030, complying with climate change *adaptation* requirements), works as a solid background for the next sustainable energy and climate action plan (SECAP 2030). The publication of SECAP 2030 in the fall of 2021 will mean the official renewal of Vitoria-Gasteiz's adhesion to the covenant of mayors' initiative (Figure 7). During the implementation stage of those three documents, the coordination will be managed by the energy and climate department, ensuring an overall common understanding and an efficient deployment process.
- Regarding urban planning instruments, specific outcomes from APIET 2030 will generate modifications as part of the ongoing review of the general land use plan of Vitoria-Gasteiz. In this sense, local regulation (*ordenanzas*) will incorporate specific modifications for a suitable APIET 2030 implementation.

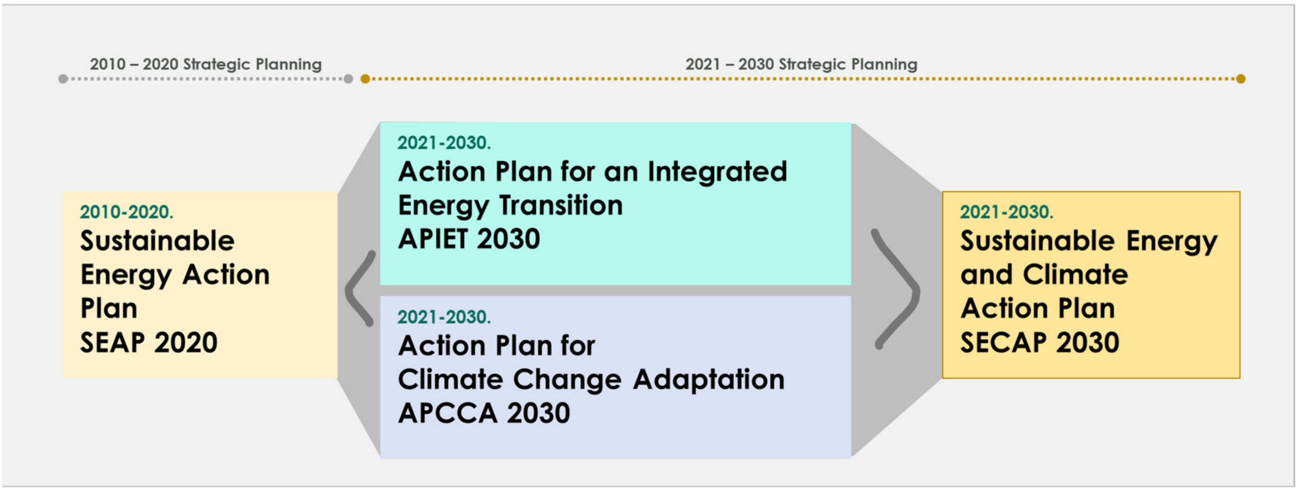

Figure 7. Energy and climate strategic planning process 2010–2030.

4. Discussion

As presented in the Results section, the Cities4ZERO methodology has been followed step by step in Vitoria-Gasteiz's APIET 2030 development. In this case, all theoretical steps have been applied in the field, showing its capacity to guide urban decarbonisation planning processes. This approach has fostered the creation of a new cross-cutting municipal department, enabling an effective public leadership on climate action. The Cities4ZERO methodology, together with this institutional adjustment, have both triggered a suitable planning ecosystem to effectively involve the key local stakeholders in the generation of each of the necessary planning steps towards the definition of the APIET 2030. Furthermore, the urban-energy model has supported the whole process and the engagement dynamics, from city characterisation, diagnosis, and 2030 scenarios' generation, to the definition of the 41 key actions of the APIET 2030. Cities4ZERO's strategic stage objective is to provide "*a strategic planning framework* (strategies, plans, actions) *which enables the city administration to perform an effective transition towards a Smart Zero Carbon City*" [10]; this "*strategic planning framework*" has been developed in Vitoria-Gasteiz. During the coming years, thorough monitoring of the APIET 2030 fulfilment will determine if the Cities4ZERO approach is also valid for the development of key actions (design stage/intervention and assessment stage), as well as for achieving decarbonisation goals after their implementation.

4.1. Interdepartmental Flexibility

One of the main learnings of this planning process is the importance of accommodating the development of a decarbonisation plan to the development of the ongoing sectoral strategies of the city as much as possible; timing must be established depending on the context favouring crossed influences and synergies. The aim of having an integrated cross-cutting approach when developing APIET 2030 forced the leading energy and climate department to look at other departments, setting a dialogue to coordinate their sectorial strategies' outputs in terms of contents and timing with APIET 2030.

In this sense, one of the main findings from this process is that it may be beneficial to adapt processes and align timings among plans to achieve the required development maturity of some sectoral plans, then aligning and integrating their outputs into the decarbonisation plan. In the case of the APIET 2030 development, the sustainable mobility and public space plan was in its final draft phase, and the integration of both was straightforward. However, the urban regeneration and renovation master plan was under development; in this case, the APIET 2030 development process delayed its progress for three months to integrate those outputs, which were crucial in the SA2 (building stock strategic area, Table 4), targeting the energy-renovation initiatives. In the case of the municipal water agency, they reviewed and updated the energy implications of their water cycle management plan for its integration in the APIET 2030, increasing their last consumption data by 0.9GWh, whilst not affecting CO_2 emissions as it would be covered by renewable energy sources.

These examples give an idea of the alignment intention, hoping that the interdepartmental flexibility effort of integrated planning practices will pay back with future increased efficiency and effectiveness in the implementation process, as well as with more coherent and synergic municipal policies. In this sense, it is important to highlight that the whole APIET 2030 development process, which has involved personnel from different departments, has significantly supported interdepartmental interaction and collaboration.

4.2. Permeability of Strategic Requirements on the Land-Use Planning Cascade

There is a hierarchy and sequential conception of planning instruments, from the EU territorial agenda 2030 to the municipal masterplans, detailing the land use of the territory and the city, both in graphic and text-regulatory terms. However, strategic plans, such as APIET 2030 do not belong to that operative urban planning cascade. Is this a barrier when implementing APIET 2030 key actions? For some decarbonisation initiatives, it seems clear the need to delve into that operative level (land ownership, rights and obligations, municipal regulation, land-use incompatibilities, etc.) if they are meant to be implemented. Let us imagine a renewable energy project that intends to install solar panels in the rooftops of both a public school and a new pergola within the public space, by the initiative of a private cooperative of investors (citizens), who will exploit the energy-generation business by selling electricity to the grid and heat to the surrounding housing area. The multiple affections to land-use rights and incompatibilities make the initiative close to utopian unless there is a deep reflection on the operative urban planning dimension. Furthermore, which kind of document shall reflect on that integration? City masterplans seem very stable in legal terms, but they may not be agile enough for such a purpose, while urban agendas may lack the operational aspect. Probably, the local context of each city, bound to its national and regional regulation, will determine the best solution for each case; what seems clear is that these potential barriers must be addressed, and urban planning stakeholders must be engaged. In the case of the APIET 2030, the involvement of the urban planning department was scarce, mainly due to the extremely slow updating process of the city masterplan, which takes several years of rigid bureaucracy, making the integration of APIET 2030 outputs in such a document a significant challenge.

4.3. The Role of Urban-Energy Models in Decarbonisation Planning

Looking at current cities' decarbonisation planning processes, there is a consensus on the crucial importance of urban-energy models and their quantitative support to set goals and define actions. However, one should not lose sight of the main purpose of the urban-energy model, i.e., the prospective analysis. The defined urban-energy model does not aim to translate already decided actions or objectives, although it can be used for that end, but to generate different alternative pathways that may support the definition of these measures and targets. In this sense, APIET 2030 can be considered as a forecasting approach, where urban-energy modelled scenarios were used to analyse the potential impact of diverse actions in the city, hence setting CO_2 reduction targets; it is an explorative vision in line with the city's potential. In the coming years, when following up APIET 2030 and generating the updated scenarios in the future, the method could link forecasting and backcasting (just objectives are defined; not actions) approaches. The urban-energy model should be used to feed the discussion and support the decision-making, rather than to justify already defined strategies, forming so-called socio-technical scenarios [20]. In the same line of inconsistency, there is no point in refreshing the base year of the model from year to year without generating updated scenarios to refine the mid/long-term visions, as that approach implies updates neither on actions nor on targets. Furthermore, looking for future updates, it would be interesting to link Vitoria-Gasteiz modelling to what the rest of the Basque region and Spain are planning, which also has significant effects on the energy balance and carbon outcomes of the city and vice versa [7]; the city is likely not going to be a disconnected energy island in the future.

Regarding that follow-up process, urban-energy modelling should be combined with assessment methodologies to evaluate results based on diverse criteria. Furthermore, the update of all necessary data can be a challenge for most municipalities, still a significant problem even in the planning phase, where the effort to provide enough detailed information to the urban-energy model is an issue. Finally, the depth of the analysis must determine some characteristics of the data to be gathered and the urban-energy model structure. The level of detail will not be the same if planners just want some rough numbers to orientate their decisions, or if they really want to check the exact potential impact of each proposed action; in this sense, both data and model characteristics must be considered.

4.4. Key Local Stakeholders at the Core

In APIET 2030 development, key local stakeholders have been at the core of the planning process since the beginning, contributing to diagnosis, envisioning, and action planning phases. This fact has been, for sure, a significant effort for the management team, which sometimes can be perceived as a toll against an agile planning process. However, to the eyes of APIET 2030 planners, this intensive engagement has reinforced the quality of the final output, and it has improved the alignment with other departmental strategies and other local public-private initiatives. Furthermore, it seems reasonable to think that the potential barriers at the implementation stage may be reduced due to this early engagement, and probably more synergies will be found at that stage due to the exchange of views during the planning process. In APIET 2030 case, a more intensive engagement of the local industry and some economic sectors would have been preferable (i.e., Mercedes, Michelin); hence the management team must reflect on how to present attractive processes for such stakeholders to participate. Local authorities must design participatory processes where every relevant local stakeholder finds an interest, branding their participation and climate action efforts as support to the local community development.

This scarce involvement in practice of the private sector in the case of APIET 2030 can be considered as a limitation of the Cities4ZERO methodology. However, when applying the methodology to the case of Sonderborg's climate neutrality roadmap 2025 (Denmark, [21]), the private sector took a key role in the process. Definitely, it is an aspect to take care of; otherwise, the final plan will find difficulties to become transversal among the local community.

Another potential limitation in the Cities4ZERO application is the lack of technical and economic support when applying the methodology. The APIET 2030 and other ongoing local plans following the methodology are supported by the European Commission's funding, which significantly helps municipalities to develop the ambitious steps and evolvements of Cities4ZERO framework implementation. It seems challenging to keep the level of ambition without such technical and economic support. In this sense, cities in the Basque region are facing the fulfilment of their Law 4/2019 on energy sustainability by opening their own procurement processes to find the necessary technical support with their own funds. However, this is only feasible if their initial commitment towards decarbonisation is solid.

Regarding the applicability of this research to other urban contexts, as the methodology has been developed by following strategic processes from different European cities, Cities4ZERO fits with the interest and needs of those, even if it represents an innovative approach to their traditional planning mechanisms. It is true that each local context is different, but most potential barriers, limitations, and solutions are common to most cities regarding decarbonisation. In this sense, the Cities4ZERO approach provides enough flexibility to be adapted to each local paradigm, and of course, APIET 2030 outcomes can be interpreted as a result of that local adaptation process.

Finally, in terms of APIET 2030 vertical integration, the development of the plan has kept an interest in the institutional and strategic multi-level alignment, a fact that will probably support the implementation process. The APIET 2030 fulfils the regional Law 4/2019 on energy sustainability of the Basque community [18] requirements and acknowledges EU directives in the field (2018/844-Energy Performance of Buildings and 2018/2002-Energy Efficiency); the plan is in line with Basque's research and innovation smart specialisation strategy (RIS3, Urban Habitat), as well as with the energy transition and climate change Spanish law 7/2021 [22], and EU initiatives such as the European city facility, the covenant of mayors and the horizon Europe innovation programme. Through this alignment, two of the main struggles in the implementation stage, such as regulatory barriers and the search for funding, will both be better addressed.

Once the APIET 2030 has been developed, the research team will focus on future lines of research. Firstly, a thorough APIET 2030 follow up and monitoring process, together with Cities4ZERO application to other cities (Bilbao, Amsterdam, Copenhagen, Riga, Matosinhos, Budapest, Bratislava, and Krakow), will provide both enough data to fine-tune the methodology and create an updated Cities4ZERO 2.0 version, as there is still room for evolving it in several aspects (i.e., co-governance, urban-energy modelling, real-time data and management, etc.). Secondly, and regarding urban-energy modelling, there is ongoing research on better supporting the envisioning engagement process (2030/2050) with better quantitative energy-modelled scenarios; there is a thin line between being too technical or too superficial regarding quantification in those engaging workshops. Hence an effort is still necessary in this regard, as it represents a crucial part of a decarbonisation plan. In this sense, a tool able to show the participants the potential affections of the different scenarios would reinforce the quality of the envisioning engagement process [23]. Furthermore, as requested by some pioneer cities in climate neutrality terms (i.e., Copenhagen), the modelling, visioning, and planning processes must offer the opportunity of accounting not just the impact of energy consumption within the city but also all other GHG emissions that occur outside the city boundary as a result of activities taking place within the city boundary (i.e., supply chains of non-energy good, such as food, water, building materials, clothing, products, etc.) [24]. In this sense, LCA approaches and extended input/output tables will be explored.

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