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The Nexus between Market Needs and Value Attributes of Smart City Solutions towards Energy Transition. An Empirical Evidence of Two European Union (EU) Smart Cities, Evora and Alkmaar

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Abstract: This study presents an experiential process and a market-oriented approach for realizing cities' energy transition through smart solutions. The aim of this study is twofold: (a) present a process for defining a repository of innovative solutions that can be applied at building, district, or city level, for two European Union cities, Evora and Alkmaar, and support the deployment of positive energy districts enabling a sustainable energy transition, and (b) understand in a systematic way the attributes of value offered by energy-related smart city solutions, in order to facilitate the development of sustainable value propositions that can successfully address city needs. The repository is assessed against four elements of value, which include social impact, life-changing, emotional, and functional attributes, according to the value pyramid of Maslow. Results show that the value attributes of quality, motivation, integration, cost reduction, information, and organization are highly relevant to the proposed smart solutions. The results presented in this study are useful for city planners, decision-makers, public bodies, citizens, and businesses interested in designing their energy transition strategy and defining novel technologies that promote urban energy sustainability.

Keywords: smart cities; monitoring; innovation; market; energy transition; business models; cultural heritage

1. Introduction

1.1. Towards a Sustainable Energy Transition—The Role of Cities and Positive Energy Districts

Cities play a vital role towards smart and sustainable development [1,2], rendering the ever-present need to realize the transition towards a low-carbon energy system [3]. An urban transition agenda addressing the challenges and impacts of climate change by incorporating innovative energy concepts and regeneration models [4], beginning from the level of a building, a neighborhood, a district, or a larger urban agglomeration and scaling-up to city level, is a developing cutting-edge research field [5]. Districts are part of a city and well-suited for the application, analysis, and impact evaluation of nearly zero energy retrofit solutions [6], as well as the promotion of citizen engagement actions [7]. Therefore, creating or readapting/refurbishing districts which can sufficiently adapt and respond to climate change is key to facilitating energy transition, poverty eradication, and for safeguarding economic growth in cities. Cities start from creating smart and sustainable districts demonstrating solutions to unleash the potential of smart energy future, but also to function as a yardstick for monitoring and evaluating the performance of key energy-related sectors.

The Net Zero-Energy District (NZED) term refers to a wide vision of urban sustainability at district level, including net zero-energy buildings (NZEB), but also additional domains to demonstrate innovative solutions such as urban mobility, street lighting, waste management, and public safety [8]. There are also similar affiliations defined in the worldwide community; namely: Energy Positive Neighborhood (EPN); Positive Energy District (PED); with the last one adopted by the member states in the EU. More specifically, a PED is defined as an energy efficient and energy flexible urban neighborhood with annual net zero energy import and net zero CO_2 emissions, aiming at an annual local surplus production of renewable energy [9,10]. PEDs can become the small-scale demonstration of interaction and interconnection between the building stock, the users and the local energy, mobility and ICT system; all embraced within an agile approach of associated technological, geographical, governmental, environmental, financial, legal, social, and economic aspects [9]. These small-scale demonstrations are the next important step, particularly for the scalability and replication potential of the solutions to other cities or regions.

A key step in the deployment of PEDs is establishing standards and creating the conditions that reduce investment risks for the stakeholders intending to provide resources for realizing the transition. An open innovation environment aligned well with the market needs and a strategic collaboration of stakeholders such as public authorities, industrial leaders, investors, research organizations, and citizen communities are key enablers in the development of cities that serve the needs of the citizens and the urban environment [11].

Parallel to the creation of PEDs, it is worth noting that at a global level, some historic cities will face an additional challenge to combine higher levels of efficiency with new and innovative ways of retrofitting archaeological monuments or buildings of cultural interest. Energy inefficiency issues and PEDs become furthermore complicated when national or international rules impose limitations and legislation obstacles to retrofitting certain types of buildings. As such, historical cities need to think innovatively to contextualize energy efficiency measures in the preserved and historic urban districts with strong territorial particularities and enhance their fundamental impact on locals leading to a sustainable yet functional urban environment [12], while preserving their cultural heritage character.

In this context, this paper presents a set of pioneering solutions in the sectors of energy, mobility, ICT, waste, citizen engagement, and solutions for historic cities, that can be demonstrated at building, district, and city level, enabling the deployment of PEDs. This set of solutions is the outcome of a consultation process with the city authorities which initiates with the identification of their specific needs and available resources, the supporting policy framework, and the adaptation of solutions to serve those needs. Then, the value propositions of the solutions identified are collected through a survey and market research is conducted to confirm that solutions selected coincide with market trends, thus enabling their successful roll-out. Then, the aim of this research is to answer the following research question: which are the attributes of value for the aforementioned solutions, that enable the design of successful business cases and can eventually facilitate their roll-out? Consumer recognition of value offered is central to any business model and many iterations of interactions with potential end-users are often necessary for testing critical assumptions and adequately addressing their needs [13]. In addressing the research question, a case study approach is adopted, capitalizing on knowledge and experience gained from POCITYF (A Positive Energy City Transformation Framework) [14], a recently funded European H2020 smart city project, which identified and will try to orchestrate the demonstration of solutions towards energy transition at two Lighthouse cities (LHs): Evora from Portugal and Alkmaar from the Netherlands; as well as the replication of solutions in six Fellow Cities

(FCs): Bari from Italy, Celje from Slovenia, Granada from Spain, Hvidovre from Denmark, Ioannina from Greece, and Ujpest from Hungary. A first iteration in capturing how potential consumers perceive the attributes of value for the aforementioned solutions is performed to guide the development of future business models.

The remain of this paper is organized as follows: Section 1.2 provides an overview of supporting policies for PEDs and smart city projects in the EU, Section 2 provides an analysis of the specific LH city needs identified for Evora and Alkmaar; being also the replication model basis for the FCs. Those specific needs form the basis for analyzing what global objectives pertain that lead the implementation of measures for realizing energy transition while linking them to certain policies. Then, a repository of innovative solutions, the implementation of which can result in energy positiveness of the selected PEDs in the two LHs, is presented along with methods for studying the attributes of value offered by each smart city solution identified in the repository. Section 3 presents the analysis of the results, which can inform the development of successful value propositions, and Section 4 concludes and provides recommendations for future research actions and initiatives.

1.2. Supporting Policies Linked to PEDs and Smart City Projects

Europe is at the forefront of energy transition and climate resilience. It aims to become the first climate-neutral continent [15] and a global example in implementing integrated, innovative solutions for the deployment and replication of PEDs [16]. The goal is to create at least 100 PEDs by 2025 [16], while the realization of many of those is already achieved or is in the phase of development [10]. To achieve the above-mentioned goals, the EU has set a number of policies and initiatives covering a wide range of aspects, including positive energy buildings and districts deployment, developments in information and communication technologies (ICT), mobility, and citizen engagement. The EU Green Deal [15] provides a set of deeply transformative policies focusing, among others, on aspects directly related to research and innovation in the energy sector, addressing the wider spectrum of energy technologies and horizontal vectors contributing to the clean energy transition. European Climate Law [17] enshrines the climate neutrality objective into legislation, by setting key targets of 40% greenhouse gases (GHG) emissions reduction and 32% renewable energy sources (RES) share for 2030 and proposing a legally binding target of net zero greenhouse gas emissions by 2050. In this context, Horizon 2020 acts as a fulcrum for the development of smart cities as well as smart, sustainable, and inclusive growth and jobs, constituting the largest financial instrument of EU Research and Innovation [18].

Smart cities shape their future by leading in technology adoption, resource efficiency, and citizen/stakeholder engagement. On a building level, the revised Energy Performance of Buildings directive (EPBD) [19], together with the Energy Efficiency Directive (EED) [20] and the Renewable Energy Directive (RED II) [21], are the major EU legislation/policies currently aiming to boost long-term renovation of the EU's building stock, creating a favorable environment for bringing innovative construction products integrated with RES systems with better specifications into the market.

Regulation and policies (especially on an EU level) are becoming more and more ambitious and strict in terms of energy performance at districts/city levels. Increased self-consumption and locally produced energy is increasingly promoted. For instance, the recast of Renewable Energy Directive II to 2030 clearly defines the Renewable Energy Communities and Citizen Energy Communities, which aim to give greater power to citizens for self-generation, and self-consumption of electricity is expected to highly increase the demand for relevant solutions.

Additionally, if Europe wants to realize its decarbonization policies and meet its CO_2 emissions reduction goal of 40% by 2030, it needs to make a transition to a cleaner energy mix and establish 10-year integrated national energy and climate plans (NECPs) [22]. Within this context, relevant solutions of decentralized and dispatchable production based on renewable energy systems are increasingly gaining attention. Furthermore, initiatives like the EU Covenant of Mayors for Climate and Energy [23] have incentivized local authorities of cities to voluntarily commit into accelerating the decarbonization of their regions, strengthening their capacity to adapt to climate change, and allowing their citizens to access secure, sustainable, and affordable energy. Thousands of local action plans have been developed and include specific actions for reducing energy consumption and carbon footprint.

Sustainable waste utilization and management, although not directly relevant to the deployment of PEDs, are also of major importance for a smart and sustainable city environment. The Waste Framework Directive [24] obliges EU Member States to adopt and implement waste prevention programs. As the requirements are becoming more ambitious and stricter for waste collection and treatment, market demand for relevant solutions will be increased. Furthermore, the new Circular Economy Action Plan [25] adopted in 2020 by the European Commission fosters the analysis and assessment of the life cycle of products and materials to ensure sustainable use of resources, addressing areas that require intensive resource use; e.g., construction, production of electronic and plastic products, as well as renewables.

Developments in the ICT sector also accelerate the pace of digitalization in the energy systems [26]. The centralized approach of the grid-level energy management does not necessarily serve the needs of smart cities [27]. Sophisticated energy management systems based on ICT novelties can nowadays optimize decentralized networks that can capitalize on distributed energy sources (DER), such as renewable energy, combined heating and power stations, or storage systems offering security of supply, CO_2, and cost reduction. Therefore, ICT is an integral part of a smart city [28–30], ensuring prompt connectivity among the various integrated elements, improved flexibility, and monitoring of performance. In addition, a big step towards the creation of energy communities and Peer-to-Peer (P2P) energy trading was realized in the EU by the recent "Clean Energy for all Europeans" package [30]. This encourages active consumers who can own and manage distributed energy resources (DERs) individually with the aim to trade or exchange, among their peers, part of the self-generated energy.

In the transport sector, which is strongly related with the energy and the ICT sector, cities are encouraged to design sustainable mobility measures and solutions towards cleaner and better transport. The Transport White Paper [31] sets the basis for sustainable urban mobility in Europe, having two (2) specific urban targets. The first target is to decrease by half the utilization of conventionally fueled vehicles by 2030, aiming also at their phasing-out by 2050, and the second one is to successfully bring up CO_2 emission-free city logistics in major urban centers by 2030. In Europe, electrification of transport is one of the main goals reflected in the revised European Roadmap Electrification of Road Transport 2017 [32]. A Strategic Action Plan on Batteries [33] was also presented by the EC in 2019. The regulatory framework that now enables the integration of Electric Vehicle (EV) charging points to the distribution network, along with high RES share in the electricity grid, was recently adopted by the EU legislation. The new Directive (EU) 2019/944 [34] sets new rules for the internal electricity market, encouraging also access to consumers into electricity price comparison tools, smart charging, and dynamic electricity price contracts. EV penetration will most probably be further increased over the next years supported by this regulatory framework.

Finally, an essential element for achieving successful outcomes of smart city projects is to focus on people's needs and embrace citizen-centric design. Solutions are adopted more easily when they are citizen-centric by means of citizens' taking personal and collective responsibility for how they 'use' their city, changing their mindset, behaviors, and actions. Bottom-up urban regeneration requires multi-directional information flows (i.e., city-to-citizen, citizen-to-citizen, citizen-to-city [35]) and co-creation tools [36] (i.e., hackathons, urban living labs [37], crowd sourcing), for citizens to be involved in designing the city in which they live in. Citizen participation and adoption of solutions is also enhanced through the use of technologies and the digitization of offline services [38]. Initiatives like the Action Cluster on Citizen Focus focus on the importance of engaging citizens and communities in the design and co-creation of solutions for smarter cities [39].

The above versatile though interlinked set of policies create a dynamic environment in which city authorities through smart city projects [40] can synthesize those enabling policy factors with technological advancements and support their energy transition demonstrating, rolling-out, and scaling-up innovative solutions. In such a context, ecosystem stakeholders attempt to successfully capture the value of those novel solutions within the market. Smart city projects are gaining popularity in many countries [41], since they are considered a useful instrument for small- and large-scale applications, that can also broaden cooperation between cities, communities, industries, and all related policymakers and stakeholders [42].

2. Research Methodology

Many factors render it difficult to scale and replicate smart city projects. Common obstacles include: (a) the technology risk, especially in the case of absence of a demonstrable proof of concept, (b) the absence of adequate financial resources to implement a smart city solution, especially when a monetized return on investment is not clear, (c) regulatory factors and administrative competence, the existence of which is a pre-condition for the successful implementation of smart solutions, and (d) social and stakeholder uptake factors, as the social norms and stakeholder behavior may impact the adoption rates of smart city solutions that may eventually build a convincing track record, attract new investors, and enable scalability. Based on the above observations, and the continuous call for cities to realize energy transformation, it is important to understand the attributes of value offered by the implementation of potential smart city solutions in order to develop successful value propositions, which can be the basis for sustainable business models. The answer to the above question will be useful for city planners, decision-makers, public bodies, and businesses interested in investing in novel technologies that promote urban energy sustainability.

2.1. Setting Up a Process to Realize Energy Transition in Smart Cities Understanding Value Attributes of Potential Solutions

In an attempt to address the above issues, this paper builds on the literature findings related to the context of smart cities, and the pertaining policies and initiatives (top-down approach). In parallel, it identifies specific city needs for two LH cities, Evora and Alkmaar (step 1), and develops key objectives that serve the realization of the urban energy transition goals, but are also eventually linked to policies (step 2). A matching process of appropriate smart novel solutions was initiated (bottom-up approach). During this process, various smart solutions were explored by each city ecosystem. Solutions explored were assessed against (a) the technology readiness level (TRL), (b) the cost effectiveness of the solution, and (c) the impact towards achieving the goal of creating positive energy districts. The solutions explored were of TRL6 to TRL8 and represented novel, highly efficient systems. The impact goal was directly related to the percentage of positiveness to be reached for the districts selected. A threshold value of more than 100% positiveness was set. Other socioeconomic aspects were also considered, such as replicability potential, payback period for all solutions should be less than 10 years, and available city budget. This process was implemented during the phase in which the two LHs were planning the creation of their positive energy districts and laid the foundations for deriving a feasible and market-oriented repository of smart cities solutions (step 3). This repository of solutions derived from steps 1–3 can vary if the same process is applied in different cities. It was not the focus of this paper to provide detailed guideline on how cities should select their solutions, but to briefly present the process followed in POCITYF which was initiated with the identification of the city specific needs and resources available, followed by linking those needs to supportive frameworks, i.e., policies and initiatives, and selecting and adapting city specific solutions.

This repository shall also form the basis for potential solutions to be adopted by the FCs based on their specific needs. The value attributes of the solutions identified were then investigated (step 4) in order to understand the related dynamics for forming competitive value propositions and facilitate the design of successful business models, while helping investors recognize potential cash flows. Steps 1–3 are more relevant to stakeholders that are on the design phase of a PED, whereas Step 4 is relevant to cities which have already defined the solutions to be demonstrated and are in the process of designing the business cases for the successful roll out of those solutions (Figure 1). We used Maslow's elements of value for our analysis [43]. This research is valuable not only for determining a method for understanding the potential value of solutions and thus help decision makers and stakeholders derive conclusions on their potential success, but also for setting up a process to align innovations with the evolving city needs and design sustainable value propositions.

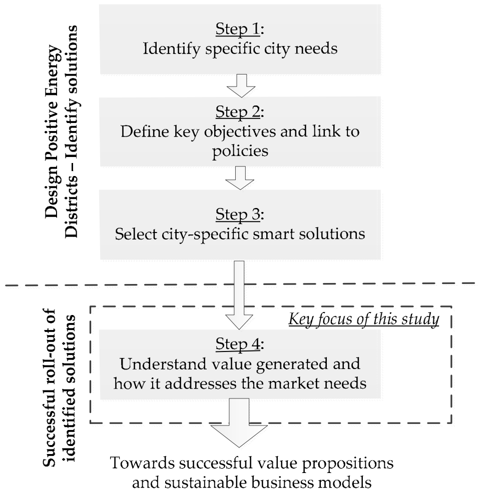

Figure 1. A four-step approach to support the development of successful value propositions.

2.1.1. Step 1: Identify City Needs—SWOT Analysis

Apart from common needs and challenges as imposed by the climate change and energy-related goals on global scale, the cities of Evora and Alkmaar (Figure 2) face city- and district-specific needs and challenges due to divergent geography, geology, climate, and socio-economic and cultural characteristics. These characteristics mean they embark towards their urban energy transition from different starting points and perspectives. A Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis was carried out at the two cities during the phase of planning their PEDs and is provided in the results section below. During the SWOT analysis, technical and innovation experts on energy transition participated in the process of identifying strengths, weaknesses, opportunities, and threats, along with city representatives and relevant city experts.

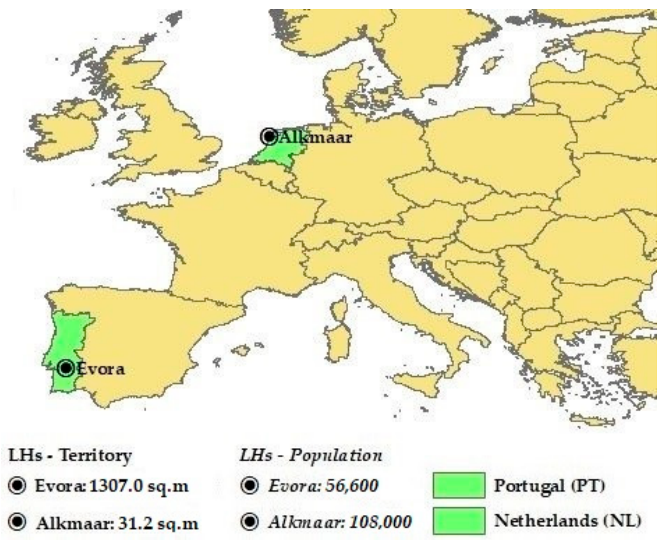

Figure 2. The two Lighthouse cities of the POCITYF project, Evora and Alkmaar.

2.1.2. Step 2: Key Objectives and Link to Policies—The Key Objectives Were Selected after a Consultation Process with the Cities—Their Needs

In the smart city project POCITYF, in order to design a feasible action plan that can realize energy transformation, the approach adopted was to decode and cluster the city needs identified in Step 1 and link them to supporting policies and frameworks. The decoding and clustering process was an internal city process, which was performed with the support of the technical and city experts. This process led to the definition of key objectives that could be addressed by a versatile energy transition strategy covering aspects such as energy, mobility, ICT, waste, citizen engagement, and specific solutions for historic cities. These aspects are certainly not exhaustive but cover to a great extent the energy transformation focus sectors of European cities. The energy transition strategy was structured in Energy Transition Tracks (ETTs). The term "ETT" is used to cluster complementary smart novel solutions which define the objective they address [44].

2.1.3. Step 3: From High Objectives and Policies to Selecting City Specific Innovative Solutions

The process of identifying the needs of the cities led to key objectives which helped in defining a clear strategy. The next step was to identify relevant solutions that would support the energy transition goal while taking into account the city specific needs. The specific solutions have been carefully selected by the two LH ecosystems after long discussions among the local authorities, energy and technology providers, the citizens, and research organizations, with a view to select the most appropriate ones addressing city needs and linking those to supportive frameworks, i.e., policies and initiatives, as described in previous sections.

Following the identification of solutions, a survey with questionnaires was conducted at the two ecosystems of Evora and Alkmaar to understand how the solutions providers defined the value offered. Participants in the survey were asked to describe the value proposition for each solution along with a linkage to potential addressable market needs. A market research was then conducted to explore market needs and trends and verify that the solutions identified have the potential to become sustainable business cases. The results are presented in Section 3.3.2. In order to allow for comparison of the solutions to be implemented in other smart city projects, we proceeded to Step 4 for understanding the underlying elements of value for each solution.

2.1.4. Step 4: Understanding Value Generated and How It Addresses the Market Needs

In order to better understand the potential of the innovative solutions to be widely deployed in the market it is important to recognize the underlying attributes of value each solution can potentially offer and then link this value to real market needs. To realize the above goal, we compared all proposed solutions identified in POCITYF repository against elements of value according to the value pyramid of Maslow [45]. Almquist et al. [45] identified 30 fundamental attributes of value, building upon Maslow's value pyramid, that fall into four categories of elements: (a) functional, (b) emotional, (c) life changing, and (d) social impact. The functional element includes attributes like saving time, simplification, making money, reducing risk, organizing, integrating, connecting, reducing effort, avoiding hassles, reducing cost, improving quality, variety, sensory appeal, and informing. The emotional element includes attributes like reducing anxiety, rewards, nostalgia, design/aesthetics, badge value, wellness, therapeutic values, fun/entertainment, attractiveness, and accessibility. The life changing element provides attributes like hope, self-actualization, motivation, heirloom, affiliation/belonging. Finally, the social impact element includes the attribute of self-transcendence.

The solutions identified for realizing energy transition in the selected districts of the two LH cities were assessed against the elements of value they address (Figure 3). A binary evaluation method was applied by the authors, scoring "1" when a solution satisfied an attribute and "0" when a solution did not satisfy an attribute. Then, for all solutions the frequency of satisfaction per attribute was calculated by summing the instances of "1" and dividing the sum by the number of attributes for extracting percentages. These percentages indicate the extent to which an attribute satisfies the selected solutions (e.g., 100% indicates that the specific attribute satisfies all solutions). All 11 authors of this study have extensive experience and knowledge on smart city energy transition projects, urban development, and energy technologies, and valued the solutions from a consumer perspective. Although a different perspective (producers, municipality) would potentially lead to a different evaluation, such work is left for future research. Two rounds of evaluation were performed by each expert to reach to a final converged decision. During the second round, the mean scores of the opinions of the first round were available so that authors could revise their answer if needed, leading to a more commonly accepted evaluation and final results.

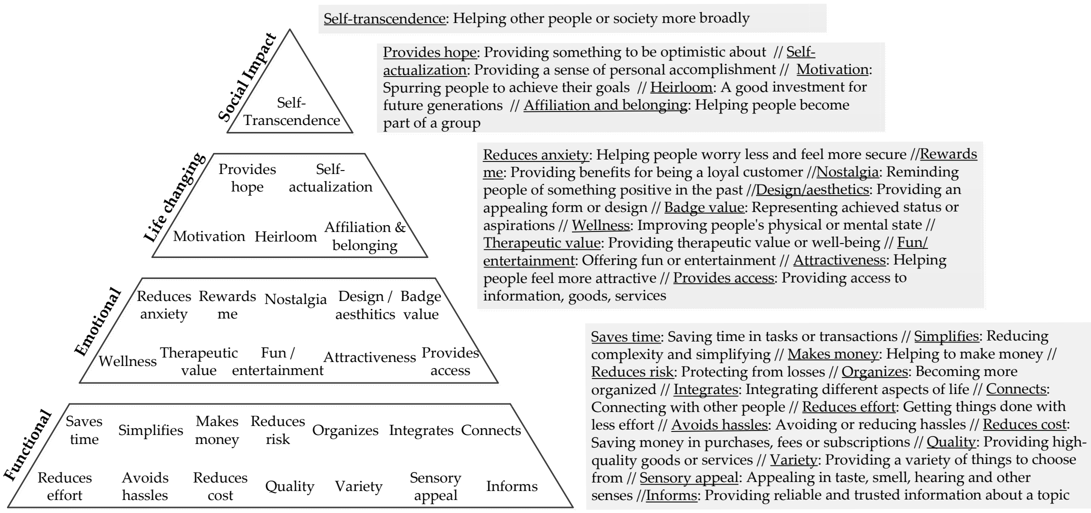

Figure 3. Elements of value (adapted from [45]).

This procedure was followed by a ranking revealing the attributes which are satisfied more frequently by the solutions identified in the POCITYF repository. An example of how the most frequent attributes were derived for solutions in ETT#1 is provided in Appendix B. This approach, of comparing the solutions with the value elements of Maslow pyramid, is a practical exercise that facilitates a deeper understanding of the underlying powerful forms of value which lie towards the top of the pyramid combined with functional elements of value and can potentially foster user adoption of energy efficiency related solutions.

3. Results

3.1. The SWOT Analysis for the Cases of Evora and Alkmaar

Evora represents South-European cities, which generally show lower investments in reducing the footprint of their households and business sector, but can enjoy an abundant solar potential. The climate of Évora is a typical Mediterranean climate according to the Köppen-Geiger classification, with rainfall distributed throughout the year unevenly. The average annual temperature is around 16 °C. Evora is an historic town in the heart of the Alentejo region and is one of the largest municipalities in Portugal, with 1307 km^2 (5% of the region) and 56,596 inhabitants. Its well-preserved historical city center is one of the richest monuments in Portugal, which earned the title of City-Museum. The total amount of energy consumption in Evora is approximately 634,000 MWh/y. The top three energy consuming sectors are transport (52%), housing (31%), and businesses and tertiary equipment (15%). The majority of the building stock is composed of buildings built between 1981 and 1990, characterized by inadequate thermal performance and high heat losses, whereas 25% of the total stock are in need of repair or very degraded. Since 2012, Évora has been implementing its Sustainable Energy Action Plan (SEAP) aiming at reducing its energy consumption, carbon dioxide (CO_2) emissions, and sustainable energy utilization by 20% in comparison with 1990 levels. The city has 31,000 domestic customers with installed smart meters; it also has an improved capability of RES and EV connections (EDP, Évora Inovcity). Évora was selected because it complies with a set of criteria relevant to this experiment: dimension, type of grid, national and international visibility, average level of consumption, inclusion in the national pilot network of electric vehicle charging stations.

Alkmaar represents West-European cities strongly dependent on gas for electricity and heating. Alkmaar has a temperate maritime climate under the influence of the North Sea and the warm Gulf Stream. The average annual temperature in Alkmaar is 9.1 °C. Alkmaar is an enterprising, modern city with almost 108,000 inhabitants, 47,000 households, 8000 companies, and a workforce of about 52,000 people. The total amount of yearly energy consumption in Alkmaar is approximately 8000 TJ. The top three energy consuming sectors are housing (38%), transport (31%), and businesses, commercial, and public services (24%). The national government has decided that all homes in the Netherlands must be natural gas-free by 2050. This is quite a challenging task for Alkmaar, where more than 23,000 buildings were built before 1975—and therefore poorly insulated—and 1/3 houses are privately-owned rental houses. In the Netherlands, natural gas is largely used for space heating and warm water. The Paris climate agreement was signed by the Dutch government on 28th June 2019 and forces the Dutch government forward with the implementation of RES and the energy transition towards a natural gas-free country. Moreover, the Dutch soil is burdened by a high amount of nitrogen composition in the form of animal most. Nitrogen oxides are formed by burning engines, like motor vehicles and industry. Mobility by road is responsible for 6% of the nitrogen damage to the environment. To maintain on a sustainable way the fragile eco system, extensive emission reduction of nitrogen oxides is required. The transition to e-mobility will further reduce the nitrogen issue.

Table 1 summarizes specific needs and challenges for implementing smart city solutions, as identified by the two LHs local authorities (district-oriented).

Table 1. Specific needs and challenges identified by the two Lighthouse (LHs) cities.

Evora	Alkmaar
• Thepivotal goal towards decarbonization is the increment of RES penetration, as well as other DER, such as energy storage systems, and optimization of electricity grid networks, actively controlling the consumption and production of the pilot buildings. • Use the increase of DER penetration to obtain district energy self-sufficiency. This enabled-flexibility can also be used for peer-to-peer trading, congestion management, and other non-frequency services to the distribution system operators (DSO), in the wholesale market (day-ahead and intraday) and even within the ancillary services market. • In the buildings' domain ranging from a set of residential, commercial, and even mixed-use buildings—composing the PEDs—the selected solutions should achieve a high level of energy efficiency and self-consumption. They should also be endowed with the capacity to exchange energy between them, as well as to export energy to the upstream (distribution network) and downstream (EV charging stations) systems. However, solar generation needs to comply with the historical facades and legal framework respecting cultural heritage.	• Informing and engaging citizens to participate in the transition towards the ambitious long-term goal of utilizing 100% sustainable energy, free of natural gas by 2050 is a key challenge for Alkmaar. • The diversity in stakeholders and the crucial role of citizens as enablers of the energy transition. Many of the inhabitants of pilot buildings are located in social housing and thus often have a low-income. Therefore, it is important to take affordability into account, as well as engaging inhabitants, and behavior change. • To become an energy positive district, a high penetration of renewables is necessary, in addition to low energy buildings and infrastructures. There is a clear need for the integration of decentralized renewable energy systems in the district, making efficient use of space and infrastructure.

Table 1. *Cont.*

Evora	Alkmaar
• From a transport viewpoint, the creation of new smart parking, smart logistics' routes, and EV sharing platforms will reduce the GHG emissions and reduce traffic. The increase in EV adoption is a fundamental part of Evora's strategy, which will leverage from current e-mobility initiatives and scale them up. • As a cross-cutting field, the ICT, from the deployment of technologies such as AI and Big Data algorithms to the integration of a city-level platform (collecting and presenting, in a visual attractive manner, the relevant data extracted from the deployed services), will enable the development of the Evora's strategy in every identified domain.	• For high penetration of renewable electricity, increasing the flexibility of the electricity grid is essential. Therefore, demand response management as well as integrating storage capacity at district scale are necessary solutions. • In order to integrate energy efficiency solutions and renewables with storage for grid flexibility and sustainable mobility, integrated urban planning methods and data sharing tools are essential. • Data-based services for integrated urban district planning, as well as a City information platform (CIP) based on open specifications can be major enablers to manage the successful transformation towards intelligent, user-driven, and demand-oriented infrastructures and information services.

3.2. The Energy Transition Strategy for the Cases of Evora and Alkmaar

The energy transition strategy formed for POCITYF comprised four Energy Transition Tracks (ETT#1–ETT#4). Together they provide a universal yet versatile framework to address both common but also diversified needs and challenges of PEDs in smart cities. The four ETTs are linked with four key objectives (Table 2), which serve common city needs and challenges, as imposed by the current smart city strategies, legislative goals, policies on climate change, and decarbonization goals. More specifically, each ETT attempts to address and be in line with the policy domains described in Section 1.2, i.e., with positive energy buildings and districts deployment, developments in ICT and P2P schemes, mobility, and citizen engagement. Within these ETTs, POCITYF seeks to enable, demonstrate, replicate, and accelerate the roll out of a set of solutions built on top of both mature and innovative technologies.

Table 2. Four key objectives (KOs) for smart city projects and POCITYF's response.

S/N	Objective	POCITYF's Response
1.	Demonstrate solutions at building and district level that enable the increase of energy self-consumption, energy savings, and high share of locally produced renewable energy—leading to energy positive districts.	ETT#1: Innovative Solutions for Positive Energy Buildings and Districts.
2.	Demonstrate P2P energy management and storage solutions supporting grid flexibility and curtailment reduction.	ETT#2: P2P Energy Management and Storage Solutions for Grid Flexibility.
3.	Demonstrate the integration of electro-mobility solutions as an enabler to grid flexibility.	ETT#3: E-mobility Integration into Smart Grid and City Planning.
4.	Demonstrate active citizen engagement services and solutions providing an open innovation ecosystem for citizens to participate in co-creation, decision-making, planning, and problem solving within the Smart Cities.	ETT#4: Citizen-Driven Innovation in Co-creating Smart City Solutions.

3.3. Identification of City Specific Innovative Solutions Satisfying Market Needs

3.3.1. Evora and Alkmaar Innovative Solutions for Realizing Their PEDs

As already mentioned, in this paper we present the repository of solutions that will be demonstrated in the two LH cities of POCITYF and will also serve as a basis for FCs to realize comprehensive action plans towards achieving their energy transition goals. In total 58 solutions have been extracted from POCITYF's repository and are presented in this study (Table 3)—21 are included in ETT#1 (separated into four categories), 18 are included in ETT#2 (separated into five categories), 7 are included in ETT#3 (separated into three categories), and 12 are included in ETT#4 (separated into four categories). In some cases, common solutions are applied in both LH cities. It should be mentioned that both the categories presented below and all relevant solutions are not absolute, and each city should revise this list based on its actual needs. However, it can serve as a great basis for action, since it offers a multitude of solutions applicable to two varying city profiles (as described in Step 1). For instance, Evora will implement a variety of solutions dealing with PV energy production due to its local climate, as well as solutions that are highly compatible with its cultural heritage character [4]. Alkmaar, on the other hand, is putting more emphasis on its district heating network (Evora does not have a district heating-cooling (DHC) network) and EV penetration (imposed also by the strong EV charging infrastructure available in the Netherlands). For those 58 smart and novel solutions identified in the POCITYF repository, the questionnaire was completed by 12 partners in the ecosystem of Alkmaar and 14 partners in the ecosystem of Evora.

Table 3. The repository of smart city solutions adopted in this study.

	Category	**Evora Solutions**	**Alkmaar Solutions**
ETT#1 (Obj.1)	RES generation (8)	PV (crystalline silicon) glass//PV canopies//PV skylights//Roof integrated PV systems//PV roofing shingles//Community Solar Farm.	Composite façades with vertical solar panels//Hybrid wind/solar generation system.
	Smart energy management, control, and self-consumption (5)	Bidirectional Smart Inverters//Energy Routers//Building Management Systems (BMS)//Positive Computing Data Center.	Building/Home Energy Management Systems (BEMS/HEMS)
	Building energy efficiency (5)	Triple Glazing//PCM in the floor//Insulation with Circular Materials//Thermo Acoustic Heat Pumps//Cascaded Heat Pumps	
	Sustainable waste utilization and management (3)	Pay-As-You-Throw (PAYT).	Reverse Collection of Waste//Material Passports
ETT#2 (Obj.2)	Grid-Level Energy Management (5)	Micro-grid controller platform//Flexibility Control Algorithms.	City Energy Management System (CEMS)//Virtual Power Plant (VPP)//DC grid
	Sustainable Energy Storage Systems (5)	LV and MV connected storage systems//Freezing storage in store//2nd Life Residential Batteries.	Stationary batteries (Li-ion)//Aquifer Thermal Energy Storage (ATES)//2nd Life Residential Batteries
	Sustainable DHC Networks (6)	DHC//Low temperature heat grid//Geothermal heat source//Low temperature waste heat//Thermal grid controller//Heat Island concept	
	P2P energy trading (1)	Peer to Peer Energy transactions.	-
	Hydrogen Technologies (1)	-	Fuel cells (hydrogen)
ETT#3 (Obj.3)	Vehicle to Grid (V2G) and EV Charging Infrastructure (4)	EV charging from PV systems//Smart Lamp posts with EV charging and 5G functionalities.	EV charging from PV systems//V2G//DC lighting with EV charging

Table 3. *Cont.*

	Category	Evora Solutions	Alkmaar Solutions
	Smart EV Charging (2)	EV charging management platform	Intelligent and optimal control algorithms
	E-mobility Schemes (1)	EV Sharing	EV Sharing
ETT#4 (Obj.4)	Changing Energy Behavior (4)	Gamification//Tourist apps//Cultural experiences marketplace//Energy consumption monitoring, automation, and control through mobile apps.	-
	City Services Infrastructures and Systems (3)	City Information Platform//Wi-fi data acquisition systems//Data lake intelligence for positive communities	City Information Platform//Wi-fi data acquisition systems//Data lake intelligence for positive communities
	Fostering Energy related Innovations (3)	Smart cloud for innovative startups//Acceleration Programs (i.e., Pocifest).	Governance innovation and co-creation (i.e., TIPPING approach)
	Decision Support Tools (2)	Design-based Value Mapping for Communities.	Planning Urban Transformation (i.e., Eco-Acupuncture)

3.3.2. Market Needs and Value Proposition of Solutions Grouped Under the 4 ETTs

Following the identification of solutions which can potentially have an impact on related policies and in addressing the city specific needs decoded into the POCITYF objectives and aimed to be fulfilled through the four (4) ETTs, the authors collated the market needs and trends with the value propositions of the 58 solutions. In total, 26 partners in the two local ecosystems of Evora and Alkmaar answered the questionnaire regarding the value proposition and addressable market needs. Market needs were then also explored by the authors through extensive market research for all solutions identified in the repository. The key current and future market needs that may influence the solutions' implementation, innovation, and value proposition are summarized per each category of the ETTs in Tables A1–A4, placed in Appendix A due to size limitations. Emphasis was given to solutions that can facilitate the deployment of PEDs. In almost all cases current market needs and future trends favored the implementation and the scale-up of proposed solutions based on their value proposition. This further supports the selection of the proposed solutions (step 3), which was performed building upon the specific city needs (step 1) and specific objectives set to address those needs while linked with policies and initiatives supporting the energy transition of cities (step 2). With a view to satisfy the special needs of Evora and Alkmaar, the repository of solutions proposed along with the value propositions is also fitted especially for old/protected buildings/areas, highly motivating cities with similar challenges to move towards energy transition. However, different solutions serve different needs and generate specific values. A one-size-fits-all solution cannot meet the versatile needs of smart cities [6] and it is up to each city to define the most appropriate combination of solutions to achieve its energy transition goals and serve its needs. A respective market research, although it requires regular updating, can also support city authorities, decision-makers, and sustainability experts to identify and adopt a variety of smart city solutions.

The market research, presented in Appendix A, revealed that the selection of solutions satisfied one or more of the following: (a) novel technical characteristics and functionalities, the application of which helps overcome implementation barriers (e.g., lack of space, minimum disruption during installation, changing the appearance of buildings—especially old/protected ones, etc.) and/or reduce energy costs; (b) the fact that novel technologies (e.g., energy storage systems, control equipment, EV chargers) are becoming more and more affordable; (c) needs imposed by strategic goals and policies on a local and national level (e.g., need to support stability of grid, reduce cost of energy, increased RES and EV penetration, utilization of sustainable materials, decentralization of energy generation); and (d) the increasing need to motivate and more actively involve citizens in co-creating and implementing solutions that can transform the energy profile of a city. The value proposition per solution, as reported by the two local ecosystems of Evora and Alkmaar, are mostly focused on the technical/functionality side, without excluding cases where impact on social aspects is of added value (e.g., increased aesthetics and quality of life, supporting engagement, raising awareness).

3.4. Value Attributes According to Maslow's Value Pyramid—Towards Sustainable Business Models

Creating value in a smart city means to bring together a large set of solutions able to address the needs, expectations, and perceptions of its citizens [46]. In order to better understand what end users would potentially value, before deciding to adopt the solutions identified in the Energy Transition Tracks (ETT#1–ETT#4) of POCITYF, it was important to clarify what combination of underlying value attributes are satisfied by each solution (step 4). This step facilitates and supports the design and development of successful, appropriate, and sustainable business models that could foster user adoption and stimulate demand [47], thus enabling roll out. Maslow's theory suggests individuals can be motivated by different and multiple priorities, but this is dependent on which of the "needs" have already been satisfied [43]. The value proposition of the proposed solutions was used to figure out which corresponding value attributes are satisfied by each of these solutions.

The higher frequency value attributes occurred within the repository of solutions under the four ETTs were motivation, quality, integration for ETT1, cost reduction, quality, integration for ETT2 and ETT3, and the provision of information, organization, and integration for ETT4 (Table 4). The attribute of *quality* (satisfied by the 90% of the solutions of ETT1 and ETT2) can improve customer's retention, facilitate brand building and trust [48] and ensure Return on Investment (ROI) [49]. Quality, although a functional characteristic, is a competitive element [50] that can affect purchasing decisions [51]. Therefore, quality of smart city infrastructure and technology is a key element for the successful provision and adoption of smart city services, taking into account the quality perspectives of end-users [52]. A good illustration of this is that the city of San Diego in US is considered by the Smart Cities journal as one of the top-ranked smart cities, because of the deployment of new innovative technologies and solutions providing services of high quality, resulting also in exchanging information and reducing cost [11]. People can be mobilized in regard to behavior change and acceptance of energy technologies if they are offered high quality services. In that respect, POCITYF solutions exhibit strong competition characteristics (Figure 4).

The attribute of *motivation* (satisfied by the 95% of the solutions for ETT1 and 92% for ETT4) lies towards the top of the pyramid as it is a life changing attribute. People are motivated to adopt sustainable energy innovations when the behavior can lead to both personal and collective benefits. Besides those pertaining to one's resources, like saving money, saving time, status improvement, as well as sense of comfort and pleasure, people may also consider aspects focusing on the well-being of others, city and society but also preserving nature and environment [53,54], thus resulting in positive contribution. Comfort is the basic principle that motivates people and often it has a greater importance than saving money, especially for higher income households [43].

The attribute of *integration* and cross-functionality of several energy systems and energy vectors enables the multi-level operation and planning of energy systems across a broad range of functions in order to deliver reliable, cost-effective energy services with low environmental impact [55]. Integration of different aspects of life in solutions that facilitate energy efficiency is a key attribute in the energy transition process. ICT for example, enables demand-response, real-time energy management, and integration of intermittent and dispatchable renewable energy sources. Appropriate ICT solutions can enhance network efficiency and improve overall system operation by matching local supply and demand optimally [30].

The *cost reduction* attribute is linked to the cost-effective energy saving potential that is recognized as a key driver for energy efficiency solutions. Consumer engagement and acceptance caused by behavioral change is key to delivering energy savings [56], triggering energy consciousness and bringing up further cost-effective energy opportunities [57]. Local communities are well-placed to bring people into full play towards the reduction of energy costs, CO_2 emissions, and city resilience, delivering targets based on local or regional energy needs [58]. *Cost reductions* can be achieved by most of the clean energy solutions proposed by POCITYF. A more detailed breakdown on the most frequent attributes of value recognized per ETT in the POCITYF repository of solutions is presented in Appendix B. Percentages indicate the extent to which an attribute satisfies the selected solutions.

Table 4. Top-10 value attributes satisfied by the proposed solutions per Energy Transition Track (ETT). Percentages indicate the extent to which an attribute satisfies the selected solutions.

ETT#1 Innovative Solutions for Positive Energy Buildings and Districts.	%	ETT#2 P2P Energy Management and Storage Solutions for Grid Flexibility	%	ETT#3 E-mobility Integration into Smart Grid and City Planning.	%	ETT#4 Citizen-Driven Innovation in Co-Creating Smart City Solutions.	%
Motivation	95	Reduces cost	94	Reduces cost	100	Informs	100
Quality	90	Quality	89	Integrates	86	Organizes	92
Integrates	81	Integrates	78	Quality	86	Integrates	92
Avoids Hassles	62	Provides hope	78	Provides access	86	Reduces cost	92
Reduces cost	48	Motivation	72	Provides hope	71	Quality	92
Self-actualization	48	Avoids hassles	72	Motivation	71	Motivation	92
Heirloom	48	Reduces risk	50	Reduces effort	71	Provides access	92
Organizes	43	Variety	50	Design/aesthetics	57	Self-actualization	83
Makes money	43	Organizes	44	Simplifies	57	Connects	83
Provides hope	38	Simplifies	39	Avoids hassles	57	Avoids hassles	75

Figure 4. Word cloud of value attributes for the smart city solutions of POCITYF—values with bigger font indicate higher satisfaction.

Energy efficiency investments require greater awareness, engagement, and adoption from citizens [59]. Communicating for *informing* the public and other stakeholders about the benefits of the solutions and the drawbacks of existing non-sustainable methods can help build acceptance and increase trust and understanding of city level decisions [60]. At the same time, informed citizens can lead *organized* local or renewable energy cooperatives that can collectively take action towards energy efficiency [61].

Results for ETT#1—"Innovative Solutions for Positive Energy Buildings and Districts" highly outline that the proposed solutions offer motives for their adoption and high-quality services towards energy efficiency. Solutions included in ETT#1 are focused on: (a) facilitating and spurring citizens/city authorities to achieve significant energy savings on both building and district level while reducing their energy bills (energy efficiency first); (b) removing barriers for enabling a high share of locally produced/consumed renewable energy on building and district level. Innovative solutions to be demonstrated and replicated include both positive energy building (level) retrofits and positive energy district level retrofits. The fitting of these two levels of retrofits, on the principles of circular economy, is considered as well with the utilization of available waste streams and waste management schemes. Most of the solutions in this ETT (as well the other ETTs) are of an integrated nature [2], serving multiple functionalities (e.g., RES generation and insulation properties) and/or can be easily customized and combined with other elements (e.g., bidirectional smart inverters, energy routers) serving cross-functional needs.

Solutions included in ETT#2—"P2P Energy Management and Storage Solutions for Grid Flexibility" and ETT#3—"E-mobility Integration into Smart Grid and City Planning" are of utmost importance with respect to reducing costs when targeting services related with sustainable energy and mobility. Solutions included in ETT#2 focus on: (a) maximizing self-consumption, (b) reducing grid stress and avoiding load and generation curtailment, and (c) increasing the financial value through providing flexibility services to the grid. The end result of all these solutions is reducing costs, either in the form of lower energy prices or indirectly due to energy savings. A better, safer, and environmentally conscious energy network increases social coherence and provides hope towards the achievement of climate change goals. Solutions included in ETT#3 focus on individual elements, such as those of (a) reducing the impact of electro-mobility on the energy system, (b) increasing the penetration of e-vehicles utilizing RES, but with the additional benefits they can offer when utilized to support grid flexibility, while reducing curtailment, thus leading to better quality energy network, (c) promoting decarbonization of the mobility sector (with the adoption of EVs), and (d) reducing citizens' mobility costs (no use of liquid fossil fuels and better traffic management). Additionally, the integration of solutions in this ETT provides access to otherwise non-available information (e.g., operational issues on charging stations, controllability of EVs, grid flexibility) facilitating the deployment of PEDs.

Solutions included in ETT#4—"Citizen-Driven Innovation in Co-creating Smart City Solutions" focus primarily on improving citizens' quality of life and increasing city efficiency and governance by involving citizens in the early development, design, and evaluation phases of the solutions and related services following the principles of the "Rapid Prototyping" approach. This is a process of creating a quick mockup and testing of solutions through an interaction layer with the citizens, followed by a simultaneous and almost real-time feedback by them; thus, ensuring a constant improvement of the solutions and/or the services provided to them. Such an approach can: (a) motivate citizens for co-creating, co-delivering, and co-capturing value through the smart city solutions demonstrated; (b) create an open innovation ecosystem between different experimentation set-ups; (c) empower consumers to become 'prosumers' by enabling them to monetize any excess of electricity (generated by rooftop solar, for example) by securely recording data and sending and receiving payments automatically. Solutions included in ETT#4 highly satisfy a multitude of value attributes (information, organization, integration, reduction of costs, quality). All of them, though, have a highly informative role providing reliable information to stakeholders and end users. It is important to highlight that this information could be a great starting point for the successful replication of most of the demonstration activities in the ecosystems of FCs. The findings are directly in line with POCITYF objectives and illustrate the nexus between the market needs and the offered value of the proposed solutions derived from the methodology applied for the two LHs.

4. Conclusions and Further Considerations

This study confirmed that energy-efficiency investments, especially for solutions on energy management, storage, grid flexibility, and e-mobility (ETT#2 and ETT#3), tend to have a specific economic profile, as the return on investment is ensured, in many cases, through energy savings and not through an increase in revenues [58]. Furthermore, the integration of various systems which manage to break vertical silos can result in high-quality services, motivating users to participate in a collective effort for realizing energy efficiency from which different stakeholders and citizens can directly benefit (ETT#1–ETT#4). Those key attributes of value identified for POCITYF repository of solutions can be directly linked to the development or adaptation of successful value propositions that respond to market needs and can form the basis for forming sustainable business models that can facilitate user adoption and thus roll-out of solutions for the two LH cities but also the FCs.

The process, namely steps 1–3, followed in this study can inform and facilitate the city and its stakeholders in forming a repository of appropriate and relevant solutions that can be applied to address city-specific needs towards its energy transition path. Different repositories with a different mix of solutions that enable energy transition and positiveness either at district or city level can be formed by different cities. Step 4 is an essential step to inform the process of building successful value propositions that will lead to sustainable business models of solutions by recognizing the attributes of value that the integrated solutions offer to citizens and design communication campaigns with simple, concrete, credible, and with emotional appeal messages [60]. What is important to highlight is that no solution alone, but a combination of integrated solutions, can holistically address the identified and versatile needs of cities and their users, and can synthesize important attributes of value that respond to city needs [62]. This synthesis can act as a multiplier facilitating value capture, and in turn attract the interest of investors, mobilize financing, and new revenue streams. However, the process of energy transition can commence with the prerequisite that there is political will and support for the realization of energy efficient related investments, with the aim to attain energy efficiency goals and increase quality of life for citizens, something that needs to be proactively and adequately communicated to citizens and stakeholders for avoiding stalling or reversing much-needed reforms.

A limitation of this study is that the repositories of solutions assessed for their value attributes do not represent conclusive lists of solutions but solutions that were selected as being relevant and appropriate for demonstration according to the specific needs of the two cities of Evora and Alkmaar when planning the realization of their Positive Energy Districts. However, in both repositories the main attributes of value proved to be similar. A recommendation for further research is then to assess other repositories of solutions for whether they fulfill the value chain of quality, motivation, integration, cost reduction, information, and organization as key pillars and model the linkage of those values with the business models developed and the associate revenue streams. Additionally, the value attributes of each solution were evaluated by the authors (with a long experience, expertise, and knowledge on smart city energy transition projects) as a first iteration of the interaction required with potential consumers. However, the process of validating the value attributes requires more iterations with end users to ensure that their needs are considered. Consumers who will be the end-users of the systems should be further explored when the solutions and the respective systems will be in operation. Other perspectives, i.e., the technology providers or city authorities, could be explored in future research. However, the specific process was performed building upon the value propositions as provided by the technology providers and the market research, thus reflecting, as far as possible, actual market needs.

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Appendix A

Table A1. Innovative solutions for positive energy buildings and districts **(Obj.1–ETT#1).**

Category	Current and Future Market Needs	Type of Solution	Brief Description and Value Proposition
RES generation (*fitted for old/protected buildings/areas*)	•Architectural constraints (e.g., appearance of the building cannot change, the weight of the structure cannot be increased) especially in old/protected buildings/areas pose significant barriers for the installation of conventional RES systems, thus there is a need for customizable and integrated solutions; •Building-integrated PVs (BIPVs) are gaining popularity among construction stakeholders; •Increased aesthetics of PV systems can support their acceptance, especially when installed in public spaces; •EV market is experiencing a rapid growth and building/district-level RES can satisfy the needs of the charging points for EVs; •During the last years, extra emphasis has been put on developing construction materials/systems that are characterized by quicker installation times, thus decreasing costs and impact during installation as well as minimizing disturbance of the occupants; •Hybrid energy generation systems are gaining popularity, since they can help overcome otherwise unsurpassed barriers (e.g., low sunshine for an extended period in the case of PV systems); •In urban areas and close to urban areas there is resistance of residents against windmills. Wind energy is associated with noise pollution and loss of visual amenity;	PV (crystalline silicon) glass	**BIPV glass-glass**//Can substitute any regular glass, changing the way we design buildings//Lets natural light in//Provides thermal and sound insulation//Filters most of harmful UV//Ease of customization, especially in terms of shape//Crystalline silicon glass can yield twice as much energy as amorphous silicon glass//Aesthetically attractive.
		PV canopies	**Photovoltaic canopies for RES generation**//Sun protection and shelter//Depending on the type of canopy, the electricity yielded can be consumed in different ways: self-consumption for surrounding buildings, lighting, ad-box illumination, back-up systems, charging point for EVs, injection to the grid//Various design options (multiple slopes, different tilts and orientations, multiple glass design options etc.).
		PV skylights	**BIPV skylights for RES generation**//Let natural light in//Provide bioclimatic properties of thermal comfort to the building//Filter UV and infrared rays//PV skylights achieve competitive IRR and offer appealing payback times.
		Roof-integrated PV systems	**BIPV systems used on roofs**//Usually light roofing element//Offer waterproofing without the need of torch on asphalt membrane or other waterproofing membranes//Possibility of installation on pitch roof//Can be made of triple-junction thin-film amorphous silicon, converting a broader spectrum of light into electricity than conventional modules.

Table A1. *Cont.*

Category	Current and Future Market Needs	Type of Solution	Brief Description and Value Proposition
	•The deployment of hybrid wind/solar generation systems is becoming more and more economically appealing, since the upfront costs are continuously reduced (until now hybrid systems were characterized by comparatively very high costs for each kWh produced). •Although there is a clear need for RES generation on a local level, this may not be the case for many buildings/districts where there is simply not enough space and the conditions to install PV systems. Increasing RES penetration in these cases is very challenging (reaching positiveness seems like an impossible task to accomplish). As a result, there is a need to provide solutions that can enable everyone to invest in RES if we are looking towards just energy transition.	PV roofing shingles	**PV roofing shingles combining the functionality of tiles with PV technology**//Thermal inertial properties typical of terracotta//The cables arrangement can be optimized, improving installation speed//Snap-on multi-contact fixtures make the replacement of modules quick and easy even by non-experts//Installation does not require tubs and/or fixing brackets (no thermal bridges)//The appearance of the building remains unchanged.
		Composite façades with vertical solar panels	**Vacuum composite facade panels with insulation and composite façade with solar cells (combining insulation and electricity production)**//A lot of unused façade surface of residential buildings (passive facades) can become useful to produce solar energy (active facades)//Multipurpose.
		Hybrid wind/solar generation system	**An innovative combination of urban wind and solar production system that can be installed on top of buildings**//Takes advantage of natural strong airflow by wind over high-rise buildings to generate wind energy//More constant energy production (night-wind/day-solar)//Can be modified architecturally (color, shape)//Aesthetically attractive.
		Community Solar Farm	**Innovative compensation model that allows citizens that live in old protected areas to invest in renewable generation placed in PV plants in the outskirts of the city, via a virtual energy wallet**//Allows the injection of renewable energy from places where more space is available.

Table A1. *Cont.*

Category	Current and Future Market Needs	Type of Solution	Brief Description and Value Proposition
Smart energy management, control, and self-consumption	•The coordinated operation of RES production and supporting storage systems can increase the flexibility of the grid, and since the RES penetration will be increasing, there will be a stronger need for technologies/products that can serve this functionality; •Growing need for technologies and solutions that can support the stability of the power networks and simplify the integration of renewables in existing power systems, avoiding and/or limiting expensive and inefficient investments on new grid infrastructures as far as possible; •New business opportunities are expected for energy communities, acting as aggregators as well, investing in renewable production, storage devices, and providing ancillary services; •Increasing need for non-invasive solutions capable of preserving the historical structures of buildings; •Increasing need for solutions with the final goal of saving energy, while increasing occupants' comfort; •Lack of integrated smart building/home solutions with reasonable cost; •Massification of smart building technologies is expected due to the introduction of the smart readiness indicator (EPBD). •The increasing usage of cloud-based technologies increases the pressure in energy grid supplying Datacenter facilities, making it fundamental to make operations more efficient and capable to adapt to growing needs;	Bidirectional Smart Inverters	**A single device for improving flexibility and controllability of multiple energy assets**//Rich user interface//Intelligent optimization of yield and self-consumption//Improvement regarding RES cut-off due to network congestion.
		Energy Routers	**A device for the integration of energy components and optimally managing the energy flux between them**//Modular design and increased interoperability capabilities//Can act as a major component in the grid/consumer energy interface, being responsible for grid-to-grid communication.
		Building Management Systems (BMS)	**Fundamental pieces of a building technological infrastructures, as they act as central or distributed controllers of the different building systems**//Real time monitoring and management of HVAC, lighting, energy consumption/production, and/or other systems/devices//Reduction of energy consumption of buildings - energy savings//Optimization of indoor comfort for occupants and usability of the building//Services built around the BMS infrastructure (e.g., maintenance, smart workspaces).
		Building/Home Energy Management Systems(BEMS/HEMS)	**Systems being able to forecast the local energy production, detect consumption profiles, and establish an optimal energy-related building operation**//Improved flexibility and controllability of residential and commercial buildings//Rich user interface and user experience//Intelligent techniques (incl. forecasting) to optimize energy usage and comfort preferences//Provide added-value services for electric grid//Self-learning systems.
		Positive Computing Data Center	**Innovative methodologies, processes, and equipment improving the energy efficiency of data centers**//Improve the ratio of total amount of energy used by a computer data facility to the energy delivered to computing equipment.

Table A1. *Cont.*

Category	Current and Future Market Needs	Type of Solution	Brief Description and Value Proposition
Energy efficiency	•Increasing need for better performant, greener insulation materials and systems, since energy efficiency should come first before moving to the installation of RE production systems; •Insulation of sound is also a significant aspect; •Extremely high renovation potential in EU; •Using Phase Change Materials gave way to unique applications of heating/cooling solutions—their commercial use has only been recently unlocked due to their high production and encapsulation costs until now; •Technologies and services that can facilitate the transition from a linear to a circular economy are already becoming a necessity if we are looking towards sustainable urban development. This is possible by making more use of circular recyclable materials. This is becoming increasingly important with renovation and new construction projects; •For climates with moderate heating and cooling needs, heat pumps offer an energy-efficient (and usually cost-efficient) alternative to furnaces and air conditioners. The market needs the heat pumps to be smaller and lighter, to be integrated in the facades.	Triple Glazing	**Triple glazing with low solar entry factor (G-value)**//Sound insulation//A special seam and crack seal can be used in the window frames to minimize the infiltration of cold air in comparison with the standard values (NEN 2686).
		PCM in the floor	**Floor insulation utilizing PCM materials that absorbs heat and stores it**//Functions as thermal battery//Re-uses waste heat//More stable climate and higher comfort.
		Insulation with Circular Materials	**Replacement of conventional insulation materials with circular materials such as flax, linseed**//Retain high insulation properties//By using used or natural materials, there is a substantial reduction in CO_2 emissions, partly because no new raw materials are mined
		Thermo Acoustic Heat Pumps	**Electrical driven thermo-acoustic heat pumps are closed systems that are filled with Helium under pressure, utilizing acoustic waves to pump heat**//Can operate over a large range of (high) temperatures and can achieve large temperature lifts//Energy needs reduction//Can be integrated in facades//Act both as booster and as part of an integrated hybrid heating/cooling system.
		Cascaded Heat Pumps	**Cascades of small heat pumps are utilized to increase performance and flexibility due to increased modularity**//Can be combined with PV-thermal panels to create an integrated high-efficient hybrid heating concept.

Table A1. *Cont.*

Category	Current and Future Market Needs	Type of Solution	Brief Description and Value Proposition
Sustainable waste utilization and management	•As population rises, more materials/products are consumed, and thus more waste is produced—making efficient waste management a necessity for sustainable development; •To reduce the environmental and health impacts of waste and to improve resource efficiency, there is a growing need for different, more efficient, and dynamic waste collection systems and motivated people, knowing what, how, and why it should be done; •The growing awareness and pressure for changing our habits, so that they are increasingly sustainable, requires a change in the way we produce and treat the waste. •Raw materials are scarce. In order to keep materials available indefinitely, they need to be reused, and their use must be documented; •Re-used material could offer financial and environmental benefits compared to newly bought materials, e.g., less transport movements, less use of water, electricity, and other resources, CO_2 reduction, job potential.	Pay-As-You-Throw (PAYT)	A **ready-to-use solution that lets municipalities track their citizens' waste production levels**//State-of-the-art technology applied to common municipal waste containers and a management platform, allowing the monitoring of the amount of urban waste deposited, the creation of multiple profiles and permission levels, optimizing the collection routes, configuring alerts, and giving access to the collected data//Change behavior of citizens.
		Reverse Collection of Waste	A **novel waste collection scheme, characterized by the separate collection of each re-usable commodity at different moments, instead of collecting mixed garbage by the garbage truck every week**//Re-usable commodities can be used to create new products. Less raw material has to be used and/or less new material has to be fabricated (energy saving, environmental saving, emission saving, etc.).
		Material Passports	**A tool for mapping material streams**//Gives insight into the materials used to create a building, and into their quantities//Contains information on the quality of materials, their location, and their monetary and circular value//It becomes a lot easier to reuse materials, minimize waste, and to reduce the cost of material consumption//Improved insight into the use of material will stimulate the circular economy.

Table A2. Peer-to-Peer (P2P) energy management and storage solutions for grid flexibility **(Obj.2–ETT#2)**.

Category	Current and Future Market Needs	Type of Solution	Value Proposition
Grid-Level Energy Management	•As the penetration of RES into the market is rising, the demand for controlling platforms to maintain power load stability and increase grid flexibility is increasing. Such solutions can introduce into the market novel services for grid support; •The lack of DERs for controllability and the integration of resources controlled by end-consumers contribute greatly to the need;	Micro-grid controller platform	**A grid level management platform that uses advanced distribution management and control strategies**//Offers high level control authority allowing for optimal RES integration//Supports prosumers in grid operation//Allows the provisioning of flexibility and market services using RES forecasting, DERs, energy models and load estimation tools//Offers improved flexibility and controllability of energy resources//Interface that allows controlling existing assets of DSOs.
	•The time variability of RES and electrification of energy demand increase the need for demand-side management (DSM) measures at different levels of power systems; •The need to modify energy consumption in real time can also be identified in other energy systems, e.g., peak demand reduction in district heating; •Need to implement DSM measures while respecting users' comfort needs and preferences.	Flexibility Control Algorithms	**Flexibility Control Algorithms that use the energy flexibility provided by different types of controllable devices**//Bringing benefits for both consumers (e.g., lower energy costs) and power systems operators (e.g., lower peak loads)//Energy performance improvement at building and district level//Energy flexibility (e.g., appliances and batteries)//Self-consumption improvement//Satisfying the comfort needs and preferences of consumers.
	•Opportunities of flexible energy management are great both for commercial and residential consumers. As RES and smart grids occupy larger shares of the market, such management is required in order to outperform centralized energy distribution and control. •The CEMS can introduce enhanced flexibility and controllability that will allow the further penetration of RES and smart grids into a city's energy system.	City Energy Management System (CEMS)	**City Energy Management System used by power system operators to monitor, control, and manage energy while allowing end users to control smart devices, unlocking the opportunities of flexible energy**//Ensures a smart global management through relevant manufacturers devices//Ease of use//Can determine power generation or power demands that minimize a certain objective such as power loss//The Energy Flexibility Interface (EFI) included in the CEMS provides additional aid on Smart Grid Management.

Table A2. *Cont.*

Category	Current and Future Market Needs	Type of Solution	Value Proposition
	•Changes in the dynamics of power grids from centralized to distributed, moderating costs, and easy accessibility of energy storage are some of the factors driving the growth of the VPPs. •Total annual VPP vendor revenue will grow from $1.1B in 2014 to $5.3B in 2023 [63]. VPPs influence multiple markets simultaneously due to their integrated character; •Small units can get access to lucrative markets that they would not be able to enter individually. Small facilities, owned by SMEs or even households, have the ability to become prosumers [64].	Virtual Power Plant (VPP)	**VPP is a virtual power network that links decentralized units and operates as a single centralized control system where the power and flexibility of the aggregated assets can be traded collectively.** Non-physical (hence virtual) aggregation of several heterogeneous Distributed Renewable Energy Resources (DRERs)//Cost-effective alternative to complement the power mismatch due to intermittent RE generation//Avoids expensive upgrades to the network infrastructure//Exploitation of the aggregated power mitigates the impact of electricity price fluctuations//Relieving the load on the grid by smartly distributing the power during peak load periods.
	•Growing demand for electricity requires measures to control energy losses as well as to reduce the economic and ecological footprint of this transition. The market needs efficient and cleaner decentralized energy supply grids [65]. •EMS, renewable systems, storage, and low carbon applications are changing the market landscape, potentially leading to a transition from an AC-dominated grid market to a DC one.	DC grid	**Direct Current Electricity Grid Infrastructure.** Electronic Waste reduction//Lower losses and Higher Transmission Capacity for the facilitation of production, storage and distribution of solar electricity than traditional AC networks//Better connection with intelligent control technology and batteries for achieving energy efficiency and optimal zone distribution in buildings.
Sustainable Energy Storage Systems	•In the industrial/services and large consumers market, storage solutions provide with backup and uninterrupted energy supply services, as well as implementing intelligent energy management strategies such as peak shaving or ramp rate control. •For grid operators and utilities these solutions provide effective tools to manage and control power quality in the grid (MV).	Low Voltage (LV) and Medium Voltage (MV) connected storage systems	**Integrated Low-voltage and Medium-Voltage electric energy storage battery systems**//Scalability of power and capacity//Ease of implementation and integration into existing electrical networks//Allowing to deal with increasing RES and their inherent variability//Multitude of offered services, i.e., peak-shaving, reactive power compensation, RE self-consumption maximization, power quality management and control etc.

Table A2. *Cont.*

Category	Current and Future Market Needs	Type of Solution	Value Proposition
	•Batteries will play a crucial role in enabling the next phase of the transition towards renewables. As more and more households have adopted PV systems, battery system integration can provide self-sufficiency and reduce the monthly electricity bills. The economic benefit is thus the driving force of the technology in an expanding market.	Stationary batteries(Li-ion)	**Innovative Lithium-ion Stationary Battery Systems**//Increased storage capacity//Energy cost reduction//Contribution to advanced load balancing//On-demand-emergency discharging capabilities//Ensuring power availability and power quality within the building (e.g., during blackouts)//Improving comfort and prolonging the lifespan of indoor devices.
	•It is critical to find solutions that can either substitute Li-ion batteries and/or extend their productive life; the EV battery supply market will undergo a major expansion over the coming years, which is also expected to affect material demand and increase price pressure [66].	2nd Life Residential Batteries	**Modular and mobile (smaller) battery system that re-uses Li-Ion battery modules coming from EVs**//Re-purposes Li-Ion battery modules (dealing with the upcoming wave of obsolete electric vehicle (EV) batteries)//Extends the productive life of EV battery modules//Affordable.
	•With the proliferation of self-consumption generation, an efficient energy management leads to energy cost savings and more efficient use of energy (particularly in large facilities—stores where energy consumption is higher, thus its impact). •At periods where energy demand is higher than supply it is of extreme relevance that consumers can shift, curtail, or switch off energy demand.	Freezing storage in store	**Energy storage system from HVAC or industrial freezers in retail stores**//Energy consumption reduction for stores//Energy cost reduction//Leveraging thermal inertia of the freezers//Providing demand side flexibility services to the grid//Complying to pre-established criteria of comfort and safety//Optimization of energy management based on daily consumption profile; intraday energy cost variation; and PV generation.
	•There is a high need for replacing traditional fossil fuel-dependent heating and cooling systems with sustainable ones; •During recent years aquifer thermal energy storage (ATES) has gained a lot of attention and the number of ATES is increasing, especially in Europe [67].	Aquifer Thermal Energy Storage	**An innovative system for heat/cold storage in the ground**//Sustainable thermal storage solution that takes advantage of otherwise wasted heat streams to provide heating and cooling to the buildings in a cost-effective way (also reducing associated CO_2 emissions)//Characterized by lower costs due to peak shavings and lower energy use.

Table A2. *Cont.*

Category	Current and Future Market Needs	Type of Solution	Value Proposition
Sustainable DHC Networks	•There is a growing need to help cities upgrade their DHC energy systems (in many cases being outdated), especially for coal regions in transition; •DHC systems can utilize waste, geothermal heat, and surplus heat which increase a region's security of energy supply.	DHC	**Connection to the district heating (both at high and at low(er) temperatures) which distributes heat from a biomass energy plant, which runs on (municipal waste) wood, and in a later stage the district heating will be connected with geothermal energy sources**//Outcomes and lessons learned from this process can provide valuable insights for the upgrade of DHC of other cities in EU.
	•The need for a green-based economy not only propels the growth of the district heating market but also imposes market related needs such as energy efficiency and quick transition to RES. •Future initiatives towards better insulation and a growing insulation market favor the further penetration of such solutions into the market.	Low temperature heat grid	**Low Temperature (80/85) Heat Network.** Cost-effective//Enhanced flexibility in the network design//Lower heat losses//Offering greater possibility for RES penetration into the heat grid (such as geothermal heat sources)// Separating the indoor installation from the heat network, which is safer in the event of leaks, lower water pressure in the home, limit-arrange return temperature.
	•Global targets for climate change mitigation and decarbonization require higher RES penetration, reliability and energy efficiency of DHC systems.	Geothermal heat source	**Geothermal Heating Distribution Network for Buildings.** Low Environmental Impact//High Energy Efficiency//Reliable//Clean heat source with energy transfer from the earth//Typically require little maintenance.
	•Various waste heating technologies are launched in the market to support smart city concept and eco-friendly development to sustain the environment.	Low temperature waste heat	**Small-scale waste heat recovery network**//Heating cost reduction//Waste heat recovery//Energy consumption reduction//Optimal heat distribution to customers.

Table A2. *Cont.*

Category	Current and Future Market Needs	Type of Solution	Value Proposition
	•Configuration and maintenance of traditional heating installations is cumbersome, leading to malfunctioning, inefficiencies, and economic losses throughout their lifetime, routinely spanning several decades. With the introduction of 4th generation DHC Networks, the need for designing optimal controlling algorithms increases [68]. •Delivering heat electrification requires dynamic, real-time demand-supply matching solutions where the interplay between heat and electricity is considered.	Thermal grid controller	**A thermal heat controlling software that saves operational costs**//Cost reduction//Energy savings//Ease of planning and configuration process//Optimal balance between producers (supply) and consumers (demand) of heat and cold//Highly scalable, allowing systems of hundreds or thousands of producers and consumers to be controlled in an efficient way//Adaptable in the available buffer capacity and flexibility that different heating system components offer//Real-time matching solution for heating and cooling systems
	•The Urban Heat Island effect results in increasing cooling and electricity energy needs, increased thermal stress, and heat-related public health issues, as well as human comfort and environmental implications [69].	Heat Island concept	**Innovative Energy Management System for Heating** Optimal energy distribution and management at building level//Increased heating efficiency//Energy savings//Algorithmic-based alignment of production and use of electricity between the several connected products.
P2P energy trading	•Increased population of energy prosumers leads to P2P energy transactions needs; •Need for universal access to affordable, fairly priced, and abundant energy; •Take control and responsibility for the self-provision of energy needs allowing the possibility to produce and sell own electricity creating investment opportunities, which can enhance energy equity.	Peer to Peer Energy transactions	**A digital fundraising and P2P energy transactions platform.** Provides energy services for the end user and makes the renewable energy sources and energy storage more attractive to end users//Facilitates virtual energy communities for energy sharing (solar sharing—i.e., for cultural heritage communities where solar power at residential level may not be an option).

Table A2. *Cont.*

Category	Current and Future Market Needs	Type of Solution	Value Proposition
Hydrogen Technologies	•The demonstration of a complete hydrogen-based fuel cell system that can supplement the existing grid can facilitate larger-scale penetration of this technology to the existing energy market. •The hydrogen fuel cell vehicle market size is projected to grow at a compound annual growth rate (CAGR) of 66.9% from 2019 to 2026 [70]. An increase in government initiatives for development of hydrogen fuel cell infrastructure is observed (e.g., Hydrogen Europe and H2KOREA [71]). Eminent recognition of fuel cell and hydrogen technologies in European energy policy (Clean Energy package 2016) is another positive parameter of hydrogen sector expansion [72].	Fuel cells (hydrogen)	**Hydrogen fuel cells are electrochemical power generators that combine hydrogen and oxygen to produce electricity, with water and heat as by-products**//Integration into local grids and hybrid heat systems provides means for increased energy efficiency//Energy storage with hydrogen fuel cells can lead to substantial cost reduction through peak shaving//Fuel cells do not need to be periodically recharged like batteries, but instead continue to produce electricity as long as a fuel source is provided//Clean, scalable, operate near-silently, and present improved efficiency, especially in combined heat and power (CHP) systems//Sustainable hydrogen can be utilized as a power fuel in heavy duty transport vehicles (HDV) and also to stabilize the grid, serving as storage for Power to Fuel concept.

Table A3. E-mobility integration into smart grid and city planning **(Obj.3–ETT#3)**.

Category	Current and Future Market Needs	Type of Solution	Brief Description and Value Proposition
V2G and EV Charging Infrastructure	•As the adoption of EVs increases, decreasing prices of EVs and new models with bigger batteries are accelerating the market growth, making V2G an attractive flexibility solution for the power system, accelerating the convergence of mobility and energy [73]. As a result, demand for charging infrastructure is rising, transforming the EV charging industry drastically [74]; •Demand for V2G and smart charging is increasing rapidly as countries move towards an electric transport sector [73]. V2G and smart charging can spawn widespread benefits for the grid while also for the city, with an expected positive impact on energy saving, environmental preservation, traffic management, and urban planning of public spaces; •Location constraints for the installation of EV charging systems generate a need for highly customizable and integrated solutions; •Solar energy is quickly becoming the cheapest source of electricity. In many countries solar is the lowest cost power option today—both in residential and commercial applications, but also increasingly in the utility-scale field [75]. In PV markets where increased self-consumption is the goal, charging EVs using solar energy is yet another way to help achieve energy independence [76]; •Distribution System Operators cannot manage congestion and ensure grid reliability. Leveling advancement of the energy grid with new assets (e.g., e-buses) can help;	EV charging from PV systems	**Smart solar charging of EVs.** RES generation//EV charging with regard to every own user profile, type of customer application, specific market, and pilot area//Carbon footprint reduction//Provides intelligent techniques for prosumers with EVs to optimize self-consumption, energy usage and cost//Improved flexibility and controllability of EVs and fleets//Rich user interface//Provides added value services for electric grid, e.g., grid pressure reduction.
		V2G	**System connected bidirectionally with the power grid in which plug-in EVs provide demand response services by either returning electricity to the grid or by controlling their charging rate.** Charging of EVs utilizing RES while providing also services to the grid from the vehicle batteries//Provides flexibility at national level by facilitating balancing in the wholesale market, and also at district level by reducing the costs associated with reinforcing local electricity grids and control or adjust charging in order to decrease simultaneously and lower peaks in demand//Cost reduction//Management as stand-alone unit or in local clusters//Allows public transport operators to access the energy markets for trading options.
		Smart Lamp posts with EV charging and 5G functionalities	**Smart Lampposts for efficient LED lighting, 4G/5G Wi-Fi, and EV charging.** Integration of wireless monitoring, computational, networking, storage, and EV charging capabilities in one infrastructure//Future-proof solution with bleeding edge technology flexible and cost-effective, tackling current e-mobility, connectivity, and communication needs//Avoids the installation of multiple infrastructures in the city, saving visual pollution//Allows the renting of the different service providers with reduced costs//Allows the integration of V2G.

Table A3. *Cont.*

Category	Current and Future Market Needs	Type of Solution	Brief Description and Value Proposition
	•The availability of EV charging stations needs to be increased rapidly to support e-mobility. Smart lighting can facilitate this transition, providing also good light quality, large area coverage, and 5G connectivity. The mobile operators are searching for opportunities to rapidly implement the 5G networks, with low installation costs and avoiding populating the city landscape with more and more antennas. •EV charging industry offers new services and capabilities for interconnection with other intelligent systems.	DC lighting with EV charging	**Direct Current (DC) infrastructure network allowing connection with smart lampposts having EV charging points, 5G, monitoring sensors, and e-storage.** Promotes adoption of EVs//Promotes increase of large-scale local e-storage capacity//Promotes more environmentally friendly, emission-free, and energy saving mobility and public lighting solutions//Successful introduction of demand-supply energy management at district-level//Data gathering for energy positive and smart neighborhoods//Better alternative from antennas, which create a disturbing view//No need of extra space for charging poles for EVs.
Smart EV Charging	•Decentralized energy generation with increased RES penetration and liberalized energy markets render the integration of e-mobility management systems of great relevance. •Key enabling technologies linked to the use of an ICT platform with a wider energy management system offer new services for smart cities, as they are cloud-based and easily integrated with other smart energy and mobility systems or software. •Grid flexibility services is a topic that is expected to become increasingly more relevant as RES penetration tends to increase in the upcoming years, therefore additional fluctuation on energy generation is set to occur. • Smart EV charging solutions can satisfy the needs for transparency, data, and information about the locations and tariffs of charging points. The adoption of such controlling solutions may lead to broadness of the available offers to EV users increasing competition in the market and therefore potentially lowering the charging costs, assisting also in widening the existing EV charging network available to EV users, fostering the transition to e-mobility.	EV charging management platform	**EV Charging Management Platform that ensures optimal energy performance of EV chargers**//Multi-level planning that offers operational efficiency and the highest performance of EV charging infrastructure//Optimization of energy management//Data management and information for aggregators, grid operators, municipality, and citizens//Providing grid flexibility or ancillary services to transmission system operators//Allows to shift or curtail energy consumption at EV chargers (on demand side), avoiding peak (high cost) periods//Customizable and adaptable to the requirements of each district or area.
		Intelligent and optimal control algorithms	**Monitoring and Controlling Software for EV Chargers.** Monitoring and control of EV chargers for public transport in real-time operation to prevent grid connection overruns and optimize utility of chargers//Lowering contracted power agreements with grid operators//Lower upfront investments in grid connection and number of chargers (CAPEX)//Providing insights, data, and information related to operational issues and needs//Ability to adjust to energy peak demand//Flexible and better usage of the available chargers//Reducing energy costs even further.

Table A3. *Cont.*

Category	Current and Future Market Needs	Type of Solution	Brief Description and Value Proposition
E-mobility Schemes	•As shared mobility grows in popularity, electrification in the shared use market will help cities to meet their climate goals, and reduce GHG emissions. Car sharing and carpooling are changing the habits of consumers. The focus is more on car use; car ownership may be less important. •Special attention is given to (electric) car/bike sharing in new urban planning strategies. EV sharing will help the quality of the historic city centers to be better reflected.	EV Sharing	**Shared Mobility Service of EVs in cities**//Traffic reduction//Cost reduction//Energy savings//Improves Air Quality//Alleviating upfront costs//Creates lower-density neighborhoods by decreasing the amount of parking spaces needed//Bringing people into familiarization with EVs//Offers additional benefits and deals for consumers (i.e., experiences and photos exchange, navigation systems).

Table A4. Citizen-driven innovation in co-creating smart city solutions **(Obj.4–ETT#4)**.

Category	Current and Future Market Needs	Type of Solution	Brief Description and Value Proposition
Changing Energy Behavior (through Digital Tools)	•Citizen-centric solutions are adopted more easily by means of citizens taking personal and collective responsibility for how they 'use' their city, changing their mindset, behaviors, and actions; •Need for multi directional information flows (i.e., city-to-citizen, citizen-to-city) and using co-creation methods to regenerate the cities bottom up; •Citizen participation and adoption of solutions is enhanced by the use of technologies and digitization; •Understand the motivations and motives of citizens leads to a more effective participation policy; •Bring a more competitive and fun character to the use of novel technologies, educate, engage, and reward toward changing energy behavior; •Travel-based mobile apps are the seventh most-downloaded app category; •Growth of tourist flows in heritage places raises a huge need for intelligent management of these flows. •Mobile apps capable of collecting information from region/city/building and suggesting good practices to optimize the tourist experience in heritage places—a mandatory request of most heritage municipalities/managers; •Enable wide citizen/tourist participation, awareness, and adoption rates, as well a faster and easier interaction between consumers and devices; •EU and government regulations promote smart grid solutions and exponentially increasing adoption of smart meters are also expected to drive the demand for big data analytics among utility vendors where mobile apps measuring energy consumption are also part of the solutions to be developed.	Gamification	**A gamification platform for changing the behavior of citizens and end-users.** Increases citizen engagement (through gamification) in energy related technologies and services//Interconnects users with mobile apps and with smart metering and automation solutions.
		Tourist apps	**Tourist mobile apps for managing crowd flows in heritage areas.** Increase quality of life for tourists but also citizens through reducing waiting times and intelligent management of crowd flows//Easy to use app in order to potentiate tourists' adhesion.
		Cultural experiences marketplace	**Mobile apps promoting touristic cultural experiences facilitating dissemination and publicity of energy related measures.** Cultural experiences app marketplace for promoting touristic experiences and cultural activities in specific regions facilitating dissemination and publicity at a national/international level of energy related apps.
		Energy consumption monitor, automation, and control through mobile apps	**Mobile apps for energy consumption/generation monitoring, automation, control, and analytics.** Integrates diverse information, from different systems (PV generation, EV charges, energy consumption, energy price, etc.).

Table A4. *Cont.*

Category	Current and Future Market Needs	Type of Solution	Brief Description and Value Proposition
City Services Infrastructures and Systems	•Cities go digital both for internal workflow processes and for new ways to engage with citizens; •Regional and local authorities need to make informed, based on real time data decisions regarding the planning and investments; •Citizens are increasingly interested in being informed about various issues—among others, traffic, air quality, waste collection, energy, and environmental aspects; •CIPs can be integrated with sensor networks and data lakes designed with functionalities that allow for cross functional operation, enabling an advanced information and interaction framework that helps cities perform more efficiently and engage citizens; •Real-time information about different environmental variables is necessary in order to, e.g., help city decision-makers make well-supported decisions regarding the planning of new infrastructures and traffic control (where not only atmospheric but also noise pollution is crucial); •Systems responsible for data acquisition must not increase burden over existing power distribution grids and should be easy to install by local non-specialized workers. Wireless networks could cover all data acquisition points with much lower cost and less effort for installation and maintenance than wired networks.	City Information Platform	**A city information platform integrating data offering standards-based management making smart cities interoperable.** Facilitates quick analysis and decision support//Serves as a data acquisition hub//Policy making tool//Provide a variety of citizen related information//Engagement through providing a feeling of co-ownership.
		Wi-fi data acquisition systems	**Autonomous Wi-Fi Data Acquisition Systems for real-time measurement of multiple environmental variables.** Real-time information on temperature, humidity, atmospheric pressure, UV radiation, harmful gases, luminosity, and noise//Correlates historical data in order to establish a map of the organic behavior of a specific area//Independent from local power distribution grids, power supply is guaranteed by the integrated PV module and battery//Autonomous systems following a modular approach and can be installed by non-specialized workers according to data measurement needs.
		Data lake intelligence for positive communities	**Data lake intelligence with advanced cognitive and semantic analysis for positive communities, providing open data and information to better manage energy blocks and players.** Produce contextualized and focused knowledge//Automatic collection of unstructured, external (online) content from several sources (media, social networks).

Table A4. *Cont.*

Category	Current and Future Market Needs	Type of Solution	Brief Description and Value Proposition
Fostering Energy related Innovations	•Increasing needs for cloud services that enable and facilitate the experimentation, design, and implementation of new products; •Co-creation: Innovative solutions requirements and specification should be co-developed together between city partners and involved Startups; •Experimental solutions deployed in integrated living labs can be scaled-up to other cities; •(Re-)design based on circular products and services is growing fast, keeping energy and product fluxes as local as possible; •Lack of pro-active and leading contribution of employees from local governments; •Hiring of external consultants can deliver the necessary temporary manpower and expertise but has the disadvantage of the local loss of expertise once the project is over and the consultants gone.	Smart cloud for innovative startups	**Mobilize the local Startup Ecosystem, providing it with big data analytics and agile coding frameworks.** Develop and test smart city solutions in a real-world context (living lab).
		Acceleration Programs (i.e., Pocifest)	**Festivals/Events for accelerating the innovation process.** The innovation eco-system accelerating startups and new ventures capitalizing on pilot demonstrations momentum
		Governance innovation and co-creation.(i.e., TIPPING approach)	**A method for Governance innovation and co-development.** Increases the opportunities for own, local innovations and new business development//Promotes the involvement of start-ups from local applied science institutes//Promotes the stimulation of out-of-the-box solutions generated by the design and art sector//Promotes co-development of city projects with citizens and crowd-funding//Build own expertise and manpower within local governments, co-creating energy transition supportive projects, in cooperation with local stakeholders all over the quadruple helix//Own, local, and long-term expertise building.
Decision Support Tools	•Increase Citizen adoption, citizen participation, and co-creation practices; •Speed up the metabolism of city governments and governance structures, giving agencies the ability to watch events as they unfold, understand how demand patterns are changing, and respond with faster and often lower-cost solutions; •More innovative solutions to be generated collectively and adopted towards more energy consumption cautious behaviors; •Transition to a circular economy—reduce the negative impacts of the linear economy.	Planning Urban Transformation (i.e., Eco-Acupuncture)	**A decision-making supportive tool.** Analyzes new locally specific starting points for urban transformation//Helps visualize future possibilities and designs a series of interventions towards a resilient urban environment//Mobilizes academic researchers, students, representatives of local government, business, and the wider community.
		Design-based Value Mapping for Communities	**A Design thinking method supporting decision-making and co-creation.** Creates opportunities for new energy and circular product/services//Co-creates with all involved stakeholders a network of lead users//Lead-users help to strengthen the initial acceptance and support for the smart city projects, accelerating them, but also increasing the adoption rates in the follow-up phases of roll out.

Appendix B

		ETT#1 (Obj.1)																						
		RES generation								Smart energy management, control and self-consumption					Building energy efficiency					Sustainable waste utilization and management				
		PV (crystalline silicon) glass	PV canopies	PV skylights	Roof integrated PV systems	PV roofing shingles	Composite façades with vertical solar panels	Hybrid wind/solar generation system	Community Solar Farm	Bidirectional Smart Inverters	Energy Routers	Building Management Systems (BMS)	Building/Home Energy Management Systems (BEMS/HE	Positive Computing Data Center	Triple Glazing	PCM in the floor	Insulation with Circular Materials	Thermo Acoustic Heat Pumps	Cascaded Heat Pumps	Pay-As-You-Throw (PAYT)	Reverse Collection of Waste	Material Passports	ETT#1 Total	ETT#1 Percentage
Social Impact	Self-transendence	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1	1	0	4	19%
Life changing	Provides hope	0	0	0	0	0	0	1	1	0	0	1	1	0	0	0	1	0	0	1	1	1	8	38%
	Self-actualization	0	0	0	0	0	0	0	1	1	1	1	1	0	1	1	1	0	0	1	1	0	10	48%
	Motivation	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	20	95%
	Heirloom	1	1	1	1	1	1	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	10	48%
	Affiliation and belonging	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5%
Emotional	Reduces anxiety	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
	Rewards me	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5%
	Nostalgia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
	Design/aesthetics	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	33%
	Badge value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
	Wellness	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2	10%
	Therapeutic value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
	Fun/Entertainment	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
	Attractiveness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
	Provides access	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	1	1	1	8	38%
Functional	Saves time	0	0	0	0	1	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	7	33%
	Simplifies	0	0	0	1	1	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	7	33%
	Makes money	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	9	43%
	Reduces risk	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	1	0	0	1	0	1	8	38%
	Organizes	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	1	1	1	9	43%
	Integrates	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0	17	81%
	Connects	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	3	14%
	Reduces effort	0	0	0	0	1	0	0	1	1	1	1	1	1	0	0	0	0	1	0	0	0	8	38%
	Avoids hassles	1	1	1	1	1	1	1	1	1	1	0	0	1	0	0	1	0	1	0	0	0	13	62%
	Reduces cost	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	10	48%
	Quality	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1	19	90%
	Variety	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	7	33%
	Sensory appeal	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	14%
	Informs	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	1	0	1	7	33%

Figure A1. Example of how the most frequent attributes were derived for solutions in ETT#1.

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