Chapter 3
Smart Cities Consumers in Search of the Potential Sustainability

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Abstract Due to the increase in the urban population concentration, cities can be considered representative of the energy consumption and the energy sustainability of their countries, and, therefore, sustainability depends on the energy consumption behavior of the urban population. In the first urban agglomerations, primary energy resources (renewable) were transformed locally to supply a relatively low demand for energy. However, with the increase in demand, centralized energy facilities that took advantage of non-renewable energy resources were required. The use of these energy resources has caused the loss of energy sustainability. Parallel to the objective of solving environmental problems through the use of renewable energy resources in decentralized generation facilities, the smart city strategy seeks to optimize the power system and make operation more flexible by empowering the consumer. However, just as sustainability depends on the urban population's consumption behavior, the effectiveness of smart cities depends on the active participation of consumers. Faced with increased demand and the need to obtain a clean and uninterrupted energy supply, the recovery of potential sustainability depends on the consumer taking advantage of the technological deployment of smart cities and becoming a smart consumer. Based on studies on demand-side response, electrification, and energy self-consumption in cities, this chapter addresses the effectiveness of smart cities. The conclusions highlight the fact that energy sustainability is not inherent in smart cities: it depends on the consumer participation. Therefore, the effectiveness of smart cities must address the design of incentives for the participation of the population from a holistic approach and be linked to the heterogeneity of consumers and circularity in the efficient management of resources.

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Introduction

This chapter is based on the doctoral thesis “Energy Sustainability of Smart Cities” (see Villa-Arrieta 2019) and is comprised of studies that the authors have previously published. Our intention is to use this chapter to extend the conclusions of the said thesis and contribute to the study of smart cities with a single concise piece. In this introduction, the importance of cities in the energy transition is discussed. Then, the mechanisms that these urban areas use to contribute to energy sustainability are identified, and in the following sections, these mechanisms are discussed before presenting the results and conclusions of this research.

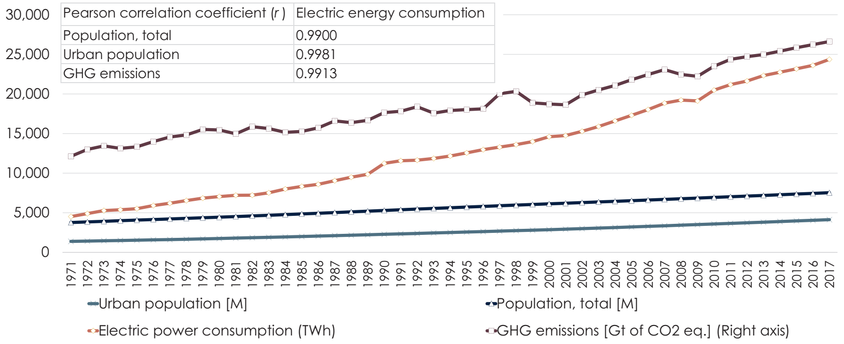
The Importance of Cities in the Energy Transition

Cities are home to more than half of the world’s population (United Nations 2018) and consume between 60% and 80% of the world’s total energy production. Because energy is responsible for two-thirds of total greenhouse gas (GHG) emissions (OECD/IEA, IRENA 2017), urban areas emit 75% of global CO_2 emissions (primary GHG) (United Nations Environment Programme (UNEP) 2012). As seen in the United Nations projections for up to 2050 (projections before the COVID-19 pandemic), if the current urban population growth trend continues, global urbanization will represent 67% of the total population (United Nations 2013), and cities will demand a more significant amount of energy.

Covering this energy demand with the current model based on fossil resources will increase GHG emissions, and the consequences of global warming will put the planet’s environmental sustainability at risk (IPCC 2018). Therefore, guaranteeing the security and quality of the energy supply to provide urban services using the planet’s resources will pose an enormous challenge in terms of our ability to manage and restore the natural assets upon which all life depends (OCDE 2012).

The rhythm of the technological change of the systems for transforming primary energy to final energy has marked the pace of development and economic growth of cities. This final energy, mainly consumed as electricity, has improved the quality of life for humanity in the modern era but has led to the environmental consequences mentioned above. As seen in Fig. 3.1 (which includes data from after the 1973 oil crisis), electricity consumption has a more significant correlation with urban population growth rather than with the total population growth. It can be concluded, therefore, that GHG emissions are linked to urban energy consumption.

To address this problem, the world’s leading economies have launched an energy transition process to move from the current economic model to one that is decarbonized and competitive. (The relationship between the COVID-19 pandemic and the



Pearson correlation coefficient (*r*)	Electric energy consumption
Population, total	0.9900
Urban population	0.9981
GHG emissions	0.9913

Fig. 3.1 Correlation between electric energy consumption and urban population. (Source: Adapted from Villa-Arrieta and Sumper 2019a)

energy transition has been studied by (Quitzow et al. 2021) and concludes that this crisis has deepened the gap between the countries that are leading the global energy transition and those which are progressing more slowly, which exacerbates the existing imbalances in an uneven energy transition landscape.)

The mechanisms to promote the energy transition are to decentralize and make the power system more flexible in order to save energy, increase energy efficiency, and replace the use of fossil energy with renewable energy. The flexibility of the system involves monitoring it in order to adjust the energy demand to the intermittency that characterizes renewable energies. Decentralization seeks to take advantage of distributed energy resources and bring generation closer to where energy is used.

This means that solar energy plays a remarkable role, given the uniformity of its distribution on a global scale (Check et al. 2015). Therefore, cities play a fundamental role in the energy transition process (Kammen and Sunter 2016), despite being the source of a worldwide environmental problem. Within cities, buildings use 31.43% of the total energy consumption, which is more than industry, transport, and other consumptions (International Energy Agency (OECD/IEA) 2018). In addition to focusing on energy consumption, buildings have a high margin of action to increase energy savings, energy efficiency, and the use of renewable energy through energy self-consumption. Flexibilization of the energy system also seeks to empower consumers so that through demand-side response (DSR) mechanisms, this agent can expand its participation in the power market.

Smart City and Energy Sustainability as Strategies

From a development of the society's point of view, advancing in the energy transition will lead to the sustainability of energy supply: reducing the negative impact of energy consumption on the environment will allow us to ensure the well-being of future generations. In this sense, there is a global consensus in defining the smart city concept as a critical strategy to address energy transition in cities and achieve energy sustainability (IRENA 2016).

Both the studies of energy sustainability and smart cities are extensive (EIB, UPM 2017; Sustentable Citiess Index. Sustainable Cities Index 2016; World Health Organization. The Rise of Modern Cities 2010). Energy sustainability is a field of knowledge which has been studied in depth. Similarly, smart cities has attracted the economic interest of the technological, industrial, and service sectors as well as governmental and supranational organizations in search of the competitiveness of cities and as a strategy to face climate change (Caragliu et al. 2011; Bakici et al. 2013). In this sense, there are several methodologies for assessing smart cities (rankings or benchmarking of cities as in the studies (IESE Business School 2014; JLL and The Business of Cities 2017) and the energy sustainability of cities (see International Telecommunications Union 2019).

The smart city strategy seeks to guarantee the efficacy of the energy service in cities to provide other services and efficiently manage available resources (energy and economic resources and infrastructures) (Villa-Arrieta and Sumper 2019a). The synergies between smart technologies (smart grids, distributed generation facilities, and smart meters) will make it possible to provide the energy service that citizens require as well as efficiently manage the resources needed to provide them (Lund et al. 2017). In particular, the deployment of smart meters in households and the energy self-consumption of nearly or net zero energy buildings (n/NZEB) will increase energy saving and efficiency and make the most of the local renewable energy resources (International Energy Agency (IEA) 2017a; International Energy Agency (IEA) 2017b; Ackermann et al. 2001).

In terms of sustainable development, sustainable energy is a source of the development and growth of societies and seeks a balance between economic, social, and environmental variables (Council HR and Germany 2007). According to the *World Energy Council* (WEC), energy sustainability at a country level relies on a balance between three pillars: energy security, energy equity, and environmental impact mitigation (Kim et al. 2013). The inclusion of smart technologies will allow involving those who take part in the management of the cities to find the balance between the these three pillars. Figure 3.2 shows the energy transition characteristics needed to meet the energy demands of a growing world and urban population: the smart city and energy sustainability concepts are constantly being evaluated to achieve the decarbonization targets.

Scalable Study of Energy Sustainability

The main contribution of the studies addressed in this chapter is the analysis of the scalability of urban energy sustainability up to the country level (see Fig. 3.3), as a new evaluation approach based on the hypothesis that cities tend to be representative of the country's population, energy consumption, and GHG emissions. Due to the trend of an increasing population concentration in cities, it can be argued that

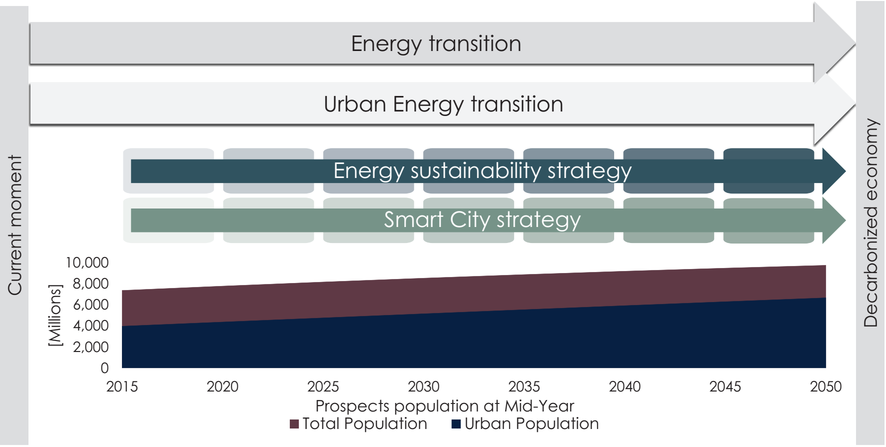


Fig. 3.2 Energy transition and population growth prospects for 2050. (Source: Adapted from Villa-Arrieta 2019)

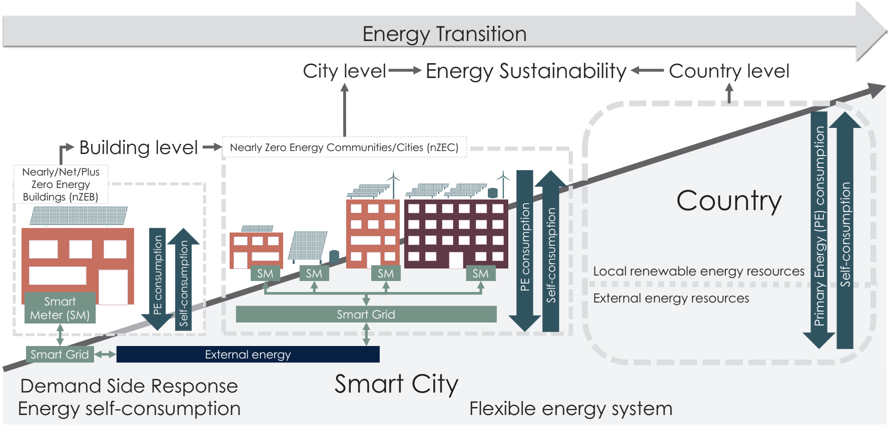


Fig. 3.3 Scalability of energy sustainability. (Source: Adapted from Villa-Arrieta 2019)

urban centers are to be representative of energy consumption and are responsible for GHG emissions. It can therefore be concluded that energy sustainability of cities is representative of the energy sustainability of their countries.

Based on a close relationship between the smart city and energy sustainability strategies, the cities' capacity to advance in energy saving and the use of solar energy resources are described below. The objective is to explain the contribution of smart technology elements to the increase of energy efficiency and urban self-consumption of cities, both of which are critical components of the energy transition to combat climate change.

Activation of Energy Saving

One of the drawbacks of electricity from solar energy is that solar radiation is maximal when many homes are empty, and household electricity usage peaks when there is no solar radiation. However, through DSR and the use of smart meters, consumers exercise active management over their demand. This is a process in which the response to energy information feedback (price signals, gamified plans, or environmental information) can be reflected in the decrease of peak demand (peak clipping), the change of consumption from the peak periods to the off-peak periods (load shifting), or in the energy-saving (strategic conservation). Therefore, with the deployment of smart meters, it is possible to activate the measures of DSR (see Fig. 3.4): the flexibility of the power system depends on the data around consumers (Kim et al. 2013).

The replacement of electromechanical meters with electronic ones is the first step in the process of empowerment, so that more meaningful and better information concerning energy consumption that leads to changes in the energy management of households can be collected (Barbu et al. 2013). Although end users were passive actors of the power system until now, with the introduction of new services that allow more significant involvement of consumers, users have begun to be an essential part of the use and management of energy.

Although the DSR peak clipping and load shifting measures offer specific advantages to achieve flexibility in power systems, strategic conservation is the set of saving efforts that modify the load curve in its entirety. Regarding the DSR of the residential sector, this conservation strategy groups households' efforts to change their consumption patterns in response to consumption and/or price signal. The results studied in this section focus on the study of this measure because it is one of the main energy strategies of countries or regions dependent on external energy.

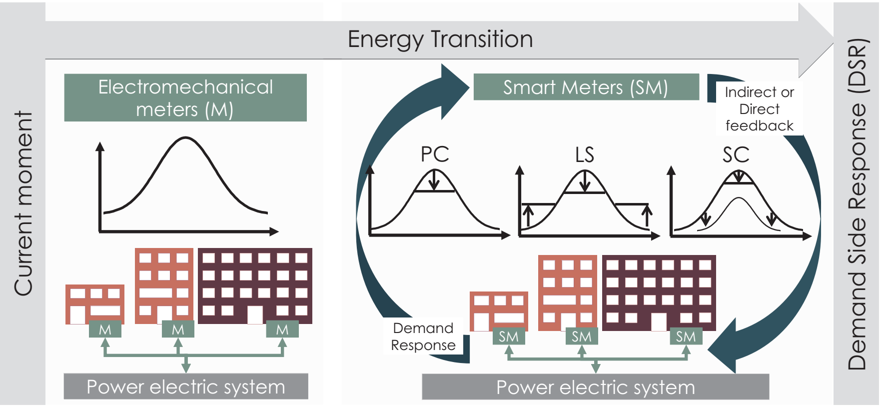


Fig. 3.4 Energy transition and demand side response (DSR). Notes: PC, peak clipping; LS, load shifting; SC, strategic conservation; M, electromechanical meters; SM, smart meters. (Source: Adapted from Villa-Arrieta 2019)

Experimental Results of the Strategic Conservation

It would seem that the use of smart meters would allow consumers to manage their demand more efficiently (Frederiks et al. 2015). However, unless users are proactive, it will not be possible for them to take advantage of the opportunities provided by new technologies. Domestic energy consumption is mainly based on routines and habits that are difficult to change. Therefore, it will be necessary to deepen the technical, psychological, social, and economic aspects that allow consumer participation and behavior adjustment (Batalla-Bejerano et al. 2020). This is precisely the field in which researchers from different disciplines seek to identify the aspects that determine consumer participation through empirical studies.

To explore this, a review of empirical works that have tried to quantify the results concerning energy savings has been carried out. This review analyzes 116 empirical studies on the strategic conservation of the DSR (to see results on peak clipping and load shifting, see (Batalla-Bejerano et al. 2020)). These studies, comprised of surveys (S), analytics (A), experiments (E), and simulations (L), looked at the indirect and direct feedback of information related to electricity consumption through smart meters. Indirect feedback includes electric bills and consumption readings, and direct feedback consists of the use of additional technologies such as smart meters (digital) that make it easier for users to check their consumption and participate in energy-saving programs. According to the results, households respond to the provision of direct and indirect information by using less electricity.

Figure 3.5 and Table 3.1 compile these results. The installation of smart meters alone in households does not guarantee the reduction of electricity consumption in the broad spectrum of their socioeconomic conditions, and it is necessary to take advantage of digital technology to ensure that households understand and react to

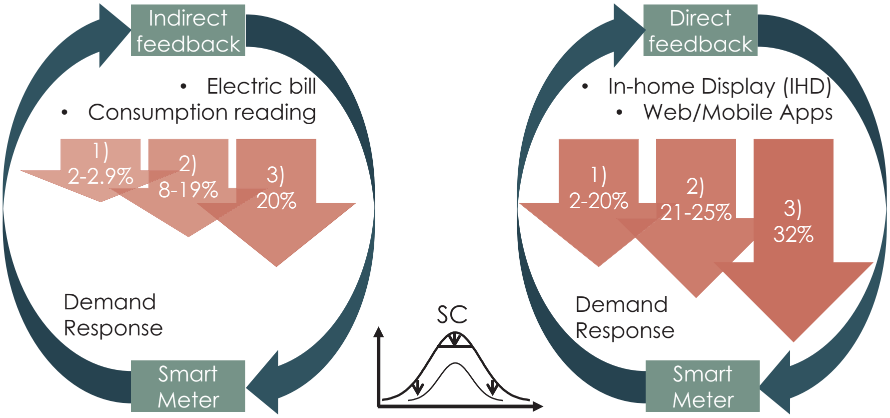


Fig. 3.5 Results on strategic conservation (SC) of the empirical works reviewed. Note: See Table 3.1. (Source: Adapted from Villa-Arrieta 2019)

Table 3.1 Strategic conservation results using indirect and direct feedback

Indirect feedback	
Figure 3.5	[Reference] Country (Methodological approach) Result
1)	(Allcott 2011) US (E-A) 2.0%; (Ayres et al. 2009) US (E) 2.1%; (Anderson and Lee 2016) US (E-L) 2.2%; (Schwartz et al. 2013) US (E-S) 2.7%; (Allcott and Rogers 2012a) US (E-L) 2.6 and 2.9%*
2)	(Gans et al. 2013) Northern Ireland (E) 11–17%; (Asensio and Delmas 2015) US (E) 8–19%
3)	(Bariss et al. 2014) Latvia (E) 20.0%; (Poznaka et al. 2015) Latvia (E-S) 23.0%
P	(Allcott and Rogers 2012b) US (E); (Ek and Söderholm 2010) Sweden (E); (Laicane et al. 2013) Latvia (S); (Lossin et al. 2016) Switzerland (E-S); (Kang et al. 2012) South Korea (S); (Rausser et al. 2018) Ireland (S); (Qingbin Wang 2016) US (S)
Direct feedback	
Figure 3.5	[Reference] Country (Methodological approach) Result
1)	(Reeves et al. 2015) US (E-S) 2.0%; (Quintal et al. 2013) Europe (E-S) 2.0%; (Fenn et al. 2012) Germany (E-L) 3.0%; (Rettie et al. 2014) UK (E-S) 3.0%; (Schleich et al. 2011) Germany and Austria (E-S) 3.7%; (Erickson et al. 2013) US (E-S) 3.7%; (Schleich et al. 2012) Austria (E-S) 4.5%; (Spagnolli et al. 2011) Europe (E) 5.0%; (Schleich et al. 2017) Austria (E) 5.0%; (Houde et al. 2012) US (S-E-S) 5.7%; (Bager and Mundaca 2017) Denmark (E) 5–7%; (Stinson et al. 2015) Scotland (E-S) 7.0%; (Shimada et al. 2014) Japan (E) 7.6%; (van Dam et al. 2010) Netherlands (S-E-S) 7.8%; (Grønhøj and Thøgersen 2011) Denmark (S-E-S) 8.1%; (Peschiera and Taylor 2012) US (E) 8.8%; (Schultz et al. 2015) US (E) 7–9%; (Jain et al. 2013a) US (E-L) 10.0%; (Nye et al. 2010) UK (E-S) 5–10%; (Chen et al. 2015) US (E) 11.0%; (Anderson et al. 2017) South Korea (E) 14.0%; (Gosnell et al. 2019) UK (E) 4–12%; (Alahmad et al. 2012) US (E-S) 12.0%; (Wood and Newborough 2003) UK (E) 15.0%; (Chen et al. 2014) US (E-S) 20.0%; (Delmas and Lessem 2014) US (E) 20.0%
2)	(Maan et al. 2011) Netherlands (E) 21.0%; (Laicane et al. 2015) Latvia (E-L) 6–23%; (Adnane Kendel 2015) France (E-S) 23.3%; (Bager and Mundaca 2017) Denmark (E) 7–25%
3)	(Costanza et al. 2012) UK (E-S) 5–32%; (Petersen et al. 2007) US (E-S) 32.0%
P	(Peschiera et al. 2010) US (S-E-S)*; (Foster et al. 2010) UK (E-S); (Strengers 2011) Australia (E-S); (Karjalainen 2011) Finland (S); (Brewer et al. 2011) US (S-E-S); (Ellegård and Palm 2011) Sweden (E-S); (Petkov et al. 2012) Australia (S); (Chiang et al. 2012) UK (E); (Chen et al. 2012) US (E-L); (Oltra et al. 2013) Spain (E-S); (Chen et al. 2013) US (E-L); (Jain et al. 2013b) US (E-L); (Loock and Staake 2013) Switzerland (E); (Buchanan et al. 2014) UK (S); (Schwartz et al. 2015) UK (E-S); (Bager and Mundaca 2015) Denmark (E); (Mogles et al. 2017) US (E-S)

Source: Adapted from Villa-Arrieta (2019)

Notes: US, United States; UK, United Kingdom; P, positive result; S, surveys; A, analytics; E, experiments; L, simulations

* Two experiments

the direct feedback of energy information. Empirical evidence shows that it is possible to reduce electricity consumption by up to 32% using such means.

Electrification and Self-Consumption in Cities

Electrification

As described previously, the deployment of smart technologies will allow cities to increase electricity generation from renewable sources to decarbonize the economy. However, according to the WEC, energy sustainability depends on the balance between energy security, energy equity and the mitigation of environmental impact. Therefore, given the intermittence of renewable energies and depending on the characteristics of each country and city (possibly similar between regions), "smart" electrification without energy storage technologies may lead to an imbalance in energy sustainability in that, although environmental benefits are possible, energy security could be at risk.

To help address this issue, the researchers studied the effect that electrification may have on countries' energy sustainability using the ETI's interactive Pathway Calculator tool. This tool can be used to determine what is necessary to improve the ranking position and understand the impact of policymaking on achieving a sustainable energy future (World Energy Council 2017). Figure 3.6 presents its elements. The procedure followed involved setting the tool variables to maximum and minimum values in order to identify the variation in the energy sustainability result of the 125 countries of the ETI 2017. This exercise was the first step to determine the photovoltaic (PV) generation capacity of cities of these countries, which will be addressed in the section below.

According to the results obtained, countries could obtain better energy sustainability by reducing energy imports and increasing the diversity of the electric generation and the diversity of the primary energy (PE) supply (see Fig. 3.7). This indicates that the use of local energy resources, such as PV electricity generation,

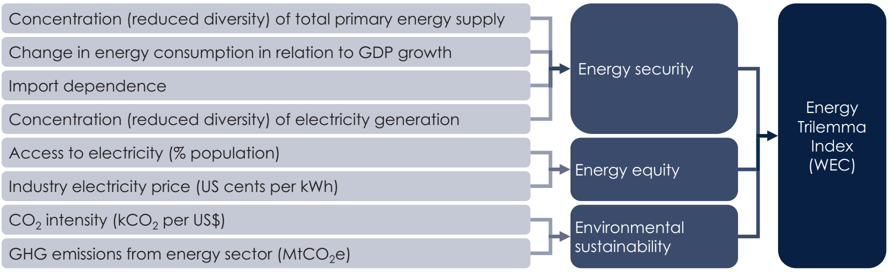


Fig. 3.6 Structure of the indicators of the Pathway Calculator of the World Energy Council (WEC). (Source: Adapted from Villa-Arrieta and Sumper 2019a)

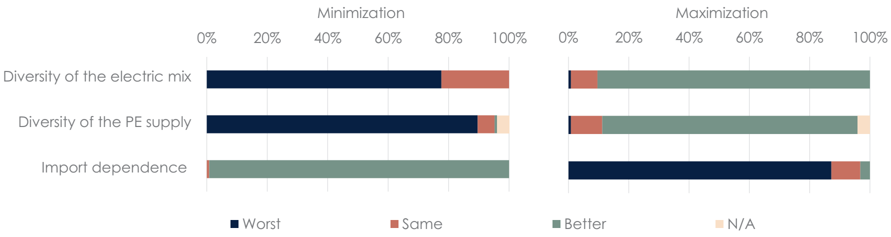


Fig. 3.7 Result of energy sustainability by variation of critical indicators. (Source: Adapted from Villa-Arrieta and Sumper 2019a)

would lead to the improvement of energy sustainability of the 125 ETI-2017 countries.

Photovoltaic Energy Self-Consumption Capacity of Cities

As mentioned above, cities are at the center of the energy transition. Given the uniformity of the solar resource, cities have the capacity to generate electricity near the same consumption points. By deploying PV systems, cities can cover part of their electricity demand and contribute to the use of local energy resources in their countries. Thus, PV generation is the leading technology to move toward the energy sustainability of cities.

To advance in this field, the contribution of urban PV generation to the energy sustainability of the ETI 2017 countries (see Villa-Arrieta and Sumper 2019a) was studied. The process was as follows:

1. Calculate the PV generation capacity of the rooftops of the most populated cities of the ETI 2017 countries (183 cities of 123 countries) taking the usable area of the Barcelona rooftops, global tilted irradiation data, and a 16% efficiency for PV panels as a reference.
2. Calculate the distribution of the electricity generation mix of the studied countries with data from the International Energy Statistics of the US Energy Information Administration (EIA) (Meyer 1991), and calculate CO_2 emissions using emission factors from International Energy Agency (IEA) (Ecometrica 2011).
3. Calculate how much fossil fuel and nuclear and hydroelectric generation (in that order) was replaced by solar power and the increases in the country’s renewable energy generation without increasing the balance of its electric mix.
4. Calculate the *Herfindahl-Hirschman Index* (HHI) with the generation values obtained from each source within the electric mix in order to obtain the concentration of the generation in a single source (high HHI result).
5. Normalize the results of HHI (0–100) to compare them with the values published for each country in the 2017 ETI results.

The results of this showed that the 125 ETI 2017 countries vary the concentration (reduced diversity) of electricity generation by an average of −15.94% due to the hypothetical increase in their urban PV generation. This would have an impact on the reduction of 56.31% of the electric power generation from fossil fuels and consequently on the reduction of 64% of the CO_2 emissions of these countries. The use of the local solar resource would allow these countries to improve their sustainability due to the reduction of the dependence on energy imports. Although the diversity of the primary energy supply would be reduced in some countries (toward concentration), increased consumption of renewable resources would allow them to reduce CO_2 emissions. Table 3.2 summarizes the results obtained.

From the results, two groups of countries were identified: one group of countries that increases the diversity of electricity generation and another that reduces it. In the former, the increase in PV generation allows 87 countries to diversify the electricity mix by up to 43% concentration. On the contrary, 38 countries increase the concentration of the electricity mix to 97%. Although in both cases, following the ETI definition, as environmental protection improves, energy security can be put at risk. It should be noted that the second group of countries is made up of countries with a large proportion of hydroelectric generation in their mix, which is a technology with low intermittency.

Table 3.2 Average results of the effect of the diversification of the electric mix with urban PV generation in the ETI 2017 countries

Indicator	Initial value	Result
Number of countries analyzed	125	125
Average concentration* of electricity generation (0–100)	66.41	N/A
… after the urban PV generation (0–100)	N/A	55.16
Average variation [%]	N/A	−15.94
Number of countries that diversify electricity generation	N/A	87
Average variation of concentration* [%]	N/A	−42.44
Number of countries that concentrate electricity generation	N/A	38
Average variation of concentration* [%]	N/A	44.73
Average variation of the consumption of fossil fuels [%]	N/A	−56.31
Average variation in CO_2 emission [%]	N/A	−64.00

Source: Adapted from Villa-Arrieta and Sumper (2019a)
Note: * Reduced diversity

An Economic Evaluation of the Use of Self-Consumption Capacity

Energy self-consumption is the strategy that seeks to take advantage of the local renewable generation capacity. In the case of cities, although each of them has different characteristics, any use of local energy resources will reduce the consumption of primary external energy of fossil origin. In this sense, energy-importing countries will be able to equilibrate their energy balance with energy self-consumption in their cities. This type of distributed generation includes nearly/net zero energy buildings (n/NZEB), which are dependencies of consumers. Therefore, the advance of energy self-consumption in cities and consequently the reduction of energy imports in the countries, if it were to be the case, depend on the investment of consumers in n/NZEB.

In order to study the advancement of n/NZEB in cities from the investment point of view, the authors previously carried out technical-economic simulations with an evaluation model of self-consumption in buildings scalable to study self-consumption in cities (nearly zero energy cities, NZEC). The results of these studies are presented below.

Evaluation Model

The model, called nZEC-EATEP (see (Villa-Arrieta and Sumper 2019b)), allows evaluating the economic performance of the energy self-sufficiency process of cities. Also, it enables to jointly assess distributed generation facilities, or n/NZEB or neighborhoods with energy surpluses (positive energy neighborhoods). Figure 3.8 conceptualizes its methodology, which is based on the relationship between the energy transition, the urban energy transition, the increase in the consumption of local energy resources to the detriment of the external ones due to the advance of the n/NZEB, and the economic calculation of the future value of this process.

Case Study: Barcelona

The objective of this study was to analyze the scope of the investment in the PV self-consumption of buildings in order to promote prosumer communities. The model included 82,652 buildings and simulated 37 years (2013–2050) of energy and economic performance: in 38,700 (34.7% of 238,213 buildings with PV generation capacity data), the investment of six packages of energy rehabilitation measures and PV self-consumption (prosumer's buildings) was studied, and in 43,952 the investment in PV generation (PV extra generation) was studied. Cross-referencing with public data on the city, the PV generation capacity of the 82,652 buildings, the electricity consumption of the prosumers, and the investment cost in the energy rehabilitation measure packages were identified as well as the electricity

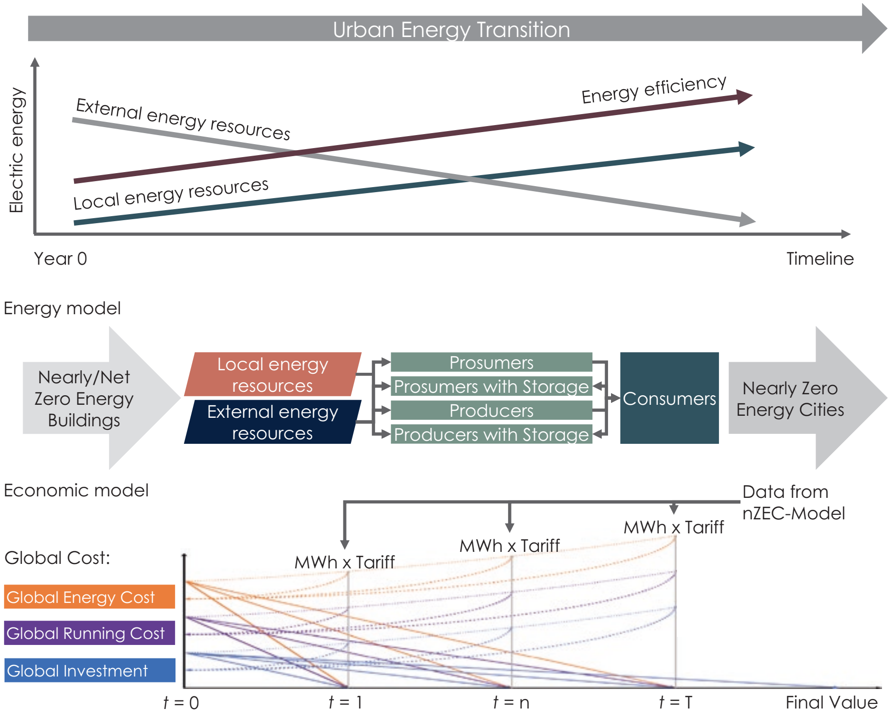


Fig. 3.8 Technical-economic evaluation of nearly zero energy cities (nZEC). (Source: Adapted from Villa-Arrieta and Sumper 2019b)

Table 3.3 Number of buildings and electric energy consumption of nZEC model for Barcelona

	No. of buildings	Electric energy consumption [GWh/Year]
Prosumers	38,700	969.363
Consumers (domestic, commercial and services, and other services	N/A	3225.927
PV_Extra	43,952	N/A
Total	82,652	4189.32

Source: Adapted from Villa-Arrieta and Sumper (2019b)

consumption of buildings extra PV generation (PV_Extra). Table 3.3 summarizes these results.

With the nZEC model studied, the city has the ability to reduce up to 9.68% of its primary energy demand, which means a reduction of up to 12.25% in energy costs and up to 11.43% in emissions of CO_2. The total investment required to achieve these savings includes the initial value and the replacement of the PV systems and the rehabilitation measures. This investment can be 1.32 times the total energy cost of the city in the same 37 years of evaluation.

Results

The results of the studies summarized in this chapter have demonstrated the remarkable capacity that cities have to contribute to the energy sustainability of their countries with the deployment of smart technologies. Table 3.4 summarizes the results obtained:

Regarding the activation of the energy-saving capacity of cities, the results compiled from the empirical works reviewed showed the importance of the feedback of energy information to reduce electricity consumption in the residential sector: the provision of direct and indirect information helps households to use less electricity (see Batalla-Bejerano et al. 2020). Regarding electrification capacity, reducing the concentration of electricity generation would allow 113 of the 125 countries from different economic regions of the world to obtain a better balance in their security of supply, energy equity, and environmental protection. If this electrification process in introduced and incorporates the use of the PV generation capacity of the rooftops of the buildings of their cities, these countries could improve sustainability thanks to the reduction of the dependence on energy imports (see Villa-Arrieta and Sumper 2019a). In the specific case of a study city, taking advantage of this electricity self-consumption capacity through distributed generation, the creation of prosumers and positive energy neighborhoods helps reduce primary energy consumption and CO_2 emissions with the joint investment in energy rehabilitation measures of buildings (see Villa-Arrieta and Sumper 2019b).

This means that energy sustainability and smart city strategies would allow for progress in the transition toward a decarbonized economy. Uniting the pillars of these strategies, it can be argued that smart technologies enable cities to be effective in the provision of urban energy service, efficiently managing available local resources to achieve a balance between energy security and equity and environmental protection. However, according to the results described above, without consumer

Table 3.4 Compilation of results

Capacity of…	Countries	Cities	Results
Energy saving	>19	>19	Reduction of between 2% and 32% of electricity consumption
Electrification	125	N/A	113 improve energy sustainability
PV self-consumption in cities	125	183	• All countries reduce on average 64% of CO_2 emissions. • 87 countries diversify the electricity mix up to 43% concentration
nZEC	1: Spain	1: Barcelona	With 34.7% of the buildings with PV generation and 16.2% of prosumer buildings: • Reduction of up to 9.68% in primary energy demand. • Reduction of up to 12.25% in energy costs. • Reduction of up to 11.43% of CO_2 emissions.

Source: Adapted from Villa-Arrieta (2019)

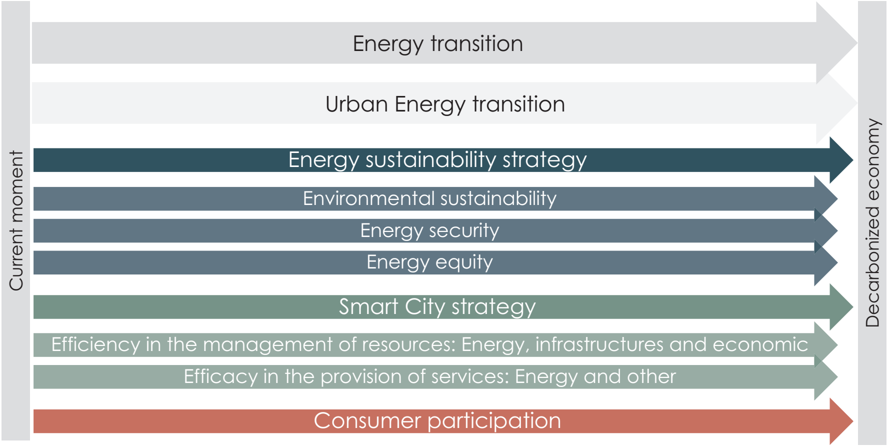


Fig. 3.9 Layers of the link between energy transition and consumer participation

participation, it is not possible to save energy or take advantage of the energy self-consumption capacity of cities through investment in buildings with almost zero energy consumption. Figure 3.9 summarizes the dependency between these layers of the energy transition.

Conclusions

The studies compiled in this chapter have been based on the study of the scalability of energy sustainability through the smart city technological strategy, from the level of buildings to that of a country. This study approach is a novel proposal to address the fact that due to the increase in the concentration of the urban population, cities tend to be representative of the energy sustainability of their countries. Smart technologies are crucial elements to keeping the balance between energy security, energy equity, and environmental sustainability of cities and their countries. The energy effectiveness of smart cities is the efficacy provision of urban energy service and the efficient management of resources around distribution systems. Smart cities allow the urban population to participate in its own sustainability, which in the context of the current energy transition process means empowering the consumer in terms of their demand to make operating the system more flexible and to optimize the efficient management of the local resources.

Of course, there are drivers that encourage consumers to participate in the achievement of global social and environmental goals, such as the sustainable development goals. However, based on specific incentive strategies for responsible consumption, consumers will exercise their participation in smart cities and in the market, helping the sustainability of local geographic frameworks that will ultimately have an impact on global sustainability. As discussed in this chapter, the information incentives to activate the demand-side response and the possibility as an incentive of pouring surplus energy into the grid in self-consumption systems are specific strategies that have an impact on energy sustainability. However, this is the particular case of the energy sector, and the incentive for responsible consumption is broader.

There are three main conclusions that can be drawn from this chapter. The first is that energy sustainability is not inherent in smart cities: it depends on the participation of the consumer to be effective in this city model. Thus, energy sustainability must be activated at an urban level to include consumers in the management of demand and consumption of local energy resources. Passing this responsibility on to consumers makes them smart consumers, or smart city consumers (SCC) at a city level. The SCC is, therefore, the future of energy sustainability and, consequently, a promoter of sustainable development. The philosophy behind the existence of the SCC is to encourage responsible consumption: that is, to promote the efficient use of resources (energy and other) and the effective acquisition of products and services with a positive impact on society and the environment.

The second conclusion is that the difficulty in reaching the SCC sustainability potential is related not only to the difference between the systems that exist in cities (different economic activities, mobility systems, types of buildings, urban characteristics, etc.) but also with the heterogeneity of consumers. Not only do cities have building owners but they also have tenants, the elderly, the student population, and short-term residents. Therefore, the decarbonization of the economy must go beyond technological innovation and address social innovation to include the heterogeneity of consumers and their different living conditions. Similarly, there must be regulatory innovation in addition to social and technological innovation in markets where there are regulatory barriers that prevent disruptive new business models within the energy transition. The objective is to obtain incentives, instruments of empowerment, and protection mechanisms for different types of consumers.

The third conclusion is related to the political implications that emerge from the conclusions above. There is a very clear need to design policies, enablers, monitoring metrics, and incentives for energy sustainability with a holistic and bottom-up approach to the economy and society, from consumers to countries. Just as sustainability is transversal to all economic activity, incentives to participate in sustainability must also be transversal to the economy, interconnecting different sectors and objectives. In this regard, two new topics must be addressed in the SCC: the decentralization of the administration and traceability of information through Blockchain technology and the inclusion of energy in the transformation toward circularity of the economy to maximize the use of resources, including the reintroduction of waste in the production chains. The design of incentive mechanisms for consumers that include the advantages of Blockchain technology to be able to cross sector borders within the framework of the circular economy will be the focus of future research by the authors.

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