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Mapping Flexibility of Urban Energy Systems (FIRST) project: Rationale and study design of an exploratory project

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Abstract. With the publication of the new Energy Performance of Buildings Directive, a large number of buildings are expected to become high energy performance and explore more the availability of renewable energy resources. Such buildings are often described in literature as nearly Zero-Energy Buildings (nZEB). Because renewable energy sources, such as wind and solar power, have an intrinsic variability, the zero-energy annual balance of nZEBs is difficult to reach at short time resolution (e.g. hourly). Thus, since electricity generation from small-scale solar renewable (typical case in Portugal) in individual households has limited capacity to be adjusted according to the power system needs, it is relevant to consider the demand flexibility potential, specially at community level (cluster of buildings). Unfortunately, there is a lack of studies on the impact of changes in electricity use at urban level on the future energy systems. Therefore, an approach addressing the energy flexibility (EF) in buildings may allow obtaining useful exploratory directions for the construction sector and related markets, policy makers and regulatory bodies. For these reasons, an exploratory project aimed at examining the potential of EF at the level of an existent neighbourhood in Lisbon was initiated. In this article we describe the objectives, design, and methods of the FIRST project, designed to map out the potential for EF in terms of benefits and costs in Lisbon.

1. Introduction

With the publication in 2018 of the Energy Performance of Buildings Directive (EPBD) recast and the implementation of a new building code in Portugal, it is expected that a large number of buildings will become high energy performance and exploit at the same time the available renewable energy resources. Although the concept is yet to be defined in the context of Portuguese strategic frame, such buildings have been described in literature as nearly Zero-Energy Buildings (nZEB). Considering the prosumer's role, the relationship between these types of buildings and the supply grid is much more complex than a regular building which only withdraws energy from the grid. Because renewable energy sources such as wind and solar have an intrinsic variability, it is difficult to reach an equilibrium between energy generation and consumption, especially at short time resolution. Moreover, the strive to achieve zero-energy performance (or even higher energy balances) may lead to an increase of the amount of intermittent energy that flows to the grid, causing occasional periods of overproduction [1]. Thus, since electricity generation from small scale solar renewable (typical case in Portugal) has limited capacity to

deliver flexibility to the power system, it is relevant to consider estimating potential of flexibility from the demand side at individual level (single buildings) or at community level (cluster of buildings).
When referring to Energy Flexibility (EF), one of the most common approaches to meet the need to shift energy consists in implementing Demand Response (DR) strategies. In this case, the available EF is used modify the electricity consumption of controllable devices (HVAC, washing machines, dishwashers, electric vehicles, etc.) from their normal consumption in response to changes in the price of electricity or to meet other grid requirements, such as periods of high renewable generation. Despite of the lack of insight into how much EF different types of buildings and their usage may be able to offer to future energy systems, there is a general agreement that changes in electricity use may lead to achieve different objectives according to e.g. grids. For these reasons, an exploratory project aimed at examining the potential of EF at the level of an existent neighbourhood in Lisbon was initiated – the FIRST project.

2. Objectives

As mentioned above, the FIRST project was designed to examine the potential for EF at the level of an existent neighbourhood in Lisbon in order to find to what extent the provision of flexibility from the consumer side could be facilitated, especially at the community level. It begins with the estimation of shifting potential of volumes of electricity consumed for short or long periods of time at individual level of buildings as a response to changes in users' comfort needs, grid tariffs and/or renewable availability. It then considers urban energy systems encompassing a larger chain of buildings within the neighbourhood domain to estimate the potential for energy flexibility at the community level [2]. Given the breadth and complexity of this research topic, the team will focus the research on three hierarchically related research tasks:

- Task1 - Study of potential for EF at individual building level
- Task 2 - Study of potential for EF at community level
- Task 3 - Mapping out the EF potential at community level

The major goal of this project is to unleash the energy flexibility potential of DR measures at a time when buildings are becoming prosumers. The focus of research is to assess the impacts of different energy scenarios related to changes in the electricity consumption of controllable devices triggered in response to grid tariffs and renewable availability and the mapping of the potential for energy flexibility in a visual form. The major advantage of this research is that it uses real data of energy systems and energy demand profiles [3] rather than hypothetical examples. The results of this research are important for understanding the benefits of using EF and will set the basis for future research in the energy flexibility domain where both energy service providers and consumers are targeted.

3. Literature review

Concerns about climate change, economic stability and energy security urge the society to change towards more sustainable energy practices [4], [5], [6]. These issues addressed in international targets and national goals prompt a transition from conventional to renewable energy sources [7]. Achieving energy transition is perceived as increasing the share of the renewable energy sources within the national grid [8], [9], [10]. In addition to this, available data shows that buildings are responsible for 40% of energy consumption in the EU and U.S. [11]. Given the existent potential for reducing the buildings' energy requirements, and the great impact exerted by the building sector on society (as the scale of energy efficiency in buildings is large enough to influence security policy, climate preservation and public health on a national and global scale), EU elected energy efficiency as the best way to establish energy security over a longer term. With respect to the building sector, it is estimated that the combination of energy efficient measures with onsite energy renewable sources has the potential to induce the adoption of nZEBs [12]. The process of transition from conventional to renewable energy sources leads to three major challenges in the grid. First, large electricity production peaks may cause damage by overloading the system [13]. Second, substantial backup electricity production plants are necessary to balance supply and demand on account of renewable production variability [14]. Third, moving away from centralized production involves two-way energy flow, thus the system requires strengthening of the grid [1]. Therefore, alternative strategies should be developed to mitigate these consequences. In this respect, one possible strategy is the development of small-scale energy systems with negligible energy exchange with the external grid [15].

In these systems, the produced energy is consumed directly by towns or city districts [16], in which case, the pressure exerted on national level planning and infrastructural changes or for grid improvements is lower [17]. In the specific context of future nZEBs, one of the major challenges regarding consuming directly the energy produced (self-consumption) is related with the mismatch between renewable sources (governed by the availability of the respective primary energy source) and the demand. This mismatch can be addressed with three categories of EF measures: Supply-side management, which is the adaptation of the electricity generation to demand through (flexible) conventional capacities; demand-supply management, which reflects the spatial and/or temporal decoupling of supply and demand by extending electricity grids or energy storage capacities; and DR, which can be defined as changes in electric usage by demand-side resources from their normal consumption patterns [18]. In the nZEB context, investments and studies on energy flexibility measures based on demand flexibility (response) are getting more relevant not only due to low cost and ease of implementation, but also because it enables consumers to take responsibility for their energy consumption and production [5].

Although various investigations of buildings in the Smart Grid context have been carried out, research on the relationship between EF in buildings and future energy grids is still in its early stages [19]. Recent developments in the field are reported by the International collaborative research initiative IEA-EBC Annex 67 – Energy Flexible Buildings, where researchers of the FIRST project are active members. According to the literature review [20] studies promoting demand response measures are reporting how much flexibility can be achieved by adapting the time of use of plug loads, such as washing machines and dishwashers and tumble dryers [21], or by application of an optimal charging schedule of electric vehicles [22]. Several studies assess the value of energy flexibility through the operational cost savings, reduction in CO_2 emissions or peak power reductions [23], [24]. Moreover, some studies propose novel flexibility indicators, such as a recent study which developed a flexibility factor that measures the ability of a building to shift its heating energy use from high to low price periods using energy prices information [25]. While these studies clearly demonstrate the potential for using energy flexibility, the research work associated to the FIRST project focuses on the Portuguese context, where there is no standard definition for nZEBs and no overview or insight into how much Energy Flexibility different types of building and their usage may be able to offer to the future energy systems at individual or community level.

4. Study design

Demand Flexibility is a relatively new concept which emerged in the context of the transition from conventional to renewable energy sources. Given the limited capacity of small-scale solar or wind, and other renewable sources, to deliver energy flexibility, it is relevant to consider the provision of flexibility from the consumer side. Thus, buildings are expected to play a central role in this transition, where consumers and “prosumers” become energy flexible in order to support generation and/or storage needs of the energy grids either as single buildings or as clusters of buildings. Although, according to literature, a large part of the energy demand of buildings – such as the energy for space heating/cooling or white goods – may be shifted in time, the added value in terms of contribution to energy flexibility is yet to be demonstrated. To address this gap with all possible combinations of strategies and technical solutions is a major challenge that goes beyond the scope of this exploratory research. For this reason, and based on the expertise of the team of this project, the research is set to assess the potential for EF when the electricity consumption of controllable devices (HVAC, washing machines, dishwashers, electric vehicles, etc.) is shifted from their normal consumption patterns in response to changes in the users’ comfort needs, price of electricity or to meet periods of high renewable generation based on two

scenarios: a generic approach and a case study approach, both analysed at the individual level (single buildings) and at community level (cluster of buildings).
Figure 1 illustrates the main design of the FIRST project involving the three research tasks: Study of potential for EF at individual building level (Task 1), Study of potential for EF at community level (Task 2) and Mapping out the EF potential at community level (Task 3).

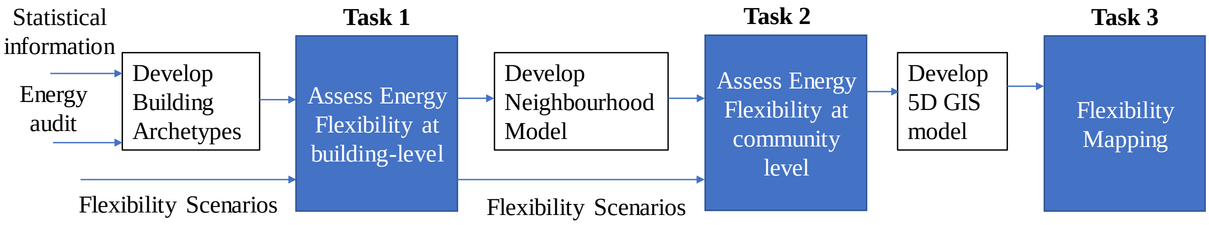
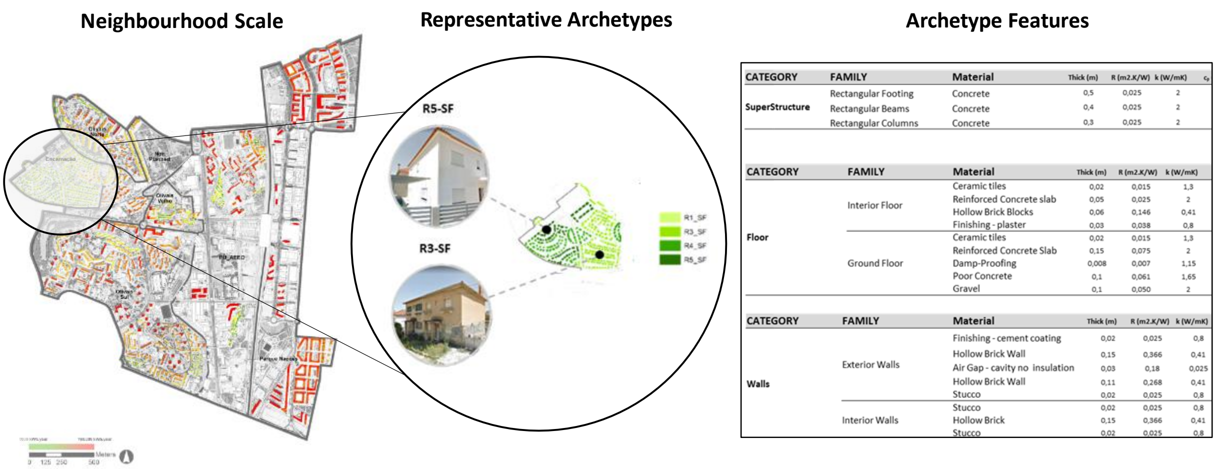


Figure 1. Schematic of main design of the exploratory project FIRST.

4.1. Task 1 - Study of potential for energy flexibility at individual building level
The first activity is fundamental for the development of this project. FIRST project relies on quality data collected within the frame of another project – SUSCITY [3] – to assess the demand flexibility (Statistical information in Figure 1). This feature represents the most important advantage of this project. This task consists of two subtasks, as described in the following.

4.1.1. Developing individual building models
In this activity, we will develop individual building simulation models for all the households in the testbed area. Buildings in the same neighbourhood usually share a set of common features (period of construction, constructive solutions like opaque envelope, windows, shading systems). Therefore, a single model of buildings sharing the same characteristics can be used for the purposes of modelling urban energy performance of the neighbourhood – an archetype, which represent any building with a certain type of features. Then, the individual behaviour of each household is simulated by changing the utilization and occupation patterns of the archetype (e.g. lighting and equipment scheduling). Figure 2 illustrates the approach adopted in this respect [26]. Table 1 presents an example of the information used for the 617 buildings in the neighbourhood.



CATEGORY	FAMILY	Material	Thick (m)	R (m2.K/W)	k (W/mK)
SuperStructure	Rectangular Footing	Concrete	0,5	0,025	2
	Rectangular Beams	Concrete	0,4	0,025	2
	Rectangular Columns	Concrete	0,3	0,025	2
Floor	Interior Floor	Ceramic tiles	0,02	0,015	1,3
		Reinforced Concrete slab	0,05	0,025	2
		Hollow Brick Blocks	0,06	0,146	0,41
		Finishing - plaster	0,03	0,038	0,8
	Ground Floor	Ceramic tiles	0,02	0,015	1,3
		Reinforced Concrete Slab	0,15	0,075	2
		Damp-Proofing	0,008	0,007	1,15
		Poor Concrete	0,1	0,061	1,65
		Gravel	0,1	0,050	2
Walls	Exterior Walls	Finishing - cement coating	0,02	0,025	0,8
		Hollow Brick Wall	0,15	0,366	0,41
		Air Gap - cavity no insulation	0,03	0,18	0,025
		Hollow Brick Wall	0,11	0,268	0,41
		Stucco	0,02	0,025	0,8
	Interior Walls	Stucco	0,02	0,025	0,8
		Hollow Brick	0,15	0,366	0,41
		Stucco	0,02	0,025	0,8

Figure 2. Multi-Scale Approach in FIRST, based on [26].

Table 1. Sample of the building characteristics of the testbed neighbourhood of Encarnação.

Building ID	Year of Construction/Renovation	Number of floors	Floor area m^2	Number of occupants	Window to wall ratio	…	Archetype
1	1945	2	45	2	18%		R3_SF
…							
617	2006	2	100	4	23%		R5-SF

In the frame of the first activity, these archetypes were reviewed in the context of the neighbourhood of Encarnação in Lisbon, which is the object of study of this project. The neighbourhood of Encarnação was built in 1945 and consists of 617 small single-family detached houses with floor areas from 45 to 105 m^2, some of which have been subjected to retrofitting in the meantime (see Figure 3). From the whole neighbourhood, 4 archetypes have been identified: single households with two floors from four different construction periods (from 1945-1960, 1960-1980, 1980-2006, after 2006). These 4 archetypes can describe the 617 buildings in the area. The data is available and was synthesized from a previous project SUSCITY [26].

Figure 3. A typical single-family house in the neighbourhood of Encarnação [27].

In addition to the above, data acquisition campaigns are performed during short period of times (one week) in one building during representative periods of the year (winter, summer and middle season) with power meters with the objective of monitoring the load profiles (Energy audit in Figure 1). Regarding the energy generation, for each archetype is assigned a PV system. The PV system model uses local meteorological data with respect to incident solar radiation and the ambient temperature to produce a one-minute resolution data series for the power produced by a typical residential PV system, composed by a PV array and a power inverter.

4.1.2. Energy flexibility at building-level

The EF characterization followed in the FIRST project is based on the assumption that the flexibility of the system under analysis results from modifying its energy consumption profile from a reference one without compromising users' comfort needs. Therefore, as proposed in [28], the EF $f_c(n)$ offered by a single controllable device c (e.g. heat pump), during a certain period of analysis, can be characterized by subtracting the original energy demand profile $d_c(n)$ to the modified energy demand profile $d_c^*(n, x_c)$ as described by equation (1), where x_c is a matrix containing all variables that can be controlled at each time-step n in order to modify the device's energy demand profile. In the FIRST project, both original and modified energy (i.e. electricity) demand profiles are obtained considering different operation scenarios from the previous subtask.

$$\mathrm{f_c(n, X_c(n)) = d_c^*(n, X_c(n)) - d_c(n)} \tag{1}$$

In terms of EF at building-level, it is characterized by adding the energy flexibility profiles $f_c(n)$ of the N_C controllable devices that can be found within the building, as described by equation (2), where the matrix $X(n)$ aggregates the N_C x_c matrices. Heat pumps, white goods or electric vehicles are examples of controllable devices to be considered at building-level.

$$\mathrm{F(n, X(n)) = \sum_{c=1}^{N\_C} f_c(n, X_c(n)),\ X(n) = \begin{bmatrix} X_1(n) \\ X_2(n) \\ \vdots \\ X_{N\_C}(n) \end{bmatrix}} \tag{2}$$

Regarding the use of EF to reduce the building's electricity consumption related costs or to achieve other specific objectives, while respecting users' comfort needs, the main challenge is finding $X(n)$ for the period of analysis, taking into consideration that a positive value of $F(n, X(n))$ is associated with an increase on the electrical device's electricity consumption whereas a negative value indicates a demand decrease. This problem is solved numerically with a building simulation tool [29] coupled to an optimization tool which uses a Generalized Pattern Search Algorithm (GPS) and a Genetic Algorithm.

4.2. Task 2 - Energy flexibility at community-level

This task covers the community-level where the EF potential of a set of *N* buildings ($N \geq 2$) is characterized. Using the building-level characterization described in Section 4.1.2, the community-level energy flexibility is estimated by aggregating the respective *N* building-level energy flexibility profiles, which are given by equation (2). Therefore, inputs such as available controllable devices, users' comfort needs or main constructive features of the *N* buildings are also required at community-level. A specific ratio of these building are prosumers while the remaining are regular buildings with no onsite generation. As in Task 1, a PV system is associated with each prosumer according with the archetype and data meteorological data available from SUSCITY.

Regarding the use of the available EF at community-level, it is assumed that the *N* buildings cooperate to reach specific common objectives (e.g. reduce the electricity-related monetary costs associated to the entire community). The referred cooperation is achieved by sharing the electricity generated onsite by the prosumers within the entire community and by using the EF offered by the controllable devices existing in all buildings (prosumers or not) so their operation can be shifted to periods that benefit the entire community. The first aspect of this cooperation is instantiated by transferring the power metering point from a building-level to an aggregation place, where the *N* building share a common power meter located at the entrance of the community (e.g. if all buildings fed by a specific Low Voltage Grid are considered to cooperate to reach a common objective, then the referred power metering point may be located at the distribution transformer's output). The second aspect is achieved by using a DR method that controls the operation of some controlled loads in an aggregated way. The assessment of the results acquired for community-level is conducted by comparing them with the ones obtained at building-level.

4.3. Task 3 - Mapping out the potential for energy flexibility

A novel component of this research is the mapping out of the potential for energy flexibility in terms of benefits and costs. This research activity is responsible for developing a 5D (space-time-scale) GIS model reproduction of the testbed neighbourhood, where the results from the models can be analysed in a visual form. Figure 4 shows the reproduction of the testbed neighbourhood mapping tool at FIRST website, already available for some featured parameters.

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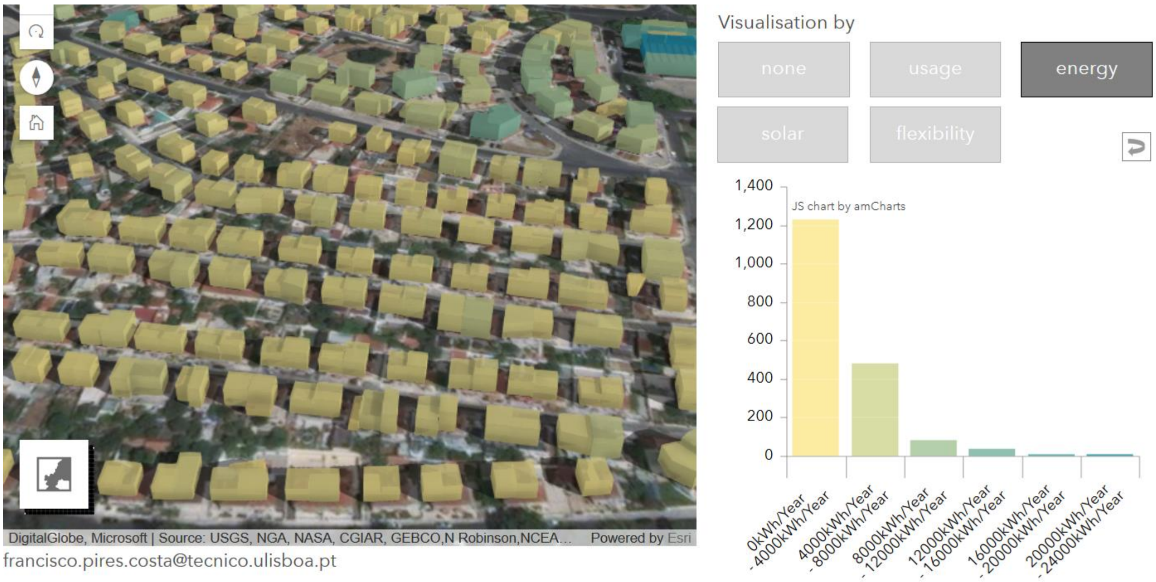

Figure 4. View of the neighbourhood and the distribution of the electricity demand represented by the 5D tool on the project website [30].

This representation will be based on GIS (ArcGIS Desktop software package, ESRI, Redlands, CA, USA, Copyright © 1999–2010 ESRI Inc) and DigitalGlobe's imagery - available through Google Earth, and will be also tested with CityScope, an advanced decision support system for cities usable by expert and nonexpert stakeholders developed at MIT, Media Lab [31] which uses advanced modelling and simulation, 3D projection mapping, and physical models to create a tangible, interactive, real-time data observatory and urban intervention simulator.

The web-based 5D reproduction of the testbed neighbourhood energy flexibility mapping tool will be publicly available to enable access to all interested viewers (expert and nonexpert stakeholders) to high quality data and legible information about the advantages and disadvantages of promoting energy flexibility.

5. Concluding remarks

The importance of this research is paramount as the outputs would provide valuable input to the construction sector and related markets, and policy makers and regulatory bodies to prepare them for the further development and implementation of the EU zero-energy strategy and recent national energy efficiency strategic plans. The participation of team members in the MIT research project SUSCITY and in the IEA EBC Annex 67: Energy Flexible Buildings is an important source of information and an opportunity for contributing in the identification of technology gaps and opportunities through establishment of a consistent basis to track research progress at national and international level.

To date, the project, which was initiated in September 2018, was able to accomplish part of the objectives of Task 1, namely, the systematic revision of archetypes from the point of view of building characteristics (opaque envelope, windows, shading), utilization and occupation patterns (lighting, equipment, etc.) and energy consumption. Task 3 was also approached in respect of the 5D model which was already fed with the building physical characteristics. Also, a numerical model is being adapted to assess the energy flexibility at the individual level as described in Task 1 and Task 2.

6. References

[1] R. A. Lopes, P. Magalhães, J. Pedro Gouveia, D. Aelenei, C. Lima, and J. Martins, “A case study on the impact of nearly Zero-Energy Buildings on distribution transformer aging,” *Energy*, vol. 157, pp. 669–678, 2018.

[2] R. A. Lopes, J. Martins, D. Aelenei, and C. P. Lima, “A cooperative net zero energy

community to improve load matching," *Renew. Energy*, vol. 93, 2016.
[3] "SUSCITY Project." [Online]. Available: http://groups.ist.utl.pt/suscity-project/home/. [Accessed: 02-Feb-2019].
[4] A. Darmani, N. Arvidsson, A. Hidalgo, and J. Albors, "What drives the development of renewable energy technologies? Toward a typology for the systemic drivers," *Renewable and Sustainable Energy Reviews*. 2014.
[5] I. E. Agency, "Energy Policies of IEA Countries - Portugal," 2016. [Online]. Available: https://www.iea.org/publications/freepublications/publication/Energy_Policies_of_IEA_Countries_Portugal_2016_Review.pdf. [Accessed: 02-Feb-2019].
[6] P. Belkin, "The European Union's Energy Security Challenges," *CRS Rep. Congr.*, 2008.
[7] R. Wüstenhagen and E. Menichetti, "Strategic choices for renewable energy investment: Conceptual framework and opportunities for further research," *Energy Policy*, 2012.
[8] EU, "Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)," *Off. J. Eur. Union*, pp. 13–35, 2010.
[9] N. Scarlat, J. F. Dallemand, F. Monforti-Ferrario, M. Banja, and V. Motola, "Renewable energy policy framework and bioenergy contribution in the European Union - An overview from National Renewable Energy Action Plans and Progress Reports," *Renew. Sustain. Energy Rev.*, 2015.
[10] B. Wesselink, R. Harmsen, and E. Wolfgang, "Energy Savings 2020: How to triple the impact of energy saving policies in Europe - A contributing study to Roadmap 2050," 2010.
[11] L. Pérez-Lombard, J. Ortiz, and C. Pout, "A review on buildings energy consumption information," *Energy Build.*, vol. 40, no. 3, pp. 394–398, 2008.
[12] L. Aelenei, H. Gonçalves, and D. Aelenei, "The nZEBs in the near Future: Overview of definitions and guidelines towards existing plans for increasing nZEBs," 2014.
[13] T. J. Hammons, "Integrating renewable energy sources into European grids," *Int. J. Electr. Power Energy Syst.*, 2008.
[14] I. R. E. A. (IRENA), "From baseload to peak: Renewables pRovide a Reliable solution," 2015. [Online]. Available: https://www.irena.org/DocumentDownloads/Publications/IRENA_Baseload_to_Peak_2015.pdf. [Accessed: 01-Feb-2019].
[15] C. Wilson and A. Grubler, "The energy technology innovation system," in *Energy Technology Innovation: Learning from Historical Successes and Failures*, 2011.
[16] G. Seyfang and A. Haxeltine, "Growing grassroots innovations: Exploring the role of community-based initiatives in governing sustainable energy transitions," *Environ. Plan. C Gov. Policy*, 2012.
[17] S. Wirth, "Communities matter: Institutional preconditions for community renewable energy," *Energy Policy*, 2014.
[18] T. Boßmann and E. J. Eser, "Model-based assessment of demand-response measures - A comprehensive literature review," *Renewable and Sustainable Energy Reviews*. 2016.
[19] I. E. Agency, "Energy Flexible Buildings." [Online]. Available: http://www.annex67.org/. [Accessed: 01-Feb-2019].
[20] G. Reynders, R. A. Lopes, A. Marszal-Pomianowska, D. Aelenei, J. Martins, and D. Saelens, "Energy Flexible Buildings: An evaluation of definitions and quantification methodologies applied to thermal storage," *Energy Build.*, Feb. 2018.
[21] J. Widén, "Improved photovoltaic self-consumption with appliance scheduling in 200 single-family buildings," *Appl. Energy*, vol. 126, pp. 199–212, 2014.
[22] K. Clement-Nyns, E. Haesen, and J. Driesen, "The impact of Charging plug-in hybrid electric vehicles on a residential distribution grid," *IEEE Trans. Power Syst.*, 2010.
[23] R. Halvgaard, N. K. Poulsen, H. Madsen, and J. B. Jørgensen, "Economic Model Predictive Control for building climate control in a Smart Grid," in *2012 IEEE PES Innovative Smart Grid Technologies, ISGT 2012*, 2012.

[24] J. V. Paatero and P. D. Lund, "A model for generating household electricity load profiles," *Int. J. Energy Res.*, 2006.
[25] J. Le Dréau and P. Heiselberg, "Energy flexibility of residential buildings using short term heat storage in the thermal mass," *Energy*, 2016.
[26] C. S. Monteiro, "BUILDING ENERGY MODELING AT URBAN SCALE USING MULTI-DETAIL ARCHETYPES: ADDRESSING THE UNCERTAINTIES AND APPLICATIONS," University of Lisbon: Instituto Superior Técnico, 2018.
[27] L. Aelenei *et al.*, "Smart City: A Systematic Approach towards a Sustainable Urban Transformation," in *Energy Procedia*, 2016.
[28] R. A. Lopes, "Extending nearly Zero-Energy Buildings Load Matching Improvement to Community-Level," FCT-NOVA, 2017.
[29] US Department of Energy, "EnergyPlus." 2018.
[30] "Mapping flexibility of urban energy systems - FIRST Project." [Online]. Available: http://in3.dem.ist.utl.pt/first/. [Accessed: 01-Feb-2019].
[31] MIT Media Lab, "CityScope." [Online]. Available: https://www.media.mit.edu/projects/cityscope/overview/. [Accessed: 01-Feb-2019].

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