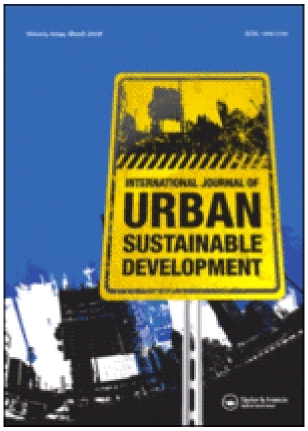

# The zero-energy challenge in districts. Introduction of a methodological decision-making approach in the case of the district of Cuesmes in Belgium

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# The zero-energy challenge in districts. Introduction of a methodological decision-making approach in the case of the district of Cuesmes in Belgium

# The zero-energy challenge in districts. Introduction of a methodological decision-making approach in the case of the district of Cuesmes in Belgium

Transforming cities with the aim of achieving cleaner energy targets is a major challenge for Europe, dealing with the immense stress on the urban and built environment during the post-industrialized period. Struggling with this problematic, in this work we develop a horizontal and cross-sectoral process as an integral part of the city planification towards the energy transition. Along with demonstrating the applicability of the approach, we validated its feasibility at Cuesmes, a district with high energy requirements. This study contributes to the scientific discussion by presenting the linkage between energy and urban structure. Notwithstanding, limitations mainly concerning the lack of data and the complexity of the applicability of the zero-energy concept at larger scales comprised the key drawbacks and weaknesses for this study. It becomes clear that future work is required focusing on the pillar of energetic hybridization subject to the maximization of the on-site use of local resources.

Keywords: case-study analysis; decision supporting methodology; zero-energy district

## 1 Introduction

Cities are living organisms with dynamic changes and processes. The post-industrial European city is characterized by dispersed urbanization, resulting in increased travel, substantial use of land social disparities and rising demand for energy (Riera Pérez and Rey 2013); the building sector as the major energy consumer worldwide, represents over than 40% of the overall consumption in Europe (UNEP 2009). At the same time, the $CO_2$ emissions have been increased by 43% with an average annual increase of 2% and 1.8%

respectively, while current predictions prove that this trend will continue dramatically in the future (US Energy Information Administration 2013).

The growing interests in environmental issues, the reduction in energy consumption in the building and the transport sectors along with the challenges of the dramatic increase in population, the scarcity of natural resources and a brutal struggle for their exploitation, distribution, etc. become the over-whelming problems related to sustainability and priorities of European policy targets for its short and long term strategies towards the cleaner energy transition, the carbon neutrality by 2050 (European Commission 2011) and its independence from the fossil fuels.

Coping with these challenges of the post-industrial period, throughout the history of cities, from the landmark of the Brundtland Report (1987) (European Union 1987) until the Paris Agreement (2015) (European Commission 2015), EU establishes plans against the climate change towards a ‘development that responds to the local needs without compromising the ability of people globally to respond to their own needs’ committing its Members to carbon and energy neutrality. Strengthening the climate objectives and policies, EU boosts for a more innovative and cross-sectoral reflexion contributing to resilient ecosystems, while already in 2008 it introduced its targets regarding the 2020 climate and energy objectives: 20% reduction in GHC emissions comparing to 90s levels by increasing the share of EU energy performance derived from renewable resources at 20% with a parallel improvement of 20% in energy efficiency. The implementation of the EU 2020 targets triggered the transition to Europe’s districts to ‘zero energy’. Undeniably, the 20/20/20 strategy leveraged the arising of measures, directives, policies, and actions towards the reduction of the energy consumption with the parallel distribution of the natural resources for ‘autonomous’ districts (European Commission 2011). This work aims to introduce a supporting methodological decision-making process approach (U-ZED) to articulate the challenge of the zero-energy applicability in larger urban scales along with a comprehensively dynamic process. The study aims to reinforce the decision and as a second step the applicability for zero-energy planning in city districts. In this paper, we investigate the feasibility of the idea in the district of Cuesmes in Belgium and we propose a preliminary district re-arrangement by testing diverse indexes of urban and more technical context to reply to its future transition and engagement to cleaner energy territory.

The manuscript is structured accordingly: Section 1 introduces and describes the problem and the objectives of the research, Section 2 highlights the importance of the urban structure for the reduction of the energy demand and consumption by its users, Section 3 presents the main methodological steps of the introduced approach as well as the challenges and limitations for its applicability. Section 4 provides the main findings and results of the proposed application in Cuesmes, while Section 5 summarizes the main conclusions of the work.

## 2 Understanding the Zero-Energy Concept. Previous Works

A first screening of the previous works and background of existing tools and planning methodologies analyzing the energy demand in districts confirms the sectoral approaches restricted on the diagnostic study of the project and the simplified analysis of the energy requirements neglecting complex and dynamic phenomena occurred in cities and districts, for instance the mobility flows, etc. (Lobaccaro 2019). The literature reveals a rising interest of the scientific community towards the zero-energy application in larger scales (Figure 1).

Figure 1. Number of papers in the Scopus for the considered scales within the zero energy objectives

The zero-energy concept in buildings has a progressive evolution of low energy and passive designs (Kylili and Fokaides 2015). Nonetheless, the term is not a new concept; its origins are traced to the early '90s, while since then around 200 constructed projects with zero energy standards have been rising steadily. The terms 'Zero Energy Building' and 'Net Zero-Energy Building' have both been adopted by scholars, while significant work had been carried out around their explanations (Sartori 2010). In an attempt to expand the concept in larger scales, we observed that studies and reports dealing with it in in districts are few in the existing literature.

A first approach towards the definition of the zero-energy concept in district was found in Carlisle et al. (Carlisle, Geet and Pless 2009) stating that: *'a net-zero energy community is one that has greatly reduced energy requirements; thermal and/or electrical* *energy comparing to the community it belongs (met at their majority by RES)'.* NREL (Carlisle, Geet and Pless 2009) also proposes a definition as: *'a community with reduced energy requirements through efficiency gains, as the balance of energy for vehicles, thermal and electrical energy, etc. within RES use'.* In an effort to 'translate' the EPBD principles in districts (Concentrated action: Energy Performance of Buildings 2002), we assume that: *'a NZED is a delimited part of a city with high energy performance and a nearly zero or very low amount of energy consumed to a significant extent by its local production'.*

At the same time, various studies argue that more compact urban forms would significantly reduce energy consumption in both the building and transportation sectors (Dujardin, Marique and Teller 2014). Gordon and Richardson (Gordon and Richardson, 1997) state that 'urban density' has a limited role in transport energy consumption. Reiter et al. (Reiter, De Herde and Marique 2014) study the impact of the territorial pattern on energy consumption in the Walloon Region in relation to the residential built environment and home-to-work commuting in terms of household location, employment and mobility infrastructure. Reihaneh et al. (Reihaneh, Shamsi, Tahsildoost and O' Donnell 2018) affirm the evolutionary trend and interest in performing the zero energy objectives in districts. Generally, there is a concern to include the energy consumed in urban areas (either in city or district) in mobility and movements, the indexed of travelled distance, etc. (Doherty, Nakanishi, Bai and Meyers, 2009; Lombard, Ortiz and Pout 2008; Marique and Reiter 2014).

Saheb et al. (Saheb, Shnapp and Paci 2019) explain that zero-energy initiatives are driven either by urban ‘retrofitting’ and are usually the impacts of the urban metabolism by the transformation of industrial areas into districts or the development of new agglomerations with high outcomes for all residents, etc. In fact, the sustainability criteria considered by local actors are differently ‘interpreted’ by different communities to assess the ‘zero energy’ concept and its applicability. Table 1 presents a comparative screening of international scientific reviews, aiming to identify the originality and innovative actions that our approach proposes.

Table 1. Methods and tools in the literature to support studies of districts and U-ZED novelty

| **Topic/Field** | **Objectives** | **Methods/Tools** | **Scale** | **Reference** |
|---|---|---|---|---|
| NZED/ NZEB | Definition proposal for NZED | Hierarchical and qualitative approach | District | (Carlisle, Geet and Pless 2009) |
| | Assessment of extending NZEB concept to district scale | Dynamic simulations | District | (Teller and Marique 2014) |
| | Assessment of alternative scenarios for NZED construction | Multicriteria decision analysis | District | (Becchio, Corgnai, Delmastro, Fabi and Lombardi 2016) |
| | Optimization of energy systems design toward NZED | Genetic algorithm | District | (Kilkis 2011) |
| Sustainability assessment tools | Analysis of existing sustainability assessment tools | Comparative analysis and data | District | (Haapio 2012) |
| | Analysis of existing sustainability assessment tools | Comparative analysis and data | Urban | (Sun, Huang and Huang 2015) |
| | Analysis of existing sustainability assessment tools | Top-down and bottom-up models | District | (Ameen, Mourshed and Li 2015) |
| U-ZED | Development of a holistic theoretical methodological approach at the conception | Parametrical concept of the NZED with the use of a GIS tool | District | (Koutra, 2017) |

| Topic/Field | Objectives | Methods/Tools | Scale | Reference |
|---|---|---|---|---|
| | phase with a zero-energy context | | | |

To this end, the subsequent section provides the analytical steps of the proposed methodology.

## 3 Methodological Approach

The main challenge for the U-ZED approach is to reply to a continuously rising energy demand with the parallel scarcity of resources considering the disastrous impacts of climate change and to ‘aid’ planners and city actors for ‘sustainable’ decisions of a consistent and ’solid’ management of the distribution and ‘smart’ use of their resources towards less consuming districts (and cities).

A preliminary definition for NZED, proposed by the U-ZED approach, is:

*‘NZED is the district, where the potential of the energy supply (on-site) is equal (or nearly equal) to the final energy demand of its users.*

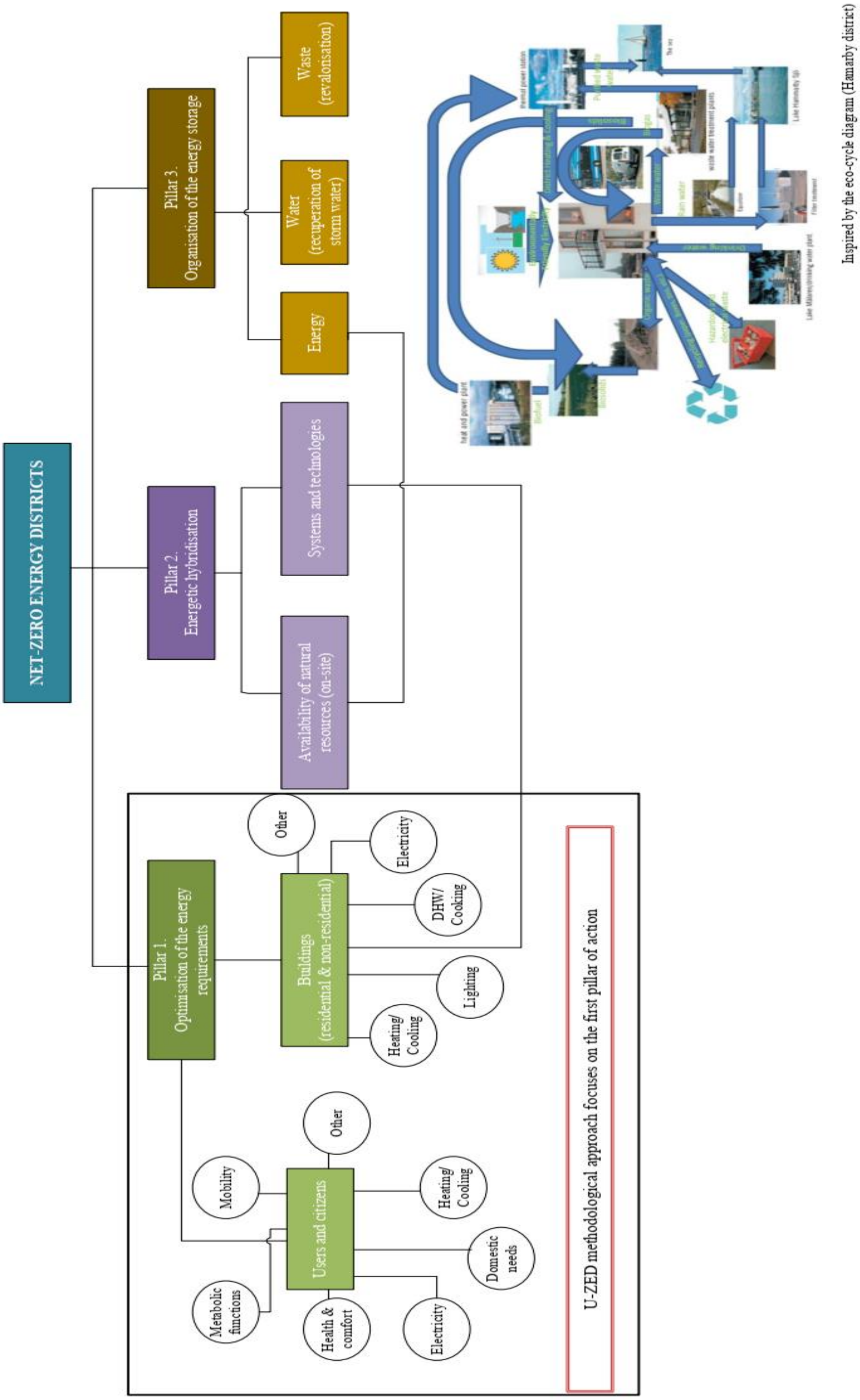
Equation 1 provides the mathematical representation of this concept:

$$\sum fDemand \leq \sum fOffer \qquad (1)$$

where the $\sum fDemand$ is calculated as the sum of the energy requirements in the districts and the offer on-site (RES potential). NZED aims at optimizing (minimizing) the energy demand (annually) with the parallel maximization of RES’ use for the local energy production (on-site) (Equation 2).

NZED objective: $min \sum fDemand$ with a parallel $max \sum fOffer$ (2)

U-ZED approach is developed along with three pillars of action (Figure 2). U-ZED 'defines' the zero-energy application in districts as the balance between the demand and the on-site offer to maximize the local energy production annually. U-ZED process is evolved along with three pillars to achieve this equilibrium in the district in an attempt to optimize the energy requirements of the district's users/citizens and buildings (Pillar 1). This step is primordial for the zero-energy objective; the 'demand' (usually expressed in kWh) refers to the requirements in energy to fulfil the metabolic functions (i.e. domestic needs, commercial, industrial and other activities) but also to ensure the operations of the existing building stock. Complementary to this, the Pillar 2 proposes the energetic 'hybridization' on-site implying the balanced combination between the use of the on-site resources and the installation of the diverse technologies on-site, while Pillar 3 focus its interest on the installation of storage energy, water and waste systems on the road to the district's autonomy in energy being inspired by the eco-cycle paradigm proposed in the Hammarby eco-district.



Inspired by the eco-cycle diagram (Hamarby district)

Figure 2. Description of the three pillars of action in NZEDs by the U-ZED approach

### *3.1 Detailed Description of the Methodological Steps*

Four phases describe the dynamic process of the U-ZED methodology (Figure 3).

**Phase 1: Strategic decision of the NZEDs' installation**

The first step of U-ZED's application is the strategic decision by planners and city stakeholders towards the zero-energy district planning. This step is mainly related to the political decisions and strategies to engage stakeholders, planners but also to empower citizens towards the successful application of the concept.

**Phase 2: Diagnosis and analysis**

The second phase of the approach is the diagnostic on-site analysis and the initial screening of the studied area, the identification of the problems, limitations, and opportunities.

Kristensen (Kristensen 2004) studied the chains and connections of the DPSIR model starting with the 'driving forces' through 'pressures' to 'states' and impacts on ecosystems, human health, etc. leading to political responses

Kristensen at his works explains the components of the DPSIR model (Kristensen 2004) by using:

- D for expressing the Driving Forces to express a 'need'. Examples of primary driving forces are the need for shelter, food and water, etc.
- P for Pressures. Driving forces lead by human activities. These human activities exert 'pressures' on the environment, as a result of production or consumption processes and ae mainly divided into three main types: (i) excessive use of

environmental resources, (ii) changes in land use, and (iii) emissions to air, water and soil

- S for States. As a result of pressures, the ‘state’ of the environment is affected; that is, the quality of the various environmental compartments in relation to the functions that these compartments fulfil.
- I for the Impacts. The changes in the physical, economic, societal or urban environment determine the quality of ecosystems and the welfare of human beings.
- R for the expression of Responses as solutions for policymakers to minimize the impacts as described previously.

### **Phase 3: Assessment of scenarios**

At the previous step, we evaluated and developed our diagnosis to identify the studied area, its actual problems, the on-site constraints and opportunities. In this Phase, planners and city stakeholders assess the diagnostic study and develop a scenario analysis explaining the different possibilities for the district’s re-arrangement or its conception. Planners develop and examine diverse scenarios towards the achievement of the zero-energy strategy and its application in the studied district. In the case of data lack, the process returns to the previous step (loop).

### **Phase 4: Implementation**

Following the strategical decision for the zero-energy planning actions and the selected scenario, which will ‘optimize’ the zero-energy strategy, the fourth Phase of the U-

ZED approach concerns the experimentation, the validation and the monitoring of the proposed plan with concrete actions.

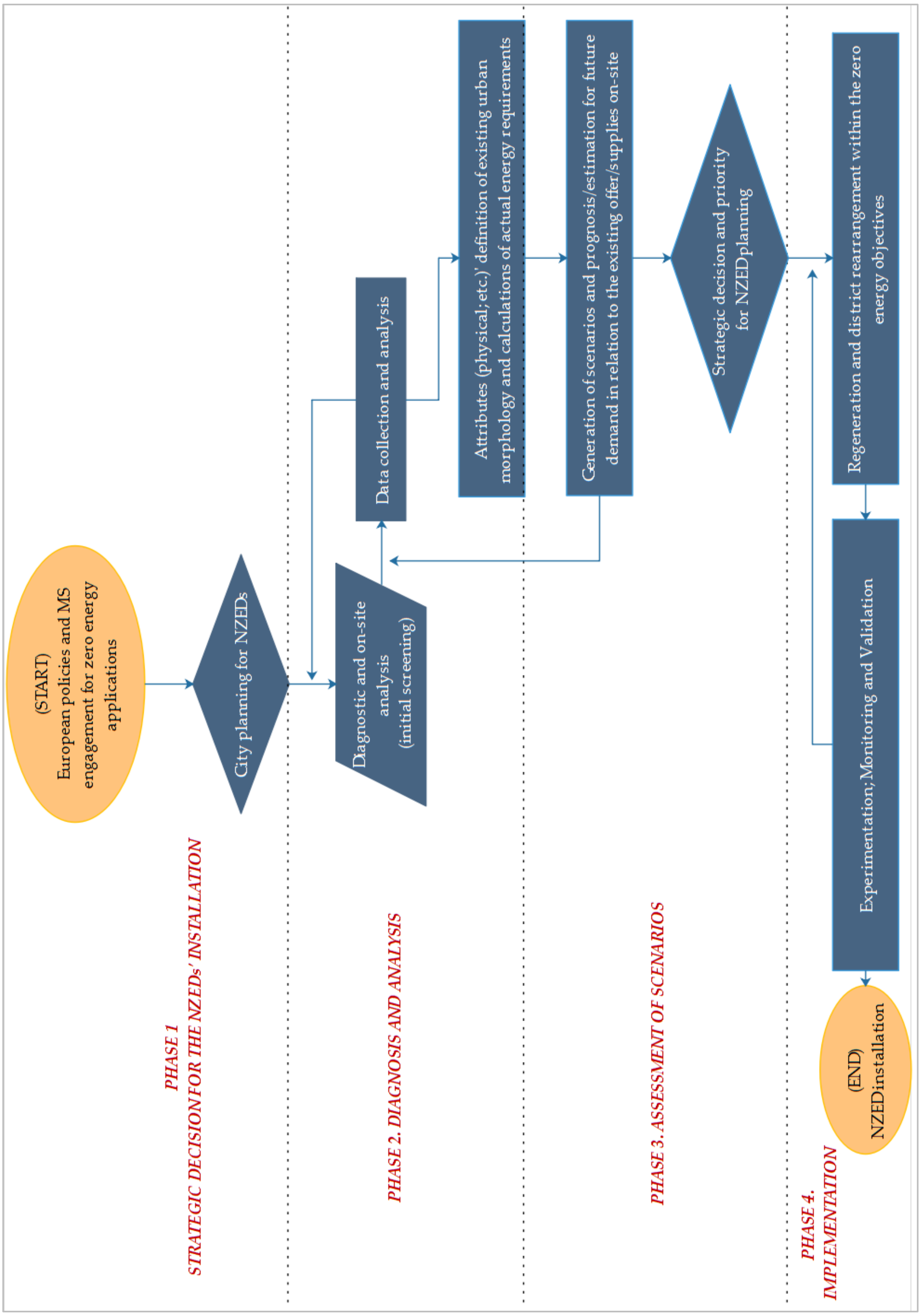


Figure 3. Algorithmic description of the U-ZED process

Developing the U-ZED process in four phases (2), as previously described, is a complex process requiring well-defined coordination procedures, collecting and analysing accurate data, managing the risks and the budget, ‘adapting’ the users’ behaviour, etc. Further steps and perspectives are expected with the involvement of local authorities and citizen participation for the conception of the zero-energy planning at their district, surveys and on-site analysis are proposed, as well but also evaluation of costs and benefits for the suggested actions for each case-study.

#### 3.1.1 *Limitations of the methodology*

As previously explained, the application of the U-ZED approach reveals the complexity of the understanding of the zero-energy concept and its principles. Below, we state the main limitations for the planners towards the zero-energy planning and the U-ZED application:

- Ambiguous definitions regarding the zero-energy concept and limited real case studies to retrieve successful lessons in practice.
- Limited access in data regarding mainly the energy consumption per household
- Social behavior and adaptation to zero-energy transition, need for continuous actions and monitoring actions by planners and city stakeholders
- Limitations on costs of proposed technologies and systems to achieve the zero-energy balance in districts.
- Administrative issues and difficulties in political engagement and related policies.

### *3.2 Key Performance Indicators*

KPIs are a concept originating from business administration with the aim to provide tools for measurement in business fields. In reality, they are quantifiable metrics reflecting the performance of achieving wider goals and help in the implementation of different strategies (Bosch, Jongeneel, Rovers, Neumann, Airaksinen and Huovila, 2017). For this study, we considered, as key aspects of the energy performance of NZEDs, site opportunities and attributes. Table 2 lists the KPIs defined in the current study. The list of the KPIs influencing the successful application of the zero-energy concept in districts is not exhaustive. Table 2 presents the KPIs included for the current study and as a preliminary application of the U-ZED approach; the selection is realized along with the objective of balancing the annual demand and on-site offer related to the data availability for each of them as a first overview of the theoretical application of the U-ZED approach.

Table 2. Key performance indicators (KPIs) in NZEDs

| KPI | Description | U-ZED | References |
|---|---|---|---|
| Location/ Topography | RES potential Proximity to city center | City center: 3-5km<br>Between the 'stops': 200-500m | (ARENE 2005) |
| Mobility | Offer in mild means of transport | 1.500m from IC/IR or less | (Teller, Marique, Loiseau, Godard and Delbar 2014) |
| | | 700m around the perimeter<br>300m between the 'stops'<br>30 passages/day (poles)<br>20passages/day (suburban)<br>5-10min between the 'passages' | (Reiter, De Herde and Marique 2014),(Senel 2010), (Marique and Reiter 2012) |
| Functional Mixing | Mixed-use, highly dense and compact | 300m of a commercial center<br>300m of a primary school<br>500m of an activity center | (Teller, Marique, Loiseau, Godard and Delbar 2014), (Reiter Marique, De Herde and De Meester 2014) |

| KPI | Description | U-ZED | References |
|---|---|---|---|
| Social Mixing | Number of social dwellings/surface (ha) | 15% in social dwellings<br>10% accessible to 'middle' revenues | (Teller, Marique, Loiseau, Godard and Delbar 2014), (Laroche 2010), (Chouvet 2007) |
| Mixing in Dwellings | Variety of dwellings' functions, number of rooms/floors, etc. | 10% of studios and/or dwellings of 'one-room'<br>10% of dwellings of 'two rooms'<br>10% of 'three rooms' or more<br>10% of public dwellings<br>R+1 to R+5 (max) | (Teller and Marique 2014),(Schulz 2006)-(ARCEA 2016)-(Ministère du logement, de l'égalité, des territoires et de la ruralité 2014) |
| Low energy consumption | Buildings' low energy standards | Heating: ≤60 kWh/m²/y<br>Electricity: ≤20 kWh/m²/y | (Yepez-Salmon 2011), (Service Public de Wallonie - DGO4 2010) |

Figure 4 represents the KPIs' selection along with the three pillars of action in the U-ZED approach. Interest for the current manuscript provides the first pillar regarding the optimization of the energy requirements of the users in the studied districts.

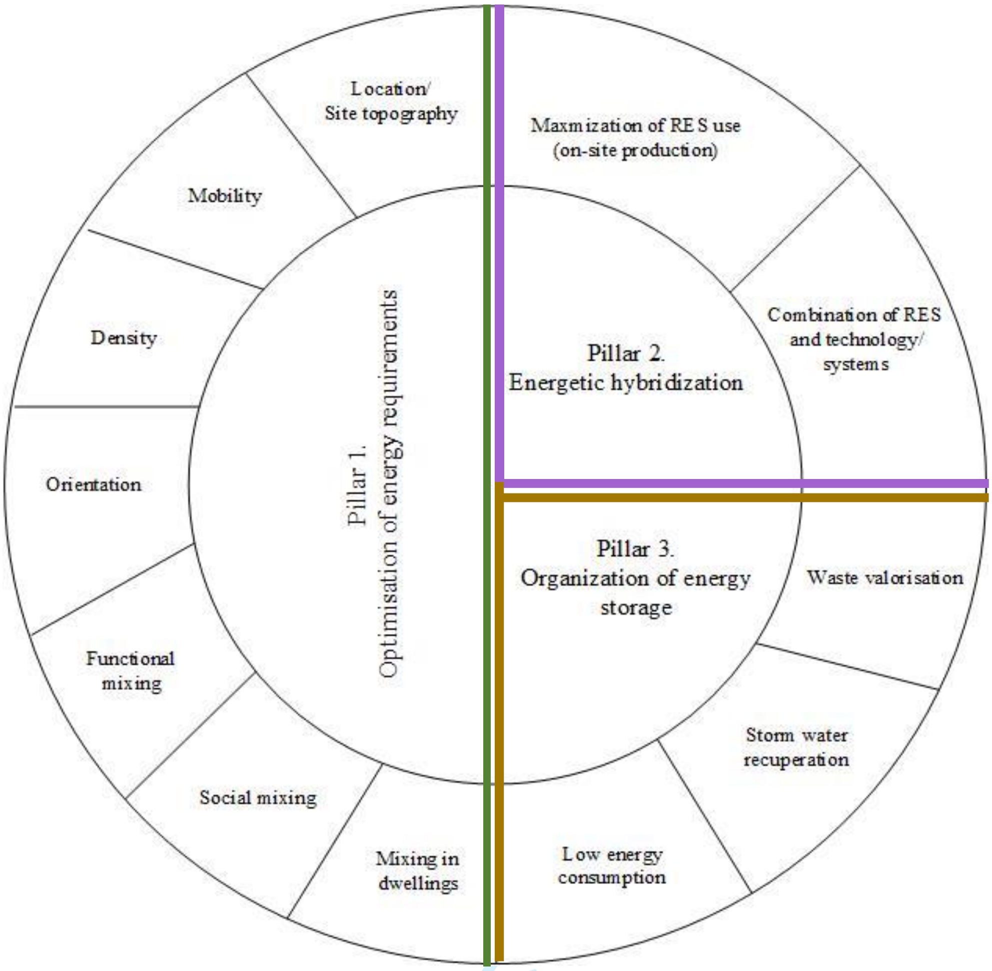


Figure 4. Representation of KPIs' selected in U-ZED approach

### 3.3 Methods and Tools

As analyzed above, at the second phase of the U-ZED method, we developed a roadmap towards the zero-energy transition in districts with the use of tools and methods, which are also presented in (Koutra, Pagnoule, Galatoulas, Bagheri, Waroux, Becue and Ioakimidis 2019) and they are summarized below:

#### 3.3.1 QGIS tool

Chuvieco (Chuvieco 1993) argues that the association of the spatial optimization models with the use of GIS formulates and develops the planning options in an attempt to maximize or minimize the objectives of the city planning. GIS, however, is also indispensable in a multi-criteria decision analysis to provide the technical inputs in the selection of planning options among diverse scenarios connected to the city planning and its objectives. For the current analysis, QGIS is used for the cartographical analysis of the representative attributes of the built and urban environment of the diagnostic study of the Cuesmes district. As a toolbox, GIS allow planners and architects to perform a spatial analysis with the use of different actions and the integration of diverse factors (Figure 5) (Chuvieco 1993).

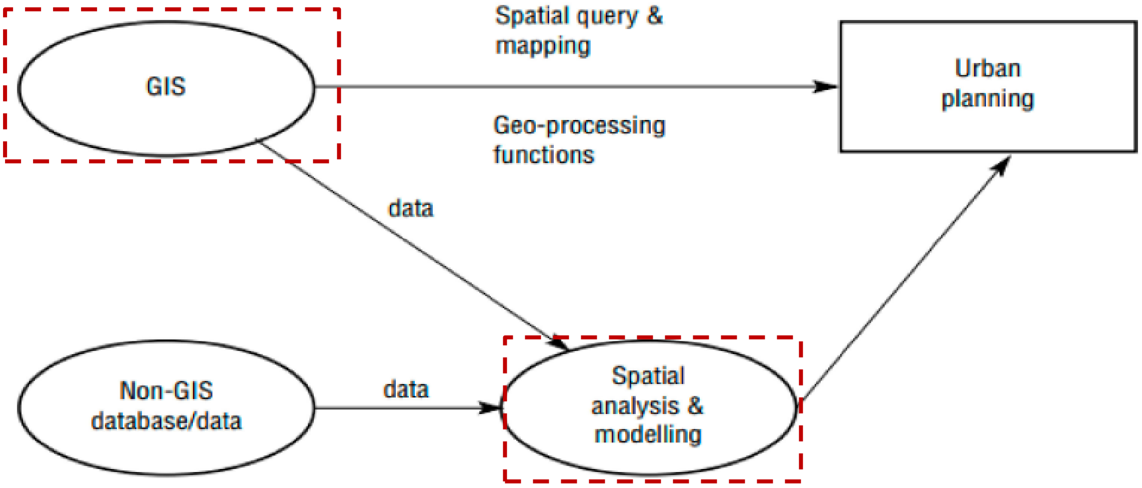


Figure 5. Urban Planning and GIS

### *3.3.2 HOMER*

Bahramara et al. (Bahramara, Parsa Moghaddam and Haghifam 2016) claim HOMER is a powerful tool for energy planning in cities with the aim of determining the optimal size of specific system elements through a techno-economic analysis considering the components in grid-connected or autonomous implementations. HOMER requires six types of data including the: meteorological data; the load profiles; the attributes of the selected components; the space; the economic and other technical data and can be adjusted to simulate or optimize an examined grid configuration. In this study, HOMER is utilized for the energy analysis of the district’s power requirements under two scenarios integrating rooftop PV on the buildings a) without and b) with a coupled battery energy storage component (detailed results presented in the Annex).

### *3.3.3 The Method of Degree Days*

Day and Karayiannis (Day and Karayiannins 1998) explain that the method of Degree Days is mainly used for estimating the heating energy demand in buildings for nearly 70 years. Moreover, attempts have been made to formalize the energy consumption monitoring targeting in buildings. The way in which the method of Degree Days is applied involves assumptions and approximations introducing the uncertainties into the problem. It is expected that the method of Degree Days provides the smallest contribution to errors and it is important to quantify this contribution; for this study, the Method is used in its simplified application for the rough estimation of the current demand in district (the detailed analysis is provided at the Annex of the manuscript).

## 4 Case Study Analysis

Cuesmes is a district close to the city of Mons (4km from the city center) with an old building stock and high energy requirements; however, with interesting site opportunities (i.e. solar irradiance, intensive agricultural activities, etc.) towards the experimentation of the zero-energy concept.

### *4.1 Phase 1. Strategic Decision of the NZEDs' Installation*

The diagnosis of the district's dysfunctions along with the site opportunities are the motivations for the zero-energy transition of the district of Cuesmes.

### *4.2 Phase 2. Diagnosis and Analysis*

The main criteria considered in Phase 2 of the diagnostic study of the U-ZED application are the analysis of the built environment, the mobility, the functional mixing, etc. (as mentioned in Table 2 above). An important component of the diagnostic study completing the analysis of its profile is undoubtably the demographic data. In 2018, the district counted 1202 citizens (City Population - Cuesmes 2018). There is also a significant number of non-active people in addition to dysfunction problems in the district. Indeed, the district of Cuesmes is considered as the district where a lowest rate of people has a high educational level (only 15% of the local population has a university degree); the unemployment rate is high (~10%) and the average income is around 1300€/month.

#### *4.2.1 KPI. Site opportunities*

The first KPI of the diagnosis includes the on-site analysis and the elements regarding the district accessibility and the connections to its surroundings. Formerly agricultural land, the district of Cuesmes was created during the years ‘50- ‘60 to accommodate low-income populations due to its urban growth.

### *4.2.2 KPI. Mobility and public means of transport*

During the ‘on-site’ analysis in the district (16-31/3/2019), we observed that citizens are ‘car dependent’ for their daily movements inside and around the district The district is not well-connected by the public means of transport; nonetheless, it is situated close to the city of Mons and surrounded by other cities, as well (5km far from Mons, 56min walk or 25min by bike from Jemappes, 1h15walk or 16min by bike from Frameries, etc.). The district is not well-served by public means of transport: the only railway stations at 5km around the district are in Quaregnon, Frameries, and Mons between 4 and 5km of the district’s surroundings.

### *4.2.3 KPI. Mixing*

a) Functional mixing

The district has a total surface of 46,17ha and 1.245 buildings and, it is an ancient and highly energy consumer district principally composed of residential land-use without mixed-use attributes.

b) Social mixing

Regarding the criterion of ‘social mixing’, we observe a mixed district in terms of age categories and a diversity of nationalities (50% of the local population in the Community of Mons are French and Italian and the rest comprises of diverse nationalities, Germans, Spanish, Greek) (Wallonie Familles 2018).

c) Mixing of dwellings and built environment

Regarding the diversity in building morphologies in Cuesmes, the current building stock consists of completely terraced housing. However, the buildings consist of a R+1 (64%), constructions on the ground floor, at 20%, constructions in R+2 (10%) and constructions in R+3 (6%). The built stock of the district is dated basically before 1850 (more than 70% of the existing dwellings) with the terraced form to be predominant. The district has low mixed-use attributes including basically residential activities, while the land-use is occupied partially by public and socio-cultural equipment as well as commercial centres.

### *4.2.4 Estimation of energy requirements*

It is expected that the corresponding space heating needs of the majority of the district's building stock would present a high value as it is concluded by examining the age of construction data (4).

After the first estimations and the outcomes, we encoded the U-values using the calculation tool of the buildings' thermal requirements provided by the Scientific and Technical Centre of Construction (CSTC). More information can be retrieved regarding the calculation tool provided by CSTC in (CSTC 2020). A detailed calculation of the annual heating energy requirements is provided in the Appendix A of the manuscript.

Combining the above, it can be supported that the district presents numerous problems related to construction, the building typologies, structures and forms as well as a low grade of renewable energy resource integration.

At the time being, RES conversion technologies remain undeveloped in the district, however a potential biomass energy production facility supplied by organic waste has been planned. Another option examined is connecting to the geothermal inventory in the city of Mons. From the point of view of the meteorological data provided by the IRM (2013) (IRM 2020) related to the solar radiation per year as well as the direction and the average velocity of the wind.

### *4.3 Phase 3. Assessment of the scenarios*

In this phase, we provide a preliminary assessment of the options towards the zero-energy transition following the proposed KPIs (selected for this study) provided in previous section. In particular, the proposed actions are:

Pillar 1: Emphasis on actions in the KPIs of: mobility, and mixing (focus on functional mixing and land-uses). The implemented scenario focuses its analysis on the expansion of the existing bus network to increase the bus stops and the passages per day with complementary itineraries and mild transportation systems. The proposed action plan introduces the idea of a more compact, mixed-use and dense district with additional infrastructure responding to the daily citizens' requirements and less 'car dependent'. Inspired by Rogers' planning theory, we proposed complementary amenities and services towards the achievement of an operational and mixed district, where the car dependency will be reduced (see scenario of implementation)

Pillar 2: Maximization of local energy production, enhancement of RES. We focused our analysis towards the autonomy of the district considering the solar potential and we proposed the PVs' installation as a preliminary step.

Pillar 3: Energy storage PV electric storage: Balancing from the one side the dysfunctions and the problems described at the diagnostic phase of the analysis, as mentioned previously, we analyzed the scenario of PVs' installations. The HOMER microgrid optimization tool was used for the study of the optimized integration of rooftop PV panel installations on the district's building stock related to the maximization of locally available RES exploitation as part of the second pillar of the U-ZED approach (energetic hybridization).

The energetic and financial analysis in HOMER demonstrated that the region of Mons offers a good solar irradiance potential with an annual average of 2.91 kWh/$m_2$/day. Consciously, and as a first step of zero-energy application in the district, more affordable and accessible, we proposed the scenario of PVs' installation as a priority. Nonetheless, as explained already, the district appears interesting agricultural activity, therefore, the scenario of the energetic hybridization could be the subsequent step of the U-ZED application on-site. Ioakimidis and Ferrao (Ioakimidis and Ferrao 2010) at their works explain the benefits of the biomass on the influence of local electric power production and fuel consumption; however, an analytical methodological and holistic approach is required to assure the application of the data and the implementation of the strategy 'on-site' followed by a Cost-Benefit Analysis to investigate the possible profits of this installation. What is important for the biomass scenario, which was hardly to assess at our current analysis in Cuesmes, is the estimation of the demand for the installation of the technology and the carriers needed to serve the requirements. Modelling tools are proposed at the same work for this analysis, such as TIMES (a dynamic model) as a further analysis.

### *4.4 Phase 4. Implementation*

Following the analysis carried out in previous sections of the manuscript, we note that the district has various dysfunctions related to mobility, social equity, a high energy consumption, a strong dependency by car, etc. It, therefore, appears important in this work to propose solutions to match the citizens' expectations and to achieve the NZED's objectives. In this section, we will establish a general situation in which we will deal with the problems mentioned at the diagnostic study. In a projected situation, we propose the analysis of the energy criterion with regard to the energy potential/inventory of the region to see how to make the district autonomous in renewable energies, the possible energy hybridizations and what would be the solutions allowing to reach and maintain this autonomy in the future.

In order to better meet the population needs, the requirements towards the NZED transition and bring attractiveness to the district, we propose the use of Rogers' theory to allocate the functions in relation to the diverse distances. By living in closer proximity to each other, we can accommodate far more of the world's population, use less energy, concentrate goods and services and move from one place to another more efficiently. For instance, building at 50 homes to the hectare and above has created all the attractive spaces we like best. At below 50 homes per hectare, it is hard to keep shops, buses, doctors, nurseries and schools within walking distance; the less dense cities are, the further they sprawl, the worse the traffic problems are. Phase 4 and U-ZED's contribution at the re-arrangement of a highly dense and compact district is inspired by the graphs provided below.

Addressing the problem of infrastructure and services' proximity, we recommended actions such as: the establishment of new services to handle the 'mono-functional' attributes appeared in the district (2,3 Fig. 6), educational activities (1 and 4, Fig. 6) and the re-arrangement of green and public spaces (5, 6 and 7, Fig. 6). In terms of accessibility, we recommended the expansion of the existing bus network with additional itineraries (streets of Ciply and Espinette) and the reinforcement of mild transportation networks with cycling secure lanes connected to the existing Ravel and the Vélib system for bike rental, (8, Fig. 6).

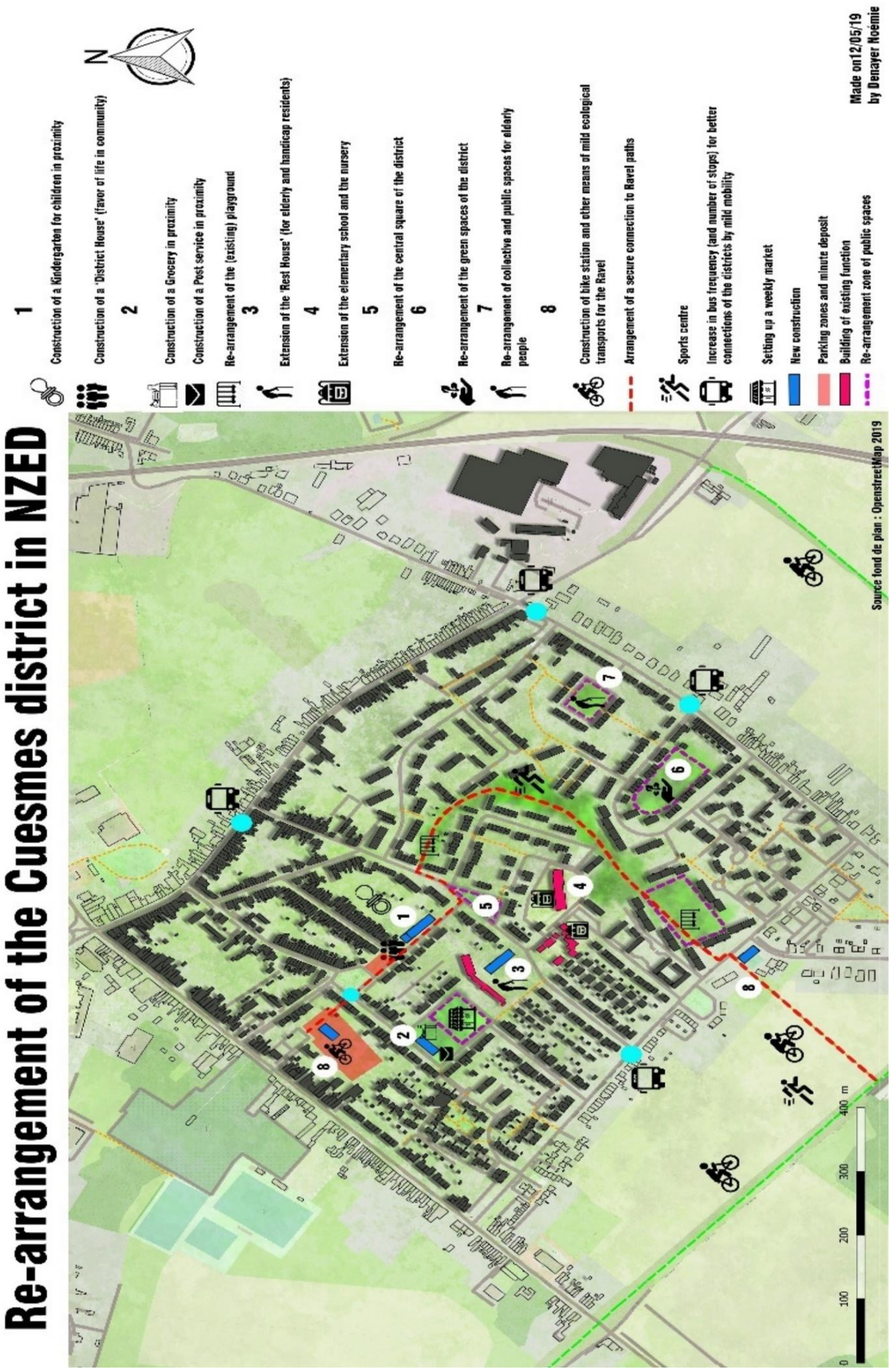


Figure 6: Proposal for the district's re-arrangement towards the transition of the zero-energy concept in Cuesmes

In the proposed scenario, we studied the possibility of energy production by PVs. As a reminder, the region of Mons has a good solar irradiance potential allowing an interesting rate of its exploitation. In addition, the other buildings on the district do not shade the buildings being sufficiently distant from each other, the roofs of the buildings. Most buildings are oriented east west to capture solar radiation throughout the day.

In the case of placing the panels required to match the district's annual electric demand on a single location, this would yield a total area of 25ha, equivalent to almost half of the total land area of the studied district. A solution promoting a large-scale centralized solar power plant, or a photovoltaic power plant is therefore not feasible due to space limitations. Moreover, this solution is not to be preferred since it entails a significant alteration on the environment and infers constraints on land-use. Hence, an applicable solution would be placing PV rooftop installations on the buildings, taking into account that the average available rooftop surface area was estimated at 25m² per building according to the findings of the diagnosis phase on the built environment. Following the proposed scenario, an optimal rooftop PV-electrical storage system for buildings located in the Cuesmes district has been sized and optimized with the use of the HOMER software tool on a 15-year project lifetime.

Furthermore, the panels' optimal rooftop orientation (slope and azimuth) was calculated with the online tool PV-GIS (European Commission 2019) enabling increased efficiency on the conversion of incident solar irradiance. Although HOMER optimizes the installation subject to the minimization of its respective Net Present Cost, the component capacity search space is configurable, offering an option for setting an upper boundary on each component's parameter search space. Acknowledging the total rooftop installed capacity limitations applying in Belgium (max. PV capacity <10kW), an upper boundary value was placed on the PV module capacity optimization search space. The equivalent peak power capacity to a 25m$^2$ total array area is approximately 4,95kW, in this case 15 PV modules per rooftop, which can be placed on a 3x5 array. The electricity tariffs were imported from the Eurostat database and were defined at 0,275 €/kWh for grid purchase and 0,15€/kWh as an indicative feed-in-tariff resulting from the Qualiwatt established averages (Eurostat 2018).

It is important to mention that PV installations in the Wallonia region are subsidized through green certificate programs and net metering, however they have been inactive since the end of June 2018, when the Qualiwatt program expired. **Error! Reference source not found.** presents the key findings of the optimization study, distinguishing between an installation including an electrical storage unit and one without any storage provisions. The purpose of introducing subcases is two-fold: a) to highlight the advantages of coupling the PV array mainly reflected on the percentage of annual energy savings and b) to contrast the tradeoff between system costs and potential energy savings. Regarding energy consumption, a synthetic annual electric load profile (3.300 kWh/yr) was compiled and inserted as the occupant usage pattern on which the energy dispatch algorithm would size the PV-system, based on energy provider data for multiple categories of residential electricity consumers (Lepage 2019). Annual energy savings are calculated as the percentage of the reduction on the purchased energy from the grid over the assumed annual energy consumption. The LCOE is defined as the average cost per kWh of useful electrical energy produced by the system, hence this figure also accounts the total injected energy to the power grid. The values of annual cashflows use discount and inflation rates evaluated at 2% and 1%, respectively, accounting for a 0,99% real discount rate, influencing the calculated net present cost.

Table 3. Results of the rooftop PV installation optimization run

| **Scenario** | **Estimated Annual Electricity Consumption (kWh/yr)** | **Net Present Cost (€)** | **Calculated PV Output (kWh/yr)** | **Levelized Cost of Energy (€/kWh)** | **Annual Energy Savings (%)** |
|---|---|---|---|---|---|
| Including storage | 3.300 | € 19.942 | 5.434 | € 0,273 | **77,3** |
| Without storage | 3.300 | € 5.843 | 5.434 | € 0,065 | 42,8 |

Figure 7 depicts the annual daily hourly means of the power flows corresponding to each rooftop PV system configuration with and without the inclusion of a battery energy storage component against the synthesized household demand. The benefits of coupling PV generation with battery electric storage are reflected upon the reduction of grid purchases during day intervals with scarcity of solar resources, which under battery discharging demonstrate finer load matching capabilities than the PV only configuration. In addition, the evening peak demand can be served with the charged energy driven to the battery from excess PV generation during daylight, leading to an overall reduction in grid sales compared to the system without a storage unit.

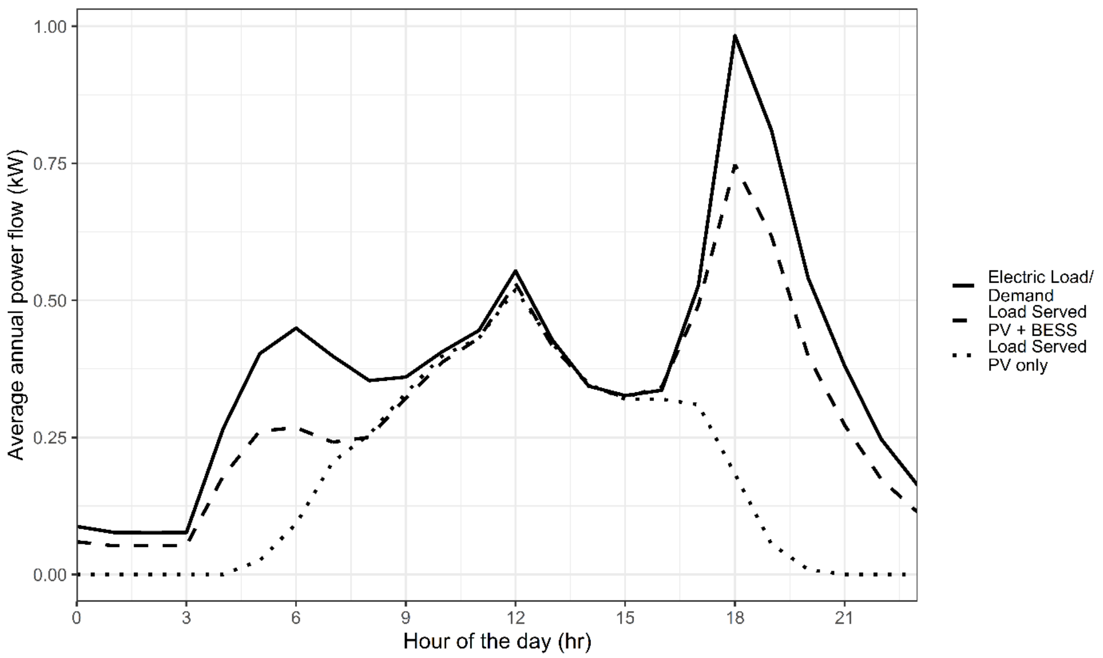


Figure 7. Annual daily hourly means of the power flows corresponding to each rooftop PV system configuration

If the results for the rooftop installation of one building are extrapolated to the district level as a proxy for the calculation of the costs and benefits of this intervention, it can be supported that from a hypothetical cumulative annual consumption of 4,1GWh, the 3,2GWh can be supplied from rooftop integrated PV-storage systems or 1,8GWh directly generated from rooftop mounted PV arrays. These values are comparable to the maximum achievable annual PV contribution towards diminishing the energy consumption on district scale, which is fixed on 3,6 GWh for the first configuration and 2,0 GWh for the second configuration due to the imposed capacity limitations mentioned above. The geometric footprint of each rooftop system is equivalent to 24,9m$^2$. The total cost of implementing subcase a) is € 18.951.390 and b) € 5.534.025 corresponding to a 1,11ktoCO$_2$ and 2,0ktoCO$_2$ emissions reduction attributed solely to reduced grid energy purchases. In the

Appendix B, we provide the key results from the HOMER analysis performed for a generic building located at the district of Cuesmes.

## 5 Conclusions

Rapidly growing world energy use and urban growth in modern ‘mega-cities’ have already created concerns regarding the RES’ exhaustion and the impacts of the climate change. Undoubtably, reducing energy demand is commonly assumed as a ‘difficult’ process in complex systems and living laboratories, the cities. Nonetheless, this is an imperative action plan derived from European policies and directives in a horizon of 2050.

In this paper, assuming a strong correlation between the factors of the energy consumption and the typo-morphological structure of an agglomeration, we introduce a simplified methodological decision approach, the U-ZED, aiming at conceptualizing the zero-energy balance in larger territorial scales. For this study, we consider the ‘district’ as an urban block and a micrograph of a city. Through three pillars of action: (1) the optimization of the energy requirements, (2) the energetic hybridization and (3) the organization of energy storage, we introduce a check-list of key performance indexes, which have a significant impact to the decision of the zero-energy district planning. Inspired by the DPSIR model, we developed an algorithmic process of the U-ZED application in districts with the introduction of four (4) phases of planning: (1) the strategic planning decision (derived mainly by the city stakeholders and the decision to the zero-energy transition), (2) the diagnosis and the analysis of the current situation in the district (including the typo-morphological analysis of its built and non-built environment as well as the calculation of the actual energy requirements of its users and the offer by RES on-site), (3) the development of a scenario analysis towards the ‘optimal’ combination and (4) the implementation.

The first attempts to validate and experiment the proposed methodology has been in the various districts in Belgium, for instance in Cuesmes, which is a district with current huge energy requirements and basically is consisted of residential dwellings. Functional and social mixing are low; however, the district has interesting possibilities towards its future transition to the application of the zero-energy concept on-site. In the relevant section we provide the diverse scenarios following our analysis as well as the cartographical simulations of the current and the projected situation with the implementation of the U-ZED approach. However, further work is required with the introduction of more alternative scenarios and KPIs focusing on the pillar of energetic hybridization with the maximization of the on-site use of local resources.

Although the zero-energy idea can be conceptualized in a district with an approach like individual buildings by articulating the main energy uses, the concept remains complicated and challenging for contemporary cities because of various constraints and limitations in different levels of action. This implies innovative approaches to interdisciplinary planning that highlight the importance of the zero-energy concept and aid city stakeholders and planners to define these structures. Indeed, the interrelation between urban structure and energy is a key aspect of this path. Related to this, a “well-structured” area is a key point that increases sustainable transport and the share of renewable resources

This study contributes to the scientific discussion on the linkage between energy and urban structure to increase the energy efficiency in districts. Notwithstanding this, limitations mainly concerning the lack of data and the complexity of the applicability of the zero-energy concept at larger scales were restrictions and weaknesses for this study. The human factor and public awareness as well as the participation process are significant for successful policies and for the zero-energy concept in districts. Further research and works can contribute on extending the presented approach and applying it on diverse case studies with respect to the longevity of modern cities and the achievement of their sustainable objectives.

**Acknowledgements**:

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## Nomenclature

| | |
|---|---|
| EU | European Union |
| U-ZED | Urban zero-energy district |
| GHGs (emissions) | Greenhouse gases (emissions) |
| MS | Member state |
| NZED | Net-zero-energy district |
| EPBD | Energy Performance of Buildings’ Directive (2002/91/EC) |
| NZEB(s) | Net-zero-energy building |
| IEA | International Energy Agency |
| RES | Renewable Energy Sources |
| DHW | Domestic Hot Water |
| RE | Renewable Energy |
| EPGP | Energy Primary Green Purchased |
| EPRES | Energy Primary from Renewable Energy Sources |
| PV | Photovoltaic(s) |
| NREL | National Renewable Energy Laboratory |
| LCA | Life Cycle Assessment |
| CBA | Cost-Benefit Analysis |

| | |
|---|---|
| GIS | Geographical Information Systems |
| DPSIR | Drivers-Pressures-States-Impacts-Responses |
| KPIs | Key performance indicators |
| HOMER | Hybrid Optimization Model for Electric Renewables |
| PEB | Performance Energetique des Batiments |
| CSTC | Charge Thermique des Bâtiments |
| IRM | Royal Meteorological Institute of Belgium (Institut Royal Météorologique) |
| LCOE | Levelized Cost of Energy |

## Appendix A. Analysis of Heating Energy Requirements in the District of Cuesmes per typology

Explanations for the calculations:

$UA_{min} = 0{,}8 * U*S$

$UA_{max} = 1{,}2 * U*S$

$D_{1min} = (UA_{min}\ X\ \text{Degree Days} * 24)/1000$

$D_{1tmin} = \text{Number of units} * D_{1min}$

$D_{1max} = (UA_{max} *\text{Degree Days} * 24)/1000$

$D_{1tmax} = \text{Number of units} * D_{1max}$

### Appendix A1. Apartment blocks non-renovated

**Table A1.** Calculations of energy requirements for apartment blocks non-renovated

| Month | Degree Days | Area of Losses(m²) | U (W/m²K) | UAmin (W/K) | Energy Demand for One Building ($D_{1min}$) (KWh) | Energy Demand for All Buildings ($D_{tmin}$) (KWh) | UAmax (W/K) | Energy Demand for One Building ($D_{1max}$) (KWh) | Energy Demand for All Buildings ($D_{tmax}$) (KWh) |
|---|---|---|---|---|---|---|---|---|---|
| January | 436 | 2,079 | 2,2 | 3.659,04 | 38.288,19 | 153.152,78 | 5.488,56 | 57.432,29 | 229.729,17 |
| February | 544 | | | | 47.772,43 | 191.089,70 | | 71.658,64 | 286.634,56 |
| March | 457 | | | | 40.132,35 | 160.529,40 | | 60.198,53 | 240.794,10 |
| April | 228 | | | | 20.022,27 | 80.089,07 | | 30.033,40 | 120.133,60 |
| May | 149 | | | | 13.084,73 | 52.338,91 | | 19.627,09 | 78.508,36 |
| June | 96 | | | | 8.430,43 | 33.721,71 | | 12.645,64 | 50.582,57 |
| July | 78 | | | | 6.849,72 | 27.398,89 | | 10.274,58 | 41.098,34 |
| August | 85 | | | | 7.464,44 | 29.857,77 | | 11.196,66 | 44.786,65 |
| September | 185 | | | | 16.246,14 | 64.984,55 | | 24.369,21 | 97.476,83 |
| October | 214 | | | | 18.792,83 | 75.171,32 | | 28.189,24 | 112.756,98 |
| November | 397 | | | | 34.863,33 | 139.453,33 | | 52.295,00 | 209.180,00 |
| December | 474 | | | | 38.288,19 | 153.152,78 | | 62.437,86 | 249.751,43 |
| | | | | **Total** | 290.235,1 | **1.160.940,21** | | **440.357,7** | **1.761.432,59** |

## Appendix A2. Apartment blocks renovated

**Table A2.** Calculations of energy requirements for apartment blocks non-renovated

| Month | Degree Days | Area of Losses($m^2$) | U ($W/m^2K$) | UAmin (W/K) | Energy Demand for One Building ($D_{1min}$) (KWh) | Energy Demand for All Buildings ($D_{tmin}$) (KWh) | UAmax (W/K) | Energy Demand for One Building ($D_{1max}$) (KWh) | Energy Demand for All Buildings ($D_{tmax}$) (KWh) |
|---|---|---|---|---|---|---|---|---|---|
| January | 436 | 2,079 | 1,1 | 1.829,52 | 19.144,10 | 134.008,68 | 2.744,28 | 28.716,15 | 201.013,02 |
| February | 544 | | | | 23.886,21 | 167.203,49 | | 35.829,32 | 250.805,24 |
| March | 457 | | | | 20.066,18 | 140.463,23 | | 30.099,26 | 210.694,84 |
| April | 228 | | | | 10.011,13 | 70.077,93 | | 15.016,70 | 105.116,90 |
| May | 149 | | | | 6.542,36 | 45.796,54 | | 9.813,55 | 68.694,82 |
| June | 96 | | | | 4.215,21 | 29.506,50 | | 6.322,82 | 44.259,75 |
| July | 78 | | | | 3.424,86 | 23.974,03 | | 5.137,29 | 35.961,05 |
| August | 85 | | | | 3.732,22 | 26.125,55 | | 5.598,33 | 39.188,32 |
| September | 185 | | | | 8.123,07 | 56.861,48 | | 12.184,60 | 85.292,22 |
| October | 214 | | | | 9.396,41 | 65.774,90 | | 14.094,62 | 98.662,35 |
| November | 397 | | | | 17.431,67 | 122.021,67 | | 26.147,50 | 183.032,50 |
| December | 474 | | | | 20.812,62 | 145.688,34 | | 31.218,93 | 218.532,50 |
| | | | | **Total** | **146.786,05** | **1.027.502,34** | | **220.179,07** | **1.541.253,51** |

## Appendix A3. Single-family houses non-renovated

**Table A3.** Calculations of energy requirements for single-family houses non-renovated

| Month | Degree Days | Area of Losses($m^2$) | U ($W/m^2K$) | UAmin (W/K) | Energy Demand for One Building ($D_{1min}$) (KWh) | Energy Demand for All Buildings ($D_{tmin}$) (KWh) | UAmax (W/K) | Energy Demand for One Building ($D_{1max}$) (KWh) | Energy Demand for All Buildings ($D_{tmax}$) (KWh) |
|---|---|---|---|---|---|---|---|---|---|
| January | 436 | 269,86 | 1,4 | 302,24 | 3.162,67 | 2.030.435,97 | 453,36 | 4.744,01 | 3.045.653,95 |
| February | 544 | | | | 3.946,09 | 2.533.387,99 | | 5.919,13 | 3.800.081,99 |
| March | 457 | | | | 3.315,00 | 2.128.232,19 | | 4.972,51 | 3.192.348,29 |
| April | 228 | | | | 1.653,87 | 1.061.787,62 | | 2.480,81 | 1.592.681,42 |

| Month | Degree Days | Area of Losses(m²) | U (W/m²K) | UAmin (W/K) | Energy Demand for One Building ($D_{1min}$) (KWh) | Energy Demand for All Buildings ($D_{tmin}$) (KWh) | UAmax (W/K) | Energy Demand for One Building ($D_{1max}$) (KWh) | Energy Demand for All Buildings ($D_{tmax}$) (KWh) |
|---|---|---|---|---|---|---|---|---|---|
| May | 149 | | | | 1.080,82 | 693.887,52 | | 1.621,23 | 1.040.831,28 |
| June | 96 | | | | 696,37 | 447.068,47 | | 1.044,55 | 670.602,70 |
| July | 78 | | | | 565,80 | 363.243,13 | | 848,70 | 544.864,70 |
| August | 85 | | | | 616,58 | 395.841,87 | | 924,86 | 593.762,81 |
| September | 185 | | | | 1.341,96 | 861.538,20 | | 2.012,94 | 1.292.307,30 |
| October | 214 | | | | 1.552,32 | 996.590,13 | | 2.328,48 | 1.494.885,20 |
| November | 397 | | | | 2.879,77 | 1.848.814,40 | | 4.319,66 | 2.773.221,60 |
| December | 474 | | | | 3.438,32 | 2.207.400,57 | | 5.157,48 | 3.311.100,85 |
| | | | | **Total** | **24.249,58** | **15.568.228,06** | | **36.374,36** | **23.352.342,09** |

**Appendix A4. Social houses non-renovated**

**Table A4.** Calculations of energy requirements for social houses non-renovated

| Month | Degree Days | Area of Losses(m²) | U (W/m²K) | UAmin (W/K) | Energy Demand for One Building ($D_{1min}$) (KWh) | Energy Demand for All Buildings ($D_{tmin}$) (KWh) | UAmax (W/K) | Energy Demand for One Building ($D_{1max}$) (KWh) | Energy Demand for All Buildings ($D_{tmax}$) (KWh) |
|---|---|---|---|---|---|---|---|---|---|
| January | 436 | 175,36 | 1,60 | 224,46 | 2.348,76 | 575.445,66 | 336,69 | 3.523,14 | 863.168,50 |
| February | 544 | | | | 2.930,56 | 717.987,25 | | 4.395,84 | 1.076.980,88 |
| March | 457 | | | | 2.461,89 | 603.162,08 | | 3.692,83 | 904.743,12 |
| April | 228 | | | | 1.228,25 | 300.921,13 | | 1.842,37 | 451.381,69 |
| May | 149 | | | | 802,67 | 196.654,60 | | 1.204,01 | 294.981,89 |
| June | 96 | | | | 517,16 | 126.703,63 | | 775,74 | 190.055,45 |
| July | 78 | | | | 420,19 | 102.946,70 | | 630,29 | 154.420,05 |
| August | 85 | | | | 457,90 | 112.185,51 | | 686,85 | 168.278,26 |
| September | 185 | | | | 996,61 | 244.168,46 | | 1.494,91 | 366.252,69 |
| October | 214 | | | | 1.152,83 | 282.443,51 | | 1.729,25 | 423.665,27 |
| November | 397 | | | | 2.138,66 | 523.972,31 | | 3.207,99 | 785.958,47 |
| December | 474 | | | | 2.553,47 | 625.599,18 | | 3.830,20 | 938.398,78 |
| | | | | **Total** | **18.008,94** | **4.412.190,03** | | **27.013,41** | **6.618.285,05** |

## Appendix A5. Social houses renovated

**Table A5.** Calculations of energy requirements for social houses -renovated

| Month | Degree Days | Area of Losses($m^2$) | U ($W/m^2K$) | UAmin (W/K) | Energy Demand for One Building ($D_{1min}$) (KWh) | Energy Demand for All Buildings ($D_{tmin}$) (KWh) | UAmax (W/K) | Energy Demand for One Building ($D_{1max}$) (KWh) | Energy Demand for All Buildings ($D_{tmax}$) (KWh) |
|---|---|---|---|---|---|---|---|---|---|
| January | 436 | 175,36 | 0,7 | 98,20 | 1.027,58 | 251.757,48 | 147,30 | 1.541,37 | 377.636,22 |
| February | 544 | | | | 1.282,12 | 314.119,42 | | 1.923,18 | 471.179,13 |
| March | 457 | | | | 1.077,08 | 263.883,41 | | 1.615,61 | 395.825,12 |
| April | 228 | | | | 537,36 | 131.652,99 | | 806,04 | 197.479,49 |
| May | 149 | | | | 351,17 | 86.036,39 | | 526,75 | 129.054,58 |
| June | 96 | | | | 226,26 | 55.432,84 | | 339,38 | 83.149,26 |
| July | 78 | | | | 183,83 | 45.039,18 | | 275,75 | 67.558,77 |
| August | 85 | | | | 200,33 | 49.081,16 | | 300,50 | 73.621,74 |
| September | 185 | | | | 436,02 | 106.823,70 | | 654,02 | 160.235,55 |
| October | 214 | | | | 504.36 | 123.569,04 | | 756,55 | 185.353,56 |
| November | 397 | | | | 935.66 | 229.237,89 | | 1.403,50 | 343.856,83 |
| December | 474 | | | | 1.117,14 | 273.699,64 | | 1.675,71 | 410.549,47 |
| | | | | **Total** | **7.878,91** | **1.930.333,14** | | **11.818,37** | **2.895.499,71** |

## Appendix A6. Social houses for elderly people non-renovated

**Table A6.** Calculations of energy requirements for social houses for elderly people non-renovated

| Month | Degree Days | Area of Losses($m^2$) | U ($W/m^2K$) | UAmin (W/K) | Energy Demand for One Building ($D_{1min}$) (KWh) | Energy Demand for All Buildings ($D_{tmin}$) (KWh) | UAmax (W/K) | Energy Demand for One Building ($D_{1max}$) (KWh) | Energy Demand for All Buildings ($D_{tmax}$) (KWh) |
|---|---|---|---|---|---|---|---|---|---|
| January | 436 | 175,36 | 0,70 | 98,20 | 1.027,58 | 251.757,48 | 147,30 | 1.541,37 | 377.636,22 |
| February | 544 | | | | 1.282,12 | 314.119,42 | | 1.923,18 | 471.179,13 |
| March | 457 | | | | 1.077,08 | 263.883,41 | | 1.615,61 | 395.825,12 |

| **Month** | **Degree Days** | **Area of Losses(m²)** | **U (W/m²K)** | **UAmin (W/K)** | **Energy Demand for One Building ($D_{1min}$) (KWh)** | **Energy Demand for All Buildings ($D_{tmin}$) (KWh)** | **UAmax (W/K)** | **Energy Demand for One Building ($D_{1max}$) (KWh)** | **Energy Demand for All Buildings ($D_{tmax}$) (KWh)** |
|---|---|---|---|---|---|---|---|---|---|
| April | 228 | | | | 537,36 | 131.652,99 | | 806,04 | 197.479,49 |
| May | 149 | | | | 351,17 | 86.036,39 | | 526,75 | 129.054,58 |
| June | 96 | | | | 226,26 | 55.432,84 | | 339,38 | 83.149,26 |
| July | 78 | | | | 183,83 | 45.039,18 | | 275,75 | 67.558,77 |
| August | 85 | | | | 200,33 | 49.081,16 | | 300,50 | 73.621,74 |
| September | 185 | | | | 436,02 | 106.823,70 | | 654,02 | 160.235,55 |
| October | 214 | | | | 504,36 | 123.569,04 | | 756,55 | 185.353,56 |
| November | 397 | | | | 935,66 | 229.237,89 | | 1.403,50 | 343.856,83 |
| December | 474 | | | | 1.117.14 | 273.699,64 | | 1.675,71 | 410.549,47 |
| | | | | **Total** | **7.878,91** | **1.930.333,14** | | **11.818,37** | **2.895.499,71** |

## Appendix B. HOMER Analysis and Simulations

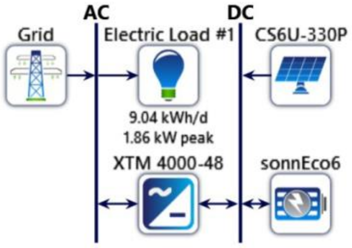
System Simulation Report

Location: Rue Louis Caty 196, 7033 Mons, Belgium (50°26.5'N, 3°54.5'E)
Total Net Present Cost: €19.941,90
Levelized Cost of Energy (€/kWh): €0,273

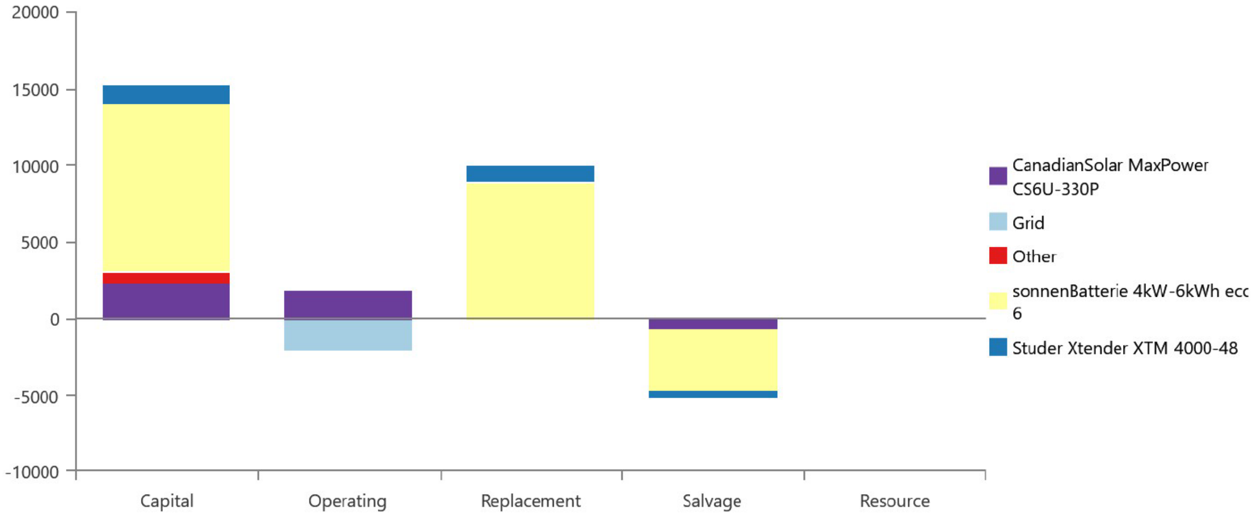
## System Architecture

| Component | Name | Size | Unit |
|---|---|---|---|
| PV | CanadianSolar All-Black CS6U-330P | 4,95 | kW |
| Storage | Sonnen Batterie 4kW-6kW eco 6 | 1 | Strings |
| System converter | Studer Xtender XTM 4000-48 | 3,34 | kW |
| Grid | Grid | 999.999 | kW |
| Dispatch strategy | HOMER Load Following | | |

## Schematic



## Cost Summary



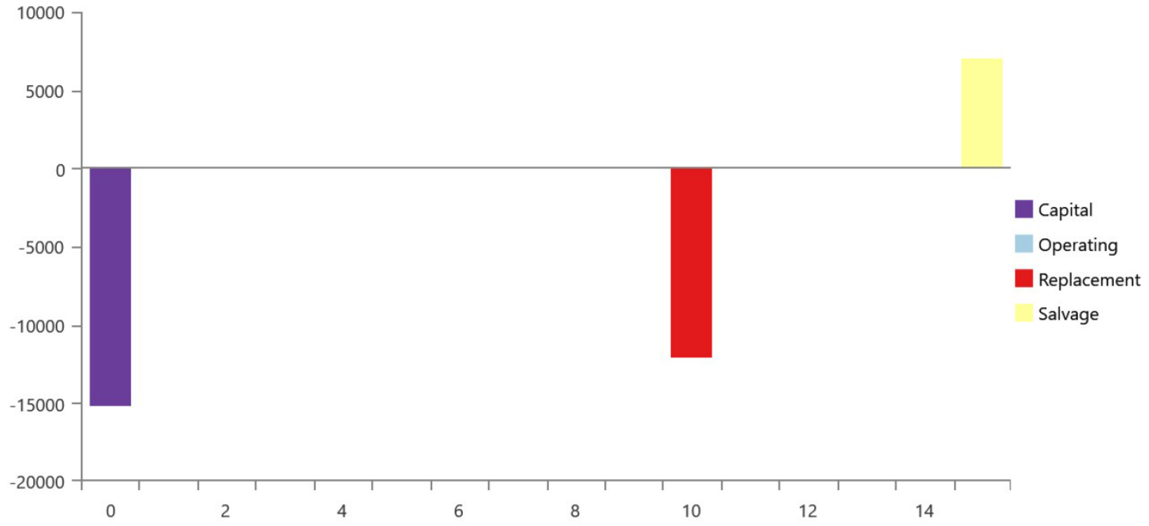
## Net Present Costs

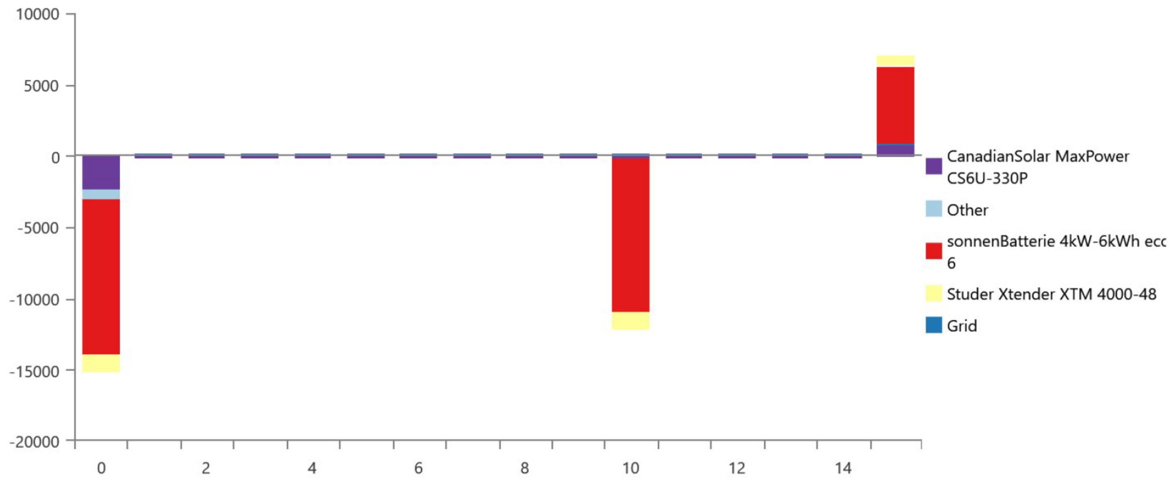
| Name | Capital | Operating | Replacement | Salvage | Total |
|---|---|---|---|---|---|
| CanadianSolar MaxPower CS6U-330P | €2.400 | €1.933 | €0 | €717 | €3.616 |
| Studer Xtender XTM 4000-48 | €1.337 | €0 | €1.101 | -€499 | €1.938 |
| sonnenBatterie 4kW-6kWh eco | €10.785 | €0 | €8.853 | -€4.017 | €15.621 |
| Grid | €0,00 | -€1.933,00 | €0,00 | €0,00 | -€1.933,00 |
| Other | €700,00 | €0,00 | €0,00 | €0,00 | €700,00 |
| System | €15.056,00 | -€1.659,00 | €5.393,00 | -€6.700,00 | €19.942,00 |

## Annualized Costs

| Name | Capital | Operating | Replacement | Salvage | Total |
|---|---|---|---|---|---|
| CanadianSolar MaxPower CS6U-330P | €186,23 | €150,00 | €0,00 | -€55,67 | €280,56 |
| Studer Xtender XTM 4000-48 | €103,72 | €50,00 | €85,42 | -€38,76 | €150,38 |
| sonnenBatterie 4kW-6kWh eco | €836,89 | €0,00 | €686,95 | -€311,69 | €1.212,00 |
| Grid | €0,00 | -€149,97 | €0,00 | €0,00 | -€149,97 |
| Other | €54,32 | €0,00 | €0,00 | €0,00 | €54,32 |
| System | €1.181,00 | €0,03 | €772,36 | -€406,12 | €1.547,00 |

## Cash Flows





### Electrical Summary

| Quantity | Value | Units |
|---|---|---|
| Excess Electricity | 118 | kWh/yr |
| Unmet Electric Load | 0 | kWh/yr |
| Capacity Shortage | 0 | kWh/yr |

### Production Summary

| Component | Production (kWh/yr) | Percent (%) |
|---|---|---|
| CanadianSolar MaxPower CS6U-330P | 5.434 | 87,9 |
| Grid Purchases | 750 | 12,1 |
| Total | 6.184 | 100 |

### Consumption Summary

| Component | Production (kWh/yr) | Percent (%) |
|---|---|---|
| AC Primary Load | 3.300 | 58,2 |
| Grid Sales | 2.374 | 41,8 |
| Total | 5.674 | 100 |

### PV: CanadianSolar MaxPower CS6U-330P

#### *CanadianSolar MaxPower CS6U-330P Electrical Summary*

| Quantity | Value | Units |
|---|---|---|
| Minimum Output | 0,00 | kW |
| Maximum Output | 4,87 | kW |
| PV Penetration | 165 | % |
| Hours of Operation | 4.385 | hrs/yr |
| Levelized Cost | 0,0516 | €/kWh |

#### *CanadianSolar MaxPower CS6U-330PStatistics*

| Quantity | Value | Units |
|---|---|---|
| Rated Capacity | 4,95 | kW |
| Mean Output | 0,20 | kW |
| Mean Output | 14,90 | kWh/d |
| Capacity Factor | 12,50 | % |
| Total Production | 5.434,00 | kWh/yr |

## Storage: sonnenBatterie 4kW-6kWh eco 6

### *sonnenBatterie 4kW-6kWh eco 6 Properties*

| Quantity | Value | Units |
|---|---|---|
| Batteries | 1 | qty. |
| String Size | 1 | batteries |
| Strings in Parallel | 1 | strings |
| Bus Voltage | 240 | V |

### *sonnenBatterie 4kW-6kWh eco 6 Result Data*

| Quantity | Value | Units |
|---|---|---|
| Energy In | 1.373 | kWh/yr |
| Energy Out | 1.186 | kWh/yr |
| Storage Depletion | 6 | kWh/yr |
| Losses | 193 | kWh/yr |
| Annual Throughput | 1.279 | kWh/yr |

## Converter: Studer Xtender XTM 4000-48

### *Studer Xtender XTM 4000-48 Electrical Summary*

| Quantity | Value | Units |
|---|---|---|
| Hours of Operation | 7.238 | hrs/yr |
| Energy Out | 4.924 | kWh/yr |
| Energy In | 5.129 | kWh/yr |
| Losses | 205 | kWh/yr |

### *Studer Xtender XTM 4000-48 Statistics*

| Quantity | Value | Units |
|---|---|---|
| Capacity | 3,34 | kW |
| Mean Output | 0,56 | kW |
| Minimum Output | 0,00 | kW |
| Maximum Output | 3,34 | kW |
| Capacity Factor | 16,80 | % |

## Grid

### *Grid Transactions:*

| Month | Energy purchased (kWh) | Energy sold (kWh) | Net Energy Purchased (kWh) | Energy Charge |
|---|---|---|---|---|
| January | 157,00 | 74,50 | 82,80 | €32.,09 |
| February | 94,40 | 105,00 | -10,60 | €10,20 |
| March | 63,30 | 176,00 | -113,00 | -€8,98 |
| April | 14,90 | 251,00 | -236,00 | -€33,56 |
| May | 7,51 | 338,00 | -331,00 | -€48,69 |
| June | 5,15 | 332,00 | -327,00 | -€48,34 |
| July | 0,00 | 350,00 | -350,00 | -€52,54 |
| August | 6,01 | 322,00 | -316,00 | -€46,62 |
| September | 32,80 | 221,00 | -188,00 | -€24,12 |
| October | 50,30 | 103,00 | -52,20 | -€1,54 |
| November | 132,00 | 76,80 | 55,30 | €24,79 |
| December | 186,00 | 25,60 | 160,00 | €47,33 |

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