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Solar urban planning: a parametric approach

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Abstract

Solar urban planning is a complex process which needs to consider the interplay between multiple factors and variables, depending on urban form and solar energy inputs. This paper presents a methodology based on a parametric approach to quantify solar energy potential from photovoltaic systems in the urban context. Solar power as a source of low carbon energy is an essential component for the sustainability of cities and its implementation and management, through urban planning practices, can play a strategic role in improving the energy efficiency of cities. Within this framework, the amount of energy provided by the integration of photovoltaic systems into existing buildings and their energy consumption, are two key indicators to identify the neighborhoods of the city that behave as urban units with positive, negative or balanced energy performances. On this basis, a workflow that combines geographical information system (ArcGIS®), parametric modeling (Rhinoceros® – Grasshopper™) and solar dynamic analysis (Geco® – Ecotect®), has been developed. A case study has been conducted in a medium-size city in Portugal: Oeiras. The research also evaluated the implementation of a smart grid model supported in the relationship between urban densities and mixed land-use. This infrastructure provides the connection between the cellular units and the city energy system in order to optimize the demand-supply balance. In this way, the results reveal how widespread integration of PV systems, in the long term, can give rise to cities with better energy performances and thus contribute to mitigate greenhouse gas (GHG) emissions related to fossil fuels consumption.

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Keywords: Solar urban planning; photovoltaic systems; GIS; parametric software; solar dynamic analysis;

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1. Introduction

The emergence of the sustainability paradigm, calls for holistic approaches to guide urban planning in a context of rapid urbanization and new urban challenges [1]. When more than 50% of EU's energy is supplied from countries outside the Union and this percentage is constantly growing, this fact can lead to not-resilient development models [2].

In the neo-classical growth model, energy was introduced as an intermediate input for the basic elements such as land, labor and capital that influence economic growth [3]. In the biophysical approach, energy becomes a key factor of income in economic context that significantly depends, and is affected, by changing patterns of energy consumption [4]. In this sense, urban development has to take into account results from relating economic, social, and environmental and governance factors with renewable energy use [5]. On the other hand the relationship between energy consumption and economic growth is closely connected to political models of development and strongly influenced by the types of energy sources and their environmental impacts.

The phenomenon of globalization has created new scenarios where growth model proceeds along an unsustainable path. Climate change and its relation to greenhouse-gas emissions (GHG) are emerging as one of the most significant development issues with regard to the future of human activities, ecosystems and economies. According to the latest analysis from the World Meteorological Organization (WMO), the greenhouse-gas emissions have roughly doubled since the early 1970s and levels of carbon dioxide (CO_2) which are the most important cause of global warming, have increased by 39% between the start of the industrial revolution in 1750 and 2009 [6]. The effects of these global trends have impacts on urban morphology and buildings, consequently the crucial need to reduce GHG emissions points to cities as strategic vehicles for addressing mitigation strategies and action in order to slowdown climate change [7]. The Decreasing energy consumption by means of energy efficiency measures and decarbonizing electricity supply through renewable energy resources are essential to achieve these objectives.

The aforementioned framework leads to the discussion on the implementation of net-zero energy buildings (N-ZEB) as a target objective for a future when buildings will produce as much energy as they use [8]. Looking beyond the individual buildings and considering the neighborhood scale, the net zero concept coupled with the planned introduction of smart grids, can play a strategic role in achieving of the rapid transition to a low carbon system putting the whole city on the path of the energy balance.

Recently, several authors have investigated the effects of urban form on building of the energy consumptions: volumes, surfaces, roads and façades orientation and solar obstructions show great influences on building performances especially at heating, cooling and ventilation function, [9]. The assessment of the potential to the renewables energy in cities show that urban areas have an enormous solar potential for the photovoltaic as well to thermal applications that at present is not exploited [10] [11].

2. Background

The model of urban development of the second half of the 20th century led to the urban sprawl phenomena and all the negative effects at increasing car-dependency for mobility, spending time daily on trips home-work, reduction of agriculture areas, the degradation of landscape, reduction of air quality and higher energy consumption [12]. On the other hand the growth of urban areas in Europe has expanded by 78% whereas the population has only grown 33% and this ratio continuous decrease [13]. Such urban growth and effective expansion of cities has no support on a coherent urban model that has the capacity of prudently predicting the impacts of urbanization. The first urban models, dating back to the deterministic and static period, were based on assumptions of equilibrium in the zoning model. This reflects the lack of a correct urban planning process with flexibility to fairly balance between economic and social factors. Today, different models have appeared, supported on multidisciplinary approaches and simulation models, according to more complex theories which take into account the principles of sustainable development and its requirements. These models have focused on simulations and correlations between the study of urban patterns and the functional correspondence with energy issues and are based on computational processes which are capable to represent and simulate the reality by means of generative algorithms to be defined [14]. The application of models from macro-scale to micro-scale offers more and better data to address the challenges created in the new urban areas and also has the capacity to establish urban units which perform like atoms. This context allows understanding the importance of a range of key issues such as: demography, urban form, built environment, uses, densities, buildings and neighborhood relations. The use of real data to support simulations requires the calibration of models that can be built, based on historical and statistical data where the factors are considered inside its geographic limits - Units. Urban Units behave like atoms and can be compared with cellular automata introduced in the 60's by von Neumann, and its implementation into urban systems realized by Waldo Tobler in the 70's [14]. The implementation of different studies with the cellular automata model has shown several deficiencies in part consequence of the difficulty in the delimitation of geographical areas through the rude expression of spatial divisions. On the other hand the use of cellular automata provides an opportunity to deal with the modeling requirements of the informatics tools in the aggregation and disaggregation of information, shifting models from a large-scale perspective to micro-simulation, [15]. In this context the entrance of Geographic Information Systems (GIS) with its fine scale of analysis in the available tools of the urban planning process, should result in the vanishing of abstraction or analogies in its morphological models. With the recent necessity to provide urban solutions with more efficiency in the energy area, the simulation models can be used and calibrated using real-world data [14], to analyze urban areas and explore future scenarios of land-use and urban expansion [16]. The study and simulation of periods of time can be used in two different types of cases: 1 – analysis between urban and rural land extensions and its relation with the level of infrastructures developed including topography modification; 2 – analysis of land-use, linear dimension of urban infrastructures, number of buildings, densities and uses with the number of years and population growth. This model is different from the SLEUTH model developed by Clarke, [17] who does not introduce population and land-use. The MURBANDY model, [18] is based on a vector of potential transition that takes in account the factors of suitability, accessibility, zoning and neighborhood effect. Related with this model, the MOLAND model [19] that has the capacity to simulate future scenarios for cities, has been applied to European cities was also considered. This model does not have the capacity to simulate capacity to urban growth and a new model appears named "DUEM" created by Batty and Xie and Centre of Advance Spatial Analysis [20]. Notwithstanding all these approaches to model development, the physical reality of urban areas still has huge problems. In the present context of energy dependence to human activities a more sustainable model of urban planning is required, one that is able to provide different solutions for urban development and take into account solar energy. In this framework, an inclusive urban planning process which focuses on solar energy potential directing its implementation to urban areas, has emerged with the name of Solar Urban Planning [5] [21] [22]. This approach is supported by different planning methodologies which consider the use of solar potential as a key issue in urban design principles to improve energy efficiency and supply existing urban areas and promote Building Integrated Photovoltaic (BIPV) in new ones. Also, as solar power is already considered as one of the main sources of low carbon energy essential for the sustainability of cities, the present study aims to quantify solar energy potential from photovoltaic systems in the urban context and its management by using smart grids in order to support solar urban planning practices and optimize the energy balance within the city. These key issues leave the planners to discuss the "ideal" neighborhood configuration and the correct path of energetic infrastructures. Another issue is the growth of energy consumption related with the economic development model and the expansion of urban areas that requires new grids.

3. Objectives

This paper aims to contribute towards solar urban planning practices which promote the energy transition to solar power implementation in the urban context, by using a model of Geographical Urban Units Delimitation (GUUD) related with solar potential. The theoretical model inspired by the structure of the atom is proposed to address the energy balance of the city. In this perspective, protons, electrons and neutrons, are represented by the neighborhoods of the city that behave as particles with positive, negative or no electrical charge according to the differential between their PV electricity supply and energy consumption. The flows are managed by means of smart grids that keep the energetic performances of the whole city stable, likewise an electrically neutral atom in which the charges of the three particles are balanced.

4. Methodology

In order to address the aforementioned objectives, a five-step methodology has been developed (Figure 1).

The operational core of the process is a custom workflow that combines geographical information system (GIS) with parametric modeling and solar dynamic analysis. In this section, the methodology proposed is explained in more detail through its application to a case study of a medium-sized city, Oeiras in Portugal.

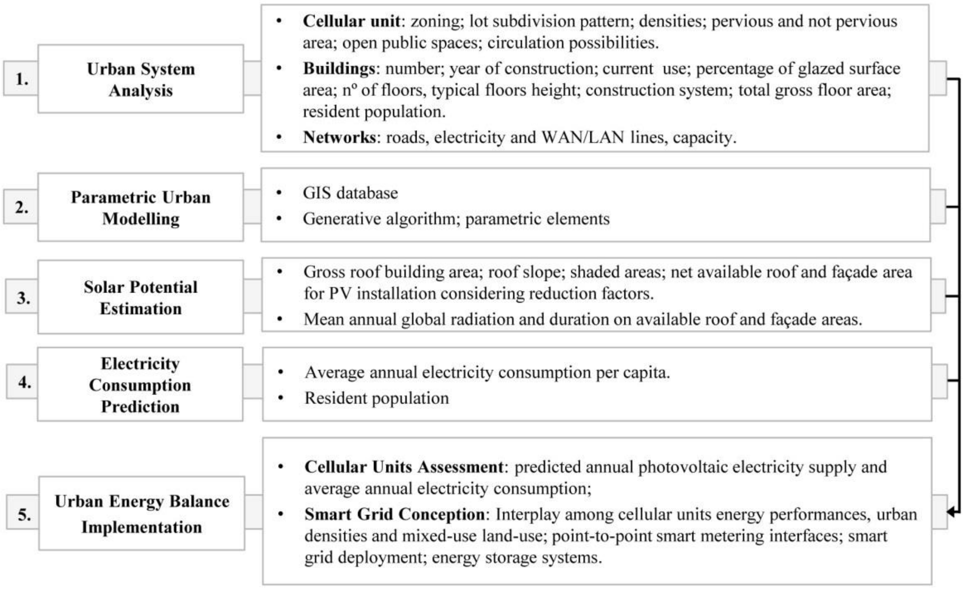


Fig. 1. Methodology

Step 1: Urban System Analysis

Urban areas are characterized by a composition of elements which are interrelated together in a comprehensive system: the City.

The urban system analysis is a fundamental step to identify the spatial and functional factors of the built environments which are related to solar potential and energy consumption issues [5] [9] [23] [24], where land uses, plot areas, façades design, roofs typology, densities and building uses are determinant factors to the research. All these information need to be integrated in a platform that can possibly the use and correlation of data.

Therefore, it is fundamental to provide a method can be used to characterize and analyze the city and then map how and where energy is used and where can be generated by photovoltaic panels installed on buildings roofs and façades.

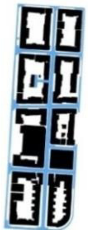
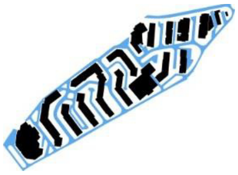
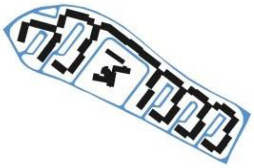
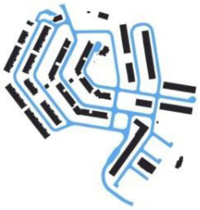
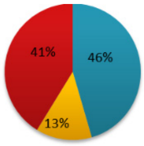
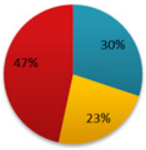
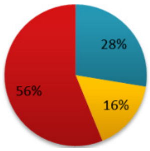
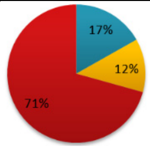
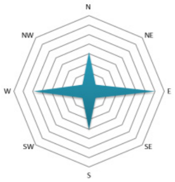
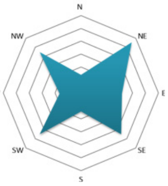
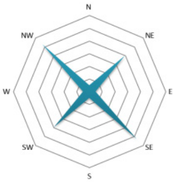
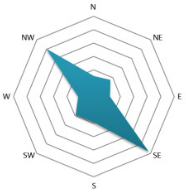
At an operative level, such results have been obtained by collecting the large number of vectors layers, satellite imagery and data tables which define the urban system in the ArcGIS® platform.

The city has been divided into "cellular units", delimited according to year period of time of construction, population density and representative morphological patterns (Table 1) [25] [24].

The synthesis of these three factors of analysis are extremely important to understand the urban system and its relationships with energy aspects and thus support solar urban planning practices on a large scale approach of existing urban areas. [9] [24] [26] [27].

Table 1 shows the cellular units which synthetize the most common systematic and irregular urban forms resulting from the urban systems analysis. The evolution of the buildings block and street patterns have been classified according to the models studied by Southworth and Ben-Josep (1997) [25].

Table 1. Urban Analysis

Oeiras *38°44'-9°24'*	**1. Orthogonal**	**2. Warped Parallel**	**3. Linear and Loops**	**4. Radial**
Buildings Block and Street Pattern				
Period of Construction	1945-60	1960-70	1970-80	2000-10
Resident Population	1354	2615	1848	574
Building Types	Multifamily low-rise	Multifamily mid-rise	Multifamily mid-rise	Single-family attached
Roof Typology	Pitched	Pitched and flat	Pitched	Pitched
Land-Use Coverage System 🟦 Buildings covered area 🟨 Street covered area 🟥 Open space area				
Façade Orientation				

Comparing the resident population and the year of construction emerges how the higher densities tend to be in the Unit 2 and 3 corresponding to the rapid growth of the city that occurred from 1960 to 1980 [28]. Another important correlation is regard to the street patterns which influence the façade orientation and consequently the PV energy potential [24].According to the geographic location and solar access conditions in Portugal, the best building roof and façade orientation for PV systems installation, is south [5]. Taking into account this factor, a clear heterogeneity can be observed among all the four Units. Unit 1, oriented along the N-S axis, has a better equilibrium in solar access terms but the relationship between the heights of buildings on each side of the streets to the width between those buildings, reduces the potential use of the façade to integrated photovoltaic systems. In contrast, this problem does not occur in the unit 3 in which the linear and loops pattern offers a greater percent of open space area and thus, less shading effects of the surrounding buildings. Unit 4, with low population density and single-family attached buildings could represent a balanced solution between solar energy production and consumption but due to NW-SW façade orientations, the pitched roofs haven´t the sufficient conditions for an efficient PV production. The Unit 2, associated to high density, multifamily mid-rise buildings and a mix between flat and pitched roof typologies, is the cellular unit that presents the more complex characteristics for solar potential implementation and thus it was chosen to apply the next three methodological steps.

Step 2: Parametric Urban Modeling

To fulfill the potential of solar power in the urban context, it is important to define the set of criteria and parameters which are relevant with regard to the specific issues to be considered. The development in computational power and the increased capacity to generate and analyses digital models have provided the tools to approach these complex issues using interactive parametric elements that contain information about the different components of the model and their relationships with the other components [29]. In this research, the implementation of a parametric approach aims to provide a interrelation of the urban model and factors linked to energy production. On this basis and applying the parametric paradigm at the city scale, a custom workflow, who combines geographical information system with parametric modeling and solar dynamic analysis, has been specifically developed (Fig.2) [30].

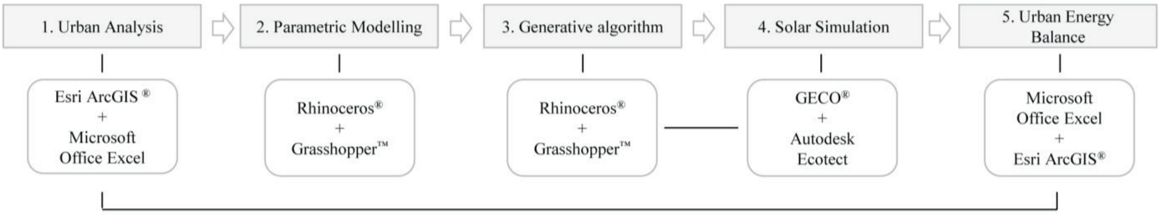


Fig. 2 Workflow

In the first stage of the workflow, ArcScene® is used to create a 3d land surface (TIN model) on which the buildings polygons and the roof elevation points are projected passing from the zero-reference to their real z coordinate. Such selection of layers is then exported to Rhinoceros® which is the software adopted in this study, to provide the digital environment for the parametric modeling.

By mean of Grasshopper™ running within Rhinoceros®, a generative algorithm has been developed to transform the imported GIS vector information in a 3d parametric model (Figure 3).

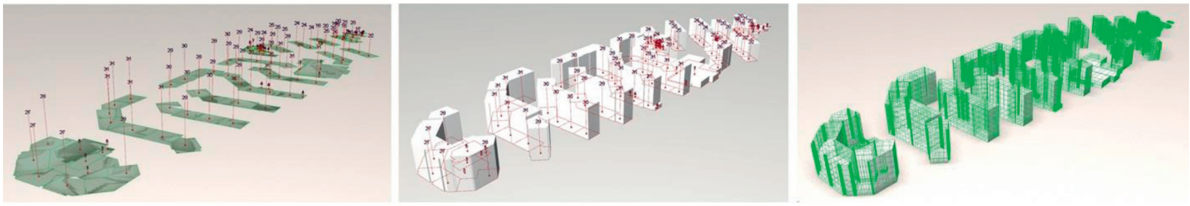


Fig. 3. Parametric Urban Model

The integration in the algorithm of a set of components which establishes in real time a live link between Rhinoceros®/Grasshopper™ and Ecotect® is the next key stage to perform solar dynamic analysis on the parametric urban model (Figure 4).

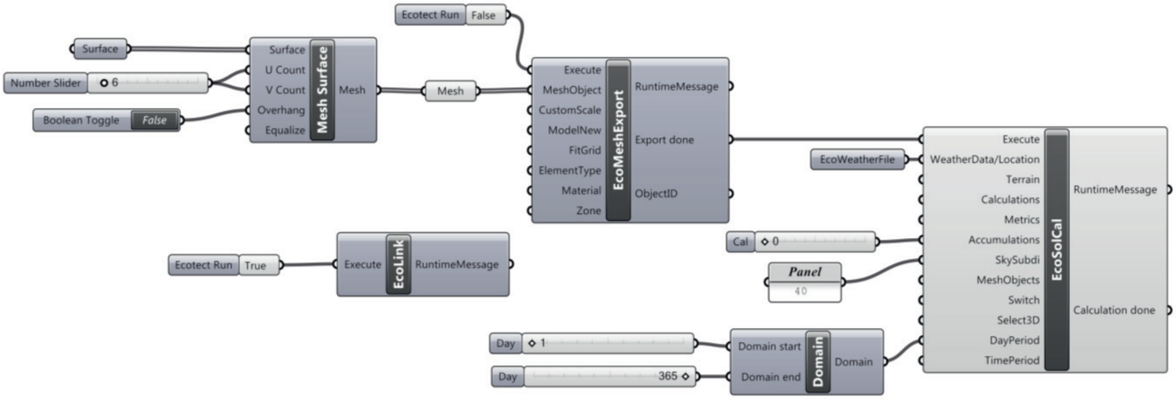


Fig. 4. “Solar Analysis” Generative Algorithm elaborated with Grasshopper® and GECO®

Figure 4 shows the “solar analysis” generative algorithm which is the final and most important part of the whole diagram that connect the morphogenetic parameters based on GIS data, the solar analysis and the respective results in terms of solar radiation incident in each roof and façade surface over a year (Figure 5).

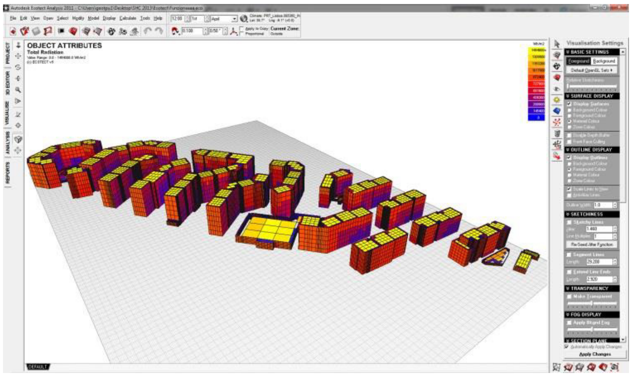


Fig. 5. Solar Urban Model

The Ecotect® analysis data have been then exported to a WExcel® worksheet supplying the numeric solar radiation values which are needed for the estimation of the photovoltaic solar electricity potential, as showed in the next step.

Step 3: Photovoltaic Solar Electricity Potential

In this moment, the characteristics and parameters of the urban system which are required to estimate photovoltaic solar electricity have been gathered by mean of quantitative spatial analysis in the GIS platform (Table 2) [5].

According to related approaches to available roof surface area for photovoltaic energy potential evaluations, some specific criteria have to be assumed for taking into account those factors that can reduce the gross roof surface.

The factors adopted in this study have been divided between exclusion factors and reduction factors in order to consider spatial aspects for PV arrays installation, shading effects, roof typologies and other roof uses and PV module efficiency [5] [31] [32] [33].

Table 2. Operational Data for the estimation of PV solar electricity potential

Exclusion factors		**Roof Typologies**		**Roof Classification**	
Roof areas lower then 42m^2					
Incidence of shadows greater than of 30%					
Reduction factors					
Facility coefficient	Cf=0.90				
Pitched roof standardization	Fr= 0.5				
PV efficiency due to orientation	S | 100% SW-SE | 95% N-NW-NE PV not considered	Flat roof area m^2	18781	🟦 Flat	🟥 Pitched
		Pitched roof area m2	3955	Flat 83%	Pitched 17%

On this basis, to estimate the annual energy production by PV systems, the following equation has been adopted [34]:

$$Y = PR \times Me \times (Gr \times A) \qquad (1)$$

PR is the Performance Ratio that considers the energy losses in the balance of system (adopted value in (1) | PR=75); Me is the nominal module efficiency rating at Standard Test Conditions: air mass AM 1.5, irradiance 1 kW/m2, cell temperature 25ºC reported by the selected manufacturer [35] (adopted value in (1) | Me = 13 %); Gr is the sum of all global solar radiation values in each metric over a year (value obtained from Ecotect® simulation, see Table 3); A is the net available roof area for PV installation (value calculated considering exclusion and reduction factors, see table 2)

Table 3. Photovoltaic Solar Electricity Potential

Gross roof area of building (m²)	21 131
Available flat roof area for PV installation considering exclusion factors (m²)	14 467
Available pitched roof area for PV installation considering exclusion and reduction factors (m²)	1 347
A | Net available roof area for PV installation considering reduction factors (m²)	15 814
Gr | Sum of all global solar irradiation values over a year (kWh/m²)	23 389 142
Mean annual global radiation on available roof area (kWh)	1 309
Estimation of the annual yield for PV systems on available roof area (kWh)	**2 280 441**

Step 4: Energy Consumption Prediction

Likewise energy consumption is strictly related to urban form but also to other variable factors such as constructive and geometrical aspects of buildings or user behavior, is quite complex to obtain an exact estimation [9] [26].

To date, the study presents only the electricity consumption of residential buildings based on the statistical information collected from the National Institute of Statistics, so considering the annual electricity consumption per capita of 1 398 kWh/*inhab* and the resident population of 2615, the average annual electricity consumption is estimated 3 655 770 kWh. It is important to refer as this statistical approach entails a considerable approximation, the ongoing targets will be focused on the integration of dynamic simulation for energy consumption analysis in order to reaching better results [28].

Step 5: Urban Energy Balance

After solar potential calculation in all different units data are carry on to the GIS platform to provide a map which makes a clear identification of the limits areas and its potential and consumptions. Through this step the energy balance of urban area is achieved and is possible to identify what areas have needs of more energy and construct urban parameters to transform and adapted the pattern of energy demand and production. In another hand through the analysis of the units who have energy excess is also possible to evaluated data and correct or improve the content of urban parameters.

Step 6: Smart grid Conception

To achieve the efficiency in the operation of city energy balance, data from the previous step are apply to establish the connection of the cellular units within the urban energy system and optimize the complex interrelations between the energy demand and supply. In this framework the implementation of a smart grid model that manage the existing cellular units hierarchical based on urban densities and mixed land-use, represents one of the great potential of the infrastructure of smart grid because the consumption is near to the production point. The design of the smart grid takes into account the limits of the calculation unit to assure the effectiveness of the presented methodology.

5. Results and Discussion

City energy balance is archived on the complex relations between energy demand and solar energy supply. To fulfill the potential of these two indicators it is important to define a set of criteria and parameters which are considered relevant with regard to the specific issues to be considered. As shown the implementation of a parametric approach in the interrelation of urban system and energy issues give a great contribute to solar urban planning implementation. The workflow enables to estimate solar potential and have the capacity to change the urban model in order to assess a different configuration more efficient to the goal or energy production supported into a PV energy supply generation. Moreover the possibility to store in the GIS platform, data related with the PV energy, permits to map the energy balance across the city and identify the positive, negative and neutral parts. Link to this map are the action of conception of smart grid delimitated to the some analysis of positive, negative and neutral areas with the goal of in real time can make compensation between needs and available. Considering the photovoltaic solar electricity potential estimated of 2 280 441 kWh and the average annual electricity consumption of 3 655 770 kWh, it is possible to observe as the potential solar energy output would be able to satisfy about 62% of current needs. The results show that high densities can have an important role if is randomness in horizontal layout take place given similar amount of usable floor area and roof. Randomness in vertical layout have also a key role in solar and uses because day light and consumption patterns. The identification and construction of parametric factors as too a significant role once related whit the computer tools make possible the simulation to the best solution before building phase. The use of real data on the conception of models make strong the capacity of obtained patterns of energy consumptions who can be linked to the thermal behavior of building and also the period of construction and build system apply. The presented methodology and is apply to new developments make possible to predict the level of production and consumption in the future. The models point out a way to reduce carbon emissions and to realize the solar urban planning. The limitation of the model is the consideration in the parametric model of the horizontal roofs, which show the need to develop the research on the PV systems integration in building stake into account the reality of urban context.

6. Conclusions

The paper has set up a model to advise solar urban planning on the factors and effects of its implementation in city contexts with support on a parametric approach. The results demonstrate that is possible to implement energy efficient models in existing and new urban areas. The workflow enables the estimation of solar potential in a rapid and flexible way and stores this information in a GIS platform. By altering the set of parameters in the algorithm, the existing urban model can be transformed in order to assess different urban design solutions and determine which conditions are better for PV energy generation. The developed parametric approach for solar urban planning represents an effective tool to improve energy performance of cities and contribute to address the global issues of energy security, energy access and sustainable development.

References

[1] UN Habitat, “Planning sustainable cities,” Nairobi, 2010.

[2] P. Belkin, “The European Union’s Energy Security Challenges,” in Report for congress, Congressional Research Service., 2008.

[3] S. Tsani, “Energy consumption and economic growth: A causality analysis for Greece,” Energy Economics, vol. 32, no. 3, pp. 582-590, 2010.

[4] C. Cleveland , R. Costanza, C. Hall and R. Kaufmann, “Energy and the U.S. economy: A biophysical perspective.,” Science, vol. 225, pp. 890-897, 1984.

[5] M. Amado and F. Poggi, “Towards Solar Urban Planning: A New Step for Better Energy Performance,” Energy Procedia, vol. 30, p. 1261–1273, 2012.

[6] WMO, “The State of Greenhouse Gases in the Atmosphere Based on Global Observations through 2010,” Geneva, 2011.

[7] UN, “Climate neutral cities,” Geneva, 2011.

[8] D. Crawley, S. Pless and P. Torcellini, “Getting to Net Zero,” ASHRAE Journal, vol. 51, no. 9, pp. 18-25, 2009.

[9] C. Ratti, N. Baker and K. Steemers, “Energy consumption and urban texture,” Energy and Buildings, vol. 37, no. 7, p. 762–776, 2005.

[10] J. J. Sarralde, D. Quinn and D. Wies, “Urban modelling for resource performance analysis: estimating cities’ renewable energy potential,” in Proceedings of Building Simulation 2011, Sydney, 2011.

[11] A. Jäger-Waldau, M. Szabó, N. Scarla and F. Monforti-Ferrario, “Renewable electricity in Europe,” vol. 15, no. Renewable and Sustainable Energy Reviews, p. 3703–3716, 2011.

[12] L. Y. Zhao, K. Zhao, P. Xie and J. Fang, “Land-cover changes in an urban lake watershed in a mega-city, central China,” Environmental Monitoring and Assessment, vol. 115, pp. 349-359, 2006.

[13] E. E. Agency, “Urban Sprawl in Europe,” EEA-EU, 2006.

[14] R. White and G. Engelen, “High-resolution integrated modeling of the spatial dynamics of urban and regional systems.,” Computers, Environment and Urban Systems, vol. 24, pp. 323-343, 2000.

[15] N. Pinto and A. Antunes, “Cellular automata and urban studies: a literature review,” Architecture, City and Environment, vol. 1 (3), pp. 368-399, 2007.

[16] A. Lagaris, “Urban sprawl simulation linking macro-escale processes to micro-dynamics through cellular automata, an application in Thessaloniki, Grece,” Applied Geography, vol. 34, pp. 146-160, 2012.

[17] K. C. Clarke, L. Gaydos and S. Hoppen, “A self-modifyingcellular automaton model of historical urbanizationin the San Francisco Bay area.,” Environmental and Planning, vol. 24, pp. 247-261, 1997.

[18] R. White, G. Engelen and I. Uljee, “The use ofconstrainedcellular automata for high-resolutionmodeling of urbanland-use dynamics.,” Environment and Planning, vol. 24, pp. 323-343, 1997.

[19] C. Lavalle, J. Barredo, N. McCormick, G. Engelen, R. White and I. Uljee, “The MOLAND model for urban and regional growth forecast. A toolfor the definition of sustainable development paths.,” European Communities Joint Research Centre, 2004.

[20] M. Batty, X. Yichun and S. Zhanli, “Modeling urban dynamics throughGIS-based cellular automata,” Computers, Environment and Urban Systems, vol. 23, pp. 205-233, 1999.

[21] U. Eicker, “Renewable Energy Sources Within Urban Areas – Results From European Case Studies,” in Chicago Winter Conference 2012, Chicago, 2012.

[22] N. Kaiser, Solar energy in architecture and urban planning, Prestel, 1996.

[23] I. Theodoridou and et al, “Assessment of retrofitting measures and solar systems' potential in urban areas using Geographical Information Systems: Application to a Mediterranean city.,” Renewable ans sustainable energy reviews, vol. 16, pp. 6239-6261, 2012.

[24] C. Christensen and S. Horowi, “Orienting the neighborhood: a subdivision energy analysis tool,” in ACEEE Summer Study on Energy Efficiency in Buildings, California, 2008.

[25] M. Southwoth and E. Ben-Joseph, Streets and the shaping of towns and cities, Washington D.C.: Island Press, 1997.

[26] M. Maïzia, C. Sèze , S. Berge , J. Teller, S. Reiter and R. Ménard, “Energy requirements of characteristic urban blocks,” in Proceedings of the CISBAT 2009 - Renewables in a changing climate - From Nano to urban scale, Lausanne, 2009.

[27] V. Cheng, K. Steemers, M. Montavon and R. Compagnon, “Urban form, density and solar potential,” in PLEA2006-Conference on passive and low energy architecture, Geneva, 2006.

[28] INE, “Instituto Nacional de Estatística,” [Online]. Available: http://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_main. [Accessed January 2011].

[29] A. Aksamija, M. Guttma, P. H. Rangarajan and T. Meador, “Parametric control of bim elements for sustainable design in Revit,” Perkins+Will research journal, vol. 03, no. 01, pp. 32-45, 2011.

[30] P. Schumacher, “Parametricism as Style - Parametricist Manifesto,” in 11th Architecture Biennale of Venice, Venice, 2008.

[31] M. Cellura, A. Di Gangi, S. Longo and A. Orioli, “Photovoltaic electricity scenario analysis in urban contests: An Italian case study,” Renewable and Sustainable Energy Reviews, vol. 16, no. 4, p. 2041–2052, 2012.

[32] S. Gadsden, M. Rylatta, . K. Lomas and D. Robinson, “Predicting the urban solar fraction: a methodology for energy advisers and planners based on GIS,” vol. 35, no. Energy and Buildings, p. 37–48, 2003.

[33] S. Izquierdo, M. Rodrigues and N. Fueyo, “A Method for Estimating the Geographical Distribution of the Available Roof Surface Area for Large-scale Photovoltaic Energy-potential Evaluations,” vol. 82, no. Solar Energy, p. 929–939, 2008.

[34] A. Bahaj and P. James, “Urban energy generation: The added value of photovoltaics in social housing,” Renewable and Sustainable Energy Reviews, vol. 11, no. 9, p. 2121–2136, 2007.

[35] Martifer Solar, “http://muellertech.it/img/pv-module/mprime/mprime-colored-module-datasheet-en-040112.pdf”.

[36] A. Angelis-Dimakis, . M. Biberacher, J. Dominguez, G. Fiorese and et al, “Methods and tools to evaluate the availability of renewable energy sources,” vol. 15, no. Renewable and Sustainable Energy Reviews, p. 1182–1200, 2011.