# THE PROPOSAL FOR A SPATIAL PLANNING SUPPORT SYSTEM TO ESTIMATE THE URBAN ENERGY DEMAND AND POTENTIAL RENEWABLE ENERGY SCENARIOS

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## ABSTRACT

A simplified methodology for the estimation of energy demand (heating, electricity, hot water) and the production of renewable energy of households at the city level based on the available data and information is presented. The aim of this work is to develop a spatial planning support system, i.e. an estimation tool based on the use of geographic information systems (GIS) in order to support public administration and stakeholders towards a sustainable energy and urban planning at the local scale. For instance, assessing urban energy quantities and potential energy productions can drive urban policies and planning decision-making. The tool was applied to the case-study area of the city of Milan, Italy. Outcomes show that in terms of energy savings, the retrofitting of households reveal huge margins for improvement, whereas in terms of energy production through RES, geothermal and solar energy represent the only valid options, because other sources require the availability of open spaces, thus far beyond the saturated urbanized land of the town. Finally, the calculation procedure is easy to run and represents a versatile and adaptable energy prediction tool to be used to link energy and urban planning in a more effective way.

*Keywords: energy consumption estimation model, urban heatmaps, energy-conscious urban planning, spatial planning support system, GIS.*

## INTRODUCTION: THE GENERAL CONTEXT AND THE OBJECTIVE OF THIS STUDY

Cities as the major actors towards energy consumption reduction. International and national programs are pushing for a drastic reduction of energy consumption, improvement of efficiency and clean energy production from renewable sources. Reports from the International Energy Agency estimate that in 2030 cities will consume about 75% of the total energy production and buildings will make use of about 40% of the global primary energy [1]. However, most of the energy related policies are addressed at the scale of the building or at the global scale (see for instance the policies on the reduction of greenhouse gases emissions). In fact, urban planning and energy planning still remain two separate dimensions. We argue that a focus on the spatial dimension of energy, which is missing in the current practice, would improve the general understanding of the phenomena. Hence, the final aim of this work is to provide municipalities with a flexible and simplified tool for the estimation of urban energies in order to allow policy- and decision makers to get a first understanding of the implied quantities, sizes and locations of the energy phenomena.

## THE RESEARCH CONTEXT

In order to setup our methodology we refer to the available literature on the approaches to mapping and a series of applications on case studies. Heatmaps and urban energy maps in particular, represent the main outcome of estimation or prediction models of energy consumption and performance at the city scale.

### Bottom-up and top-down models

The construction of urban energy- and heat maps can be based on different approaches depending on the scopes. Swan and Ugursal [2] present a classification of urban heatmap models based on two approaches, namely top-down and bottom-up approaches (Figure 1). Bottom-up approaches start from the analysis of energy consumption for single final uses, and from those the sampling and aggregation methods of data at the larger scale are consequently defined. The extrapolation methods of data are of two types, namely the statistical or the engineering type. The first type is based on the use of the historical information which undergoes a series of statistical procedures; the second one relies on the use of technological information, like the type and efficiency of energy appliances, which are investigated and then aggregated through three methods: the population distribution method, the archetype method and the sample method [2]. On the contrary, top-down approaches rely on aggregated data, based on historical records such as econometric variables (GDP, occupation rates, etc.) and technological variables (climate data, rate of construction/replacement of the building stock, average number of appliances per household, number of employees per household, etc.). In these models, the built fabric is considered as an energy absorber and dissipater, with no need to take into account the final uses in detail.

In general, top-down approaches are applied at the large scale (regional and national), whereas bottom-up procedures are often used at the urban or district level. Nevertheless, the overlapping of procedures within the same model is possible, and often, different methods (for example the statistical and engineering one) are integrated.

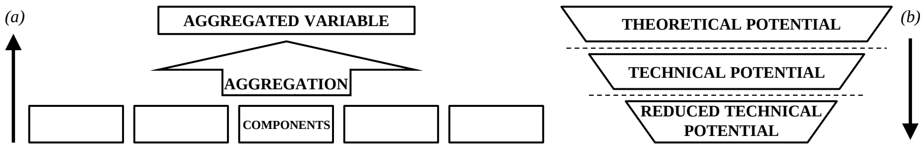


*Figure 1: (a) Bottom- up and (b) top- down approaches applied in the construction of urban energy models. An elaboration from [2].*

### Case studies on urban energy consumption maps and renewable energy maps

The first exploration refers to the heatmaps, i.e. maps that estimate urban energy consumptions. All the analysed methods are bottom-up procedures and most of them are limited to the computation of heating consumption for the household sector alone. Only some methods include other land use than households [3, 4], and only few provide scenarios with energy reduction [5, 6, 7].

Concerning the energy production maps through RES, numerous references adopt top-down approaches [8, 9]. Some works aim at investigating the potential production of one source alone: Bergamasco and Asinari [10] provide a quick methodology for the estimation of electricity production through photovoltaic technologies at the city scale. Fiorese and Guariso [11] work on the optimization of the localization of biomass plants at the regional scale. Other studies take into account multiple energy sources to promote energy diversification [12, 13].

## METHODOLOGY: THE CONSTRUCTION OF THE MODEL

We implemented a model for the estimation of the energy demand, the energy performance and the potential of renewable energy applicable to a city or larger territory. Thanks to the implementation of the methodology with GIS software, it is possible to geo-refer every estimated information.

The model is divided into three distinct parts (Figure2): (i) the current energy consumption of residential buildings of the case study (estimation of current consumptions) are defined; (ii) improved consumption scenarios based on the implementation of a number of measures to reduce the energy demand (estimations of future consumptions) are assessed;(iii), the energy demand that can be satisfied from local RES is estimated (estimation of RES potential).

Hence, this work does not only assess the current energy consumption, but designs future scenarios, evaluating possibilities and benefits in two steps: first, through an overall reduction in consumption due to the increase of efficiency, and second, through the coverage of part of the demand by local RES, thus reducing the use of conventional and imported sources.

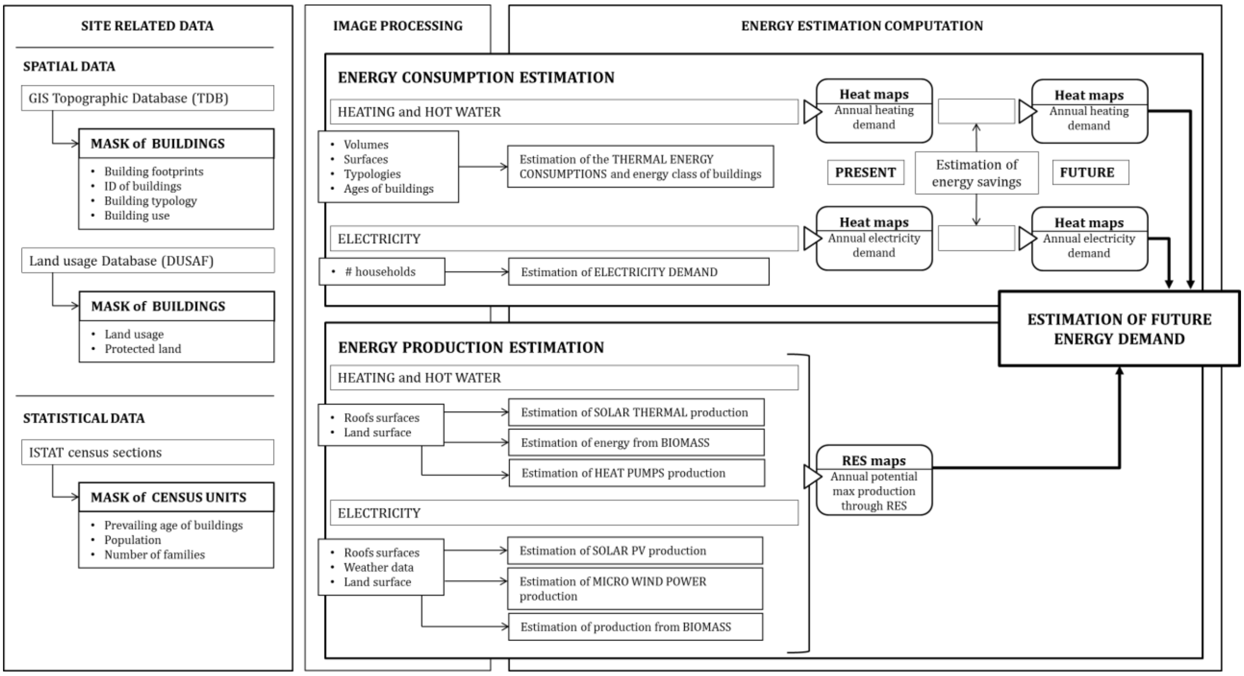


*Figure 2: Conceptual scheme of the structure of the model*

## THE APPLICATION

We applied the model to the municipality of Milan. Past studies [4] and CEER (Catasto Energetico Edifici Regionale), i.e. the official energy cadastre that collects certificates [14] represented our main references to validate the outcomes of this work. Data available for the city of Milan and used as the main entry information are: (i) the topographic database (TDB) and statistical data from the national census referred to the local units. The first step was the construction of the database of residential buildings. A series of operations on the TBD crossing the census data have been carried out in order to eliminate noise and derive the total number of residential units. Moreover, by crossing these two databases with GIS software, we could define the age classes, the S/V ratios and the number of floors for each building, and from this the building typology.

### The estimation of thermal energy demand and improved scenarios

For assessing the consumption of thermal energy for space heating and hot water production we refer to TABULA [15, i.e. a database with 28 archetypes of buildings, obtained by crossing four building typologies and seven age classes to define the thermal primary energy for each one. We aggregated the archetypes according to an engineering bottom-up approach. As a limitation, we have to state that retrofitting measures and the presence of RES on the current building stock cannot be addressed. Hence, we start from a more restrictive baseline.

Current thermal energy demand is overall very high (Table 1a). In fact, for heating 92% of the buildings belong to the worst energy class (G class), while this percentage becomes 95% for hot water. The main reason is the obsolescence of buildings; even if Milan is characterized by one of the most efficient building typology (72% of buildings are apartment blocks), about 90% of Milan stock was built before 1971, and only 4% after 1981.

Two retrofitting scenarios (a standard and an advanced one) were proposed on the basis of current best available technologies and are based on TABULA [15]. As it clearly emerges from Table 1b, there is a great difference between current and future estimated demand. For instance, the maximum potential energy saving for heating is estimated to reach 83% for a standard retrofitting, and 89% for the advanced retrofitting; for the hot water consumptions, the savings are lower, but still relevant. Hence, we can finally argue that the existing stock could be a huge source of energy savings. It is true that these predictions appear to be very optimistic, but we looked forward to long-term scenarios and considered the expected technology advancement to happen in the next 20 years.

**(a) Current estimated thermal energy consumption for heating and hot water**

| | **Heating consumptions** | **Hot Water consumptions** |
|---|---|---|
| Average consumption (kWh/m$^2$/year) | 258 | 48 |
| Global consumption (GWh/year) | 12.763 | 2.374 |

**(b) Future estimated thermal energy consumption for heating and hot water**

| | **Current consumptions** | **Standard retrofitting** | **Advanced retrofitting** |
|---|---|---|---|
| Average heating consumption | 258 | 43 | 26 |
| Energy saving (%) | | 83,3% | 89,9% |
| Average HW consumption | 48 | 26 | 14 |
| Energy saving (%) | | 45,8% | 70,8% |

*Table 1: (a) current estimated thermal energy consumption for heating and hot water; (b) future estimated thermal energy consumption for heating and hot water*

## The estimation of electric energy demand and scenarios

For the current electricity consumptions we refer to MICENE dataset [16]; even if quite old, it is representative for the case study, containing most of the measures from Milan households. Considering the average annual electricity demand per household of 3.250 kWh and the number of household for every census section, the calculation for the city was easy to derive (Table 2a). In order to assess the improvement scenarios, we referred to Intelligent Energy Europe projects [17]. These quantify the maximum potential of electricity savings per household in percentages of around 40% of current electricity consumption (Table 2b).

| **Legend** | **(a) Current demand** | **(b) Future demand** |
|---|---|---|
| Average yearly demand per section | 345.313 kWh/year/section | 207.188 kWh/year/section |
| Global annual municipal demand | 2.058 GWh/year | 1.234 GWh/year |

*Table 2: Estimated electricity demand for Milan aggregated on the census sections*

## Energy improvement scenarios through renewable energy sources

This last part of the work aims to estimate the share of the global energy demand that can be satisfied by RES, in order to reduce the import of conventional fossil fuels. It is important to stress that RES have to be found locally within the municipality borders, thus maximizing the benefit of this fuel switching and, at the same time, minimizing the ‘energy transferring’ (e.g. biomass transport, electricity infrastructure, pipe grids). Before introducing the results, it is important to state that the above introduced thermal energy demand scenarios already consider various types of RES for the production of thermal energy (i.e. geothermal heat pumps and solar thermal), particularly in the advanced retrofitting scenario; hence, in this section we decided to consider those RE plants that provide electricity only. The technical potential of the following RES were considered in the model through feasibility analysis: very-small and small-wind turbines, cogeneration of biomass, biomass anaerobic digestion and solar PV systems.

Numerous RES do not represent an option. Wind turbine systems were discarded because of the low natural ventilation and the aesthetic and environmental intrusiveness make this technology not convenient. Biomass cogeneration plants is unsustainable, because Milan in 2009 has less than 30 ha of woody crops, while a cogeneration plant of 1 MW needs at least 150 ha. Anaerobic digestion plants from animal manure are not an option due to the lack of heads (Milan has just 40 swine, while a 100 kW plant needs at least 3.000); moreover, all the cattle of the municipality (424) could feed a 180 kW plant, able to satisfy 1,2% of the future electric demand (1,5 GWh/year), but this is not convenient due to the dispersion of the farms on the territory. About anaerobic digestion of crops, we have estimated that if all the arable land was converted into energy crop, we could build 21 biogas plants of 300 kW each, which could produce 50,4 GWh/year (4,1% of future electricity demand), but this is an and unsustainable scenario, if we consider a more convenient food production.

Finally, we checked the potentiality of PV systems on building roofs, and we can state that the energy output is more efficient. We estimated the available roof surface for PV panels [11]; for electricity production we drew up six different scenarios, depending on the possibility or not to install PV panels in the city centre and to install only Monocrystalline Silicon panels, only Polycrystalline Silicon panels or to install the same share of panels as currently applied in Italy (Table 3). PV systems could potentially cover from nearly a half (best scenario) to about 1/3 (worst scenario) of the future electricity demand.

| Scenarios | | Total production (GWh/year) | Quote on future demand (%) |
|---|---|---|---|
| PV in city center | **Mono Si scenario** | **583,1** | **47,2** |
| | Poli Si scenario | 501,6 | 40,6 |
| | IT mix scenario | 522,3 | 42,3 |
| NO PV city center | Mono Si scenario | 483,9 | 39,2 |
| | **Poli Si scenario** | **387,1** | **31,4** |
| | IT mix scenario | 431,7 | 35,0 |

*Table* 3: *PV electricity production in Milan and table with estimated numerical data*

## CONSIDERATIONS AND CONCLUSIONS

General considerations emerging from the application of the tool are as follows: (i) taking into account the spatial dimension of territories allows to give a better understanding of the potential provision of energy scenarios and the implementation of RES; (ii) the calculation procedure is easy to run even with poor entry data, mostly derived from geometrical information derived from the 3D urban model; (iii) it can be easily replicated, thus representing a versatile and adaptable energy prediction tool to be used to link energy and urban planning in a more effective way.

Specific considerations on the application in Milan are: (i) the city goes far beyond the current political boundaries that today correspond to an almost 100% urbanized land with few open spaces: hence, the metropolitan area would be the proper dimension for energy planning; (ii) the different urban tissues and locations offer alternative opportunities and corresponding energy scenarios; (iii) only a first broad estimation of RE production can give a clear understanding about the potential efficient strategies to promote and the sources to discard.

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