Improving cities' resilience to the peak oil through solar energy. An estimation method applied to Bressanone city.

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1. Introduction

1.1 Dependency of Cities from external resources of energy

The population growth and the rise of standards of living around the globe are causing significant increases in energy demand and competition for fossil energy sources.

The Peak Oil is defined in literature (Financial Times, 2012) as the point in time when the maximum rate of fossil fuels extraction is reached, after which the rate of production is expected to enter terminal decline.

As demand increases, the costs of non-renewable, finite resources rise as finite supplies fall.

Ecosystem resilience is defined by (Walker, B et al. . 2004) as the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes. A resilient ecosystem can withstand shocks and rebuild itself when necessary. Resilience in social systems has the added capacity of humans to anticipate and plan for the future (Bennett, E.M. et al. 2005).

Cities are considered by many scholars "urban ecosystems" (Alberti, 2008).

Connecting together the previous assumptions, it is possible to theorize a resilience of cities to the modifying energy system, the Peak Oil.

It is clear in fact that the dependence on external sources of energy has political and economic impacts on cities that affect their capacity to provide services, that need energy, to their citizens (Newman et al, 2008).

This issue is related to an hyper-dynamic context characterized by the socio-economic and ecological processes of the cities. It is a new challenge for urban planners, in fact, to improve the resilience of cities to the peak oil facing the models of eco-efficient and low-carbon urban settlements.

This demand can only be met in the mid-term through energy generation from a diverse set of sources with clean energy demonstrating the most promise in terms of stability, cost and impact on the environment.

One of these promising sources is the sun (IEA-SHC Task 41, 2012).

1.1.1 Resilient cities and solar energy

Solar energy integration in cities is one of the most debated issue in the field of urban and energy planning. A recent international publication, the Global Energy Assessment (GEA Writing Team and IIASA, 2012) states that solar photovoltaic (PV) potential in cities is a myth that can cover only less than the 4% of the electric energy needs of cities. Some analysis carried out in Tokyo showed a percentage of 2%. This study concludes that solar energy is not suitable for cities. But Tokyo is a very high compact city: what's about less compact cities where more than 50% of the world population is living?

To answer this important question very few operational tools and very few case studies are available in literature.

The thesis of the authors of this paper is that Solar Energy can be in many cases a good solution to be implemented in mid-density cities in order to reduce their dependency from external sources of energy.

Methods and tools are needed to help Public Administrations in the strategies elaboration to improving the resilience capacity of their cities to the peak oil (and for the reduction of direct and indirect CO2 emissions) and to protect their citizens from the variability and raising of the oil prices (percentage of income per capita spent in energy every year).

2. Research Objectives

The objectives of the research presented in this paper are:

- to contribute to the resilience of cities to the peak oil by the means of solar energy;
- to provide a method to quantify the percentage of electric energy demand (EED) of a city covered by the PV potential of the city;
- to provide a method to compare EED and PV potential supply from the spatial patterns point of view.

2.1. Quantitative estimation

The first part of the research provides in particular methods and procedures for the quantification of the gap between the potential electric energy producible by solar panels installed on rooftops of the city's buildings and the current EED of the city. Moreover a method to estimate the current production of electricity provided by installed solar panels is carried out. This part is useful to understand the actual chances of a city in producing a percentage of needed electricity from their own solar collectors and to provide and estimation of the state of the art of the current electric energy production by existing and installed solar PV panels in the city.

2.2. Spatial patterns comparison

The second part of the research provides method and procedures to spatially assess and compare the distribution of EED and electric energy production by potential installation of PV panels in the city. This part is useful to understand the spatial implication of energy production by solar sources and energy demand by urban activities. The results helps to plan in a better way the urban activities allocation in the space and to plan the city's network for electric energy distribution, by districts or by the entire urban context, taking into account the possible spatial synergies between demand and supply sides of energy (Vettorato et al. 2011).

3. The case study: Bressanone city

Bressanone is an Alpine city with 20.000 inhabitants located northern Italy in the South Tyrol Province. It is settled in a narrow valley floor, north to south oriented, at an average altitude of 560 m a.s.l.

The rain precipitations have an average of 700 mm per year with some peaks between July and August.

The economy is mainly based on three sectors: tourism, services and industry (mainly manufactory of aluminum and buildings).

The most ancient part of the city is located northern and corresponds to the mid-compact historical center, mainly composed by 3 to 4 floors buildings. The southern part is instead characterized by the presence of several industrial activities. The surrounding is characterized by low building density areas as well as some satellite towns.

This case study and the research has been chosen in the framework of the CO^2 reduction plan of the city and in the framework of the EU Alpine Space Project "Alpstar" (Alpstar, 2012).

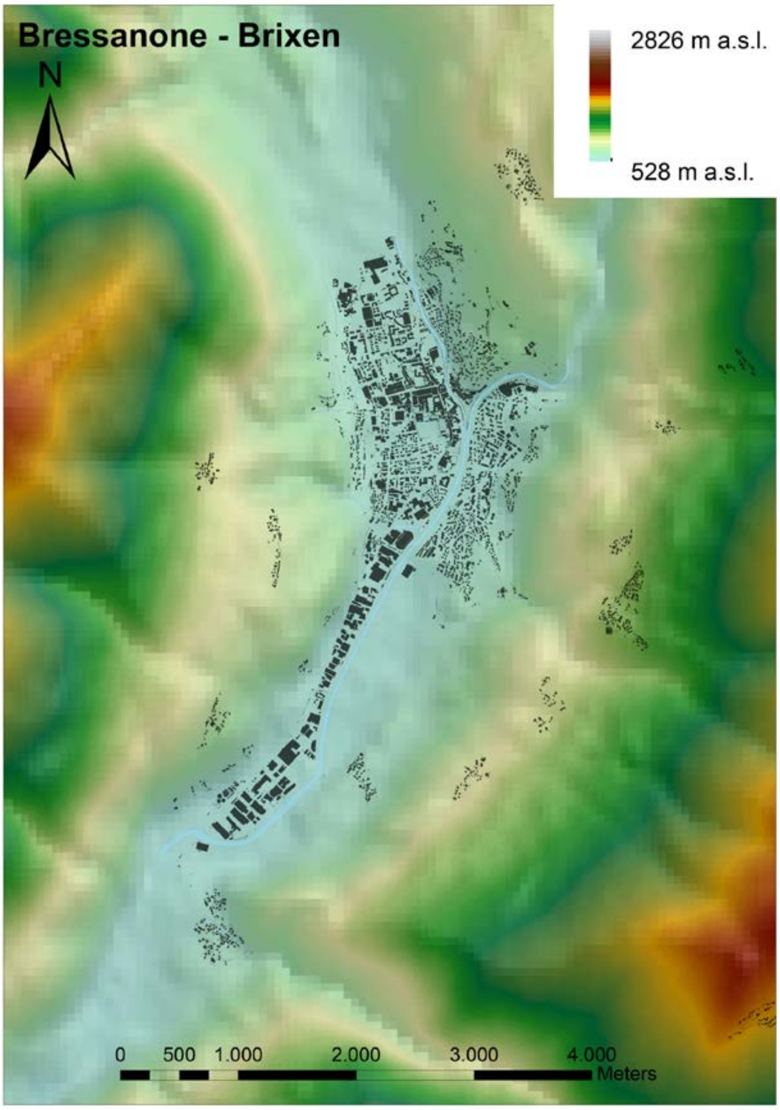

Figure 1: Digital Elevation Model of the case study area with buildings

Figure 2: Satellite photo of the case study area (Bressanone city)

4. Methodology

The proposed method follows a two tiers approach. The first is quantitative oriented and aims at identify development strategies for the energy system of the urban settlements, with particular focus to the electric energy production from PV. The second tier is spatial oriented and aim at support urban layout design taking into consideration the PV and EED spatial patterns.

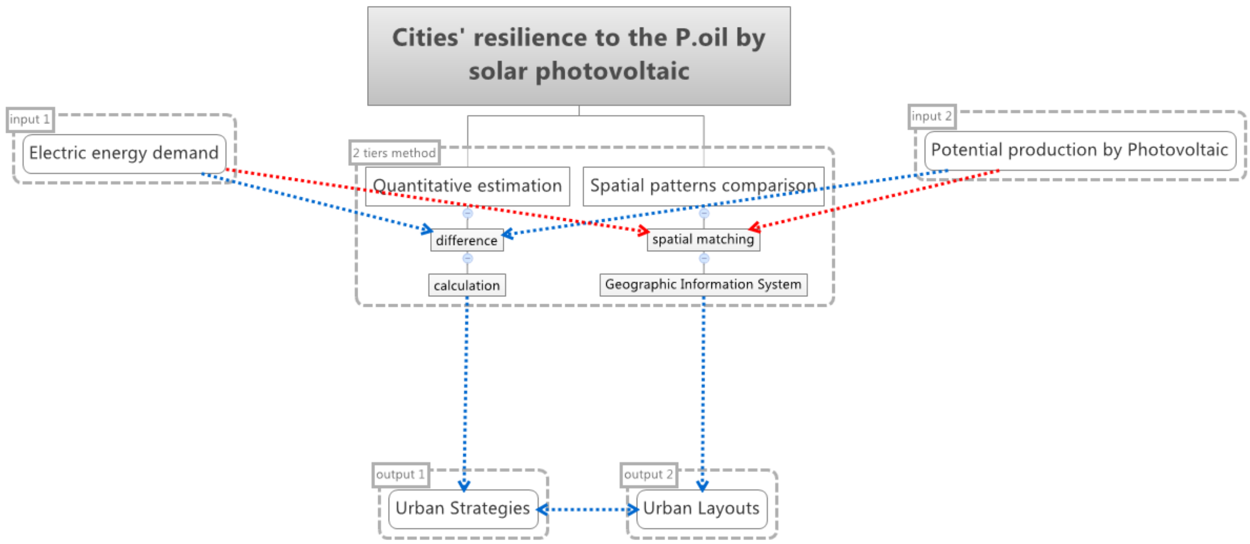

Figure 3: Methodology scheme

4.1. Quantitative estimations

The tier 1, quantitative estimation, based on the difference between EED and PV potential production for the whole case study area.

4.2. Spatial patterns comparison

The tier 2, spatial patterns comparison, based on the comparison between the EED spatial pattern and the PV potential spatial patterns.

5. Data sources and Procedure

The following scheme presented the data sources and the procedure of the research activity.

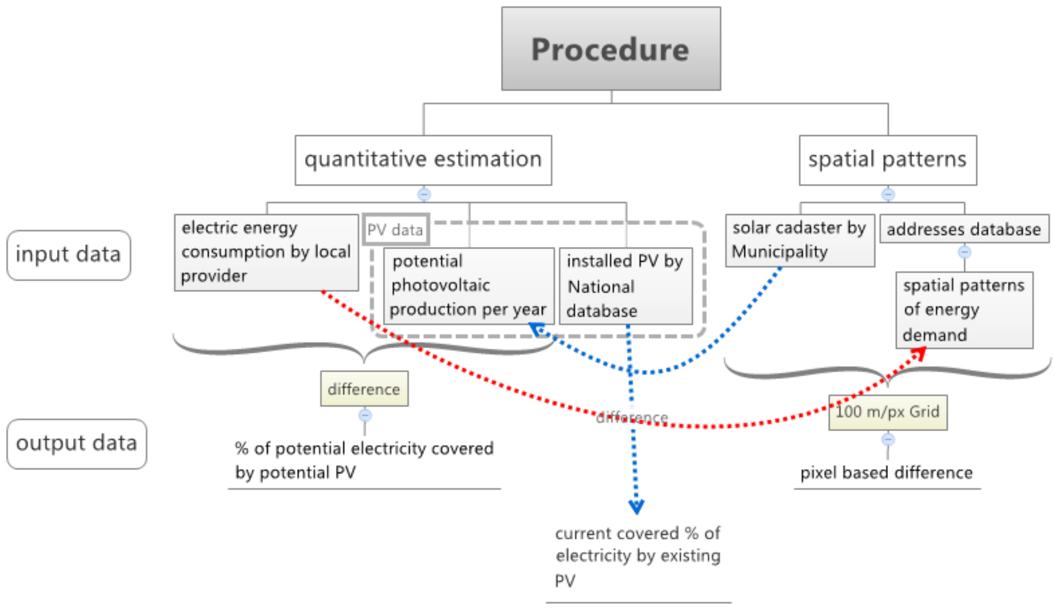

Figure 4: Procedure scheme

5.1. Input data

The EED has been derived by the dataset provided by the local energy provider of Bressanone and is referred to the year 2010. The database refers to each single electric energy counter and contains the address of the counter.

The addresses database of the buildings has been provided by the Municipality of Bressanone.

The solar cadaster for the whole city has been provided by the Municipaliy of Bressanone (Città Solare, 2012). It refers to the PV potential of each single roof dividing the potential in 4 classes:

Class	**Range**
Class 1 (not suitable):	< 800 kWh/m2
Class 2 (low suitability):	800-1000 kWh/m2
Class 3 (medium suitability):	1000-1200 kWh/m2
Class 4 (good suitability):	>1200 kWh/m2

Table 1: PV potential classes

According to (Vettorato & Geneletti, 2009) only the class n.4 has been considered in the calculations due to the economic unsustainability of the other classes for PV panels.

The National database (GSE, 2012) provided the PV power capacity already installed in the city of Bressanone in number of kWp.

The JRC database (JRC, 2012) provided the estimation of the average yearly production per kWp for the case study area, that is 1080 kWh/year per 1 kWp.

5.2 Procedure

5.2.1 Quantitative estimation

The records of each single electric energy counter have been summed up to obtain the whole EED for the city of Bressanone.

The solar cadaster has been imported in the open source Geographic Information System (GIS) software QGIS (QGIS, 2012) in order to extract the values of PV potential per single roof for the class n.4. The values has been summed up to obtain the total PV potential of the city.

Afterwards the values of EED, PV potential and PV power already installed in the area have been compared to calculate:

- The potential coverage of the EED by PV potential;
- The current coverage of the EED by existing PV panels;
- The % of PV potential already exploited by the existing PV panels.

5.2.2 Spatial patterns

The record of the single electric energy counter have been connected through a GIS software to the addresses database in order to geolocate (assign geographic coordinates) the values of EED of each single counter. The operation output was a set of geolocated points with the value of the EED as attributes.

The polygons of the solar cadaster, class n.4, have been transformed in geolocated points (the polygons centroids) with the PV potential as attributes.

Afterwards the two sets of points has been spatially aggregated through a 100m/px grid resolution. For each 100x100 meter cell the sum of the values of the point included in the cell has been calculated.

The operation produced two maps presented in Figure 5 (EED spatial patterns) and Figure 6 (PV potential spatial patterns).

Afterwards the difference between EED map and PV potential Map has been calculated in percentage in order to spatially visualize the local coverage of EED possible by PV potential. Figure 7 presented the output of this operation.

6. Results

The total calculated EED for the city of Bressanone is: 110.059.527 kWh/year.

The total estimated PV potential of Bressanone rooftops is: 51.909.917 kWh/year.

The total estimated PV yearly production by the existing PV panels already installed in Bressanone is: 6.890.596 kWh/year.

According to these data:

- the PV potential of Bressanone city could cover the 47% of its internal electricity demand;
- The PV installed are covering the 6% of the total EED, that correspond to the 13% of the total PV potential of the area.

The spatial patterns analysis shows that:

- the EED is mainly concentrated in the historical center and in the industrial area;
- the PV potential is spatially distributed on the territory with some concentration in the industrial area where the roofs are wider and in the historical center that is better exposed to the sun;
- the EED covered by PV potential is low in the industrial area, is medium in the historical center while is higher in the surrounding areas and in the satellite settlements.

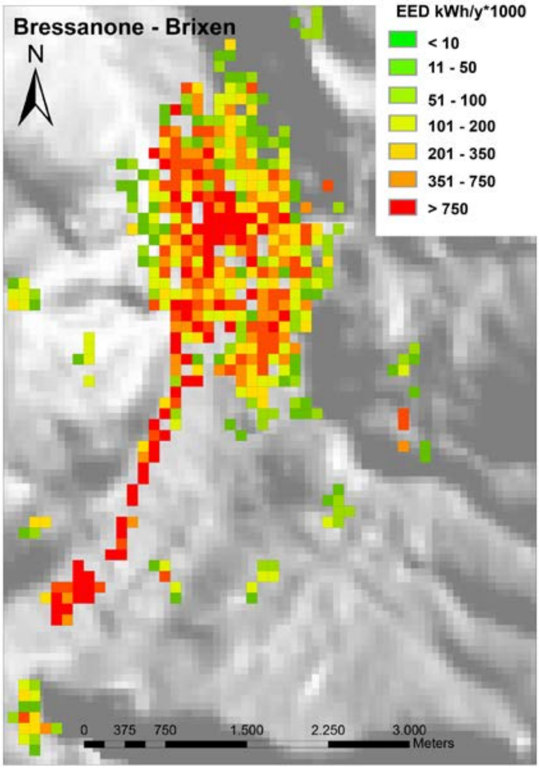

Figure 5: EED in kWh/year

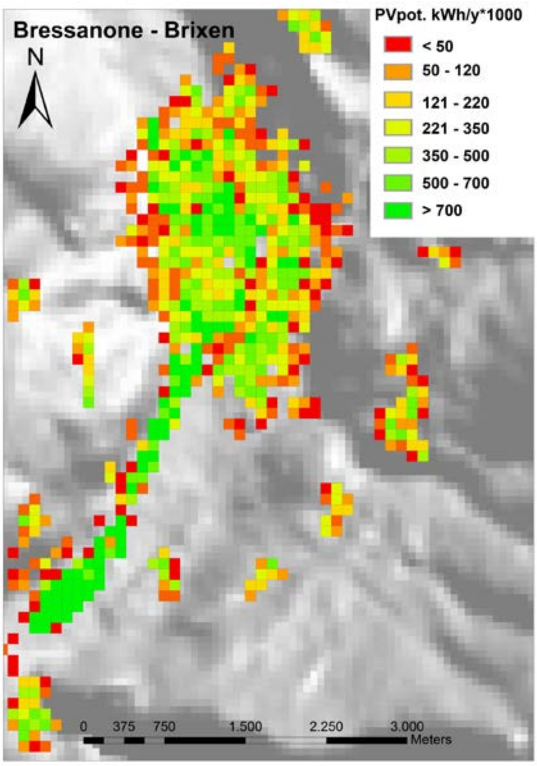

Figure 6: PV potential in kWh/year

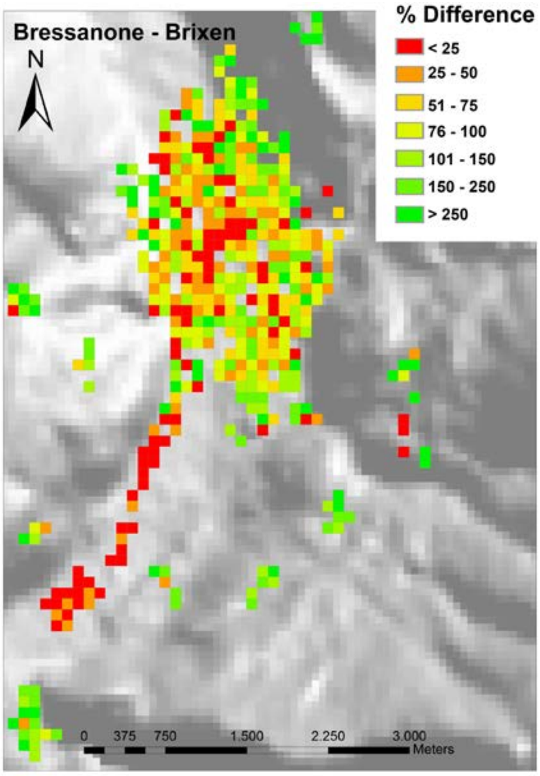

Figure 7: % of EED covered by PV potential

7. Conclusions and discussion

The application to the case study shows that the city of Bressanone has the potential capacity to cover 47% of its EED by PV panels, but so far only the 13% of this potential is exploited.

From the spatial point of view very interesting is the graphical results showing the spatial distribution of the difference between EED and PV potential. The historical center, the most compact one, shows low spatial matching between EED and PV potential with a percentage of coverage between 20% and 70 %. This can be explained by the medium-high EED density located in the historical center, and the low availability of roofs capable to harvest the solar irradiation. Very similar is the case of the industrial area, even if the spatial matching are more heterogeneous, with an coverage percentage between 2% and 45%. This can be explained by a very high EED located in few spots, that is coherent with the industrial nature of the area. The less dense surrounding urban areas and the satellite towns show a better spatial matching between EED and PV potential. This can be explained by the low density EED and the high availability of roofs capable to harvest the solar irradiation.

The presented method is replicable to other context and shows to be useful

- to quantify the percentage of electric energy demand (EED) of a city covered by the PV potential of the city;
- to compare EED and PV potential supply from the spatial patterns point of view.

Moreover the presented method shows to be useful:

- to understand the actual chances of a city in producing a percentage of needed electricity from their own solar collectors and to provide and estimation of the state of the art of the current electric energy production by existing and installed solar PV panels in the city;

- to better plan the urban activities allocation in the space and to plan the city's network for electric energy distribution, by districts or by the entire urban context.

These kind of estimations should be integrated in the urban planning tools available for Urban Planners, in order to let a better integration of solar power potential into the urban design and urban strategies elaboration, helping cities and their citizens to be more resilient to the peak oil.

Finally the results of this research are in conflict with the conclusions of the Global Energy Assessment (IIASA 2012), re-lunching solar energy as one of the most promising energy sources in medium and low compactness cities like Alpine cities and towns are.

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