Available online at www.sciencedirect.com
ScienceDirect
Energy Procedia 83 (2015) 310 – 319
Energy Procedia

§7th International Conference on Sustainability in Energy and Buildings

Geographical Information System as support tool for Sustainable Energy Action Plan

Antonio Gagliano[a]*Francesco Nocera[a], Antonio D'Amico, Catalina Spataru[b]

[a]*Department of Industrial Engineering, University of Catania, Viale A. Doria 6, 95125 Catania, Italy*
[b]*UCL Energy Institute, University College of London, Central House, 14 Upper Woburn Place, London WC1H 0NN, United Kingdom*

Abstract

The Sustainable Energy Action Plan (SEAP) shows that in 2008, the European Commission approved a package of measures entitled "Energy for a Changing World" which is also known as "20–20–20" targets. Therefore, for quality control management and efficiency in the SEAP, it is essential obtaining suitable information on the building's energy performance and consumptions. This paper illustrates a methodology to support energy policies at the urban level using Geographical Information Systems (GIS) in order to characterize and monitoring the energy performance of a region. In this way, the GIS platform provide a mapping representation of the actual state of energy resources in order to develop sustainable energy policies. It was concluded that the GIS can be a useful support during the phases of organization of a SEAP and, for monitoring the actuation of the actions which were foreseen. As a case study, a small town in the Sicily region (Italy) was considered. The proposed methodology aims to help local communities to make decisions for estimating and monitoring the energy consumption in buildings (residential, commercial, industrial), and to simulate effects of energy policies.

Peer-review under responsibility of KES International
Keywords: energy policy, GIS, urban planning, SEAP .

1. Introduction

EU leaders have committed to transforming Europe into a highly energy-efficient, low carbon economy. After the adoption, in 2008, of the EU Climate and Energy Package, the European Commission launched the Covenant of Mayors to endorse and support the efforts deployed by local authorities in the implementation of sustainable energy policies [1,2]. Indeed, local governments play a critical role in mitigating the effects of climate change, especially that 80% of energy consumption and CO_2 emissions are associated with urban activity [3,4]. The recent Covenant of Mayors Agreement demonstrated strong local support for active involvement in sustainable energy planning. The

* Corresponding author. Tel.:+39-095-7382451; fax:+39-095-738-2496.
E-mail address: agagliano@dii.unict.it

Peer-review under responsibility of KES International
doi:10.1016/j.egypro.2015.12.185

agreement focuses on communities reducing CO_2 emissions and waste, as well as foreign energy dependence reduction and increase of energy efficiency and sustainable urban mobility. In order to achieve the European target every city must develop its own SEAP [5]. After that, the plan will be monitored and evaluated by an outside organization to determine its compliance.

The actions of the SEAP affect the following sectors: built environment; municipal infrastructure (heating, cooling, public lighting,); land use and urban planning; distributed renewable energy sources; public and private transport policies and urban mobility. Consequently, the local communities have the opportunity to have an impact on the climate change initiative by starting a new energy policy based on energy efficiency and renewable energy sources in order to diminish emissions of CO_2.

Undoubtedly, cities have a high level of complexity, especially considering problems related to obtaining suitable information on building's energy performance and consumption. So, obtaining suitable information about the building's energy performance and consumption became essential for quality control management and efficiency in the SEAP. A useful tool that can help the development and the monitoring of the SEAP is the geographic information system platform (GIS), which makes possible the management of all available information. GIS method has been valued for improving communication and collaboration in decision making, for effectively managing resources and assets, enhancing the efficiency of workflows, improving the accessibility of information, and generally offering tangible cost savings to small and large organizations. The energy class of buildings and their energy consumption can be stored in the GIS platform and periodically updated for estimating, monitoring and verification of any reductions in energy consumption. In addition, the forecast of the CO_2 emissions due to improving energy efficiency and/or use of renewable energy sources (solar thermal, solar PV, wind, etc.) can be verified.

Furthermore, a web interface or interactive informative totem can be created, which inform citizen on the energetic consumptions of their communities and encourage them to perform sustainable actions in their own houses or work activities. In the last ten years, many studies have used GIS platforms for energy and environmental prediction models [6, 7, 8]. Many researchers investigated energy consumption in the buildings sector, such as the work done by Tommerup et al [9], Dascaloaki et al. [10], Theodoridou et al.[11]. In addition to these, there are studies for energy performance classification of residential building stocks at the urban scale such as Dall O' et al. [12], studies on energy strategies in the building sector at urban scale such as Caputo et al [13] which support energy policies.

2. Methodology

The proposed methodology in this study aims to help local communities to make decisions for estimating and monitoring the energy consumption in buildings (residential, commercial, industrial), and to simulate effects of energy policies. In this way, the implementation of GIS platform became essential to give a mapping representation of the actual state of energy resources in order to develop sustainable energy policies.

In Italy, information on the building stock can be obtained from the National Census database, (ISTAT population census year 2001, 2006, 2012) [14], and from the buildings' map that are available at the Technical Departments of the Municipalities (TDM).

The National Census database provides information about the population and buildings for a geographic area. While the buildings' map provides information about the layout, dimensions (area, perimeter and height of buildings) and destination of use of the buildings. In some cases the energy building consumption are also available.

After data collection, the first step was dedicated to link the ISTAT National Census information with the buildings 'geometric data in order to characterize the building stocks considering construction period classification as reported in the National Census.

Whereas energy-building behavior is not only related to the construction period but also to the architectural, morphological and technological solutions that characterize each building [15]. Consequently the authors used the ''ANNEX B'' reported in the standard UNI TS 11300-1 (2008) [16] in order to define the thermo-physical and construction characteristics of buildings such as: size, number of floors and the form factor (S/V), that is the ratio between external surface of the building envelope and heated volume. The relative energy consumptions for space heating and Domestic Hot Water production (DHW) were evaluated by taking into account typical system and efficiencies regarding gas boiler as reported in the national standard UNI TS 11300-2 (2008)[17] and cooling systems from national standard UNI TS 11300-3 (2010) [18]. Figure 1 shows the different step used for implemented the proposed procedure.

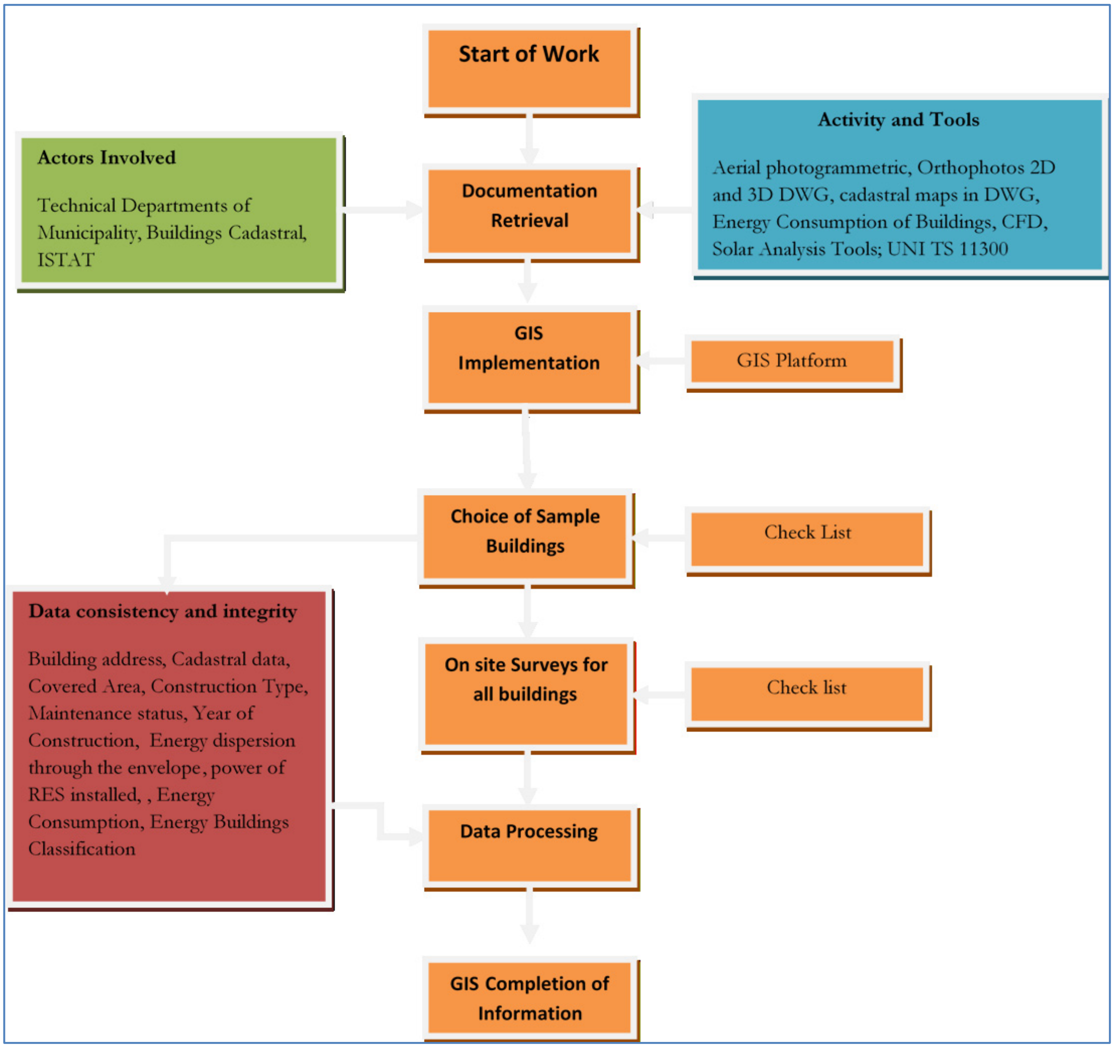

Fig.1: Flowchart of the implemented procedure

ArcGIS 10.1 was used to evaluate the solar potential in the investigated area [19]. Such tool uses point-based imagery of local level elevation, slope, and aspect to determine the amount of energy available. Optimized algorithms account for variations in surface orientation and atmospheric weather data. Moreover, the GIS platform can host results data calculated by means other software. As an example, it can be mentioned the possibility to calculate the wind field within the urban environment through computational fluid dynamic simulations (CFDs), and then input that wind field in the GIS for evaluating the energy yields of micro wind turbines.

Gagliano et al. [20], [21], proposed the following steps for evaluating the potentiality of micro wind turbines in urban area:

a) anemological characterization of the site coming from available wind measurements
b) CFDs within the investigated urban environment to calculate the wind flow field

c) transfer of CFDs output results in GIS environment
d) evaluation of urban wind turbines (UWTs) energy production.

3. Case Study

The GIS platform was used as support tool for developing the SEAP in the municipality of Randazzo, which is situated at the northern foot of Volcano Etna (37°52'37"56 N; 14°57'1"80 E; altitude 765 m), 70 kilometers northwest of Catania. Figure 2 shows the view in ArcMap of the aerial photo of Randazzo.

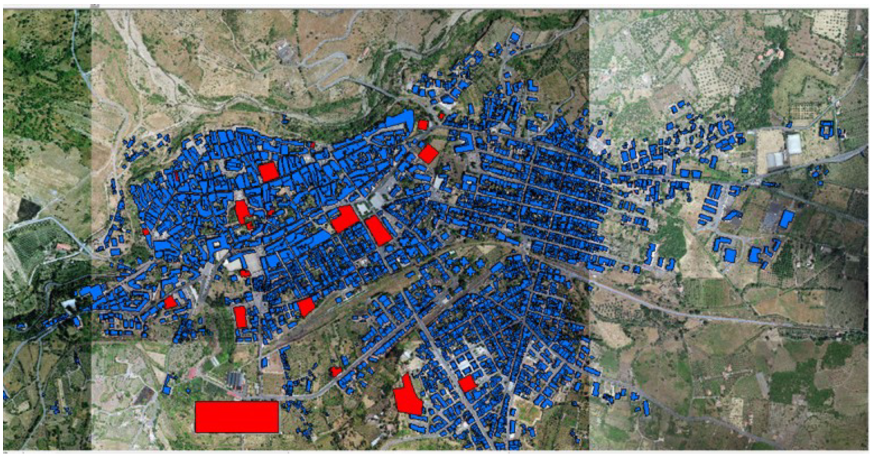

Fig.2: View in ArcMap of the Aerial photo of Randazzo

Energy consumption and CO_2 emissions are dependent on many factors: level of economic activity, population, density, characteristics of the building stock, usage and development of the transport modes, citizens' attitudes, climate, and so on [22]. Table 1 summarizes the general information of the municipality of Randazzo. The degree days of a location (GG) are calculated through the sum, extended to every day of an annual conventional heating period, of only positive differences between the indoor temperature, defined conventionally by every nation, and the mean daily external temperature.

Table 1. General data of municipality of Randazzo

Surface	Inhabitants	Population density	Average annual temperature	Average annual irradiance	GG
208.84 km^2	11,019	52.76 In./km^2	13.92 °C	1,880 kWh/m^2	1,934

Figure 3 reports the classification of the buildings stock according to their construction date. Amongst 5,884 buildings, 4,468 are residential buildings with an inhabitable surface of 411,524 m^2. About 94.0 % of building stock has a heating system for DHW production or space heating.

The following databases sources: the Regional Informative System for Environment and Energy, the National Census database (ISTAT year 2001, 2006, 2012) were used in the calculation of the energy consumption of the Randazzo municipality.

Figure 4 reports energy consumption per each sector considered. As a result, a total yearly energy consumption of 113.51 GWh was calculated. Consequently, the energy consumption per capita is 10.06 MWh, which is about 70% lower than the national energy consumption per capita, which is approximately 34.77 MWh [23]. The difference is due to the modest industrialization of Randazzo and its territory.

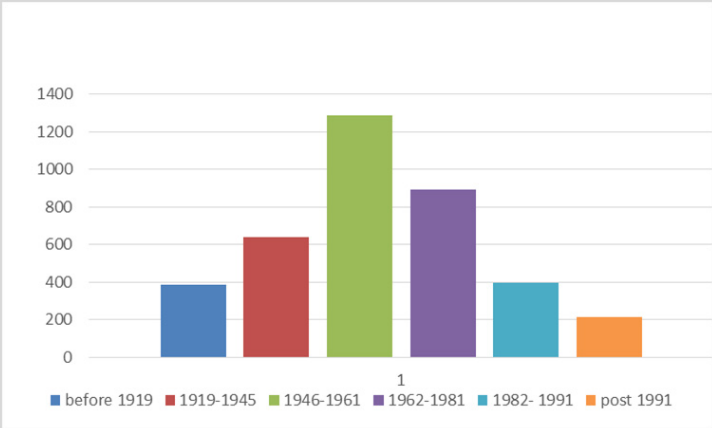

Fig.3: Classification of the existing buildings

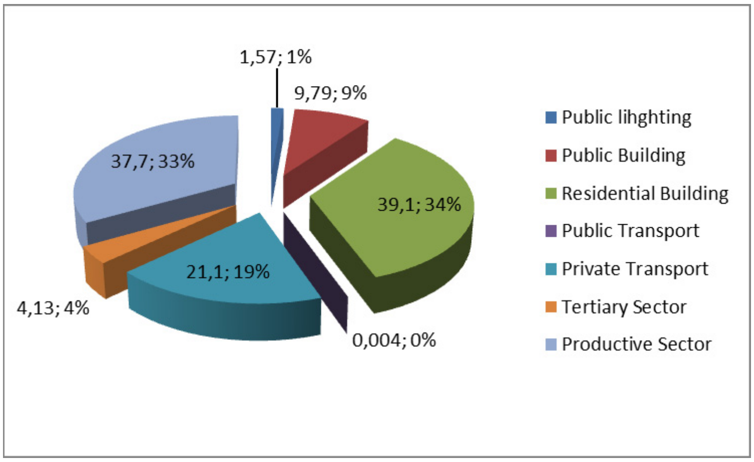

Fig.4: Energy consumptions differenced for energy vector

The Baseline Emission Inventory (BEI) of Randazzo for the referee year 2011 was calculated using the Italian greenhouse gas inventory [24]. In addition, the emissions from road transport made by ISPRA[25] that provides provincial emissions into the atmosphere classified by activity level based on CORINAIR (SNAP), was done through disaggregation of the national inventory, adopting a top-down approach. Thus, CO_2 emissions of 34.317 tons (3.11 tons per capita) were evaluated.

Table 2 reports the CO_2 Emission (ton) for different vectors and sectors.

Table 2. Energy Consumption and CO_2 Emission for different vectors and sectors

Sector	**Electricity**		**Gas**		**Biomass**		**Diesel/Oil**		**Gpl**		**Gasoline**		**Carbon**		**Total**	
	GWh	CO_2	GWh	CO_2	GWh	CO_2	GWh	CO_2	GWh	CO_2	GWh	CO_2	GWh	CO_2	GWh	CO_2
Productive	12.71	5,786	8.88	1,794	0.027	0	11.46	3,090	2.31	524	0	0	2.34	799	37.74	11,998
Residential Building	12.54	5,705	15.10	3,051	0.74	0	0.55	15	10.14	2,302	0	0	0	0	39.07	11,209
Tertiary	5.54	2,521	2.91	588	0.017	0	0.019	5	1.30	295	0	0	0	0	9.79	3,410
Transport	0	0	0.24	48	0	0	9.03	2,410	0.83	189	11.0	2,740	0	0	21.10	5,394
Public Building	2.95	1,343	1.18	239	0	0	0	0	0	0	0	0	0	0	4.134	1,583
Public lighting	1.56	713	0	0	0	0	0	0	0	0	0	0	0	0	1.566	713
Public Transport	0	0	0	0	0	0	54	9.74	0	0	0,034	14,46	0	0	0,09	18
Total	35.32	16,068	28.31	5,720	0.78	0	21.12	5,666	14.58	3,310	11.04	2,754	2.34	799	11.35	34,325
TEP	6,604		2,435		67		1,816		1,254		950		202		**13,328**	

Starting from this figure, it was planned the energy policies actions to achieve the 20% reduction by 2020, one of the headline target of the Europe 2020 growth strategy.

Table 3. Intervention planned in the public sector

Sector	Field	ID	Action	Energy Savings (MWh)	Renewable Energy (kW/MWh)	CO_2 Reduction (ton)	Expected Contribute (%)
Buildings, equipment / tertiary municipal	Building Envelope	PA 1	Improvement of thermal insulation	160.10	0	33.04	0.48
	Generator/ RES	PA 2	Opportunities of Energy Savings	35.59	0	7.37	0.10
		PA 3	Replacing the heat generator	90.54	0	22.00	0.32
		PA 4	PV on public buildings	76.78	100/ 97.82	79.45	1.15
		PA 5	Micro hydro power plant	864.00	2x75/864.0	432.58	6.30
		PA 6	Micro Wind Turbine	100.00	75/100.00	91.03	1.32
		PA 7	Solar thermal	72.90	72.90	30.23	0.44
		PA 8	Energy exploitation of sewage sludge	20.0	20.0	18.20	0.26
	Other	PA 9	Reducing water consumption	367.52	0	167.28	2.43
		PA 10	New arboreal vegetation	_	0	12.44	0.18

The energy actions planned were categorised in the following main sectors: buildings and public services, private buildings, transport, tertiary and industry. An analysis of the energy efficiencies and vulnerability, for each of these sectors and specific interventions of energy revamping have been evaluated.

Table 3 summarizes the intervention planned in the public sector. The energy revamping will act on the energy retrofit of the building, improve the efficiency of heating and cooling generation systems, installation of RES (biomass, wind, photovoltaic, solar thermal), refurbishment of public lighting plants and installation of micro hydro turbine on the water main.

One of the actions, which will allow obtaining significant energy savings, is the installation of micro hydro power plants [26] along the conducts of the public aqueduct. It has been discussed also that the production of renewable energy should increase from the current 13 MWh to 5977 MWh. The energy consumptions will be reduced of about 14.52 MWh, that is of about 12%. As regard the building energy consumption, the GIS platform can be used for storing all the collected data, but also especially for monitoring the progress of the interventions proposed and for developing new scenarios.

3.1. GIS platform as support tool for the SEAP.

For the GIS platform of Randazzo, we used the ArcGIS 10.1 software that is produced by ESRI Corporation. ArcMap was used to create the layouts while ArcScene was implemented to build 3D Models of the 5,884 buildings existing in Randazzo. Aero-photogrammetry, cadastral maps and aerial-photos were imported in geodatabase. After that, the authors obtained the Shape File of the urban aggregate. The 3D model of the City of Randazzo was obtained by importing the shape file with the software Google SketchUp Pro 8.

Table 4. Data record in the database

Field	Description	Units	Information
01	Building ID	-	ID number of a building
02	Cadastral Maps Reference	-	Information detected from Cadastral maps
03	Building typology	-	Information detected from the municipality's technical department or direct survey
04	Destination	-	Type of Destination (e.g., residential, tertiary, commercial, etc).
05	Construction period	-	Construction period of the building
06	Maintenance status	-	Information detected from the municipality's technical department about status
07	Roof type	-	Information detected from aerial photogrammetric
08	Roof orientation	-	Information detected from aerial photogrammetric
09	Number of floors	-	Information detected from the municipality's technical department about status
10	Height	m	Information detected from the municipality's technical department about status
11	Roof area	m^2	Calculated by tools
12	Volume	m^3	Calculated by tools
13	Gross surface ext. walls	m^2	Calculated by tools
14	Window area	m^2	Calculated by tools
15	S/V	m^{-1}	Calculated by tools
16	Thermal dispersion area	m^2	Calculated by tools
17	Solar thermal	m^2	Available field for entering data from survey
18	Solar PV	kWp	Available field for entering data from survey
19	Incident radiation	kWh/ m^2	Available field for entering data on Solar Radiation Tool
20	DHW	kWh/m^2 y	Primary energy for DHW supply calculated on the basis of standard use conditions
21	EP_H real.	kWh/m^2 y	Available field for entering data from Energy Audit.
22	Energy class real	-	Energy class assigned referred to the real EP_H
23	EP_H ideal	kWh/m^2 y	Calculated by tools
24	Energy class ideal	-	Energy class assigned referred to the ideal EP_H
25	Electrical Consumption	kW	Available field for entering data from Energy Audit.

Thus, for each building, information on activities were extracted from different databases (Table 4) and included in the GIS platform.

Therefore, for each of the above field a graphical representation has been obtained. Figure 5 shows the Maps of Buildings in function of the ratio, S/V, between the external surface of the building envelope and the heated volume. Moreover, for each building all the stored data can be visualized by clicking on it.

Figure 6 shows the data that are available selecting a specific building (e.g building city hall).

Fig. 5. Maps of Buildings in function of S/V ratio

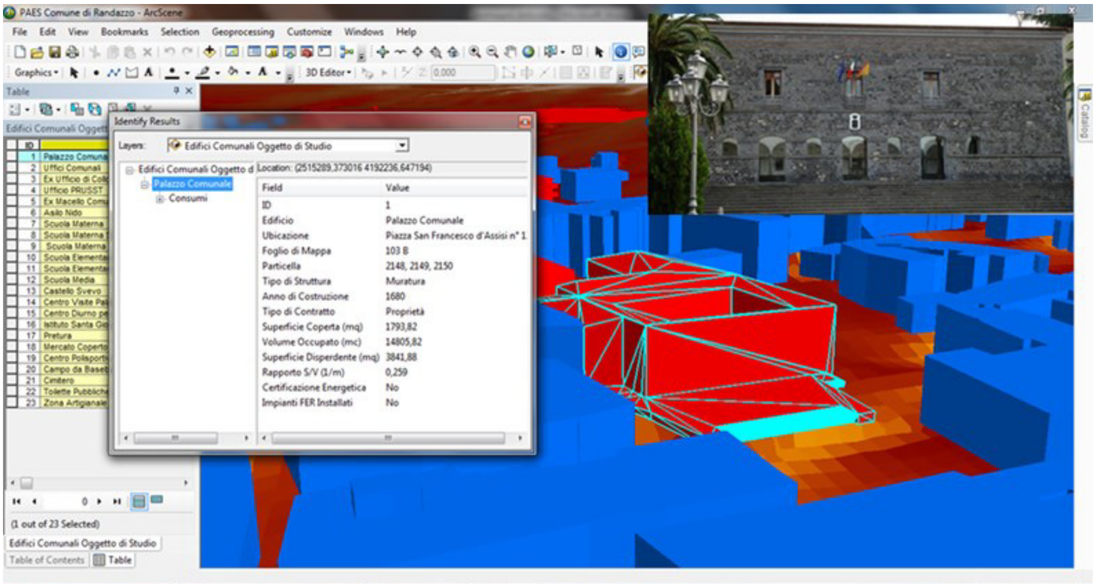

Fig. 6. An example of query of Randazzo City Hall

Starting from the 3D model of the urban area, the solar radiation incident on any building surface has been calculated through the "Solar Radiation Area" function, which is a sub-application of "Solar Analyst" tools. This tool uses point-based imagery of local level elevation, slope, and aspect to determine the amount of energy available.

Optimized algorithms account for variations in surface orientation and atmospheric weather data. Total global radiation ($Global_{tot}$) was calculated from the sum of the direct and diffuse radiation of all sectors on the topographic surface. The output of the Solar Radiation Area function was the incident radiation measured in watt hours per square meter (Wh/m^2) that allows to build the irradiance map for the whole studied area. Therefore, it is possible to know for each building, which is the potential energy production.

Obviously, this database must be continuously updates, and in this manner, it will be possible to monitoring the state of actuation of the SEAP actions.

Figure 7 shows an example of an inquiry related to the state of actuation on the public sector.

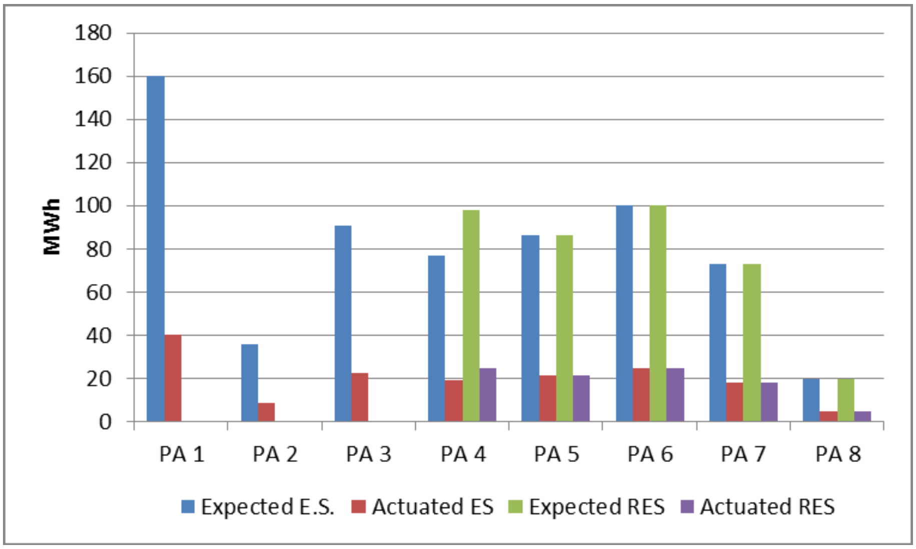

Figure 7: Comparison between programming and realization

where:

- expect ES indicates the previsions of the energy saving programmed
- actuated ES indicates the reached energy saving at specific time
- expect RES indicates the prevision on the power of Renewable Energy plant programmed
- actuated RES indicates the installed power of Renewable Energy plant at specific time

Such analysis allows monitoring each planned intervention and verifying its current state of actuation. Thereby, the city administration can incorporate the necessary actions in the foreseen time or modify the SEAP if new perspectives appear. Understanding these interactions will allow for a more efficient integration of activities and sustainable energy measures, and the development of synergies within the SEAP and the urban development strategy.

4. Conclusions

A Geographical Information System has been adapted as a tool support of the Sustainable Energy Action Plans, which permits the identification of action to reach and control the 20-20-20 targets. Starting with information that is already available on building stock (i.e., cartographic documentation, thematic maps, geometric data and others) the Geographical Information System allows to organize, systemize and geo-reference all the available data.

The spatial geographical energy needs are estimated by using primarily data and when these are not available, statistical values were included. This will allow the identification and localization of existing renewable energy resources and energy needs within the urban area. Based on this case study, the adoption of a Geographical Information System proved to be a suitable support tool during both phases: elaboration and realization of the Sustainable Energy Action Plans. Moreover, it is possible to propose such methodology for application in different geographical areas or context. Indeed, such methodologies will be able to support energy policies at the urban level, make decisions for estimating and monitoring the energy consumption in buildings (residential, commercial, industrial) taking into account the approaches of different stakeholders to develop low carbon models.

Acknowledgments

We wish to express our sincere thanks to the municipality of Randazzo for providing us with all the necessary support for the research.

References

[1] Directive 2002/91/EC of The European Parliament and of The Council of 16 December 2002 on the energy performance of buildings.
[2] Energy Cities. EU 2020 position paper. Making the Covenant of Mayors a successful multilayer governance test in the energy and climate field.Brussels; January 2010.
[3] European Commission, 2014. The 2020 climate and energy package. (http://ec.europa.eu/clima/policies/package/index_en.htm, accessed April 2014).
[4] Parliament, E., 2008. Survey: Europeans ' attitudes towards climate change, 145p.
[5] European Commission, 2014. (http://www.covenantofmayors.eu/index_en.html, (accessed April 2014).
[6] P. J. Jones, S. Lannon, and J.Williams. Modelling building energy use at urban scale, Seventh International IBPSA Conference Rio de Janeiro, Brazil August 13-15, 2001
[7] L. Thuvander. Towards environmental informatics for building stocks, Göteborg, Sweden: Department of Built Environment & Sustainable Development, Chalmers University of Technology, 2002
[8] Thuvander L. Tornberg, J. A Gis model for the building stock of Goteborg. Proceedings of the 25th Annual ESRI User Conference, 2005.
[9] H. Tommerup, S. Svendsen, Energy savings in Danish residential building stock, Energy and Buildings 38 (2006) 618–626.
[10] E. Dascalòaki, K. Droutsa, A.G. Gaglia, S. Kontoyiannidis, C.A. Balaras, Data collection and analysis of their building stock and its energy performance – an example for Hellenic buildings, Energy and Buildings 42 (2010) 1231–1237
[11] I. Theodoridou, A.M. Papadopoulosb, M. Hegger, Statistical analysis of the Greek residential building stock, Energy and Buildings 43 (2011) 2422–2428
[12] G. Dall'O', A. Galante, M, Torri, A methodology for the energy performance classification of residential building stock on an urban scale, Energy and Buildings 48 (2012) 211–219
[13] P. Caputo, G. Costa , S. Ferrari, A supporting method for defining energy strategies in the building sector at urban scale, Energy Policy 55 (2013) 261–270
[14] ISTAT, homepage of ISTAT.www.istat.it
[15] CNR, 1982. Repertorio delle caratteristiche termofisiche dei componenti edilizi opachi e trasparenti. Roma, Italy.
[16] UNI TS 11300-1, 2008. Prestazioni energetiche degli edifici – Parte 1: Determina- zione del fabbisogno di energia termica dell'edificio per la climatizzazione estiva ed invernale – Ente Nazionale Italiano di Unificazione (UNI), Milano, Italy.
[17] UNI TS 11300-2, 2008. Prestazioni energetiche degli edifici – Parte 2: Determina- zione del fabbisogno di energia primaria e dei rendimenti per la climatizza- zione invernale e per la produzione di acqua calda sanitaria – Ente Nazionale Italiano di Unificazione (UNI), Milano, Italy.
[18] UNI TS 11300-3, 2010. Prestazioni energetiche degli edifici – Parte 3: Determina- zione del fabbisogno di energia primaria e dei rendimenti per la climatizza- zione estiva – Ente Nazionale Italiano di Unificazione (UNI), Milano, Italy
[19] Gagliano, A., Patania, F., Nocera, F., Capizzi, A., Galesi, A., GIS-based decision support for solar photovoltaic planning in urban environment (2013) Smart Innovation, Systems and Technologies, 22, pp. 865-874
[20] Gagliano, A., Patania, F., Capizzi, A., Nocera, F., Galesi, A. A proposed methodology for estimating the performance of small wind turbines in urban areas (2012). Sustainability in Energy and Buildings, pp. 539-548
[21] Gagliano, A., Nocera, F., Patania, F., Capizzi, A., Assessment of micro-wind turbines performance in the urban environments: An aided methodology through geographical information systems, (2013) International Journal of Energy and Environmental Engineering, 4 (1), pp. 1-14
[22] Spataru, C., Gauthier, S. How to monitor people 'smartly' to help reducing energy consumption in buildings?(2014) Architectural Engineering and Design Management, 10 (1-2), pp. 60-78.
[23] http://data.worldbank.org/indicator/
[24] Italian Greenhouse Gas Inventory 1990-2011, National Inventory Report 2013
[25] ISPRA ,National Inventory of road transport emissions and breakdown, Reports 124/2010
[26] Gagliano, A., Tina, G.M., Nocera, F., Patania F. Technical and Economic Perspective for Repowering of Micro Hydro Power Plants: A Case Study of an Early XX Century Power Plant (2014) Energy Procedia 62, pp.512-521.