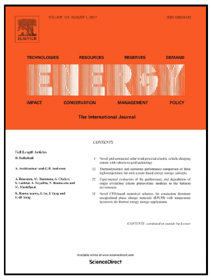
Accepted Manuscript



A Renewable Energy System for a nearly Zero Greenhouse City: case study of a small city in southern Italy

G. De Luca, S. Fabozzi, N. Massarotti, L. Vanoli

PII: S0360-5442(17)31178-7

DOI: 10.1016/j.energy.2017.07.004

Reference: EGY 11191

To appear in: *Energy*

Received Date: 27 November 2016

Revised Date: 28 June 2017

Accepted Date: 01 July 2017

Please cite this article as: G. De Luca, S. Fabozzi, N. Massarotti, L. Vanoli, A Renewable Energy System for a nearly Zero Greenhouse City: case study of a small city in southern Italy, *Energy* (2017), doi: 10.1016/j.energy.2017.07.004

A Renewable Energy System for a nearly Zero Greenhouse City: case study of a small city in southern Italy

G. De Luca, S. Fabozzi, N. Massarotti, L. Vanoli*[1]

Engineering Department

University of Naples "Parthenope", Isola C4, Centro Direzionale, 80143 Naples, Italy

e–mail: giusi.deluca@uniparthenope.it

salvatore.fabozzi@uniparthenope.it

massarotti@uniparthenope.it

laura.vanoli@uniparthenope.it*

ABSTRACT

This paper presents an economic and energy feasibility analysis of a renewable energy system for a small city in southern Italy to convert it to zero greenhouse gas city by 2030. The proposed energy infrastructure utilises different technologies: wind turbine, photovoltaic panels and biogas cogeneration plants to produce electric energy, and thermal solar panels, cogeneration and heat pumps to meet the thermal energy demand of the city. The electrification of transport sector is also considered. The whole city energy system is analysed by the EnergyPLAN software to evaluate streams combination and potential synergies between the different sectors. In order to improve the analysis, PhotoVoltaic technology has been simulated in TRNSYS environment, to obtain detailed prediction of this component of the energy infrastructure. The system behaviour was analysed considering different time bases: daily, weekly and yearly. The EnergyPLAN outputs include the aggregated yearly

[1] *Corresponding Author: laura.vanoli@uniparthenope.it

production and demands of all modelled energy conversion systems, as well as hourly values useful to identify the measures to make Altavilla Silentina nearly zero carbon city. Every measure identified becomes a new input in EnergyPLAN to evaluate its effect on city energy balance. The economic analysis has been performed to evaluate the electricity and thermal energy costs.

KEYWORDS

Smart Energy Systems, Smart City, Energy Planning, Renewable Energy, TRNSYS, EnergyPLAN.

1. INTRODUCTION

In Europe, a number of municipalities and public bodies have already adopted integrated urban approaches to energy saving, for example by developing and implementing the Sustainable Energy Measures Plan (SEAP), proposed under the Covenant of Mayors initiative [1]. These plans need to be updated every five years in order to take in account the development of new regional and local energy plans and strategies [2]. In fact, Member States have to encourage municipalities and other public bodies to adopt integrated and sustainable energy efficiency plans with clear objectives, to involve citizens in their development and implementation, and to adequately inform them about their content and progress in achieving objectives [3]. Indeed, the urban dimension is crucial due to the fact that 70% of the world population will be living in urban areas by the next 40 years [4].

Future energy solutions must be developed locally based on sustainable and realistically achievable plans, that must be tailored to the local context, perspective, needs and constraints such as:

- Specific territorial characteristics and climate conditions;

•Current and forecasted end user's demands in locations with sufficiently high population/activity densities, and in the proximity of energy sources;

• Opportunities to further develop the energy infrastructure, as well as the integration of highly efficient cogeneration plants;

• Availability of Renewable Energy Sources;

• Availability of waste heat sources at urban and industrial level (waste heat from incineration, power plants and other industrial facilities, sewage networks, transportation, aquifers, etc.) .

The analysis of the territory is important to design new energy systems that can convert cities in to zero or nearly zero greenhouse city. A city can be defined as "zero greenhouse" when the CO_2 production is zero [5], in other words when the energy production system is a renewable energy system.

Examples of possible 100% renewable cities have already been reported in literature [6-12; 28]. One of the most interesting is represented by the Danish city of Frederikshavn [6] The energy demand of the city is satisfied by off-shore wind plants, district heating supplied by heat recovery of thermal waste and by low-temperature geothermal heat pumps [7]. The authors of this study outline a scenario for the transition of Frederikshavn's energy supply from predominantly fossil fuels to locally available renewable energy sources. The scenario includes all aspects of the energy demand in Frederikshavn, such as electricity demand, thermal energy demand, industrial energy demand as well as the energy demand for transportation.

For Aalborg Municipality in Denmark [8], the possibilities to enable the city to become independent from fossil fuels have been investigated, through a combination of low-temperature geothermal heat, wind power and biomass. The results of the analyses show that it is possible to cover the city energy needs through the use of locally available energy sources if additional significant electricity and heat savings measures are combined with fuel substitution in the transport sector.

Climate change and energy security are imposing also for the city of Hong Kong to shift from a fossil based to a clean and low-carbon energy structure, as proposed in [9] where the present energy structure of the city is examined, and alternative future sustainable energy strategies are analysed. The Hong Kong government has planned to import more nuclear power from mainland by 2020, however this will not be possible in the near future due to Fukushima nuclear accident. In [9] an alternative scenario based on a more extensive use Renewable Energy Sources proposed to replace nuclear power. The results show that both scenarios can achieve the targeted carbon reduction, however, RES present better results in terms of environmental, social benefits and long-term sustainability.

Another interesting study of zero carbon energy system, one large scale, has been presented by Dominkovic et al. [10], who analyse the steps necessary for a transition of South East Europe Regions to a 100% renewable energy system by 2050. The countries interested by this study have distinct geographical features, different climates and significant differences in gross domestic product per capita; the integration of their energy systems and the search for 100% renewable solution are considered to be very challenging. However, biomass has been determined to have the potential to meet the target of 100% renewable energy in all the countries considered, despite their differences.

Many studies focused on energy planning by using the EnergyPLAN software [13-27] to simulate the current and future territory energy balance. Despite its extensive use, EnergyPlan must be used in combination with software that can model the actual performance of the systems that use renewable energy sources, such as TRNSYS software [29], in order to perform energy balance simulations. In fact, the energy production values are input data to EnergyPLAN, and when a technology is new or not yet available on the territory, production data must be predicted. In this case, a simulation software is needed in order to estimate energy production of the proposed technology.

In this work, EnergyPLAN is used to analyse the possibility for the transition of a city in southern Italy to a 100% RES by 2030, in combination with a simulation tool (TRNSYS) that can reproduce the dynamic behaviour and performance of the systems that use renewable energy sources. The whole energy infrastructure of the city is analysed by using EnergyPlan, in order to evaluate fluxes combination and potential synergies between the different sectors, while, PV technology is modelled in TRNSYS environment, in order to obtain a detailed simulation of this component of the infrastructure. These two models, coupled for the first time in this work, allow the authors to outline a new energy scenarios for the city, establishing a new methodology to carry out an analysis of the energy planning of a city.

The proposed approach is crucial in the development of a new RES energy system because it allows to take into account large temporal variations in energy availability of the RES systems and to design an appropriate management and control system, which is crucial for the effective use of these systems.

2. A CASE STUDY: ALTAVILLA SILENTINA

Geography, Climate and Population

Altavilla Silentina is a Municipality of Campania Region, in southern Italy (
Figure 1); more precisely in the province of Salerno. The City is developed along a hill characterized by different heights, from 275 m .a.s.l, where the “Saint Blaise's Door” is located, up to the 313 meters a.s.l .where the Municipal building is ubicated; the top of the hill reaches about 424 m a.s.l. [42].

The climate is typically Mediterranean: the coldest month of the year is January with the average temperature equal to 6.8 °C and the hottest month is August with the average temperature of 24.4 °C [42].

The population trend of Altavilla Silentina from 1861 to 2011 has been estimated on the basis of the official Italian database (ISTAT) [43]. The population increases of about 100 % from the years 1921 to 1961 reaching the maximum value of 7000 inhabitants in 1961. In following years, the number of inhabitants is remained almost constant (Figure 1).

(Insert Figure 1 here)

Industrial activities

According to data available from the last survey by ISTAT in 2011 [43], the number of companies in Altavilla Silentina is equal to 390.Figure 2 shows that the largest share (34%) of these companies is classified as "Wholesale and retail trade, sale of Vehicles and motorcycles". The "Construction” sector represents a significant part of the local industry, with a 15%, as well as the Manufacturing and Scientific activity (13%).

Figure **3** reports the number of employees for each category. According to data from the ISTAT [43], the 32% of 890 employees, about 285 employees, work in the “Manufacturing” sector and the 23% of them, about 205 employees, for " Wholesale and retail trade, sale of motor vehicles and motorcycles” category.

(Insert Figure 2 here)

(Insert Figure 3 here)

Number of vehicles

In Figure 4 is shown the number of vehicles per category registered in the years 2010 and 2014 in the City of Altavilla Silentina [44]. It is interesting to note that there has been a slight increases in the number of motorcycles (+3.4 %), cars (+2 %) and trucks to transport goods (+5.4 %) from 2010 to 2014. Most significant changes recorded are: a decrease of tractors (-32 %), a decrease of the three wheelers and quadricycles for freight (-22 %) and, an increase of buses (+8 %). In total, an increase in number of vehicles on the road equal to 2 % between 2010 to 2014 has been found, in accordance with the population growth.

(Insert Figure 4 here)

State of the buildings

The City could be divided into four main areas: the city center on the hill, and three minor areas:

• "Borgo Carillia" (20 m a.s.l): 779 inhabitants, located along the PR 317;

• "Cerrelli" (50 m a.s.l): 586 inhabitants, located along the PR 174 and PR 314;

• "Cerrocupo" (93 m a.s.l): 234 inhabitants, located along the PR 246 [42].

In according to the ISTAT data-base [43], from 1970 the number of buildings has steadily grown over the years. In Table 1 the number of new residential buildings built during each time period are reported.

(Insert Table 1 here)

3. PREDICTIVE MODELS

The energy system of a city is characterized by fluctuating demands and productions and by interdependencies between heat production, heat demands, electricity production, electricity demands and transportation needs. In order to evaluate the transient behaviour of an energy system, a dynamic model must be used. One such model is the EnergyPLAN model. Among the tools present in literature the authors choose EnergyPLAN because it has been previously used to simulate a 100% renewable energy system for several cities such as Aalborg and Frederikshavn.

EnergyPLAN software allows users to simulate the whole energy infrastructure of a territory (Municipality, Region or State), considering potential synergies between the different sectors. EnergyPLAN can be used to design and analyse the energy system/infrastructure on an hourly basis with reference to a typical year, including electricity, heating and cooling, energy consumptions of residential, industry and transport sectors.

The software can take into account many energy conversion systems such as heat pumps, combined-cycle power stations, etc. and every energy carrier [11], it has been widely used in Denmark and in the countries such as China and America [30].

The software is designed to provide users with:

- An energy plan for a territory, obtained from a comparative analysis of several alternative energy systems;
- A clear methodology to produce results understandable to all stakeholders.

The following inputs are requested for EnergyPLAN simulations: yearly energy demand-production and hourly energy demand-production trends. EnergyPLAN evaluates the hourly value of energy demand/production from the annual value [13].

The yearly energy demand/production can be obtained from data monitoring, upon request to energy distributors and/or retail energy sales companies, or from national databases. In case national database is available, a “Top-down” methodology can be used: local data are scored from the national database based on the local representative parameter (population, number of buildings etc.) [31].

The most recent data available in the Italian national database refer to the year 2010-2011. In this work, where the authors planned an energy scenario by 2030, the energy consumption based on the estimate of the population increase and urban expansion. In particular, the increase of the population is calculated following the trend between 1861 and 2010. The urban expansion is tied to the population increase, which implies new buildings (private and public), new areas and the increase of public and private transportation.

In addition, the work considers specific measures for reducing energy consumption and CO_2 emissions, the expected increase of systems efficiency related to technology development, and the energy production from plants already installed or planned by the municipality before and after 2016.

In order to estimate energy and CO_2 emissions reduction due to the implementation of specific measures, and the increase of system efficiency between 2010 and 2030, the AEEG procedure presented in Technical Data Sheets [32] for energy savings evaluation has been used.

Data for the new energy production plants, obtained from the municipal and regional authorisations granted to companies for installation of wind turbine and biogas CHP plant; for PV plants, the GSE ATLASOLE database [33] has been consulted.

As regards the hourly trend, standard hourly energy demand and production curve, are reported in EnergyPLAN data-base for every country. In most cases, municipal energy demand is different from the national one, and therefore users have to build it before running the simulations . Users also have to implement the hourly energy production of plants, such as photovoltaic plants, wind turbines and, geothermal plants, that depend on local climate conditions.

In this work, for plants already installed, the hourly production is obtained from field measured data. Instead, for new systems/technology proposed for use in the energy plan, a detailed model has been used to simulate the performance and calculate hourly production. This has been the case also for energy production from photovoltaic, that is not available for case under study, and has been simulated by using TRNSYS software. The mathematical model implemented in TRNSYS (type 194 [34] developed by De Soto et al. [35]) is based on this current-voltage relationship:

$$I = I_L - I_o[e^{\frac{V+IR_s}{a}} - 1] - \frac{V + IR_s}{R_{sh}}$$

Where:

$$a = \frac{N_s n_1 k T_c}{q}$$

Five-parameter (the light current I_L, the diode reverse saturation current I_o, the series resistance R_s, the shunt resistance R_{sh}, and the modified ideality factor a) affect the current–voltage curve of a PV systems at operating conditions and are functions of the solar radiation incident on the cell and cell-temperature. In order to compare several technologies, generally the electric performance of PV systems is calculated referring to Standard Test Condition (STC) defined by IEC/EN 60904 [36]. These conditions are rarely encountered during actual operation, in which case the energy output can be significantly lower. In this work the authors take in to account solar radiation and a semi-empirical model for the prediction of energy production for four different cell technologies (single crystalline, polycrystalline, silicon thin film, and triple-junction amorphous) under operating conditions.

The trend of thermal energy for space heating has been assumed directly proportional to the outdoor air temperature. The energy demand is considered to be zero when the outdoor temperature is higher than 16°C. In fact, the temperature within a building is 18.0-20.0°C, so when the outside temperature is 16.0°C, inside of a building it is assumed that the temperature is 2-3°C higher than the outside one [37].

For cooling demand, the trend has been considered a function of the sol-air temperature, which is defined as the equivalent outdoor air temperature that gives the same rate of heat transfer to a surface as it would the combination of incident solar radiation, convection with the ambient air, and radiation exchange with the sky and the surrounding surfaces [38]. In this case, the demand for cooling is considered absent when the sol-air temperature is lower than 28°C.

The electric energy trend has been estimated on the basis of the national electricity hourly data provided by the Italian company Terna SpA [39], which manages the national electric grid.

Finally, the hourly energy production from wind turbines has been obtained from the monitoring conducted by a plant installed in the municipality. The company that owns the plant has provided the authors with the measured data for wind speed and plant electricity production for an entire year.

The abovementioned curves have been normalised with respect to the peak load in order to obtain a load curve representing 0-100% of the energy demand/production.

The use of EnergyPLAN, coupled with TRNSYS results and the monitoring data allows to produce realistic result, and to outline detailed scenarios.

In Figure 5, it is possible to see a block diagram that describes the model used for the analysis and the construction of the scenarios for the city of Altavilla Silentina.

(Insert Figure 5 here)

The outputs of EnergyPLAN include aggregated yearly production and demand of all modelled types, as well as the hourly values, useful to identify the necessary measures to turn any city into a zero carbon city. Every measures identified becomes a new input in EnergyPLAN, in order to evaluate its effect on energy balance of the city. The process becomes iterative until a zero carbon scenario is obtained.

Finally, in this work an economic analysis has been carried in order to evaluate the electricity and thermal energy cost. Prices per kWh of both thermal and electric energy have been calculated according to the following equation:

$$C_{kWh} = \frac{Investments + Operational + Aquisition - Sales}{EnergyDemand} \qquad (1)$$

4. SCOPE and METHOD

In this work, the authors carry out the energy planning of Altavilla Silentina Municipality in order to convert it to a nearly zero greenhouse gas emissions by 2030.

In 2013, the Municipality adhered to the Covenant of Mayors [40], and developed a Sustainable Energy Measures Plan (SEAP) [41]. A SEAP includes an assessment of the current situation, i.e. a “Baseline Emission Inventory” (BEI), and a “Measures Plan” with reduction emissions targets and the measures to achieve them.

The Baseline Emission Inventory quantifies the amount of CO_2 (or CO_2 equivalent) emissions due to energy consumption in the territory, it identifies the main sources of CO_2 emissions and their respective reduction potentials.

Based on the most energy-intensive sectors as given in the BEI, it is possible to identify and analyse specific measures to reduce the consumption and emissions of 20% by the year 2020 with respect those evaluated in the BEI reference year (2010 for Altavilla Silentina).

The authors analysed measures that go beyond the minimum requirements of Covenant of Major, and developed a new energy plan in order to convert Altavilla Silentina to a nearly zero greenhouse gas emissions by 2030.

The transformation of the city is scheduled in two steps

- From 2010 to 2020 with the implementation of measures considered in the Sustainable Energy Measures Plan;
- From 2020 to 2030 with the analysis of measures needed to fully decarbonise the city.

3.1 *Baseline: Altavilla Silentina 2010*

The scenario Altavilla Silentina 2010 is the baseline used by the authors to analyse future development of the municipality energy system/infrastructure. The authors analysed the geography and climate of the city, the population and its density, the level of economic activity, characteristics of buildings, usage and development of transportation, citizens' attitudes, in order to evaluate energy consumption and CO_2 emissions related to all of these factors. The choice of the reference year for the BEI (2010) is based on the data available for this year to build the inputs for the EnergyPLAN model, which are more accurate and complete than previous years.

The main data collected for this work are reported below.

Primary Energy Consumptions

The yearly energy consumptions for the year 2010 has been obtained through a "top-down" methodology using several national data-bases [43; 45-47]. In Table 2 and Table 3, the local parameter and the reference database used in order to apply the "top-down" methodology are presented.

(Insert Table 2 here)

The results of the "Top-down" analysis are shown in Table 4. The energy consumptions have been divided by sector and energy carrier respectively. Residential buildings and industry have the highest energy demand, while the industrial and transportation sectors show a lower consumption than the formers.

(Insert Table 3 here)

(Insert Table 4 here)

The analysis has demonstrated that 67% of residential heating demand is supplied by biomass. In order to evaluate the primary energy demand, a cognitive survey on the type of biomass used by Altavilla citizen has been performed. Results shown that wood, wood pellets and wood briquettes biomass are widely used. The net calorific value is different for these type of woods (from 3.5 kWh/kg for chips, 4.1 kWh/kg for logwood, 4.8 kWh/kg for pellets and briquettes to 5.3 kWh/kg for solid wood [48]), thus in this work an average value, equal to 4.4 kWh/kg, and has been considered. The conversion efficiency value has been set to 80%, due to the size of the plants that generally varies from 10-20 kW_t to 50 kW_t. Biomass plants have been considered CO_2 neutral, as indicated by the European guide on "How to develop a Sustainable Energy Measures Plan (SEAP)" [31].

As it can be seen from Table 4, the remaining heating demand is satisfied by LPG (32%), diesel (1.3%) and oil (0.07%). For such systems, the energy conversion efficiency has been set equal to 80%, in order to find the primary energy used for these energy carriers.

The analysis has also shown that LPG boilers are the most common heating system in the tertiary sector; this is mainly due to the absence of natural gas distribution system in the municipality. In addition, in this case, the efficiency of such systems has been considered equal to 80% [49]. Industry presents the highest electric energy demand of all sectors.

Table 5 shows the primary energy consumptions for the transport and agriculture sectors. The data demonstrates that the electric vehicles are practically not used, mainly because of the high investment cost of this technology [50], while diesel is the most used fuel for both agriculture and transport activities due reduced tax fee provided by Italian law for this sectors [51].

CO_2 emissions have been calculated by using the standard CO_2 emission factor [31] for different fuels and the national emission factors for electricity.

The results in terms of CO2 emissions have been shown detailed in Table 6.

(Insert Table 5 here)

Table 6 even shows, that the highest CO_2 emission are due to the industrial sector (50%), although the energy consumption of the industrial is equal to that of the residential buildings (31%); that is because the biomass systems used for space heating in buildings are considered globally as zero emissions plant.

(Insert Table 6 here)

Although the national emission factors for electricity is lower than the others energy carriers, the highest CO_2 emissions are related to its large consumption in the municipality.

4. RESULTS

4.1 *Altavilla Silentina 2020: the SEAP strategy*

The measures set in the Altavilla Silentina SEAP have been derived on the basis of the energy consumptions and CO_2 emissions of 2010, in order to achieve the European objective of CO_2 emission reduction of over 20% by 2020. Particularly, Altavilla Silentina has set a far more restrictive target that is 27% by 2020, with respect to the values of 2010.

To analyse the impact of these measures on the CO_2 emission, the authors took into account:

- The population increase and the related urbanization effect.
- The measures implemented by the municipality before 2015 and their effects on the CO_2 emissions in 2020;
- The reduction of CO_2 emissions from new renewable energy systems that are going to be built in the future (a project has already been approved by the municipality);
- The increase of systems efficiency linked to technology development;

The expected CO_2 emissions increase due to population and buildings growth are shown in Table 7.

In order to estimate the CO_2 reduction due to the implementation of every measures, the authors used the above AEEG methodology [32].

Table 8 shows a list of the aforementioned measures and the expected CO_2 emission reduction effects.

(Insert Table 7 here)

The measures planned in the SEAP have been designed in order to reduce energy consumption and CO_2 emissions reduction for the residential, transporting and, industry sectors. The construction of wind farms implies a significantly CO_2 reduction (50%). The other planned actions affect for a few percentage points on the reduction of emissions except some measures for the residential sector, such as the installation of photovoltaic systems.

(Insert Table 8 here)

Figure 6 shows that the implemented measures generate a reduction of previous CO_2 emissions of at least 70% by 2020 with respect to the emissions of 2010. This result exceeds the 27% which was the initial target set by the administration for 2020. In fact, the reduction of 27% is estimate equal to 5566 t of CO_2 while the measures implementation imply a reduction equal to 14811 t of CO_2, as shown in this figure.

(Insert Figure 6 here)

In 2020, wind plants will be able to cover the yearly municipality electricity demand and to export the overproduction in national grid (Figure 7); however, wind power depends on wind velocity thus the production is not able to match the energy demand. Furthermore, 7.2% of renewable electric energy will come from photovoltaic plants; also in this case production is a function of the solar radiation that is not continuous. The electricity produced by biogas cogeneration plants is constant but it will represent only 10% of renewable energy production thus, even if only for a few hours per day, a supply of electrical energy from the national grid should be considered.

Because of this daily un-matching between the energy demand and its production, results of simulation shows that the yearly energetic balance is not sufficient to define the municipality as “Electric self-sufficient city”. On a daily basis, even a small amount of energy comes from the national grid, however, on a yearly basis Altavilla Silentina will be self-sufficient.

Regarding the electric energy consumption, no significant increase is expected by 2020, due to the small population growth instead a large gap between production and consumption occurs by 2020.

(Insert Figure 7 here)

Figure 8 shows the primary energy consumption for heating and heat available from the cogeneration biogas power plant. The thermal energy demand decreases between 2010 and 2020 due to the improvement of energy efficiency of buildings supported by the state financial instruments [52-53]. The gap between production by RES and consumption represents the energy for space heating that needs to be supplied by fossil fuel plants, which affects negatively CO_2 emissions.

(Insert Figure 8 here)

4.2 *Altavilla Silentina 2030: Decarbonisation Process*

The 2030 Altavilla Silentina energy scenario is outlined on basis of the 2020 SEAP results, by using EnergyPLAN.

The initial assumptions are stated below:

1) The yearly electric energy consumption in the residential and public buildings are obtained following the consumption trend between 2010 and 2020;
2) The yearly electric energy consumption for public lighting will equal 585 MWh/year in 2030 considering an increase of the number of lamps;
3) The yearly thermal and cooling demand will increase proportionally to the population increase;

4) Industrial and agriculture consumptions will not increase during the decade 2020-2030;
5) Common increase of systems efficiency due to technology development are based on the trend between 2010 and 2020;
6) The yearly thermal energy production by biomass plants in the residential buildings will be equal to that of 2020;
7) The expected consumption for transportation will equal 4918 MWh in 2030. Fuel consumption nearly halved in the period 2010-2020 due to the rapid development of transport technology. In order to estimate primary energy consumption in 2030, the same trend has been considered.
8) Finally, the total primary energy consumption (residential buildings, public buildings and service, public and private transporting fleet, industry, agriculture and public lighting) equal to 44837 MWh has been estimated for 2030.

Furthermore:

9) The electric and thermal energy production by RES (wind farm, PV systems and biogas cogeneration) will be equal to that of 2020. In 2020 in fact, the electricity production by RES is already sufficient to meet the heat and electricity demand. Thus, thermal and electric energy production is supposed the same in 2030.

The authors modelled in "EnergyPLAN" environment the above described "Altavilla Silentina 2030 scenario" in order to find the solutions that will enable to convert Altavilla Silentina into a zero greenhouse gas emission municipality by 2030.

The assumptions relating to the energy demand/production trend are the ones above described in the "Predictive Models" paragraph.

(Insert Figure 9 here)

(Insert Figure 10 here)

In Figure 9 and in Figure 10 are reported the hourly energy demand and production trend of Altavilla Silentina Municipality expected for 2030, respectively. Curves have been normalized with respect to the peak load.

Results of the EnergyPLAN software show that Altavilla Silentina can became zero carbon emissions city if:

1) The fossil fuel plants that will still be present in 2020 scenario are substituted with electric heat pumps, increasing the electric energy consumptions. The authors have considered heat pumps with a Seasonal COefficient of Performance (SCOP) equal to 3, thus an electric energy increase for residential sector equal to 1212 MWh_e is expected with respect to that of 2020.
2) In the industry sector, 23% of thermal demand has to be supplied at high temperature (above 70°C) while the 77% has to be supplied at low temperature (60°-70°). The authors propose the installation of electric heat pumps in order to satisfy the request of low-temperature thermal energy, and biomass plants for the high temperature one. The heat pumps installation implies an electric energy increase of 419MWh/year with respect to 2020.
3) In the tertiary sector, 83% of thermal energy demand for heating will be supplied by heat pumps, for a total of 888 MWht, biomass plant will supply the rest of the demand;
4) In 2030 only electric cars must be considered. The authors have evaluated the electric energy consumption for the transport sectors by using a typically hourly consumption profile.

Figure **11** shows an overview of the expected electric energy consumptions for sectors of Altavilla Silentina in the year 2030.

(Insert Figure 11 here)

It is important to note that the yearly electricity production by RES will be even higher than the demand in 2030, even though electricity consumption will increase (Figure 12). This is also clear in the yearly balance reported in Figure 13 where the energy exported in national grid and the energy consumption is indicated.

The electric energy production by RES should be equal to energy demand in order to achieve a zero energy balance of the city. In fact, the Critical Excess in Electricity Production (CEEP) could make problems in the managing of the energy grids.

In the case of Altavilla Silentina, the construction of RES plants has already been planned before the SEAP development, and the relationship between production and consumption had not been evaluated.

For this reason, in the 2030 scenario the authors aim to electrify the city in order to reduce the gap between production and consumption. Despite the efforts of authors, this gap remains. An energy planning extended to neighbouring territories can considered as an interesting solution, which is analysed in paragraph 5.

(Insert Figure 12 here)

(Insert Figure 13 here)

The EnergyPLAN results show that electricity production by RES will not cover the electric energy demand on hourly base.

As an example, the hour demand and production of electric energy are shown in Figure 14 for a typical day in January. From this figure, it is clear that it will be necessary to import electric energy from the national grid. To avoid this situation, an electric energy storage should be considered in the energy system, thus completing a self-sustained "zero emissions energy system/infrastructure".(Insert *Figure 14 here)*

reports a list of the RES power plants to be installed by 2030 in order to convert Altavilla Silentina to "nearly zero carbon emissions". In case of heat pumps and biomass boilers, the overall power installed is calculated considering a mean size equal to 10 kW_e/unit and 35 kW_t/unit respectively for residential and tertiary sector, and average sizes of heat pumps and biomass boilers equal to 20 kWe/unit and 50 kWt/unit respectively for industrial sector.

(Insert Figure 14 here)

(Insert Table 9 here)

In Figure 15, the total primary energy supply for the years 2010, 2020 and 2030 can be observed. The "electricity" nomenclature refers to the primary energy required for the "electric energy end-use". The conversion efficiency for electric production is considered for the nation equal to 0.47 [54].

(Insert Figure 15 here)

Finally, an economic analysis has been performed in order to evaluate the cost of electricity and thermal energy. In Table 10 a list of the investment and operating costs for new plants needed for the decarbonisation by 2030 [54] is reported. In the analysis, the cost for electric energy storage and the costs related to electric energy exchange with the national grid have not been taken in account.

(Insert Table 10 here)

Assuming that:

1) The cost of electric energy to be acquired on the market is equal to 0.20 €/kWh$_e$ [56];
2) The sale price electric energy is equal to 0.05 €/kWh$_e$ [56];
3) The price of wood chips and wood pellets is equal to 679 k€/year [48].

The results of the cost analysis are:

1) The total costs for electricity production is equal to 31612 k€ (1304 k€/year);
2) The total costs for thermal energy production is equal to 929119 k€ (19865 k€/year).
3) The total acquired electric energy cost is equal to 2698 k€/year;
4) The electric energy sales revenue is equal to 1211 k€/year.

Prices per kWh of both thermal and electric energy have been calculated according to Equation (1).

Results shown that prices of both thermal and electric energy could be significantly lower than current price, 11 c€/kWh$_e$ and 12 c€/kWh$_t$, making the whole system highly profitable also from an economic point of view.

5. POSSIBLE SOLUTION TO CRITICAL EXCESS ELECTRICITY PRODUCTION

The influence of the control volume on which energy planning is based obviously very important. Moreover, the ability of a system to operate in "Island mode" , "connected mode" or "connected island mode" is a very interesting point to analyse and there are a lot of arguments in favour or against each of these approaches[57].

In this work, the authors investigate an energetic analysis of the neighbouring territories ("connected mode"), in order to evaluate the possibility to export the over-produced electricity. The excess of electricity production, due to the wind plants in Altavilla Silentina, can be a problem for the national grid.

The electricity demand of the neighbouring territories has been estimated considering the pro-capite electricity demand of Altavilla Silentina by 2030 (including the electrification of transport sector) and the population number of close municipalities (Albanella, Controne and Castelcivita). Moreover, the authors have considered an analysis of RES plants in the surrounding territories in order to evaluate their electric energy balance. The results demonstrate that the yearly energy demand of these close neighbouring municipalities is higher than the local production. (Figure 16). Therefore the electricity produced in Altavilla Silentina can be an interesting opportunity to solve the CEEP problem and to increase the share of green energy in their energy balance, without the need of new plants.

(Insert Figure 16 *here)*

However, yearly energy results are not adequate to establish that energy over-production by Altavilla Silentina can be used by neighbouring municipality. Therefore, a further analysis is necessary that takes in to account both energy demand of the surrounding cities and that of Altavilla Silentina.

The hourly results confirm that the excess electricity produced in Altavilla Silentina can be completely used by neighbouring cities, meeting a large part of the three municipalities demand. The choice of a larger control volume offers two-fold benefit: it solves the CEEP problem of Altavilla Silentina, and it increases the share of RES energy in the balance of the area.

Another benefit that should be considered is the sharing of the costs among the municipalities. Infact, a shared service agreement among the neighboring municipalities has the potential to decrease the operational costs and the investment ones. Every municipality may provide its energy resources available for the agreement municipalities sharing the investment and operational costs for the resource exploitation.

The study has demonstrates that proper energy planning must take in account also the dependence of results on control volume considered.

6. CONCLUSION

The work presents a feasibility assessment of a novel strategy to make the Italian city of Altavilla Silentina dependent only on renewable energy sources by 2030. An analysis of the actual energy consumption, as well as the evaluation of CO_2 emission have been carried out. The energy demand of the municipality in 2030 has been evaluated by using the software EnergyPlan, integrated with TRNSYS software, through which a possible and effective energy system based on renewable sources has been modelled in order to cover both the future electric and thermal energy demands.

The analysis of the energy demand in 2010 shows that the most of the energy consumption of the city is due to both residential and tertiary buildings (the former has 32% of global energy consumption the latter 31%), followed by public transportation (21%). The analysis also shows that electric energy (31%), heavy fuel (i.e. diesel 20%) and LGP (18%) are the three most used energy carriers. Based on these evaluations, the Altavilla Silentina CO_2 footprint has been evaluated by using emission factors and top-down method for public and private sectors respectively. Emission factors measure the amount of CO_2 released per kWh of primary energy converted into electricity or/and heat. As expected, the results show that industry has the highest CO_2 footprint, with more than 6881 tons of CO_2 per year (31% of total emissions), followed by the tertiary buildings, 4173 tons of CO_2 per year (more than 21% of total emissions).

In order to reduce the energy demand and the related CO_2 emissions, the authors studied a number of measures for each sector mainly:

- Increase the efficiency of energy systems for both public and residential buildings;
- Installation of new and more efficient systems for electricity and heat production;
- Increasing the efficiency of public transportation.

Each measure gives a significant contribution to both energy consumption and CO_2 emission reduction. The analysis shows that, if all the proposed measures are undertaken by 2020, there will be a reduction of more than 10900 tons of CO_2 per year, mostly thanks to wind energy.

In the last part of the present work, the authors simulate the energy balance of the whole city for the year 2030 by using the software Energy Plan integrated with TRNSYS, and defined an effective and complex system of multiple technologies able to feed Altavilla Silentina only through renewable energy sources by 2030. The results show that, starting from the 2020 scenario, by replacing conventional boilers with electric heat pumps and by using electric public transport, the goal can be achieved. However, a CEEP problem occurs in this scenario due to a large electric production by wind farms.

In order to verify the system feasibility, an economic analysis of the system has been carried out. The results show that prices of both thermal and electric energy could become as low as the actual ones, 0.11 €/kWh$_e$ and 0.12 €/kWh$_t$, making the whole system profitable also from an economic point of view.

Finally, in order to solve the CEEP problems, an inter-municipality energy balance has been considered. In this new scenario, the whole energy production due to wind plants is used by citizens and the exportation in the national grid is equal to zero. The larger volume-control offers two-fold benefit: it solve the CEEP problem of Altavilla Silentina and it increase the share of RES energy in the balance of the closed cities.

ACKNOWLEDGMENTS

The authors would like to acknowledge Scientific Consortium for the Industrial Research and Engineering (CRAVEB) for providing the energy data of Altavilla Silentina. The "Terralavoro Costruzioni SRL" Company and the Altavilla Silentina Municipality have to be greatly acknowledged for providing data of wind turbine production and the PV plants of school buildings, respectively.

NOMENCLATURE

a.s.l	above sea level
BEI	Baseline Emission Inventory
C	Costs
CE	Cooling Energy Demand
CEEP	Critical Excess Electricity Production
CHP	Combined Heat and Power
EE	Electric Energy Demand
ENEA	Italian National Agency for New Technologies, Energy and Sustainable Economic Development
GSE	Gestore Servizi Energetici
HP	Heat Pump
ISPRA	Istituto Superiore per la Protezione e la Ricerca Ambientale
ISTAT	Italian National Institute of Statistics
LPG	Liquefied Petroleum Gas
PR	Provincial Road
PV	PhotoVoltaic
PVP	PhotoVoltaic Energy Production
RES	Renewable Energy Sources
SCOP	Seasonal Coefficient Of Performance
SEAP	Sustainable Energy Measures Plans
TE	Thermal Energy Demand
WP	Wind Turbine Energy Production

REFERENCES

1. Covenant of Mayors for Climate & Energy: http://www.covenantofmayors.eu/
2. Delponte I., Pittalunga I., Schenone C., Monitoring and evaluation of Sustainable Energy Action Plan: Practice and perspective, Energy plocy, Vol.100,pp 9-17, October 2016.
3. The European Parliament and the Council of the European Union. Directive 2012/27/EU of the European parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. 2012.
4. De Santoli L., *Le comunità dell'energia,* Quodlibet, 2011, pp 109-110.
5. Kennedy S., Sgouridis S., Rigorous classification and carbon accounting principles for low and Zero Carbon Cities, *Energy Policy,* Vol. 39, pp 5259-5268, June 2011.
6. Østergaard P. A., Lund H., A renewable energy system in Frederikshavn using low-temperature geothermal energy for district heating, *Applied Energy,* Vol. 88, No 2, pp 479–487, February 2011.
7. Carotenuto A., De Luca G., Fabozzi S., Figaj R.D., Iorio M., Massarotti N., Vanoli L. Energy analysis of a small geothermal district heating system in Southern Italy, *International Journal of Heat and Technology,* Vol. 34, Special Issue 2, pp S519-S527, 2016.
8. Østergaard P. A, Vad Mathiesen B., Möller B., Lund H., A renewable energy scenario for Aalborg Municipality based on low-temperature geothermal heat, wind power and biomass, *Energy*, Vol. 35, No 12, pp 4892–4901, December 2010.
9. Tao M., Østergaard P. A., Lund H., Yang H., Lu L., An energy system model for Hong Kong in 2020, *Energy*, Vol. 68, pp 301–310, April 2014.
10. Dominkovic D.F., Bacˇekovic´ I., Krajacˇic´ G., Pukšec T., Duic N., Markovska N., Zero carbon energy system of South East Europe in 2050, *Applied Energy*, In Press, Corrected Proof, Available online 19 March 2016.
11. Novosel T, Pukšec T., Krajačić G., Duić N., Role of District Heating in Systems with a High Share of Renewables: Case Study for the City of Osijek, *Energy Procedia*, Vol. 95, pp 337-343, September 2016.
12. Dominković D.F., Bačeković I., Sveinbjörnsson D., Pedersen A.S., Krajačić G., On the way towards smart energy supply in cities: The impact of interconnecting geographically distributed district heating grids on the energy system, *Energy*, In Press, Corrected Proof, Available online 27 March 2017.
13. Lund H., EnergyPLAN - Advanced Energy Systems Analysis Computer Model. Available online: http://www.energyplan.eu/
14. Thellufsen J. Z., Lund H., Cross-border versus cross-sector interconnectivity in renewable energy systems, *Energy*, Vol. 124, pp 492-501, February 2017.
15. Komušanac I, Cosić B, Duić N., Impact of high penetration of wind and solar PV generation on the country power system load: The case study of Croatia, *Applied Energy,* Vol. 184, pp 1470-1482, July 2016.
16. Thellufsen J. Z., Lund H., Roles of local and national energy systems in the integration of renewable energy, *Applied Energy*, Vol. 183, pp 419–429, September 2016.
17. Xiong W., Wang Y., Vad Mathiesen B., Lund H., Zhang X., Heat roadmap China: New heat strategy to reduce energy consumption towards 2030, Energy, Vol. 81, pp 274-285, January 2015.

18. Cerovac T., Pukšec T., Cosić B, Duić N., Wind energy integration into future energy systems based on conventional plants – The case study of Croatia, *Applied Energy*, Vol. 135, pp 643–655, July 2014.
19. Kwon P.S., Østergaard P. A, Priority order in using biomass resources – Energy systems analyses of future scenarios for Denmark, *Energy*, Vol. 63, pp 86-94, October 2013.
20. Cosić B, Krajačić G., Duić N., A 100% renewable energy system in the year 2050: The case of Macedonia, Energy, Vol. 48, pp 80-87, June 2012.
21. Duquette J., Wild P., Rowe A., The potential benefits of widespread combined heat and power based district energy networks in the province of Ontario, *Energy*, Vol. 67, pp 41-51, January 2014.
22. Zhao G., Guerrero J. M., Jiang K., Chen S., Energy modelling towards low carbon development of Beijing in 2030, *Energy*, Vol. 121, pp 107-113, January 2017.
23. Child M., Nordling A., Breyer C., Scenarios for a sustainable energy system in the Åland Islands in 2030, Energy Conversion and Management, Vol. 137, pp 49-60, January 2017.
24. Pillai J. R., Heussen K., Østergaard P. A, Comparative analysis of hourly and dynamic power balancing models for validating future energy scenarios, *Energy*, Vol. 36, no 5, pp 3233-3243, May 2011.
25. Østergaard P. A, Comparing electricity, heat and biogas storages' impacts on renewable energy integration, *Energy*, Vol. 37, No 1, pp 255-262, January 2012.
26. Lund H., Hvelplund F., The economic crisis and sustainable development: The design of job creation strategies by use of concrete institutional economics, *Energy*, Vol. 43, No 1, pp 192-200, July 2012.
27. Kwon P.S., Østergaard P.A., Priority order in using biomass resources – Energy systems analyses of future scenarios for Denmark, *Energy*, Vol. 63, pp 86-94, December 2013
28. Østergaard P. A, Reviewing EnergyPLAN simulations and performance indicator applications in EnergyPLAN simulations, *Applied Energy*, Vol. 154, pp 921–933, September 2015.
29. University of Wisconsin-Madison. A TRaNsient SYtems simulation program.Available on line: http://sel.me.wisc.edu/trnsys/ .
30. Lund H., Renewable Energy Systems A smart Energy Systems approach to the Choice and Modeling of 100% Renewable Solutions. Second ed, ed. Elsevier. 2014.
31. JRC Scientific and Techincal Reports, *Reporting Guidelines on Sustainable Energy Measures Plan and Monitoring,* 2010.
32. GSE- Technical Data Sheets Available on line: http://www.gse.it/it/CertificatiBianchi/Modalit%C3%A0%20di%20realizzazione%20dei%20progetti/Schede%20tecniche/Pagine/default.aspx
33. GSE ATLASOLE: http://atlasole.gse.it/atlasole/
34. TRNSYS 17 – *a TRaNsient System Simulation program-Mathematical reference*". Vol.5. Available on line: http://web.mit.edu/parmstr/Public/Documentation/05-MathematicalReference.pdf
35. De Soto W., Klein S.A., Beckman W.A., Improvement and validation of a model for photovoltaic array performance. *Solar Energy*, Vol. 80, No.1 pp. 99-106, January 2006.
36. The International Standard IEC 60904-1. Photovoltaic devices-Part 1: Measurement of photovoltaic current-voltage characteristics. 2006.09
37. Connolly D., *Finding and Inputting Data into EnergyPLAN.* Aalborg Universitet. Vers. 5, January 2015. Available on line: http://www.energyplan.eu/wp-content/uploads/2013/06/Finding-and-Inputting-Data-into-the-EnergyPLAN-Tool-v5.pdf
38. Kreider J.F., Curtiss P.S., Rabl A., *Heating and Cooling of Buildings- Design for Efficiency*, CRC Press December 2009.

39.TERNA. http://www.terna.it/
40.Covenant of Mayor –Signatories: Altavilla Silentina: http://www.pattodeisindaci.eu/about/signatories_it.html?city_id=6228
41.Piano d'Azione per l'Energia Sostenibile- Comune di Altavilla Silentina. Available on line: http://www.covenantofmayors.eu/about/signatories_en.html?city_id=6228&seap
42. Altavilla Silentina Municipality website. http://www.comune.altavillasilentina.sa.it/
43.ISTAT, Italian National Institute of Statistics. http://www.istat.it/
44.ACI. Automobile Club of Italy. http://www.aci.it/
45.ISPRA Istituto Superiore per la Protezione e la Ricerca Ambientale. http://www.isprambiente.gov.it/it
46.ENEA Agenzia Nazionale per le nuove tecnologie, l'Energia e lo sviluppo economico sostenibile http://www.enea.it/it/pubblicazioni/rapporto-energia-e-ambiente/rapporto-energia-e-ambiente-2009-2010/i-dati-2009-2010/statistiche-regionali
47. E-distribuzione. https://e-distribuzione.it/it-IT
48.Bibbiani C., Fantozzi F., Gargari C.,Campiotti C.A., Schettini E.,Vox G., Wood Biomass as Sustainable Energy for Greenhouses Heating in Italy. *Agriculture and Agricultural Science Procedia*, Vol. 8, pp. 637 – 645, 2016.
49.IEA, ETSAP Energy Technology Systems Analysis Programme, *Industrial Combustion Boilers*, May 2010. Available on line: http://www.iea-etsap.org/web/e-techds/pdf/i01-ind_boilers-gs-ad-gct1.pdf
50.Bishop J.D.K., Martin N.P.D., Boles A. M., Cost-effectiveness of alternative powertrains for reduced energy use and CO_2 emissions in passenger vehicles. *Applied Energy*, Vol. 124, pp. 44-61, July 2014.
51.Legislative Degree n.504 of 26 October 1995, *Testo Unico delle disposizioni legislative concernenti le imposte sulla produzione e sui consumi e relative sanzioni penali e amministrative*
52.Economic Ministry Decree of 28 December 2012*, Incentivazione della produzione di energia termica da fonti rinnovabili ed interventi di efficienza energetica di piccole dimensioni*.
53.Law n . 208 Of the 28 December, *Disposizioni per la formazione del bilancio annuale e pluriennale dello Stato (legge di stabilità 2016)».*
54. Ministry Decree of 26 June 2016, *Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici.*
55.Connolly D. *EnergyPLAN Cost Database*. Aalborgh University, January 2015.Available on line: *http://www.energyplan.eu/useful_resources/costdatabase/*
56.Gestore Mercati Energetici. Ritiro dedicato. 18-11-2014]; Available from: http://www.gse.it/it/Ritiro%20e%20scambio/Ritiro%20dedicato/Pages/default.aspx
57.Henrik Lund, Brian Vad Mathiesen The role of Carbon Capture and Storage in a future sustainable energy system, *Energy*, Volume 44, Issue 1, August 2012, Pages 469-476.

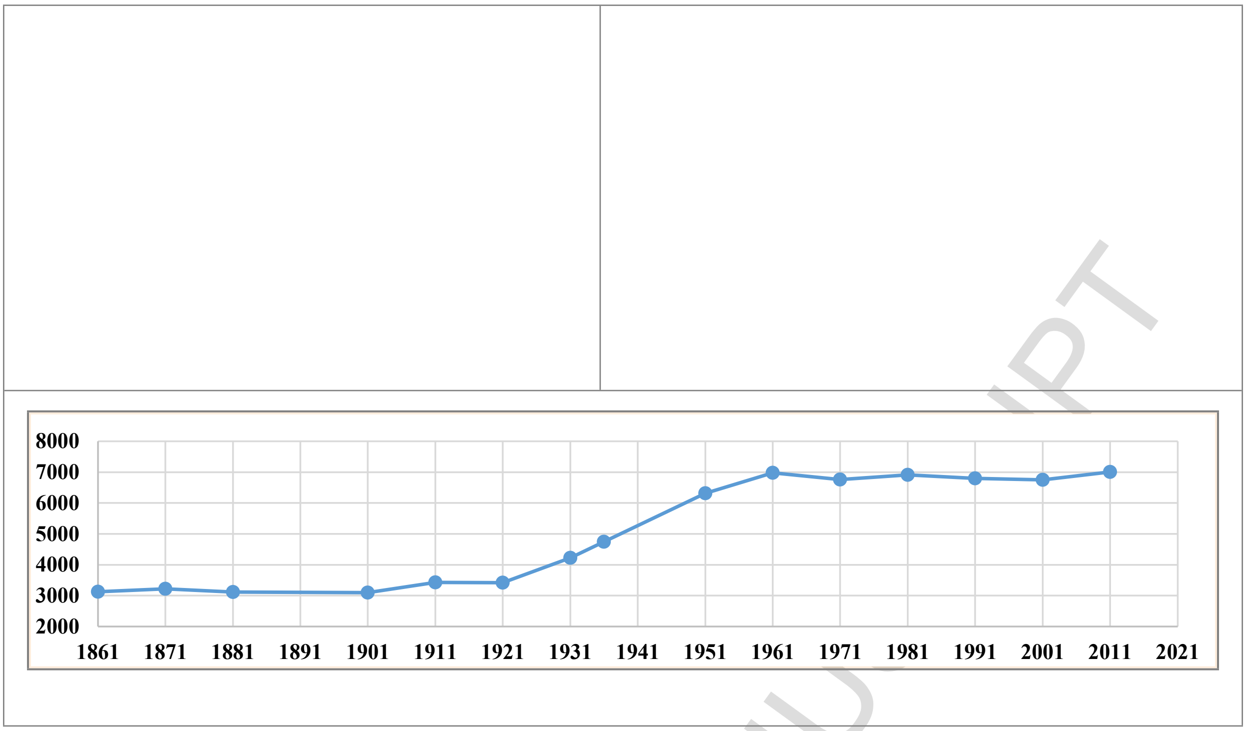


Figure 1 Geographic position and Trend of the population from 1861 to 2011, *Altavilla Silentina*, (*ISTAT* [43].).

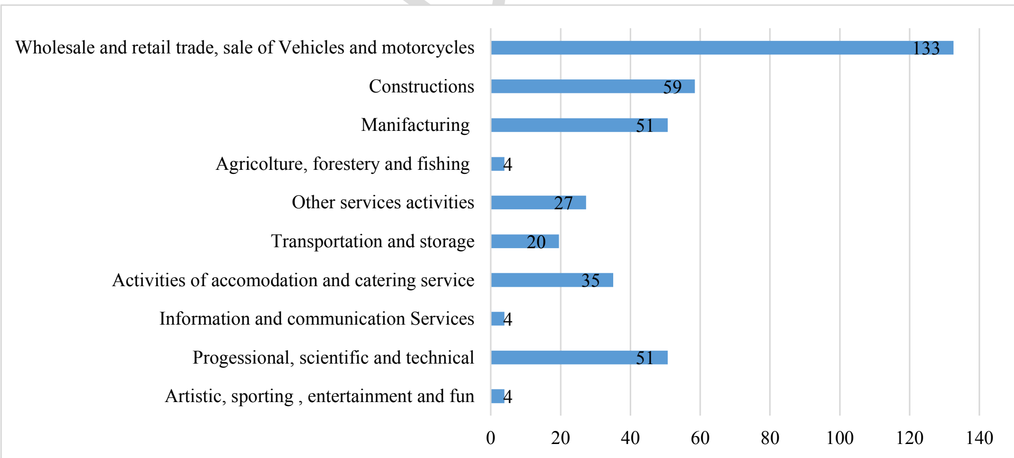


Figure 2: Active companies in 2011, Altavilla Silentina, (ISTAT [43].).

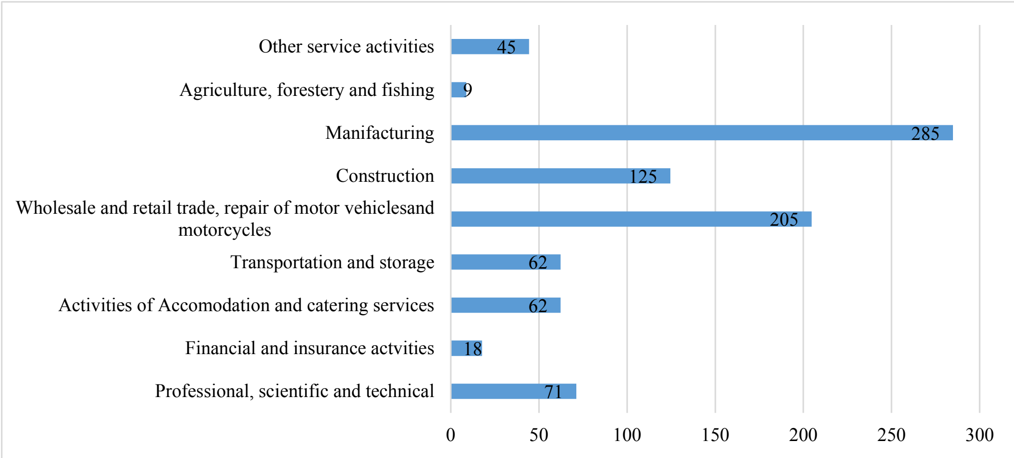


Figure 3: Employees in 2011, Altavilla Silentina, (ISPRA [43].).

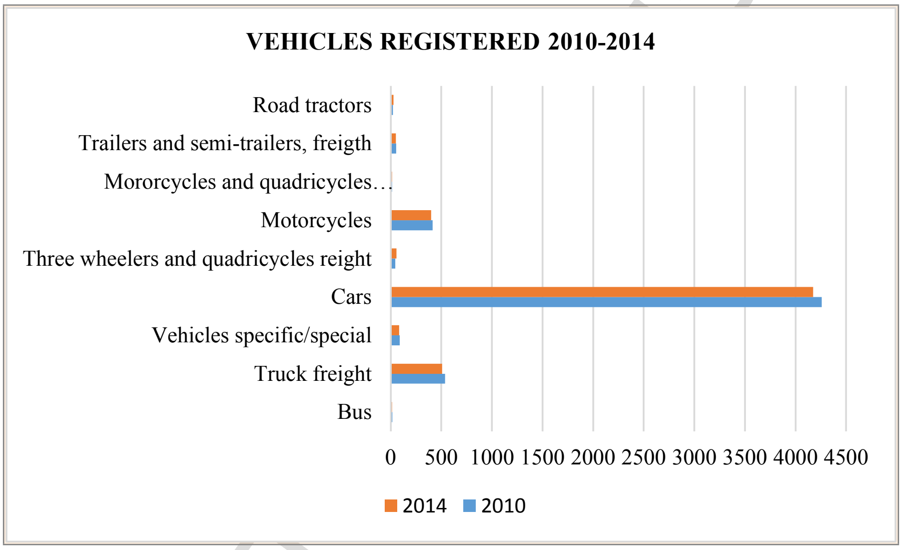


Figure 4: Vehicles on the road 2010-2014, Altavilla Silentina, (ACI [44])

Table 1: Age of residential buildings in Altavilla Silentina (ISTAT [43].)

Residential Buildings built in Altavilla Silentina						
Time interval	Until 1970	1971-1990	1991-2000	2001-2005	2006-2011	Total
Residential Buildings	1515	455	154	98	119	2341

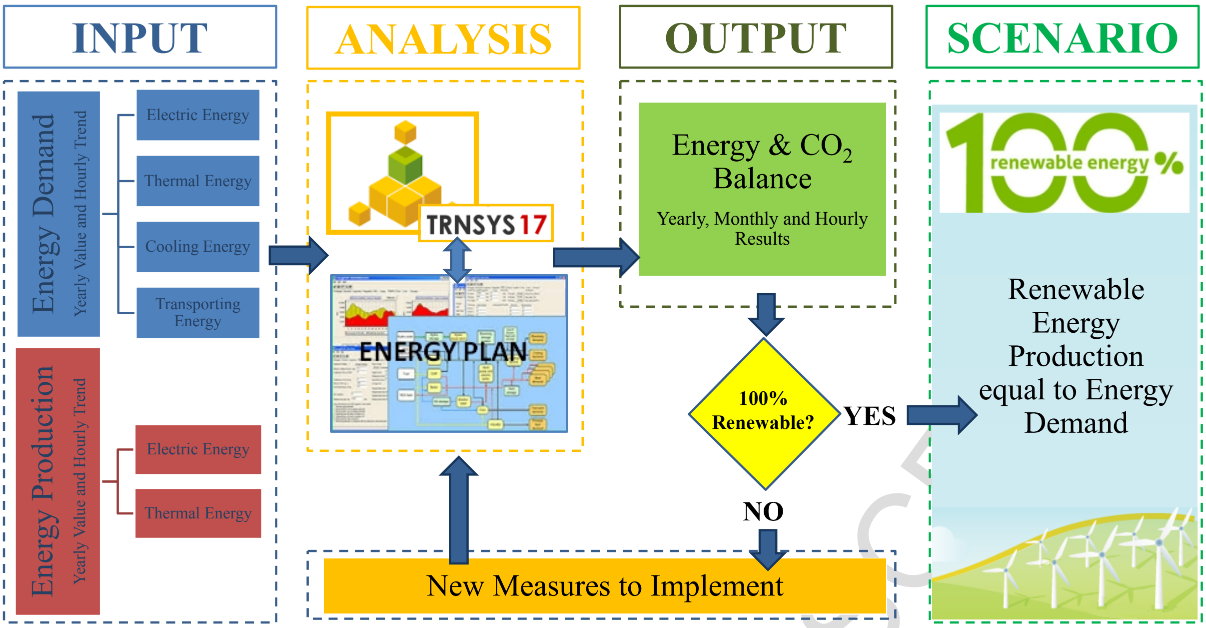


Figure 5: Input and Output of EnergyPLAN software.

Table 2: References Local Parameters for Top-down analysis

Vector	***End User Sector***				
	Residential	***Service Sector***	***Industry***	***Agriculture***	***Urban Transport***
Electric Energy	Number of inhabitants	Number of active units	Number of employees	Utilized agricultural area	Number of vehicles
Other Vector	Residential Surface				

Table 3: Reference Databases used in the Top-down analysis

Sector	***Gasoline***	***Diesel***	***LPG***	***Heating oil***	***Electricity***	***Lignite***	***Waste***	***Coal***
Residential	ISPRA	ISPRA	ISPRA	ISPRA	TERNA	ISPRA	ISPRA	ISPRA
Tertiary	ISPRA	ISPRA	ISPRA	ISPRA	TERNA	ISPRA	ISPRA	ISPRA
Public lighting	-	-	-	-	e-distribuzione	-	-	-
Industry	Energy Regional Balance /ENEA	Energy Regional Balance /ENEA	Energy Regional Balance/ ENEA	Energy Regional Balance/ ENEA	TERNA	Energy Regional Balance /ENEA	Energy Regional Balance /ENEA	Energy Regional Balance /ENEA
Private and commercial Transport:	ISPRA	ISPRA	ISPRA	ISPRA	ISPRA	ISTRA	ISPRA	ISPRA
Agriculture	ISPRA	ISPRA	ISPRA	ISPRA	TERNA	ISTRA	ISPRA	ISPRA

Table 4: Primary Energy Consumptions for the Buildings and Industry per energy carrier

	Gasoline	***Diesel***	***LPG***	***Heating oil***	***Electricity***	***Lignite***	***Waste***	***Coal***	***Total***
Municipal buildings, equipment/facilities	0	387	0	0	110	0	0	0	497
Residential buildings	0	167	3871	8	6942	8116	0	0	19105
Tertiary (non municipal) buildings, equipment/facilities	0	12	6581	0	3206	2	151	0	9952
Public lighting	0	0	0	0	827	0	0	0	827
Industry	115	1048	814	6807	9047	93	0	753	18677
Total	**115**	**1603**	**11266**	**6815**	**19194**	**8211**	**151**	**753**	**48109**

Table 5 Primary Energy Consumptions for the Transport and Agriculture sectors per energy carrier in 2010

	Gasoline	Diesel	LPG	Heating oil	Electricity	Natural Gas	Lignite	Waste	Coal	Total
Transport:										
Municipal fleet	28	14	0	0	0	0	0	0	0	42
Private and commercial	5633	6035	607	0	0	220	0	0	0	12496
Sub-total trasport	5661	6049	607	0	0	220	0	0	0	12538
Agricolture and Forestry	0	5940	95	0	1837	0	49	0	0	7922

Table 6 CO_2 emissions per sector and per energy carrier in 2010

	Gasoline	Diesel	LPG	Heating oil	Electricity	Lignite	Waste	Coal	Natural gas	Total
Municipal buildings, equipment/facilities	0	103	0	0	51	0	0	0	0	155
Residential buildings	0	45	879	2	3247	0	0	0	0	4173
Tertiary (non municipal) buildings, equipment/facilities	0	3	1494	0	1500	0	50	0	0	3047
Public lighting	0	0	0	0	387	0	0	0	0	387
Industry	29	280	185	1899	4231	0	0	257	0	6881
Transport:										
Municipal fleet	7	4	0	0	0	0	0	0	0	11
Private and commercial	1403	1611	138	0	0	0	0	0	220	3196
Agriculture and Forestry	0	1586	22	0	859	0	0	0	0	2467

Table 7 Expected CO_2 emissions increase from 2010 to 2020, due to the population and buildings growth.

	Value	Sector	CO_2 Emission Increase (t)
Building increase (m^2)	17936	Heating Energy Consumptions for Residential Buildings	57
Population Increase	146	Electricity Energy for residential Buildings	68
		Public Lighting	8
		Public and Private Trasporting	67
Total			***200***

Table 8 CO_2 Emissions reductions expected for each of the SEAP measure

Sector	*Measure*	*Measures*	*Energy Saving (MWh)*	*Energy from RES (MWh)*	*CO_2 Reduction (t)*
Public Building	01_RES_01	PV plants in the School Buildings (20 kW_e) (2012-2020)	0	28	13
	01_RES_02	Energy Efficiency for School Building (2012-2020)	0	0,57	2
Residential Buildings	03_EE_01	Replacement lamp(2010-2020)	858	0	400
	03_EE_02	Replacement fridge freezers (2011-2020)	465	0	217
	03_EE_03	PV plants (822 kW_e) (2013-2020)	0	2123	989
	03_EE_04	Install automatic shutoff devices TVs / decoder (2010-2020)	223	0	104
	03_RES_05	PV plants (1077 kW_e) (2010-2013)	0	715	333
	03_RES_06	Wind farm (900 kW_e) (2017-2020)	0	1350	629
	03_RES_07	Wind farm (600	0	1200	569

		kW_e) (2012-2020)			
	03_RES_08	Wind farm (14 MW_e) (2019-2020)	0	21000	9874
Industry	05_RES_01	Biogas plant for electric energy production (256 kW_e)	0	1228	170
	05_RES_02	Biogas Cogeneration plant (190 kW_e)	0	1520	708,6
		Biogas Cogeneration plant (261 kW_t)	0	835,2	110
Transporting	08_RES_01	Renewal of the vehicle fleet (2010-2020)	3394	705	1049

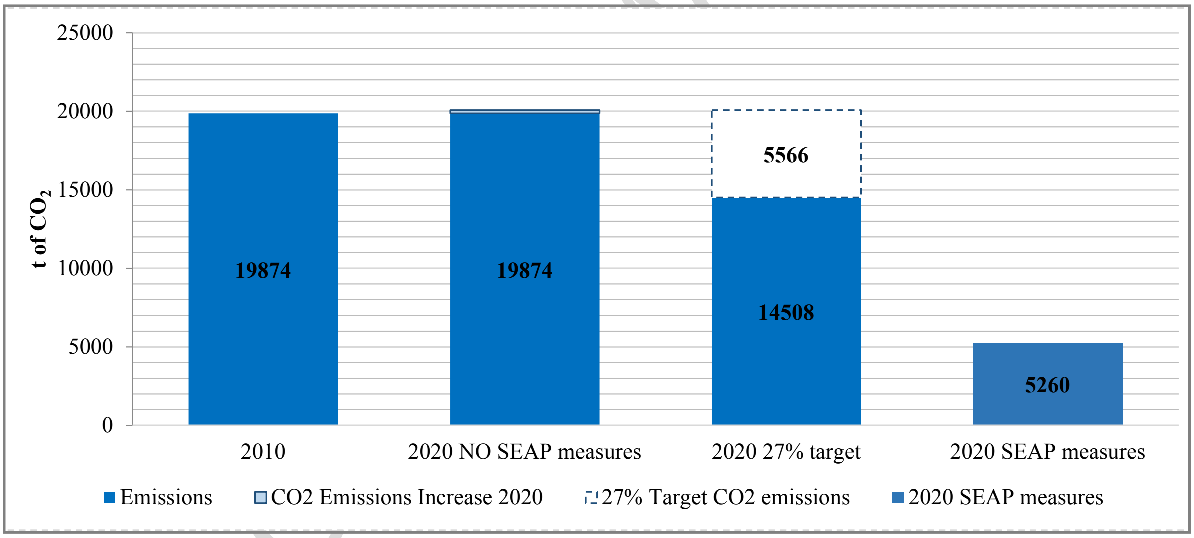


Figure 6 Comparison of the CO_2 emissions of Altavilla Silentina in the years 2010 and 2020.

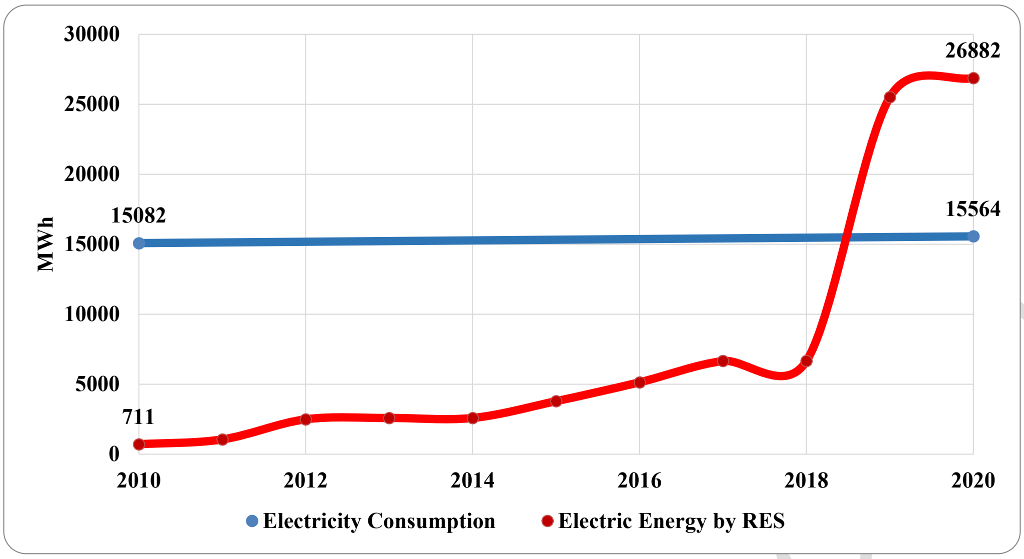


Figure 7 Electric Energy Consumptions and Electric Energy Production by RES of Altavilla Silentina Municipality in the year 2010 and 2020.

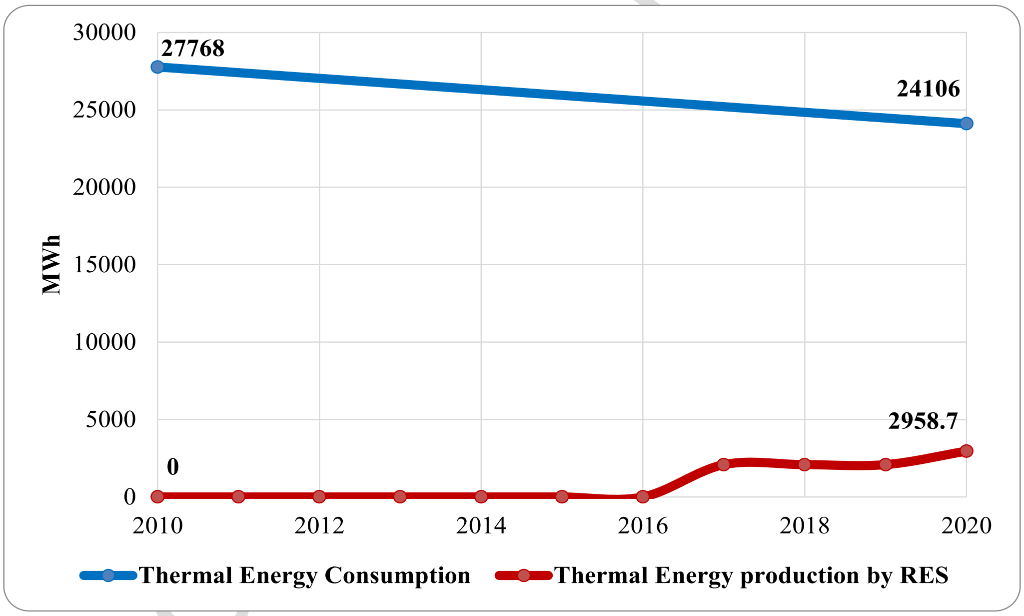


Figure 8 Primary Energy consumption for heating and thermal energy production by RES of Altavilla Silentina from the year 2010 to 2020.

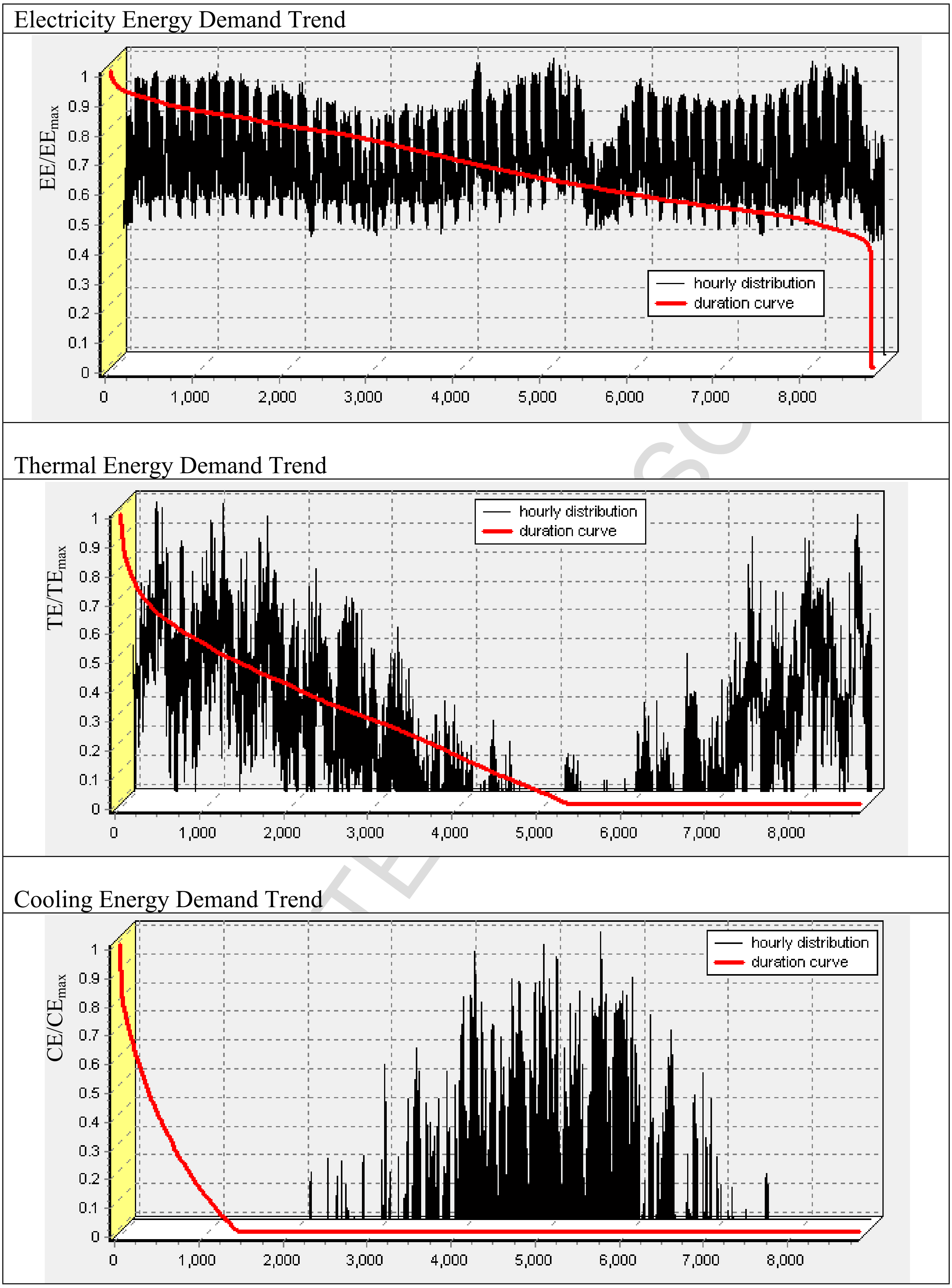


Figure 9 Hourly energy demand trend of Altavilla Silentina Municipality expected for 2030

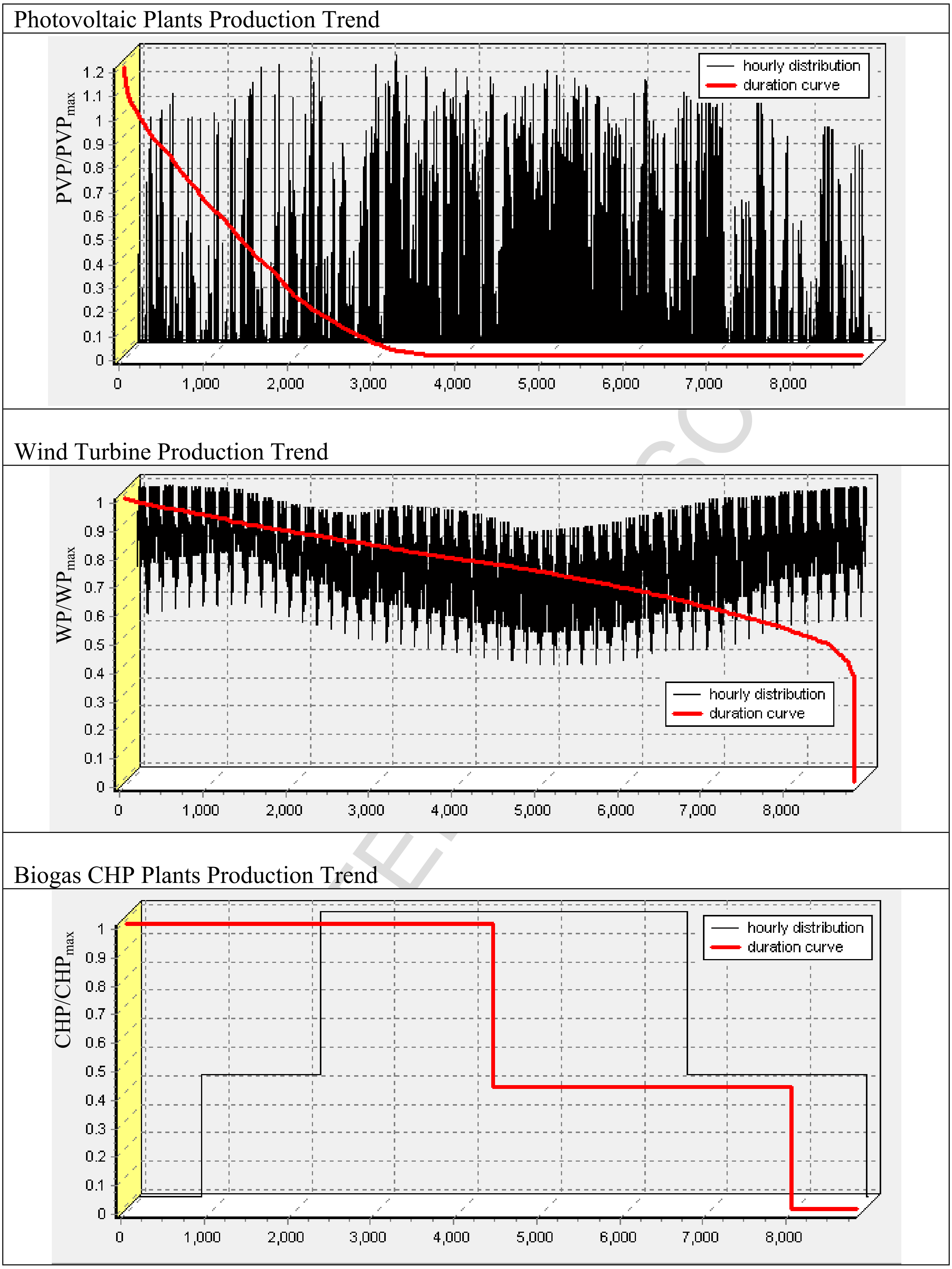


Figure 10 Hourly energy production trend of Altavilla Silentina Municipality expected for 2030

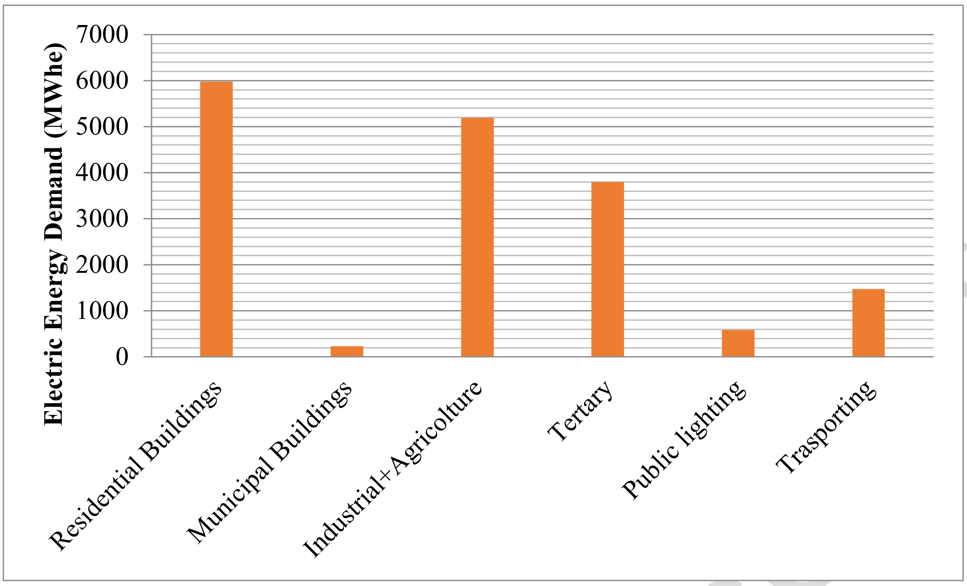


Figure 11 Expected electric energy consumption of Altavilla Silentina in 2030.

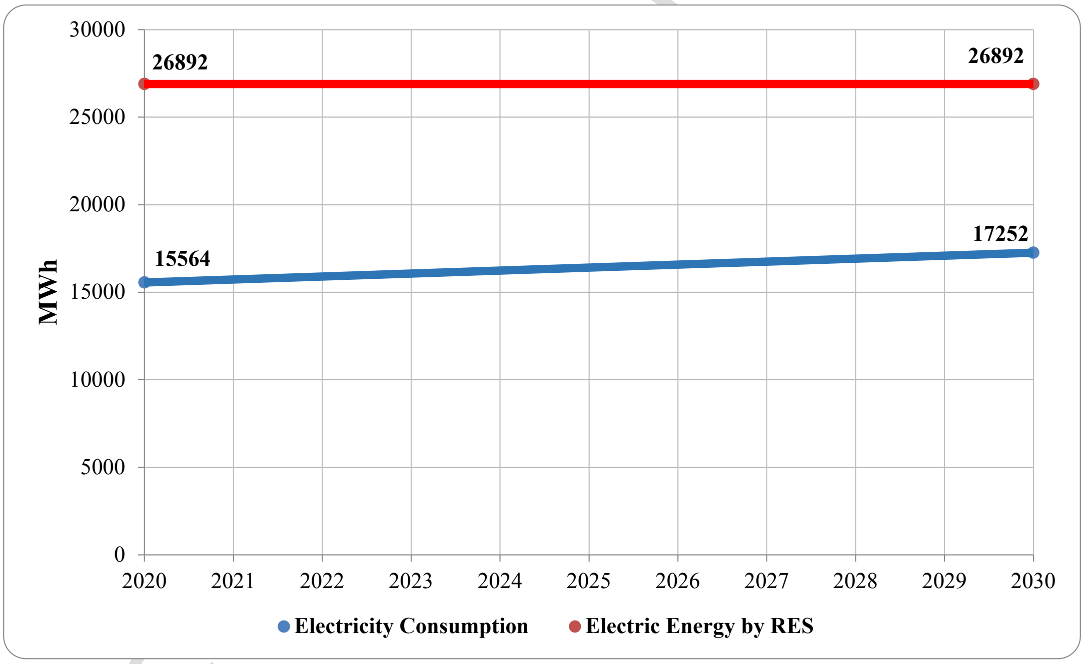


Figure 12 Electric Energy Consumptions and Electric Energy Production by RES of Altavilla Silentina Municipality in the years 2020 and 2030.

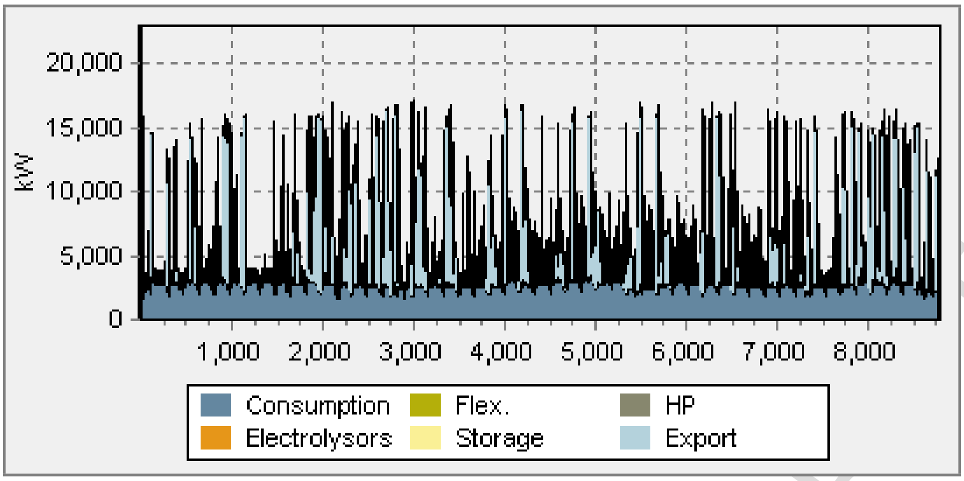


Figure 13 Yearly electricity consumption and electricity import from national grid.

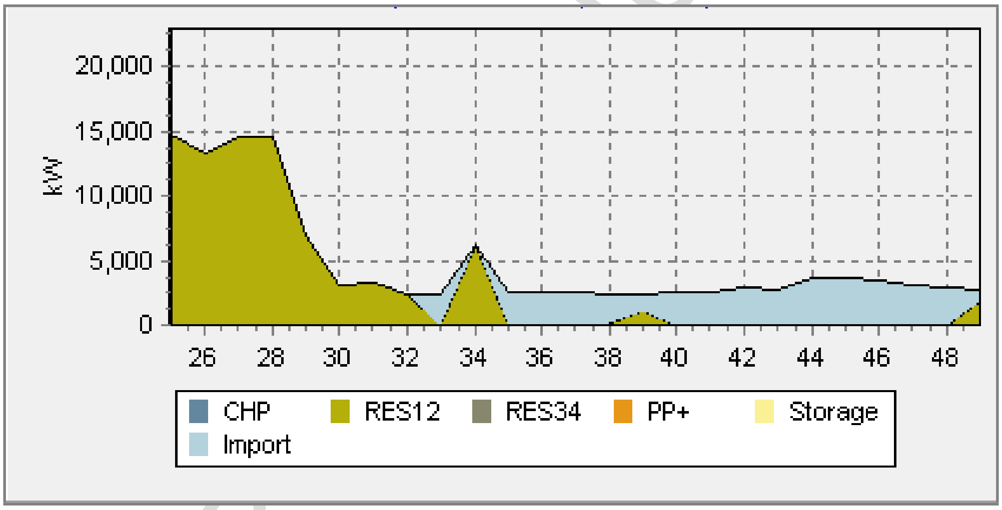


Figure 14 Electricity production by RES and Electricity import from national grid in a day of January.

Table 9 Installed power plants in the Altavilla Silentina 2030 scenario.

Plant	Power
Residential/ Tertiary Heat Pumps	~30.0 MW_e
Industry Heat Pumps	~60.0 kW_e
Wind Farm	15.5 MW_e
Photovoltaic	1.92 kMW_e
Biogas CHP	456 kW_e – 261 kW_t*
Residential/ Tertiary Biomass Boilers	~63.1 MW_t
Industry Biomass Boiler	~250 kW_t
* Two biogas plant have been considered: the first one produces only electric energy (256 kW_e) and the second one, to be built for cogeneration (190 kW_e- 261 kW_t)	

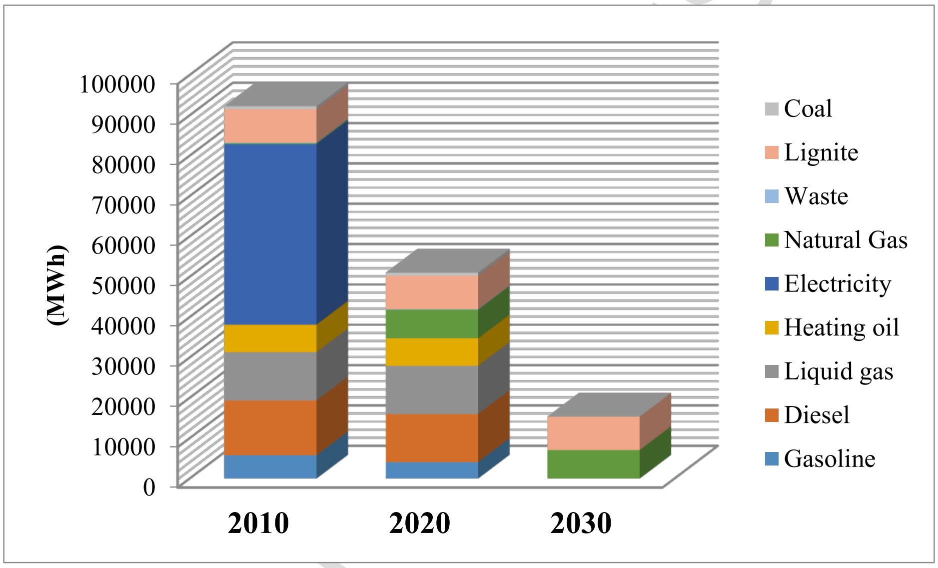


Figure 15 Primary energy supply Altavilla Silentina in the year 2010, 2020 and 2050.

Table 10 Investments cost and operating costs of new plants to be built by 2030

Plant	Investment Costs (2020)		Operating Costs	Period
	Unit	€/Unit	% of investment	Years
Heat Pump	kW	500	0.98	20
Wind Farm	kW_e	1840	2.97	25
Photovoltaic	kW_e	850	2.09	20
Biogas CHP	kW_e	6400	7.32	20
Biomass Boiler	unit	2500	1.79	20

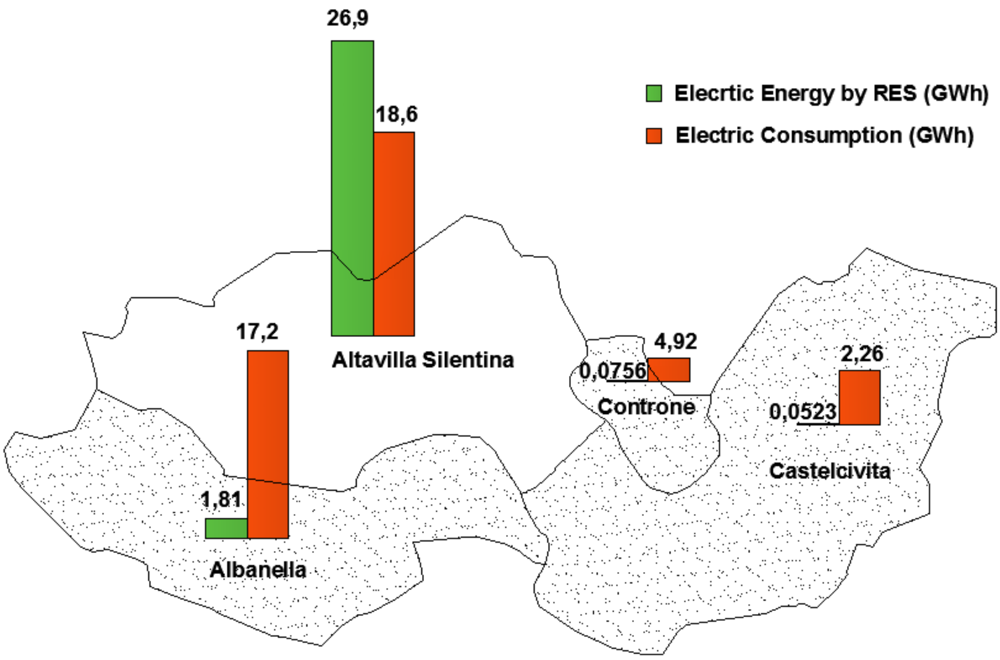


Figure 16 Electric consumption and RES production and of the neighbouring territories