A GIS-based model to assess buildings energy consumption and usable renewable energy potential in urban areas of Lazio Region

Livio de Santoli[a], Francesco Mancini[b], Davide Astiaso Garcia[*] [a]

* Corresponding Author – Resident Address: Via Eudossiana, 18 - 00184 Rome, Italy - Phone: +39 3492303498 – Email: davide.astiasogarcia@uniroma1.it

[a] *Department of Astronautics, Electrical and Energy Engineering (DIAEE)*, Sapienza University of Rome, Via Eudossiana, 18 - 00184 Rome, Italy - Phone: +39 0649918585 – Fax: +39 0649919171 – Emails: liviodesantoli@uniroma1.it (L. de Santoli); davide.astiasogarcia@uniroma1.it (D. Astiaso Garcia);

[b] *Department of Planning, Design and Technology of Architecture*, Sapienza University of Rome, Via A. Gramsci, 53 - 00197 Rome, Italy - Phone: +39 0649919172 – Email: francesco.mancini@uniroma1.it

A GIS-based model to assess electric energy consumptions and usable renewable energy potential in Lazio Region at municipality scale

Abstract

The ongoing energy transition processes need a rapprochement between the places of energy production and consumption with the aim of creating innovative and integrated territorial models. Consequentially, models and strategies for increasing the use of local and renewable energy sources (RES) play a key rule for enhancing energy independence and sustainability of the considered areas. The main objective of this study is to analyse the energy system of the Lazio Region in Italy, comparing electricity consumptions and production from renewable sources at municipality scale. In order to estimate the electricity consumptions and the local production by RES, the main sectors of electricity consumption together with the potential of the available RES for the electricity production have been analysed. The obtained results pinpointed the main critical aspects of the Lazio region, that are mainly focalized in the city of Rome and in the most densely inhabited municipalities. Furthermore, research outputs provide an overall framework on the regional RES potential and allowed the formulation of proposals aimed at overcoming the identified criticalities and increasing the share of electricity production from renewables. Finally, the research approach could be replicated in other areas, providing a useful process for decision makers and stakeholders.

Keywords: GIS (Geographic information System); renewable energy potential; energy consumption; electricity production; RES (renewable energy sources)

1. Introduction

The strategic role of renewable energy sources (RES), characterized by very low marginal costs and a fluctuating nature (McDonagh et al., 2019), has been widely recognized as the main pillar for the energy transition (Meza et al., 2019).

Several researchers analysed the impacts of the increasing RES penetration in the energy systems, often comparing historical data with future scenarios (Paraschiv et al., 2014) (Clò et al., 2015).

According to Bloomberg's latest Energy Outlook (Bloomberg New Energy Finance, 2017), in 2035 global electricity generation by RES could reach 16,000 TWh and could exceed the production from fossil fuels. Moreover, as stated by Bloomberg's, wind and solar energy, that currently covers the 12% of the global installed capacity and the 5% of the electricity generation, could increase their penetration to respectively 48% and 34% in 2040.

Extending the forecasting to 2050, the role of renewables becomes even more essential, particularly in some countries that aim at a total decarbonisation of energy consumption (Ćosić et al., 2012) (Zappa et al., 2019). This increasing RES penetration will involve significant variations in monitoring and managing the electricity networks (Noussan et al, 2018).

According to a recent IEA / Irena scenario, two thirds of the world's energy consumption in 2050 are met by renewables, with a 70% of electricity production by RES (IEA_IRENA, 2017).

The European Commission set that the contribution of renewables in 2030 will cover the 32% of the final energy consumptions. As regard the electric sector, this ambitious goal implies that more than half of the European electricity demand will be met by renewables. The European decision to raise to 32% the share of final consumption covered by RES requires a qualitative leap in the drafting of the national energy and climate plans of the member states (Simoes et al., 2018) (Lombardi et. al, 2018).

Considering the Italian situation, the reference scenario for electricity consumption, according to the latest calculations elaborated with the Primes model (Capros et al. 2016) and confirmed by the TSO data, indicates an annual electricity consumption of 323 TWh.

In the Greenpeace Energy [R] evolution scenario is expected an increase of the total electricity production from 300 TWh in 2010 to 320 TWh in 2030 (Greenpeace, 2013), while in Anie's calculations the annual grid demand at the end of the next decade will be between 342 and 356 TWh (Anie et al., 2017).

Moreover, it is important to consider two variables that will strongly influence the electricity demand by the end of the next decade: the spread of electric vehicles (Fischer et al., 2019) and heat pumps (Haakana et al., 2018). The Italian National Energy Strategy, published in November 2017, foresees 5 million electric vehicles in 2030, with a consequent increase of the electricity estimated between 7.5 and 9 TWh per year. Furthermore, it assessed an additional increase of around 10 TWh per year due to the spread of heat pumps.

So far, the Italian 2020 objectives about RES penetration have been achieved mainly thanks to the already installed hydroelectric plants, together with a significant reduction of energy consumptions due to the economic crisis of the previous years, and a substantial incentive program between 2008 and 2012 for the installation of new wind / photovoltaic (PV) and thermoelectric plants powered by bioenergies.

However, the higher increase of RES plants for achieving the new European objectives by 2030, can be hampered by the local communities' resistance (Astiaso Garcia, 2017) and the presence of landscaping, environmental or historical constraints especially in the case of large plants (Pueyo, 2018).

In order to overcome these resistances, it is necessary to spread a greater awareness in individuals and local communities about their energy consumption and the different ways of energy supplying. Working at regional scale, it is possible to accurately identify the limits and the potential of the considered area, making the energy planning more effective.

The approach of RES plants to the main consumption areas allows a reduction of energy distribution losses limiting dispatching complications and facilitating the localization of storage areas where the energy production should exceed the electricity consumptions.

In this context, the present research has been focused on the Italian Region of Lazio, assessing the electricity consumptions and the production from RES at a municipal scale, in order to identify the critical elements and highlight the main tools and strategies for fostering the energy transition.

Analysing previous researches on analogous topics, Asfaq and Ianekiev (2018) investigated the wind and solar potential at country level in Pakistan considering the electrical-load demand, while Chatri et al. (2018) focalised their research on the economic effects of RES penetration in the electricity sector considering the Malaysian characteristics.

Additionally, Gnansounou E, et al. (2007) analysed the integration between electricity supply and power generation systems of some countries at regional scale, Noorollahi et al. (2016) investigated a multi-criteria decision support system to estimate wind energy potential using western Iran as pilot area; moreover, Pfeifer et al. (2018) recently examined the combination of RES potential and demand response technologies in interconnected island energy systems.

In the light of the outcomes of the above mentioned researches, this paper integrates an electricity consumption assessment with an estimation of renewable energy potential using a small scale (municipality) approach and analyses data gathered and methods used in previous researches to identify specific strategies for increasing the RES penetration in the electric sector.

Furthermore, similar researches can be developed focusing on thermal energy consumption and the use of RES in the thermal sector (Astiaso Garcia, 2016) (Benato and Stoppato, 2018). The support of Geographical Information Systems (GIS) facilitates both a spatial overlapping of the obtained results with other regional cartographies (e.g. landscaping or environmental constraints) and facilitates a spatial overview of the results localizing each single municipality in a geographical context in order to allow comparisons with neighbouring municipalities.

In conclusion, detailing energy data at municipality scale and pinpointing the main criticalities to reach the settled energy targets, the research outputs can be used by other researchers and academics for further investigations that replicate the described approach in other pilot areas or aimed to highlight new tools and strategies for fostering the energy transition in the same region.

2. Methods

The research methodology includes the following four steps, described in this paragraph:

- State of the art analysis, examining research methods already tested in previous researches for assessing electricity consumption and productivity of plants powered by RES
- Selection and improvement of the chosen methodology (GIS approach);
- Implementation of the GIS database with electricity consumptions data and characteristics and locations of RES power plants data
- Elaboration of a queried maps and tables with percentages of electricity consumptions covered by local RES, identifying the most critical and suitable areas for the installation of new RES plants;

During the first step of the research, the main methods already used in energy planning researches on pilot areas have been analysed in order to pinpoint the best procedure for a geographical subdivision of the regional surface.

A geographical subdivision based on homogeneous energy characteristics has been carried out in many energy planning researches on specific areas (Arabatzis et al., 2017) (Kousksou et al., 2015), usually recalling the administrative boundaries at regional or municipal level (Tyralis et al., 2017) (Alsayegh et al., 2018), and reducing data complexity and dispersion (Noussan and Nastasi, 2018).

Different research approaches (Terrados et al., 2009) (Mourmouris, & Potolias, 2013) and different tools (Mirakyan & De Guio, 2013) (Huang et al., 2015) have been examined and it was decided to use a GIS (Geographic Information System) approach (Aydin et al., 2010) (Sliz-Szkliniarz & Vogt, 2011) (Resch et al., 2014), already tested by authors in previous studies for the evaluation of electricity consumption and productivity of plants powered by RES (Groppi et al., 2018) (De Santoli et al., 2017) (Mancini et al., 2017). Furthermore similar approaches have been selected for assessing the built environment energy use (Torabi Moghadam et al., 2018) (Carbonara et al., 2015), the energy renovation rate of private building stock (Caputo & Pasetti, 2017), the LEED-ND sustainability (Pedro et al., 2018), the residential water demand (Jayarathna et al., 2017) and other sustainability indicators applied on specific case study areas (Jing et al., 2018) (Astiaso Garcia et al., 2014).

A GIS approach made it possible to create a regional map of percentages of electricity consumptions covered by local RES, useful for identifying the most critical areas (Woldeyohannes et al., 2016) (Astiaso Garcia et al., 2015).

A GIS tool can also be used to identify suitable areas for the installation of new RES plants (Jahangiri et al., 2016) (Sánchez-Lozano et al., 2013) (Höhn et al., 2014) as well as for territorial planning aimed at increasing the percentage of electricity consumptions through RES (Yeo et al., 2013) (Yeo & Yee, 2014) (Saretta et al, 2019) that foresees the involvement of local communities (Brandoni & Polonara,

2012) (Simão et al., 2009) (Van Hoesen & Letendre, 2010). Although ambitious, the final goal is to achieve a full coverage of electricity consumption with RES (Heard et al., 2017) (Mason et al., 2010). Following a similar methodological approach, it was decided to assess energy consumptions and RES potential using the Lazio Region administrative structure at municipality scale.

Characteristics and locations of RES power plants data have gathered by the Italian Manager of Energy Services (GSE) (GSE, 2018) at province scale. Specifically, the following data have been considered: electricity production from PV, wind, hydroelectric and bioenergy thermoelectric plants. Energy consumptions data have been extracted from the Italian TSO reports at province scale (Terna, 2018), classifying it into the following sectors: residential, tertiary, industrial and agricultural.

The RES electricity production at municipality scale has been extrapolated using an open source GIS software (QGIS) and considering the localization and the energy characteristics of each plant as well as the provincial production of RES.

The distribution on a municipal scale of electric consumptions data has been estimated considering the number of inhabitants of each municipality and the localization of industries and land uses following the CORINE land cover classification (Bruschi et al., 2015; Astiaso Garcia et al., 2013).

Furthermore, using this GIS approach, it was possible to get spatial data at municipality scale both on electric energy consumptions and RES electricity production, allowing a geographical comparison and implementation with additional and already existing spatial data, such as landscaping and environmental constraints.

3. Results

3.1. Lazio region gathered data

Lazio is a region on the Tyrrhenian cost of the central Italy (figure 1), that includes the city of Rome. With almost 6 million inhabitants it is the second most populated region in Italy after Lombardy. The territory is divided into 5 provinces (Frosinone, Latina, Rieti, Rome, Viterbo) and 378 Municipalities; among these only 78 have more than 10,000 inhabitants (Table 1).

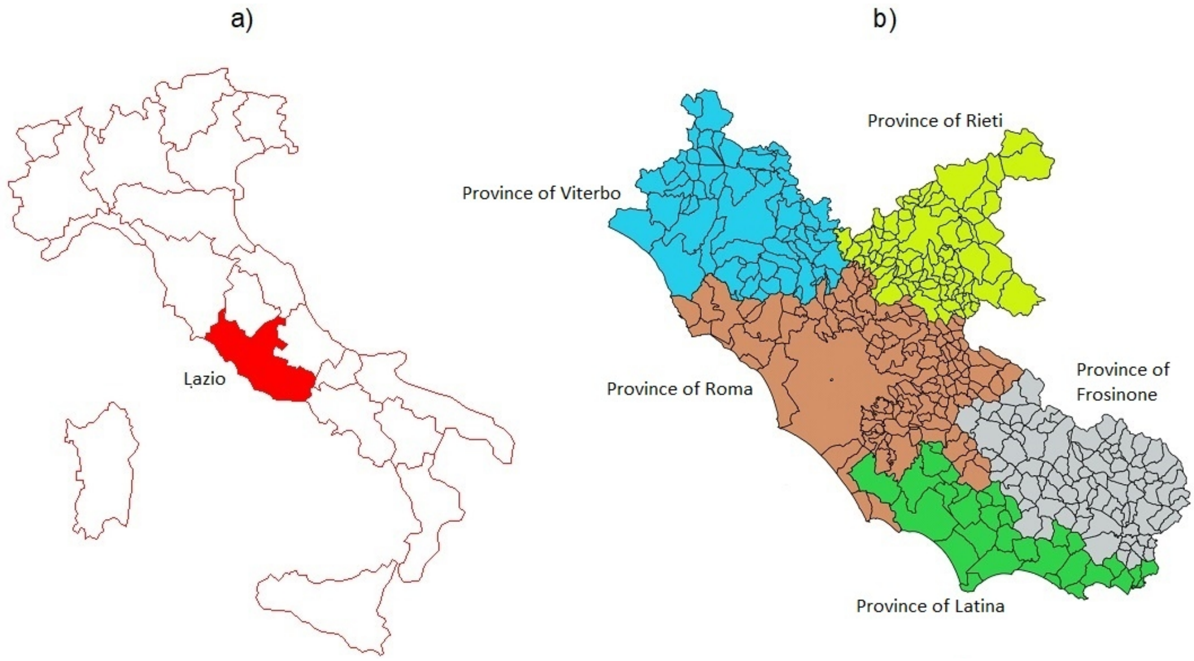


Figure 1 - a) Geographical overview of the Lazio Region - b) Subdivision of the territory in Provinces and Municipalities.

	Inhabitants	Surface [km^2]	Population density [inhabitants/km^2]	Municipalities	Municipalities > 10,000 inhabitants
Frosinone	495,026	3,244	153	91	12
Latina	1,148,452	4,501	255	33	15
Rieti	316,934	5,498	58	73	2
Roma	426,380	2,347	182	121	44
Viterbo	640,558	7,223	89	60	5
Total (Lazio)	2,532,819	19,572	129	378	78

Table 1 - General information on the Lazio provinces

As regard the coverage of electricity consumption from renewable energy sources (RES), Lazio is one of the last Italian regions (GSE, 2018) with a 14.1% coverage compared with the national average of 33.6% (Figure 2). Considering the short-term previsions and projecting current trends to 2020, according with the physical, socio-economic and environmental constraints of the region (Regione Lazio, 2017) there are no strategies and plans to increase that percentage above the 21% in 2020.

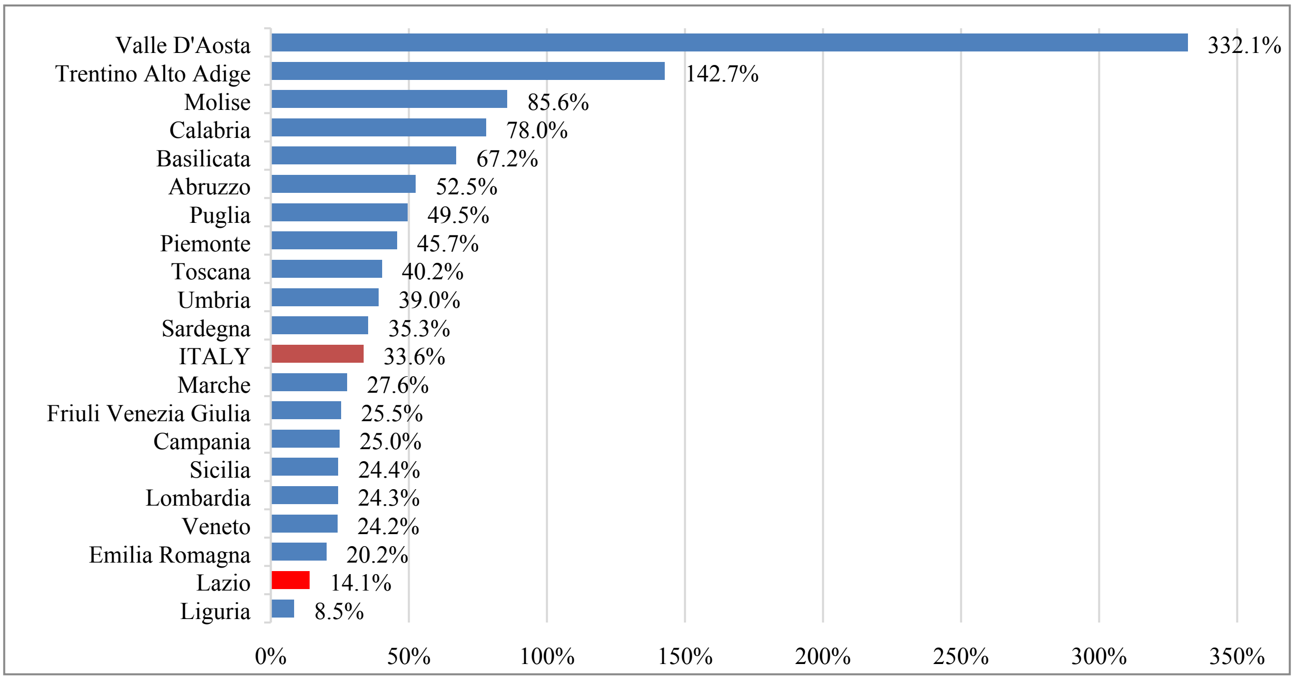
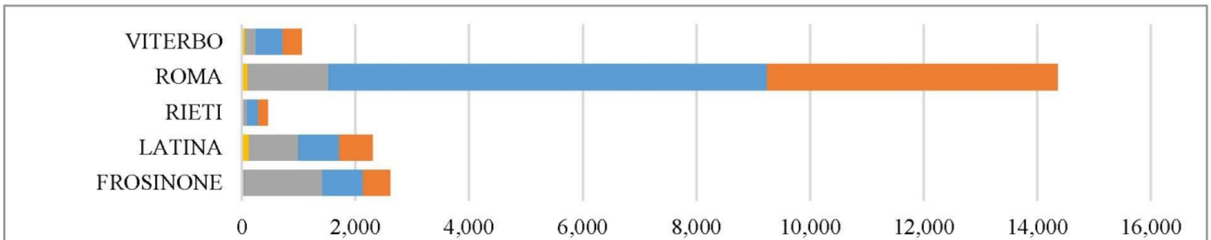


Figure 2 - Percentage of gross final electric energy consumption covered by RES for each Italian region in 2015 (Data source: GSE, 2018)

Although this percentage is in line with the regional objectives set by the national program (Ministry of Economic Development, 2012), it was essential to study the motivations of this particular situation and to formulate hypotheses for improving the current scenario based on the obtained results of this research.

3.2. Analysis of electricity consumption in the Lazio Region

The electricity consumption of the Lazio Region has been analysed starting from the Italian TSO data (Terna, 2018a) at a provincial scale and subdivided into the main sectors (Figure 3).



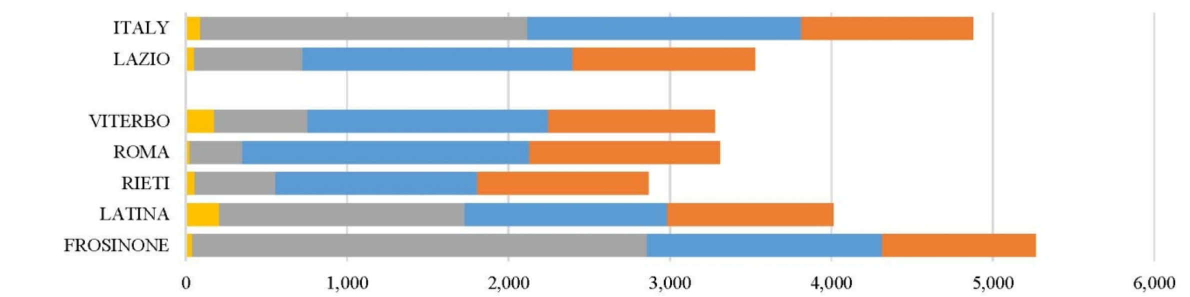
	FROSINONE	LATINA	RIETI	ROMA	VITERBO
agricultural sector	21	119	9	104	57
industrial sector	1,395	874	79	1,418	185
tertiary sector	721	721	198	7,727	477
residential sector	470	591	168	5,111	331

Electricity consumption [GWh/y]

Figure 3 - Electricity consumption of the Lazio Region for each considered sector

The 69.1% of the total electricity consumptions comes from the province of Rome, 46.2% considering only the city of Rome.

Analysing the electricity consumption for each sector, the tertiary (49.1%) and the residential sectors (31.1%) prevailed, with smaller shares for the industrial (18.4%) and the agricultural one (1.4%). Analysing the data at provincial level, a greater share of the industrial sector is particularly evident in the Frosinone and Latina provinces, where it accounts respectively for the 53.5% and the 37.9%. In the province of Rome, the weight of the industrial sector is the lowest (9.9%), while the weight of the tertiary sector (53.8%) is the largest one. The percentage of electricity consumption in the agricultural sector is higher than 2% only in the provinces of Viterbo and Latina. Turning to the results of the per capita consumption analysis (Figure 4), analysing TSO data (Terna, 2018a) peculiar characteristics of the electricity consumption of Lazio region have been observed compared to the Italian average.



	FROSINONE	LATINA	RIETI	ROMA	VITERBO		LAZIO	ITALY
agricultural sector	42	207	57	24	179		53	92
industrial sector	2817	1522	500	327	577		671	2026
tertiary sector	1457	1255	1251	1780	1490		1672	1698
residential sector	949	1029	1059	1177	1034		1133	1061

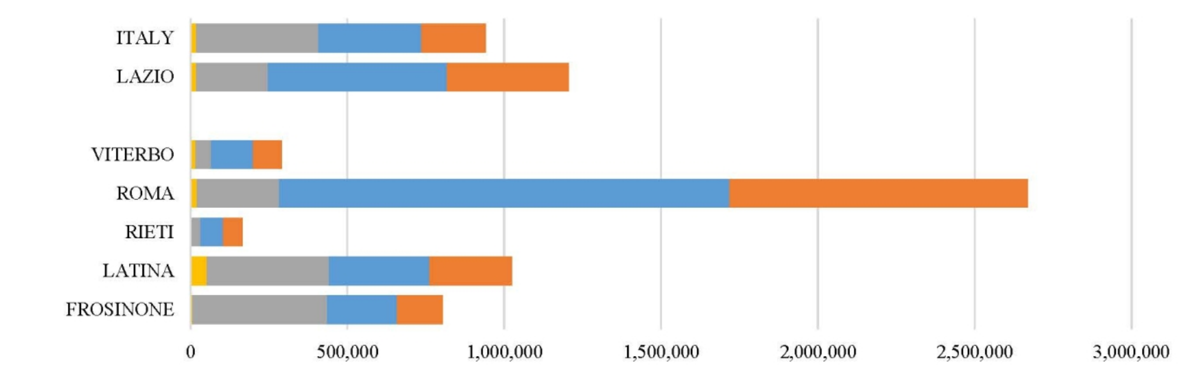
Electricity consumption per capita [kWh/y]

Figure 4 - Electricity consumption per capita (Data from Terna, 2018a)

The average per capita consumptions of electricity in Italy is 4,877 kWh / inhabitant, while in Lazio is 3,640 kWh / inhabitant (-25.4%). At the provincial level, the per capita electricity consumption of the provinces of Frosinone and Latina is higher than the regional average, while the consumption of the other provinces is lower. In particular, the per capita consumption of the province of Frosinone (5.263 kWh / inhabitant), is the only higher than the national average.

In the residential sector, the average national per capita consumption is equal to 1,061 kWh / inhabitant. In Lazio, per capita consumption is higher (1,164 kWh / inhabitant), albeit with a limited percentage difference (+ 9.6%). Furthermore, analysing the obtained results at a regional level, there are very similar per capita consumption among the different provinces, with a minimum value in the

province of Frosinone (970 kWh / inhabitant) and a maximum data in the province of Rome (1,211 kWh / inhabitant) where residential per capita consumptions are among the highest in Italy.
As regard the tertiary sector, the average national per capita consumption is equal to 1,698 kWh / inhabitant while in Lazio is 2.6% higher (1,743 kWh / inhabitant). That difference is mainly due to the province of Rome, with a per capita consumption of 1,876 kWh / inhabitant, + 10.5% compared to the national average. All the other provinces of Lazio have lower per capita consumptions, both compared to the regional and to the national average, with minor differences between provinces (the minimum value of 1.231 kWh / inhabitant has been gathered in the Latina province).
The agricultural sector is the one with the lowest per capita consumption; the national average is 92 kWh / inhabitant while the Lazio one is 53 kWh / inhabitant. The provinces of Latina and Viterbo are characterized by a per capita consumption among the highest in Italy, while the province of Rome is one of the lower in Italy. However, although at a percentage level there are high differences, comparing the absolute values they are very limited (less than 200 kWh / inhabitant).
The industrial sector has the highest per capita consumption; the national average is 2,026 kWh /inhabitant while in Lazio there are decidedly lower consumptions (679 kWh / inhabitant, -66.5%). The provinces of Frosinone and Latina have per capita consumption much higher than the regional average; in particular, the province of Frosinone has per capita consumption in the industrial sector even higher than the national average. On the other hand, Lazio region, and particularly the provinces of Viterbo, Rieti and Rome, have per capita consumption in the industrial sector among the lowest in Italy.
The analysis of electricity consumption per unit area (Figure 5) shows how the Lazio Region is characterized by higher consumptions compared with the national average (+ 28.1%). The unit area has been assessed considering the total surfaces of provinces and region, including consequentially both natural areas, built environment and infrastructures.
Consumptions in the province of Rome, due to is higher population density, are extremely higher than the national average (+ 121.4%) and the regional one (+ 183.6%). Latina and Frosinone data are in line with the national and regional average, while the provinces of Rieti and Viterbo have much lower consumptions than the national and regional averages.



	FROSINONE	LATINA	RIETI	ROMA	VITERBO		LAZIO	ITALY
agricultural sector	6350	52834	3274	19327	15838		17968	17731
industrial sector	429947	388413	28845	263541	51197		229236	390885
tertiary sector	222326	320293	72131	1436048	132105		571172	327702
residential sector	144795	262571	61037	949814	91734		387016	204791

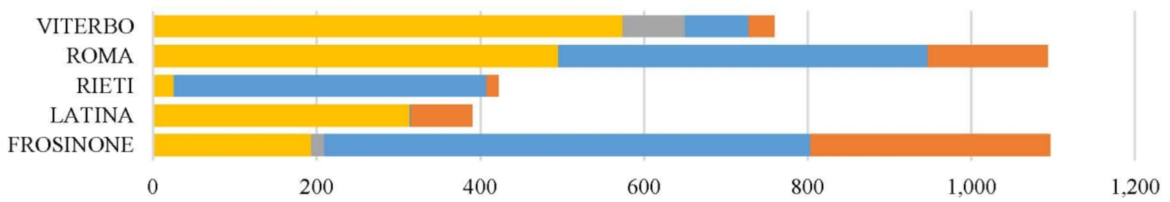
Electricity consumption per unit area [kWh/(y*km²)]

Figure 5: electricity consumption per unit area including both natural areas, built environment and infrastructures. (Data from Terna, 2018a)

Concluding, the obtained results underlined that Lazio Region consumes electricity mainly in the city of Rome; therefore, a significant portion of the regional averages are influenced by that city where electricity consumptions are mainly related to the residential sector with a consequential high per capita consumption. Among the provinces of Lazio, Frosinone and Latina are characterized by high electricity consumption per capita in the industrial sector, while a high per capita electric consumption in the agricultural sector has been highlighted in Latina and Viterbo provinces.

3.3. Renewable energy production in the Lazio Region

Starting from the data gathered from each one of the 43,277 plants powered by RES in the Lazio Region (the whole data details are reported in Annex 1), the electricity production has been calculated considering the average production between 2012 and 2016, assessing for each province the production per capita and per unit area (Figure 6).



	FROSINONE	LATINA	RIETI	ROMA	VITERBO
Solar	193.3	313.5	25.5	495.2	574.0
Wind	16.2	0.0	0.0	0.1	76.4
Hydro	594.3	2.1	382.4	451.9	77.3
Bioenergy	292.4	74.7	14.5	146.0	31.4

Breakdown of the electricity production of electricity from RES [GWh/y]

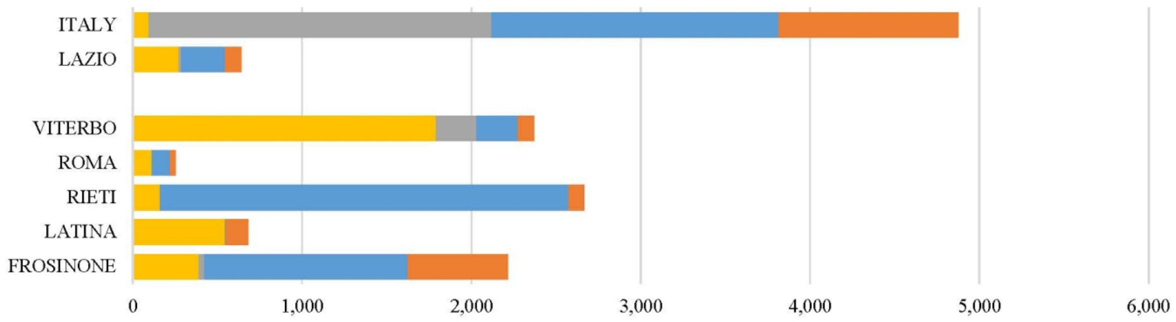
Figure 6: electricity production of electricity from RES in the Lazio Region

Contrary to what has been observed for electricity consumption, considering the regional distribution of electricity production from RES, the largest share still belongs to the province of Rome, although with a lower percentage (29.1%) and with the same share in the Frosinone province. Analysing the RES typologies, the largest shares are related to PV (42.6%) and hydroelectric (40.1%) plants, with smaller shares for biomasses thermoelectric (14.9%) and for wind (2.5%) power plants

Lazio provinces are characterized by a different distribution of electricity production:

- in the province of Rome the production of RES electricity is mainly obtained from PV (45.3%) and hydroelectric plants (41.3%), while in Rieti province the 90.5% is related to hydroelectric plants;
- in the province of Frosinone, hydroelectric plants account for 54.6% and biomasses plants for 26.7% (biogas: 1.6%; liquid biomasses: 10.7%; solid biomasses: 13.6%; wastes: 0.8%);
- PV systems are prevalent in the provinces of Latina and Viterbo (with 80.3% and 75.6% respectively).

Considering the RES production per capita results, he whole Lazio Region is characterized by values significantly lower than the national average (Figure 7). At the regional level, the province of Rome has a low RES production per capita while the values of all the other provinces are higher than the regional average. Furthermore, the average per capita production of the Rieti, Viterbo and Frosinone provinces are higher than the national average.



	FROSINONE	LATINA	RIETI	ROMA	VITERBO		LAZIO	ITALY
Solar	390	546	161	114	1792		272	92
Wind	33	0	0	0	238		16	2026
Hydro	1200	4	2413	104	241		256	1698
Bioenergy	591	130	92	34	98		95	1061

Per capita electricity production from RES [kWh/y]

Figure 7: Per capita electricity production from RES in the Lazio Region

Analysing the electricity production sources, it was possible to highlight some remarkable data from each province:

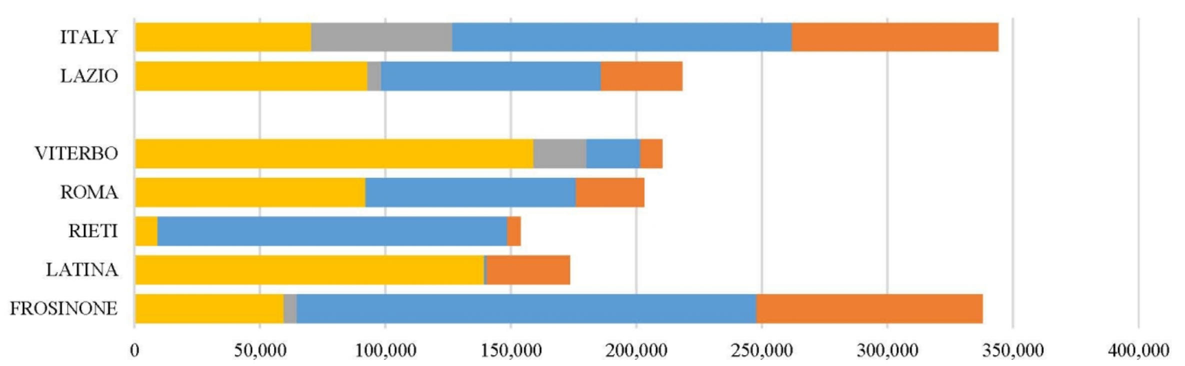
- with reference to PV production, the province of Viterbo is undoubtedly one of the areas with the highest per capita production (more than twice the national average and six times higher than the regional average); the provinces of Latina and Frosinone also exceed the national average;

- considering the electricity production from wind, also in this case the province of Viterbo is the first one in the Lazio region, with a production of 238 kWh / year per inhabitant, just below the national average;

- the provinces of Rieti and Frosinone have a very high production from hydroelectric sources; in both cases the obtained values are above the national average and very significant in absolute terms (2,413 kWh / year for the province of Rieti and 1,200 kWh / year for the Frosinone one);

- the province of Frosinone is the first in Lazio for thermoelectric production of electricity from RES (biomasses), with a production per inhabitant of 591 kWh / year.

The analysis of RES production per surface unit offers a slightly different detail from what has been highlighted (Figure 8). However, the regional average remains well below the national one (-39%) and there is a greater uniformity among the Lazio provinces, with values always lower than the regional average, except for the province of Frosinone, which amounts are in line with the national average. On the other hand, very low values has been obtained for the provinces of Latina and Rieti.



	FROSINONE	LATINA	RIETI	ROMA	VITERBO		LAZIO	ITALY
Solar	59579	139297	9279	92029	158925	0	92912	70396
Wind	5002	16	0	13	21147	0	5379	56333
Hydro	183192	954	139114	83986	21401	0	87495	135133
Bioenergy	90139	33179	5288	27131	8696	0	32432	82157

Electricity productions from RES per unit of area [kWh/(y*km^2)]

Figure 8: Electricity productions from RES per unit of area in the Lazio Region

Focusing on the electricity production from PV, major differences have been pinpointed between Lazio provinces: very high values have been observed in the provinces of Viterbo and Latina, while very low ones characterized Rieti province. This discrepancy could be related to the low population density of the province of Rieti, finding no prerequisites at the territorial level since the energy production of the PV plants is quite uniform in the whole Region (1,270 ÷ 1,370 kWh / kWp for optimally- inclined photovoltaic modules) (Joint Research Centre, 2018), as shown in Figure 9.

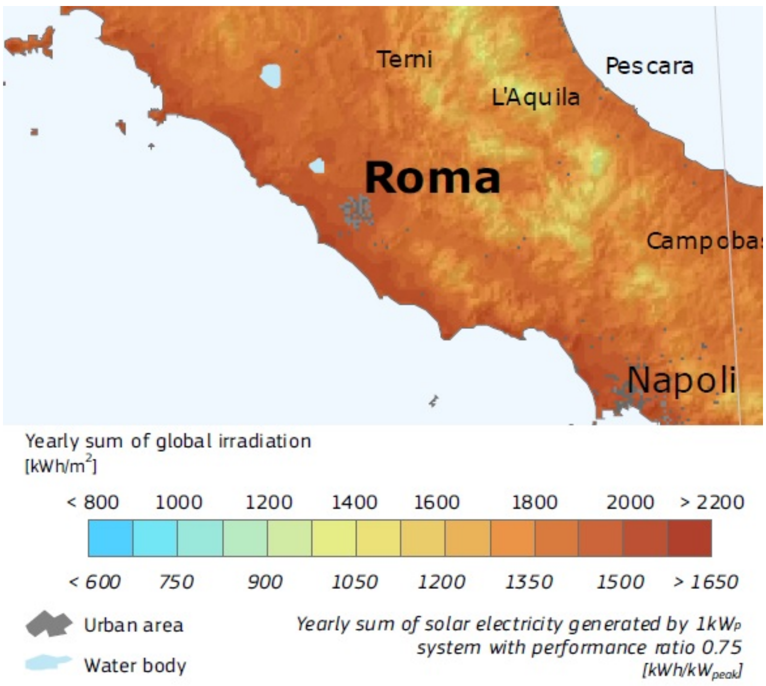


Figure 9: Yearly sum of global irradiation [kWh/m^2] in the Lazio region.

Turning to the analysis of wind production, major territorial differences have been highlighted. In particular, the location of the plants is strongly related with the site wind availability, generally with medium / low values compared to other regions and limited to some areas mainly located in the Viterbo and Frosinone provinces (Figure 10) (RSE, 2018).

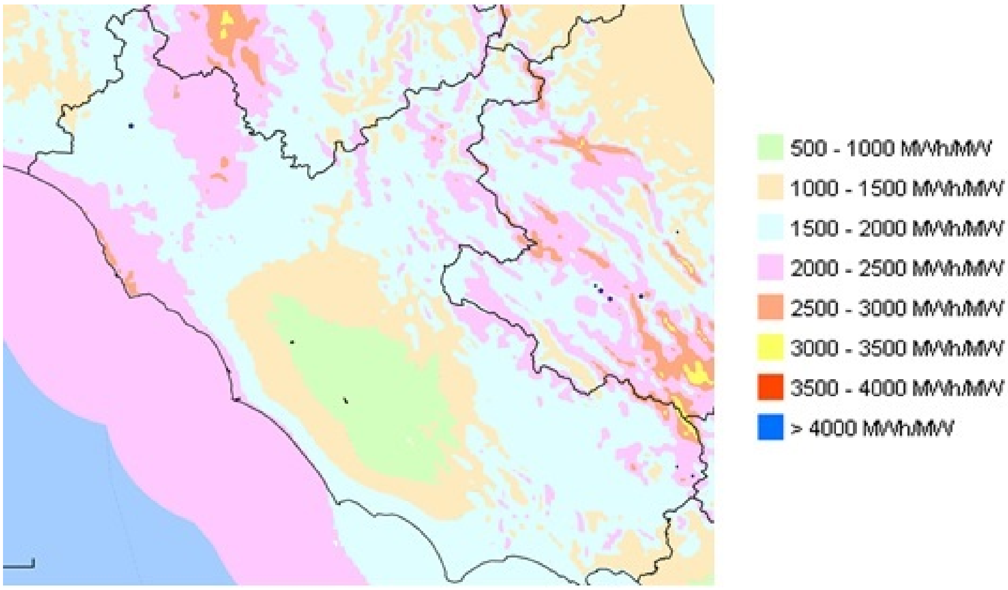


Figure 10: annual potential production of a wind power plant [MWh / MW] in the Lazio region.

As regard the electricity production from hydroelectric power, similar considerations can be stated: the analysis of the production per unit area shows significant territorial differences, mainly linked to the natural characteristics of the region. However, although the hydroelectric plants distribution in the region is higher compared with the wind ones, the production in the Latina and Viterbo provinces is rather low.

Lastly, considering the electricity production from bioenergy, Lazio values are significantly below the national average, with a production of 32,432 kWh / km^2 compared to 85.608 kWh / km^2. Frosinone province has a production higher than both the regional and the national average, while all the other provinces have lower productions per surface units.

3.4. Territorial analysis

365 municipalities of the Lazio region have with at least one RES generation plant (96.6%); in the remaining 13 municipalities there are only 4,185 inhabitants altogether (Figure 11 – the whole data are reported in annex 2).

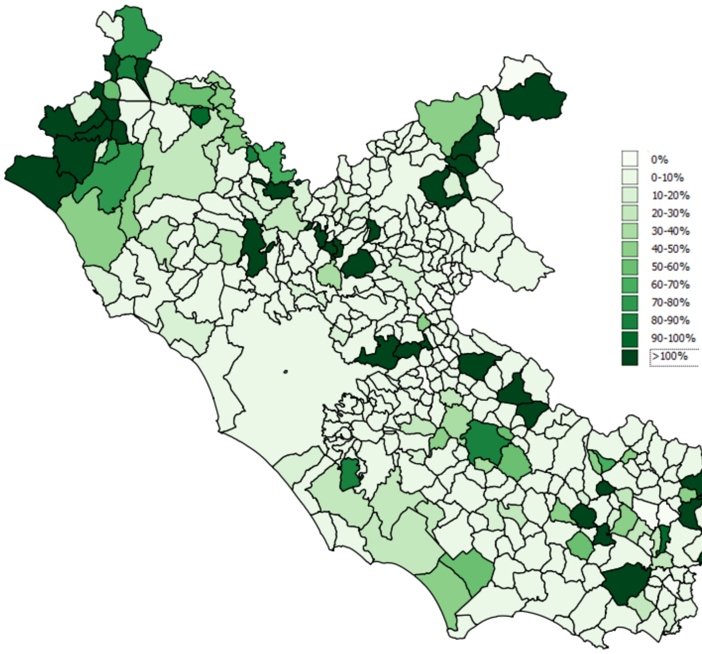


Figure 11: Percentage of electricity consumptions covered from RES in each Lazio municipality

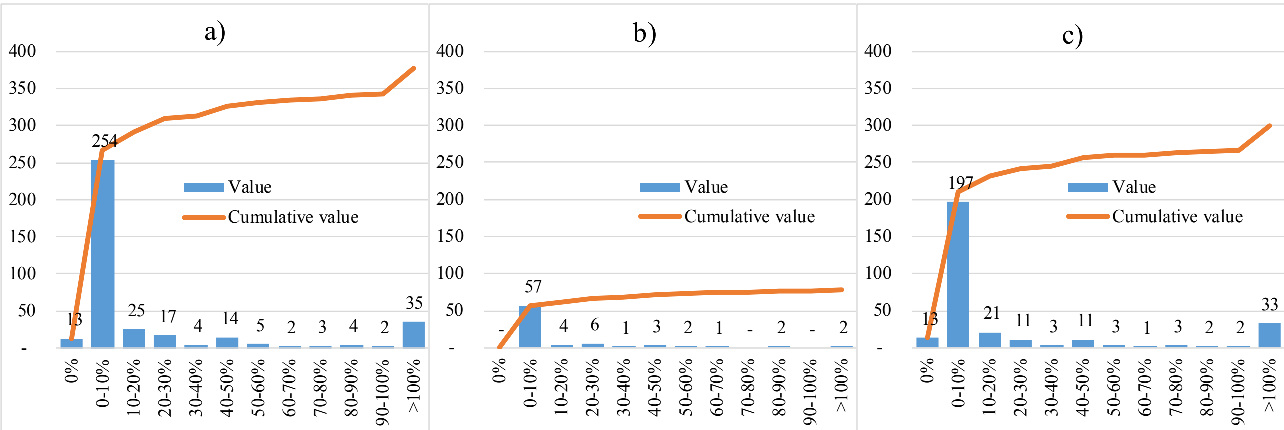


Figure 12: Number of municipalities and related percentages of RES covering electricity consumption. a) all the Lazio municipalities; b) municipalities with more than 10,000 inhabitants; c) municipalities with less than 10,000 inhabitants

The energy self-sufficient municipalities are 35 (Figures 12-a) and totally include 174,787 inhabitants. Usually, energy self-sufficiency is due to the presence of a large-scale hydroelectric, wind or biomasses-thermoelectric plant. Exceptions are some municipalities in the province of Viterbo (Montalto di Castro, Ischia di Castro, Cellere, Canino, San Lorenzo Nuovo, Valentano, Onano) in which self-sufficiency depends on large PV systems. Among the self-sufficient municipalities, only two (Tivoli and Fara in Sabina) have more than 10,000 inhabitants.

Analysing the inhabitants, it can be observed that:

• in major municipalities (with more than 10,000 inhabitants), the coverage of electricity consumption from RES reaches 8.1% and is therefore significantly lower than the regional average; in the city of Rome the coverage percentage is 2.9%; among these municipalities, only Fara in Sabina and Tivoli are self-sufficient thanks to the presence of hydroelectric plants; the municipalities with a renewable source coverage of more than 30% are just 11; almost half of the major municipalities have a RES coverage lower than 5%; the overwhelming majority of municipalities (Figure 12-b) have a RES coverage lower than 10% (56 municipalities);

• in smaller municipalities (with less than 10,000 inhabitants) the coverage of electricity from renewable sources is 70.9%; the minor municipalities with a RES coverage of more than 30% are 58, while the majority (179 municipalities) have a renewable source coverage lower than 10% (Figures 11-c).

As expected, the PV source is the most widespread (Figure 13). The presence of wind farms and hydroelectric plants is strongly linked to the characteristics of the territory and in some municipalities it allows to reach significant coverage percentages. Bioenergy plants, that in some cases reach high coverage rates, are present in 47 municipalities as follow: 48 biogas plants (56,69 kW); 31 liquid biomasses plants (61,26 kW); 18 solid biomasses plants (62,10 kW); 1 waste plant by-products and residues (3,360 kW).

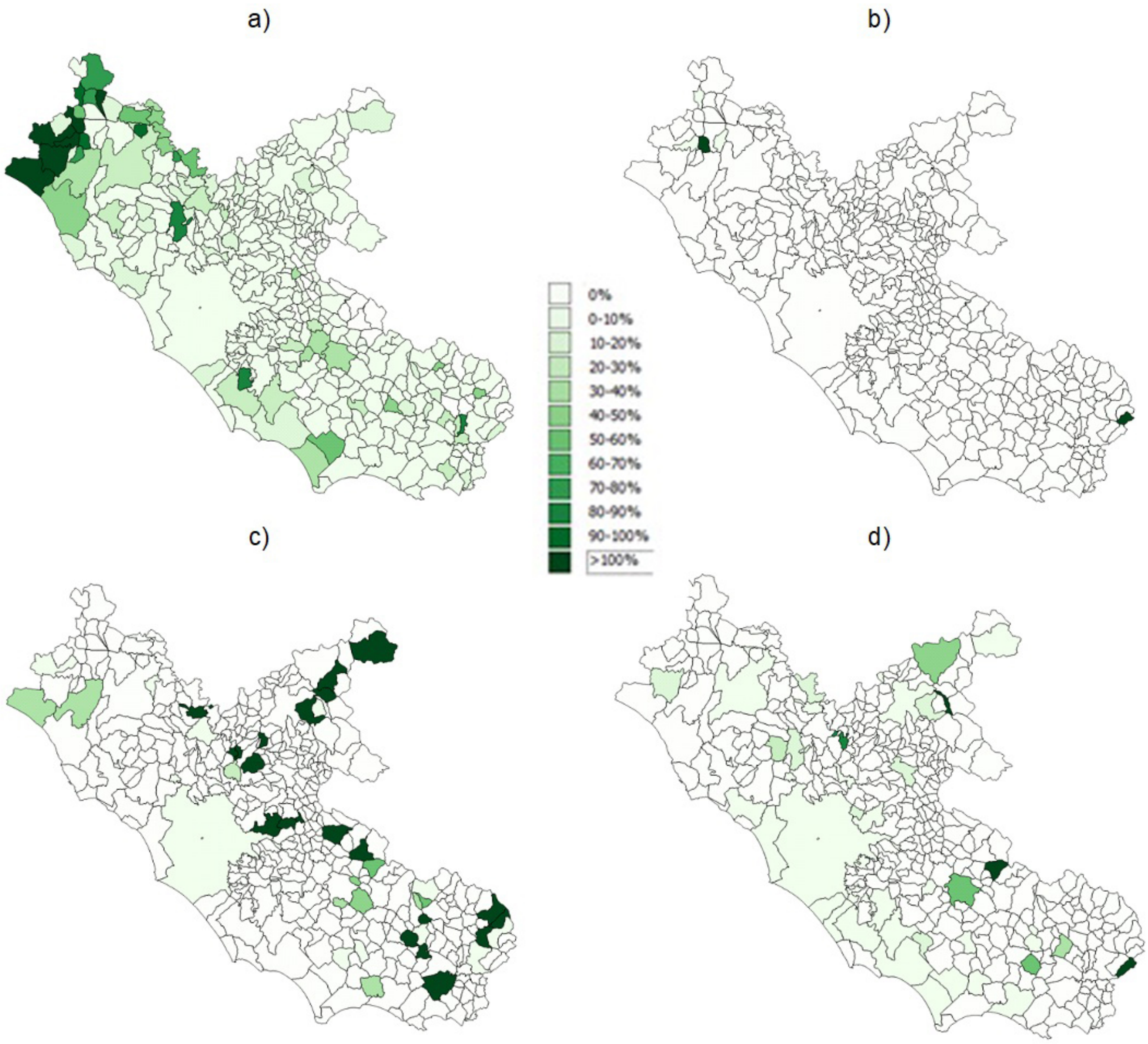


Figure 13: Percentage of energy consumptions covered from RES. a) PV b) wind c) hydroelectric d) thermoelectric from bioenergy.

3.5. Trend of electricity production from renewable sources

To fully analyse the production of electricity from RES in Lazio, the evolution over the years of installed power and production has also been considered (Höhn et al., 2014).
Observing Figure 14, it can be said that the period between 2009 and 2012 was the one with the most significant growth; the installed power of hydroelectric plants has remained almost constant and the wind power increased significantly only in 2011, with the installation of a wind farm. On the other hand, the power of plants powered by bioenergy has grown significantly and constantly throughout the years, together with the installed power of PV systems that starting from values close to zero in

2008 became the most significant among the various sources, with an installed power of 1,238.8 GW in 2016.

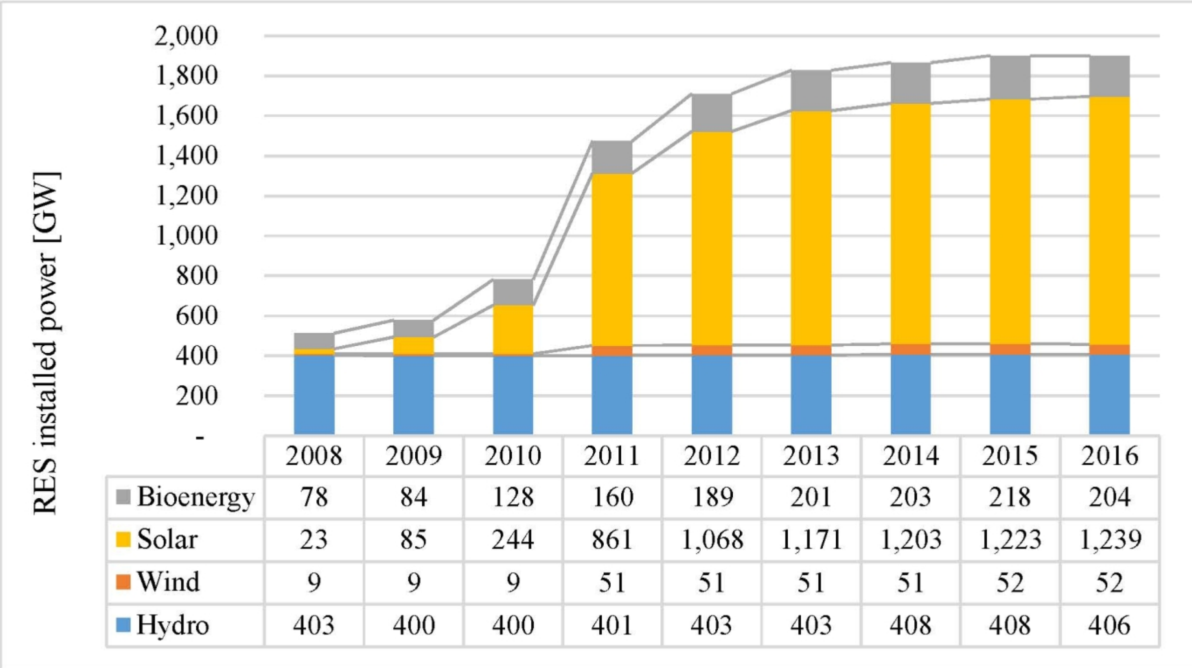


Figure 14: evolution of RES installed power [GW] from 2008 to 2016.

Figure 15 shows the trend, in the same period (2008-2016), of the electricity production from RES. This trend is influenced not only by the evolution of the above described power values, but also by the different characteristics of the plants and the seasonality of each production.

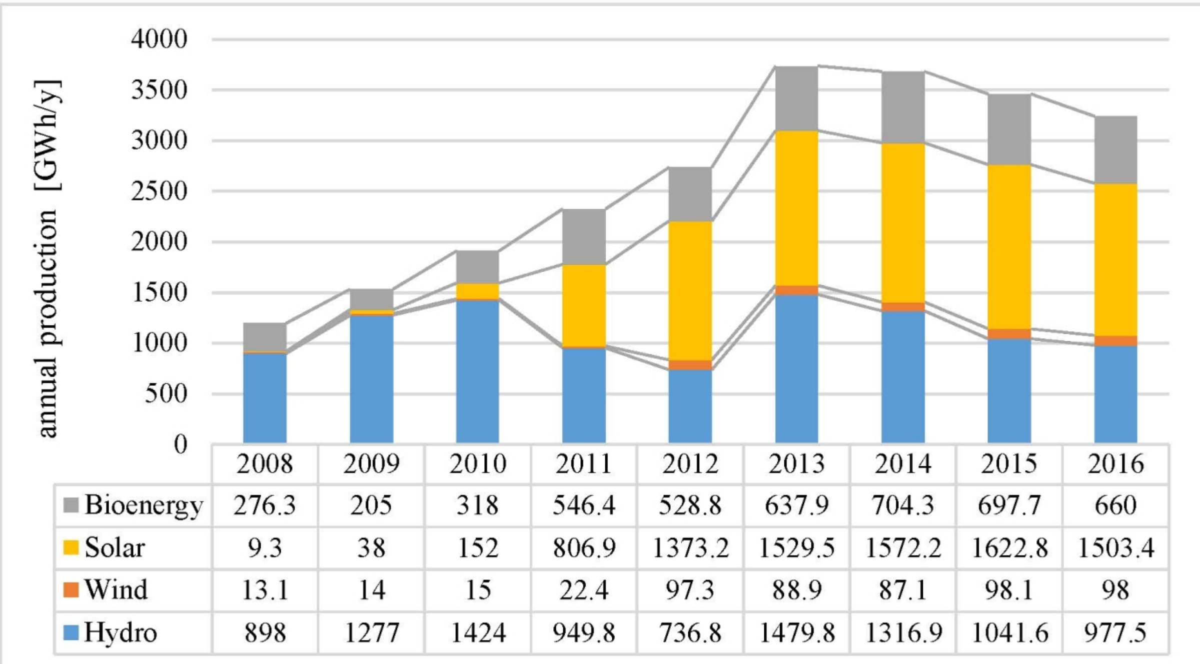


Figure 15: evolution of annual production from RES between 2008 and 2016.

The energy consumption trends in Lazio was then evaluated between 2011 and 2016 (Figure 16), observing a steady decline over the years, both for the whole region and for each single province; in particular, the electricity consumption of the Lazio Region decreased from 22.934 to 20.776 GWh, with a reduction of 2.177 GWh (-9.4%, -1.9% per year).

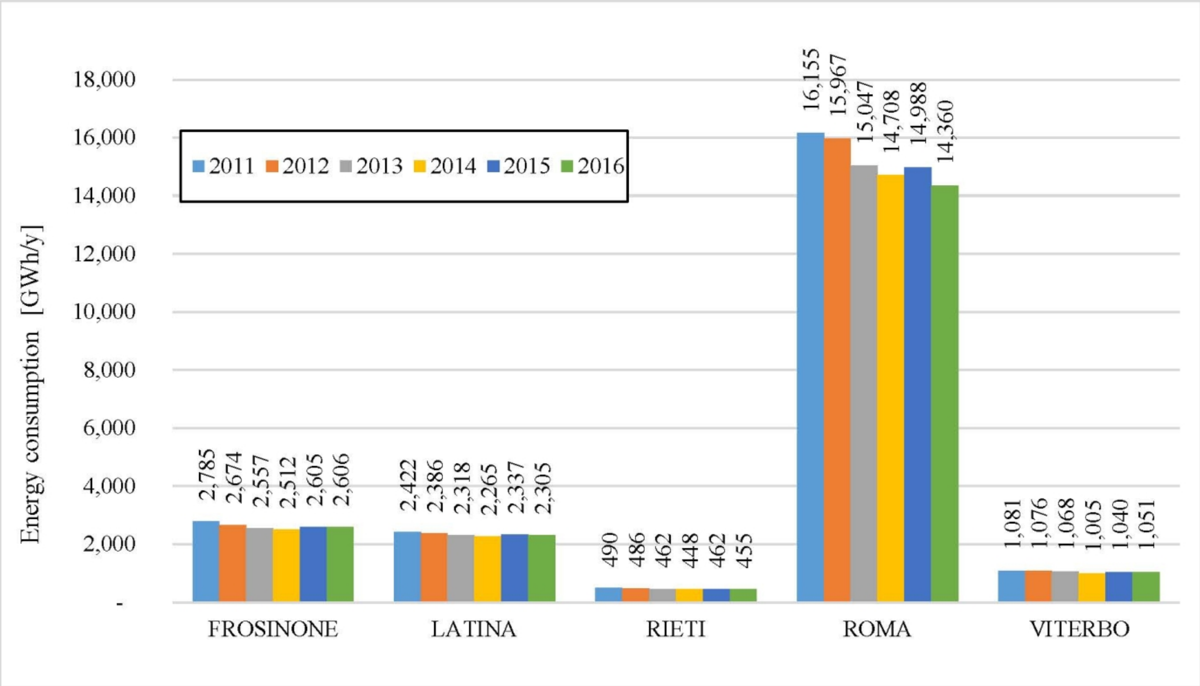


Figure 16: Energy consumption in the Lazio region from 2011 to 2016.

In the light of the above electricity consumption and RES production data, the percentages of electricity consumption from RES has been calculated for each province. According with these data, the average energy consumption percentage covered by RES in 2016 for Lazio region is 16.2% (Figure 17).

A projection of the current situation was then carried out to 2020 and 2030, based on the following assumptions and considerations:

• the energy consumption trend remains constant; the effects of a possible electrification of energy consumptions are not considered (Regione Lazio, 2017);

• the installed power of hydroelectric plants is only slightly increased (+ 0.2% / year) and mainly due to the repowering of existing plants, considering that the territorial potential has been already fully exploited (Regione Lazio, 2017);

• the power of bioenergy plants will increase of 7.8% by 2020 (considering the current trend that leads to an exploitation of 17.5% of the residual potential) and will reach 27.4% by 2030, with a 60% exploitation of residual potential (Regione Lazio, 2017) (De Santoli et al., 2015);
• the power of wind farms will increase of 21% by 2020 (considering the current trend for small and large plants already authorized) and will reach 150% by 2030, with a 30% exploitation of residual potential;
• PV production will increase a 4% per year, maintaining the current trend.

Based on these hypotheses, Lazio would remain one of the Italian regions with the lowest RES penetration, with a coverage of 19.0% in 2020 and of 28.2% to 2030; however, the provinces of Rieti and Viterbo in 2030 could reach full coverage of electricity consumption with local RES production (Figure 18).

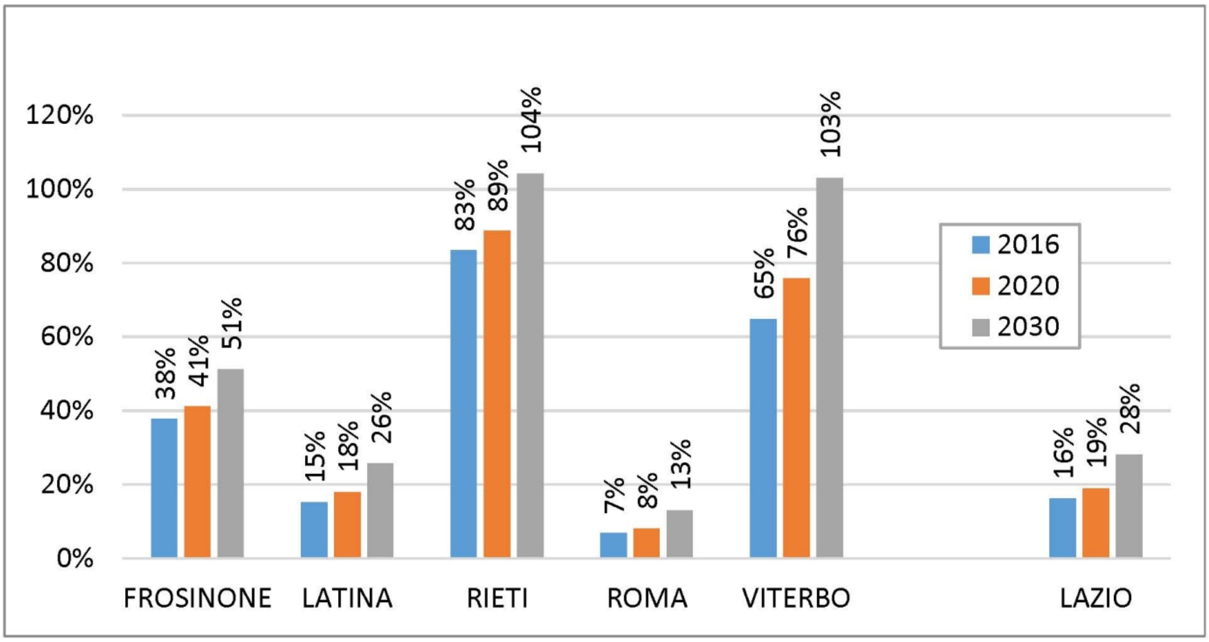


Figure 17: Current percentage of electricity consumption covered by local RES.

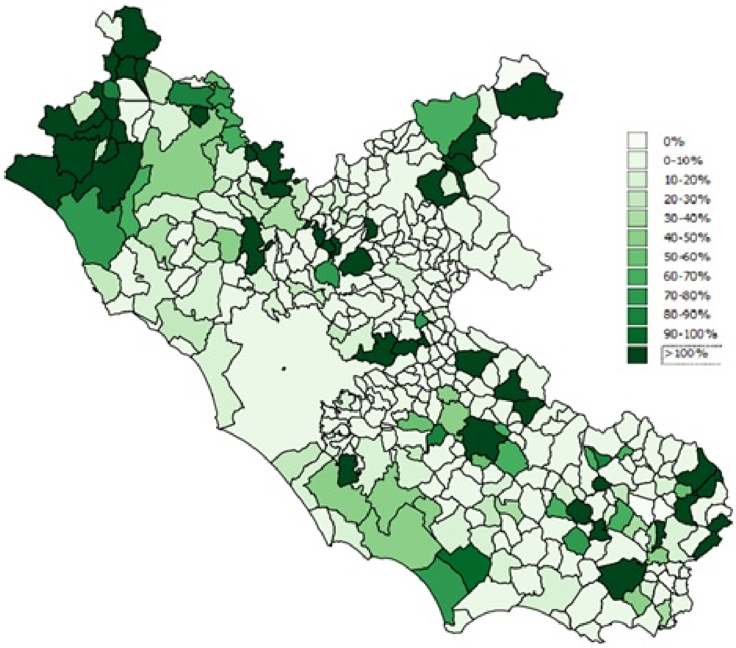


Figure 18: Percentage of electricity consumption covered by local RES in 2030 considering the BAU (business as usual) scenario.

3.6. Development proposals for the Lazio Region

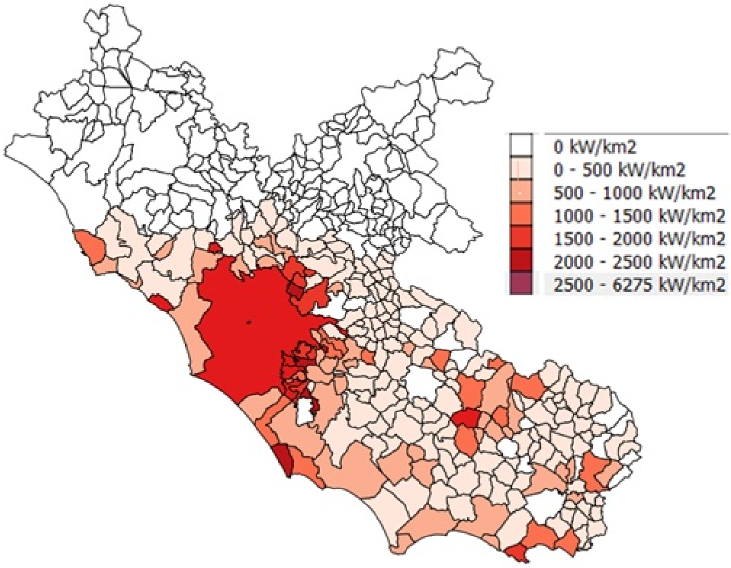
The analysed data show that Lazio is one of the Italian regions with lower coverage of electricity consumption from RES, with a percentage of 15% significantly below the national average (33.6%). In a BAU (business as usual) scenario, there are no plans to increase that percentage coverage, estimated at 19.0% in 2020 and at 28.2% in 2030.

The main reason for this low coverage is mainly due to the presence of the city of Rome which has an electric consumption density reachable only in very few Italian metropolitan cities and in contrast with some peculiar RES properties such as their distributed and low-density characteristics.

Generally, for all the major consumer centres, represented by municipalities with more than 10,000 inhabitants, the RES coverage is low, while it is rather high for smaller consumption centres. It is therefore in the larger consumption centres that the placement of new plants powered by RES is more necessary.

This need appears even stronger, considering the critical issues highlighted by Terna, the Italian TSO, (Terna, 2018b) regarding the lack of infrastructures, the limited capacity of the existing grid in the Rome metropolitan area (which could reduce in some cases quality and continuity of the service) and the saturation of the transport capacity on the coastal areas between the South of Rome, Latina and Garigliano, especially during the summer period (with possible risks of power failure).

Based on the identified critical issues, it is possible to hypothesize a plan for the development of renewable sources in the Lazio Region which leads to a RES penetration on electricity consumptions higher than the previous estimations.
Considering the potentialities and the limits of the whole regional area, it should be noted that: i) the hydroelectric resource has little room for growth; ii) that exploitation of more than 60% of the residual potential of biomasses appears very difficult because it requires a major change in many production chains; iii) the installation of large wind farms with a total power of more than 1 MW meets significant licensing difficulties for obtaining the authorization.
On the other hand, considering PV plants the following positive aspects have been observed: i) the solar resource is equally widespread in the territory, with high unused potential for furtssible new plants; ii) it is not the best option to install large PV plants, rather the diffusion of many small PV plants is preferable, in a self-consumption logic; iii) the authorization processes of small plants is very easy; iv) small plants can be easily integrated into existing structures, hangars and buildings, without an additional land consumption.It follows that a plan for the development of renewable sources for the production of electricity in the Lazio Region should be mainly based on PV plants (Perpiña et al., 2016), possibly with the introduction of new business models (Overholm, 2015); this plan should necessarily include an assessment of the feasibility and the sustainability of a large-scale PV installation (Phillips, 2013) (Turney & Fthenakis, 2011).
Considering the spatial distribution in the regional area, new plants powered by RES should primarily be installed in the larger municipalities, bringing production closer to consumption and decongesting the energy distribution networks. In particular, they should preferably be installed in the province of Rome and in the southern coastal areas, which, as above detailed, may suffer from overloads in the summer season.
In purely indicative terms, excluding the provinces of Rieti and Viterbo for which the full coverage of electricity consumption can be achieved in the BAU scenario, Figure 19 reports the additional powers per unit area of the new PV plants to be installed in the municipalities of the provinces of Rome, Latina and Frosinone to reach the full consumption coverage (the whole data are reported in annex 3). These powers must be considered as additional compared to the 2030 “as usual” scenario.



Figures 19: Additional power needed for the energy independence per unit of surface of each Lazio Municipality compared to the 2030 "as usual" scenario.

Although the full coverage of electricity consumption is very far from the current levels, the analysis carried out shows that the energy independence goal is achievable also in the areas with higher electricity need.

As example, the city of Rome needs an additional power of about 5 GW to reach a full coverage of electricity consumption, equivalent to a about 50 million square meters of PV plants, that means the 3.8% of the total municipality surface. Comparing this value with the percentage of built-up land (26.1% according with (ISPRA, 2014), the obtained result shows that a full coverage of electricity consumption by RES could be achievable also in the city of Rome only adding building integrated PV plants (BIPV), excluding areas of environmental interest or subject to constraints of historical and architectural protection and privileging the architectural integration of the PV plants.

4. Conclusions

Lazio Region is one of the Italian regions with lower coverage of electricity from renewable sources. Although it is expected to increase the production of electricity from RES, in the "as usual" scenario, the percentage of coverage will remain below 30% at 2030. This low coverage partly depends on the population density and the high density of electricity consumption in the city of Rome and partly depends on the territorial vocation of Lazio which has already exploited almost the whole potential of hydroelectric production and that shows little margins of further exploitation for the wind resource and for thermoelectric production from bioenergy.

On the other hand, the potential of the photovoltaic resource is still wide, which can be used to cover electricity consumptions, especially in the larger municipalities of the provinces of Rome, Latina and Frosinone.

The used GIS platform allows a user-friendly overlap of the obtained results with other existing digital cartography layers to pinpoint the best areas for new RES installations.

Starting from the obtained results, a further research can be focalized to the assessment of RES potential and energy consumptions in the thermal sector, identifying possible synergies and combining energy redevelopment interventions with the installation of new plants using both electrical and thermal RES.

Moreover, the obtained results make it possible to extend the territorial scale analysing potential synergies with neighbouring municipalities.

In particular, Figure 19 pinpointed the possibility of installing new plants in the municipalities of the province of Viterbo and Rieti to partially compensate the installation difficulties that may occur in the municipalities of the province of Rome where the obtained results highlighted the need of a strong implementations of RES plants to reach a full coverage of electricity consumption from RES.

Having quantified at a territorial level the power of the new PV plants to be installed, next steps should foresee an identification of the actually available surfaces, excluding areas of environmental interest, areas subject to constraints of historical and architectural protection and privileging the roofing of buildings and in general the architectural integration of the PV plants. Consequentially, although there are not defined rules to prevent BIPV in protected buildings and rather the national guidelines for energy retrofit in historical buildings contemplate BIPV on the roofs, this opinion could make easier the penetration of PV.

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