School of Energy System
Master's Program in Electrical Engineering
BL20A1400 - Renewable Energy Technology

Italian Energy System

Technologies and constraints for the future 100% RE-based energy system in Italy

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Contents

1 Introduction

The total demand of electricity in Italy in 2021 was 318.1 TWh, with a peak of 52.79 GWh in July as shown in Figure 1 [1] due to air conditioning systems, but this number is expected to grow in the future, due to the massive electrification of consumption which is essential in order to achieve a 100% renewable energy system. At the moment, just 33% of the actual electricity generation comes from renewable energy sources [2], without taking into account the imported energy from other countries, such as France, Switzerland and Austria, which is about 12.5% of the total demand.

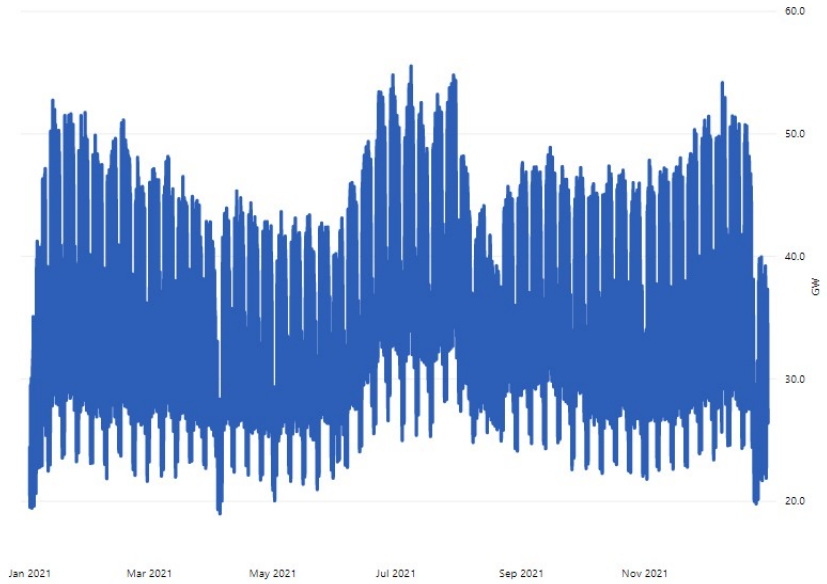


Figure 1: Load demand in Italy during 2021

Table 1: Actual generation per primary source in 2021 [2]

Energy Source	Actual Generation [GWh]	Actual Generation [%]
Thermal	173,456.1	57
Hydro	48,340.9	16
Self-consumption	31,008.3	10
Wind	23,129.9	8
Photovoltaic	21,257.1	7
Geothermal	6,006.6	2

Moreover, mobility and heating sectors are still predominantly fossil fuel-based. In fact as shown in Figure 2 [3], more than half of the heating consumption relies on natural gas, then biomass and petroleum/oil in a smaller percentage, while alternative solutions, such as electric heating or solar thermal, aren't common at the moment.

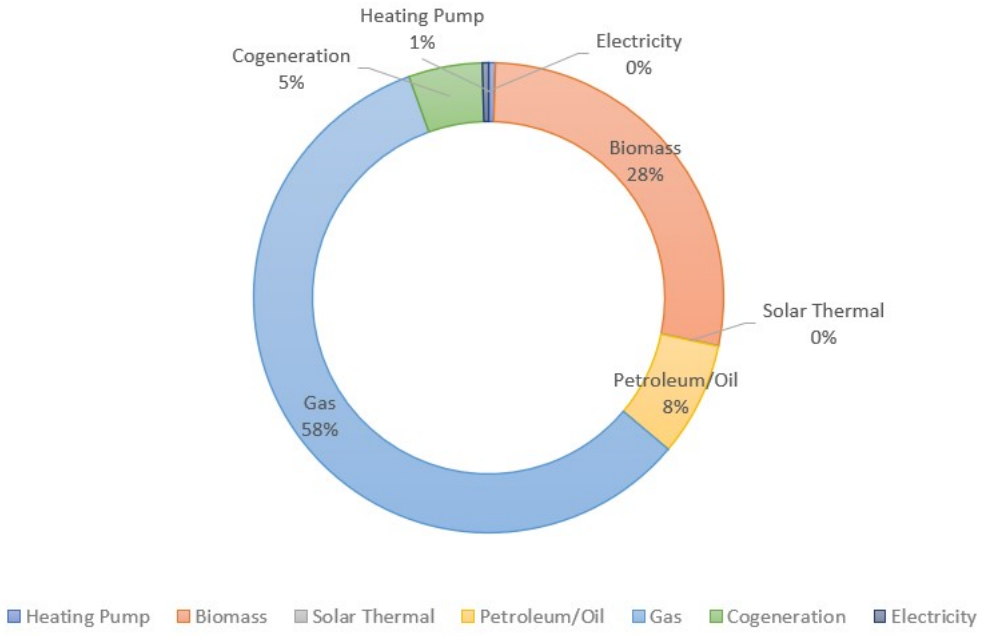


Figure 2: Heating consumption by source during 2018

About the mobility sector, fossil fuels cars are still the most widespread as shown in Figure 3 [4], even if the registrations of electric-hybrid vehicles presented an increment of more than 150% between the years 2017-2018 and 2019-2020.

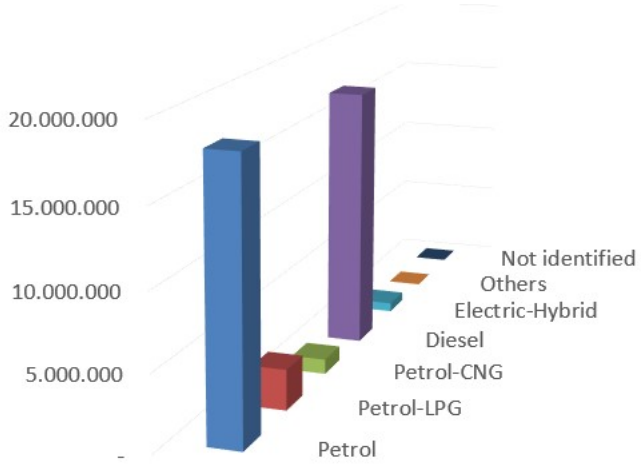


Figure 3: Registered cars until 2020

2 Available Resources For Electricity Production

The energy system of the future will probably be based on wind and solar energy since they are the most easily accessible resources.

2.1 Solar Energy

The solar resource is available everywhere in the country, leading to the possibility to install solar technologies in almost every Italian region as shown in Figure 4 [5], but the areas with the highest direct normal irradiation are located in the South of Italy [6].

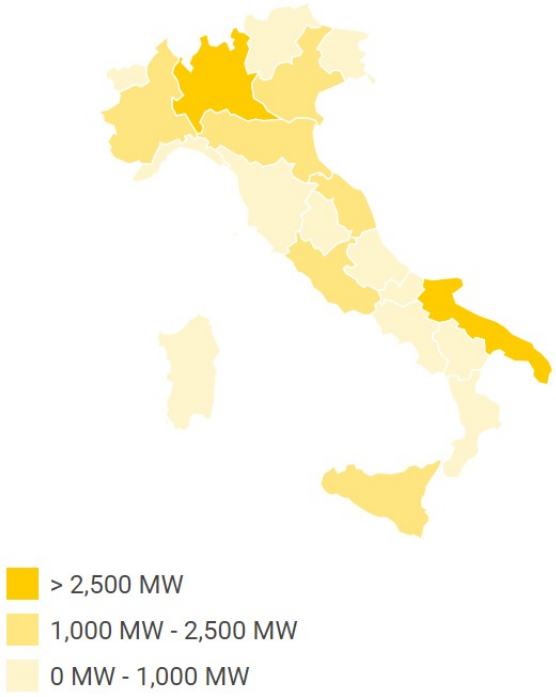


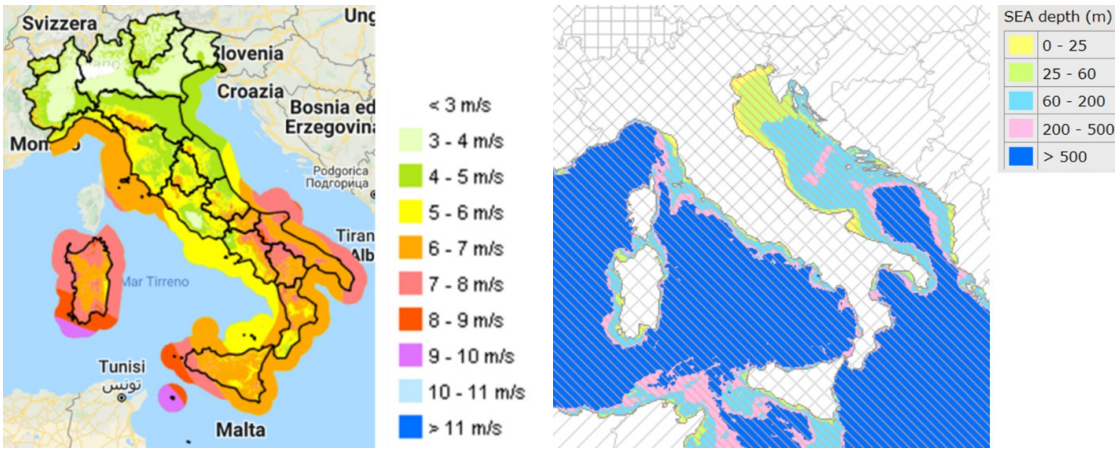
Figure 4: Solar power plants distribution in Italy

Solar energy can be used in the electricity production thanks to a wide range of technologies of which the most popular is photovoltaic panels: besides PV farms, which are at present mostly installed in the region of Apulia in South Italy where they will probably grow also in the future, they can be installed by private consumers as well, to reduce their electricity consumption from the grid. In some cases, the surplus of energy that isn't simultaneously utilised can be injected into the network: in this way the consumer also becomes a producer, leading to the birth of a new role, called prosumer, in the energy context.
Other trends in PV sectors are linked to agri-PV and floating PV systems: they will probably be more studied in the future since they resolves partly the sustainability problem related to the usage of land, in particular in the agri-PV systems in which the land is retrained to a double utilization. Panels in agri-PV systems can also facilitate the growth of particular plants, such as strawberries, which take advantages of the shadow created by them, while panels in floating PV

systems are usually more efficient since the sea water helps keeping down the panel temperature, improving in this way its production, even if problems due to saltwater corrosion might occur. Energy from PV systems will probably represent the majority of electricity production in the future since this technology is the cheapest and it's very easy to implement.
Another technology that makes use of solar energy is the one implemented in Concentrated Solar Power (CSP) systems: the heat from the sun warms a fluid, that can be water or another one, such as some kind of oil, in order to run a steam turbine to produce electricity. Using an oil instead of water has the advantage of choosing the fluid that most retains heat, but on the other hand it requires a heat exchanger, so more losses, costs and size of the system. This technology won't probably grow as much as PV systems, but it can provide support in supplying the future electricity demand that will be higher than now for the reasons explained before.

2.2 Wind Energy

As it's possible to observe from the first picture of Figure 5 [7], windy areas are mostly located near the shore: despite that, the Mediterranean sea is in large part too deep to install off-shore wind turbines, as highlighted in the second picture of Figure 5 [8] in which the sea depth goes up to 200-500 m in some of the windiest areas. For this reason, it may be necessary to invest in floating off-shore wind farms to make use of the wind resource, but avoid possible construction problems that can occur for off-shore wind turbines. Furthermore, the presence of wind farms far from urban centres may also resolve the annoyance due to the turbine noise which is one of the most recurring problem shown by people living close to wind farms. Regarding on-shore wind farms, Italian bureaucracy requires plenty of authorizations before starting the construction works, such as the seismic permission and the acoustic impact, so it may be necessary to deal with long waits.



(a) Annual average wind speed at 100 above s.l. (b) Sea depth in Mediterranean sea

Figure 5

2.3 Hydro Energy

Even if the energy system of the future will be based on wind and solar energy, a large share of renewable energy production is still linked to hydro power plants (about 16% in 2021 [2]) which represent the oldest renewable energy source in Italy. As it's possible to point out from Figure 6 [5], most of the hydro power plants are located in North Italy, thanks to the presence of the Alpes and of the largest lakes in the country, and in Centre Italy along the Apennines, while in South Italy the availability of water resources is limited. With the development of all the previous technologies, new hydro power plants are unlikely to be built since the construction process isn't very sustainable due to the environmental damages that it causes. The hydro power plants that are already present in the country will be still used in the future for the electricity production, but also as energy storage when it's possible.

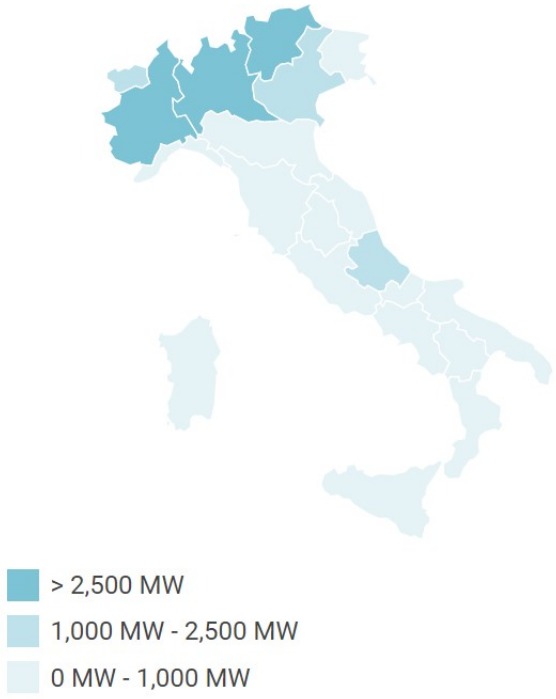


Figure 6: Hydro power plants distribution in Italy

3 Interconnection With Other Energy Sectors

In order to achieve a 100% RE-based energy system, all the energy sectors should be interconnected between each other to accomplish a more efficient energy network. A particular insight into mobility and heating sectors should be consider.

3.1 Mobility Sector

The mobility sector of the future will be based on electric vehicles: electric cars are still too pricey if compared to their corresponding fossil fuel-based ones, but they are starting to become more and more popular, so their share is expected to grow in the future, while their cost is expected to decrease.
Other electric vehicles, such as train and public bus, are already quite developed, in particular in big cities where the strengthening of the public transportation may be a side-solution to reduce traffic and energy demand linked to mobility. Also changing a bit our lifestyle can help relieving stress on the mobility sector, for example by implementing smart-work when possible or by spreading the load during the day to ease the peak hours.
Even electric ferries can be realized, but at the moment the cost linked to the storage solutions and their size are still too high to implement this technology on a large scale. Anyway, some consumption can't be electrified, such as those regarding the fuel demand for long-distance planes: in this case biofuels can be a solution since their production starts from electricity produced with renewable energy sources and CO2.

3.2 Heating Sector

Regarding the heating sector, a hybrid energy system may probably be the most feasible scenario. A growth of geothermal energy for heating systems would be desirable, coupled with the use of heating pumps: the energy production process is quite sustainable if compared to other solutions, even if at the moment the installation price is still too high, and the energy resource is unlimited and present almost everywhere in the country. Moreover, the ground can be used as seasonal storage of heat since its temperature is constant about all year: in winter, water is warmed up by the ground heat and then used in buildings; in summer, heat is removed from rooms and it can be released into the ground.

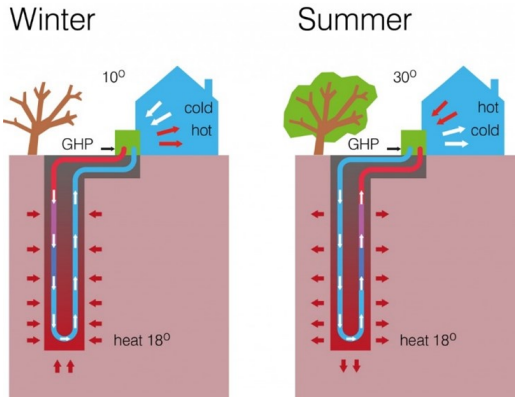


Figure 7: Example of geothermal heating system

Another possible solution might be using energy from waste recovery to warm water in district heating systems or producing synthetic gas starting from electricity produced with renewable energy sources and CO2 (PtG) and utilizing it as natural gas. In fact, as shown previously in Figure 2, most of the buildings in Italy relies on this technology at the moment, so it would be very easy to continue using the already present infrastructures, but simply switching to a fuel with a more sustainable production process.
Solar energy may be used for heating systems as well thanks to thermal collectors that make use of the energy from the sun to warm sanitary water: applying this technology to heating of buildings may be not so efficient since it's much easier to directly utilize the warm water.

4 Role Of Storage

In a 100% renewable energy system, storage is essential because it improves the reliability of the system which must be able to handle the users demand in every conditions.
Concerning the electricity sector, the presence of an European integrated day-ahead and intra-day market is useful to plan the energy transactions of the following day, so the energy units that are going to be in service, and share resources among countries, but it may be not enough since RES are mostly non-programmable and the actual load may be very different from the load forecast. They also need a back-up energy source to participate in the ancillary services market, which is another powerful tool for the integration of RES in the grid, but where just controllable units are now allowed.
First of all, Li-ion batteries can be used as short-term storage in a wide range of applications: they can be installed in the network, for example in PV-farms, to provide support as a back-up energy source, but also in microgrids to optimize the consumer use of energy.
Another type of storage that may be easily implemented is strongly interconnected with the electric vehicles, whose batteries can be used as a storage for the system in a bidirectional relationship: when the vehicle battery needs to be recharged, it takes electricity from the network (G2V); when it's charged, but still connected to the grid, it works as a back-up energy source for the reasons explained before (V2G).

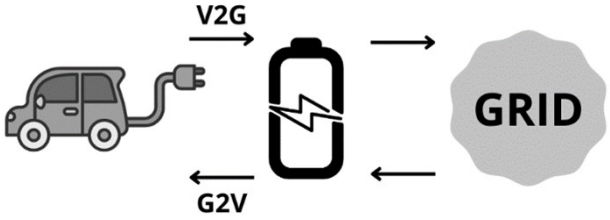


Figure 8: G2V and V2G

One of the last storage technologies that can be carried out makes use of pumped hydro power plants: when energy is required, water flows from the upper reservoir to the lower reservoir and energy is produced because the water flow spins a turbine connected to an electric generator; when the load energy demand is lower and electricity from the grid is cheap, for example during the night, electric energy is used to bring back the water from the lower reservoir to the upper reservoir. In this case the electric generator works as a motor and the turbine as a pump.

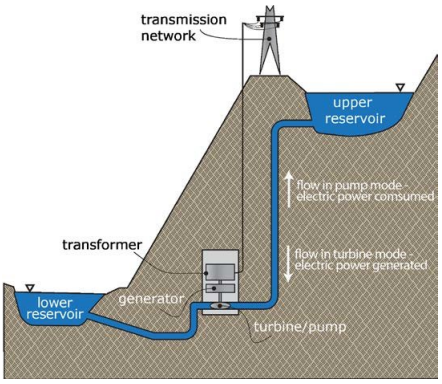


Figure 9: Example of pumped hydro power plant

5 Technical Constraints

In order to reach the ambitious, but necessary, goal of a 100% RE-based energy system in Italy, it's necessary to take into account some critical aspects that need to be resolved.
For example, most of the electricity demand is concentrated in the North of Italy, where the industrial areas are located for the most part, while the regions with the highest production from renewable energy sources are placed in the South of Italy. The electric lines that connected North and South Italy are a bottle-neck in the Italian transmission systems due to the geographic conformation of the country. This means that investments to improve the Total Transfer Capacity (TTC) among the Italian zones of the electricity market, which are shown in Figure 10 [9], are required.

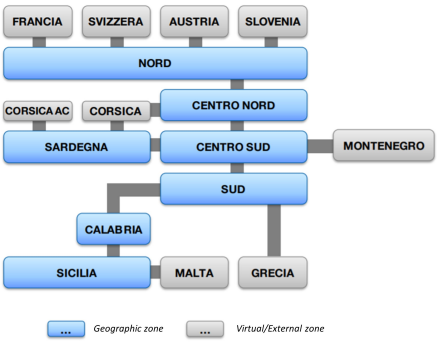


Figure 10: Italian zones of electricity market

Furthermore, the connection of distributed generation units to the network, usually on the Medium Voltage, can be very stressful for the grid since the Italian distribution system wasn't meant for connecting generation units, but for dispatching electric energy to the loads. Even if the distribution system is weakly interconnected, this is particularly crucial when there is a surplus of generation in one point of the network, so energy is injected into the grid, and at the same time a fault happens in another part of the system: the injected current, that flows in the opposite direction with respect to the load current, can interfere with the automatic re-closing of the circuit-breakers placed on the medium-voltage lines. For these reasons, the standard CEI 0-16 imposes the installation of an Interface Protection System (SPI) in which a switch opens to avoid this situation, but still a more efficient communication system is necessary: a faster development of Smart Grids, in which the signal lines are placed side by side with the power lines, can surely help the integration of the renewable energy sources in the network.
In the end, since a power converter is placed between the renewable energy source and the network, the inertia con the grid is gradually decreasing and, even if some technologies are characterized by a high level of inertia, such as wind turbines, their inertia can't pass through the converter. The progressive decreasing of the inertia of the grid might cause stability problems due to large perturbations, for example in case of a fault near a generator, so other solutions will be required to solve this problem in order to always guarantee safe operating conditions on the network, such as installing more and more storage systems which help increasing the inertia [10].

6 Conclusions

A 100% renewable energy system is possible, but it surely requires a lot of works to implement new technologies and to develop suitable infrastructures able to handle those kind of resources. The journey is still long and just with the cooperation of all the parties, such as the government and the companies responsible of the energy sectors, it will be possible to achieve this challenging, but efficient and interconnected, energy system, necessary for opposing the effects of Climate Change.

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