Exploiting Geothermal Energy for Renewable Energy Communities in Italy

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***Abstract*—The adoption of key directives by the EU Commission for reaching the ambitious energy and climate targets by 2050 and to reduce greenhouse gas emissions by 55% by 2030, allowed to an increasingly use of renewable energies in the last years. In this framework, sharing of renewable energies through energy communities plays an important role in fastest reaching the energy transition. Renewable Energy Communities (RECs) aim to generate, distribute, share and consume renewable energies collectively. This work deals with the identification of the areas where RECs are more suitable in Italy through the use of an energy platform. This platform monitors actual energy consumption and production but also the territorial constraints and the availability to exploit all the renewable resources still available. A focus on the use of geothermal energy, which could be used to share both thermal energy and electricity within RECs, is presented. Areas with the greatest geothermal potential have been shown, explaining also how geothermal energy can be exploited through specific technologies. Considerations on how it is the social perception in using geothermal energy and why it is not still use as it should be, have been also introduced.**

Keywords—Geothermal potential, renewable energy sources, renewable energy communities, atlas, platform, self-sufficiency, direct heat technologies, Geographic Information System, place-based analysis, territorial constraints, social perception.

I. INTRODUCTION

Geopolitical developments of the last two years have led to the attention on an increasing need for decarbonization. As reported in a recent executive summary by the International Energy Agency [1], the global energy demand is constantly growing and it is expected to quickly increase over the next three years, by an average of 3.4% per year within 2026. All these factors demand an acceleration of deploying local renewable energy sources to increase the resilience of the energy sector, in terms of supply security and political autonomy [2]. To this regard, Renewable Energy Communities (RECs) can surely represent an added value promoting a faster Europe's energy transition toward the ambitious targets of achieving carbon neutrality by 2050, even if still challenging. These communities, first introduced by the Renewable Energy Directive II, certainly represent innovative energy systems based on sharing clean and renewable energy, ensuring environmental, economic, energetic, and social advantages.

A recent Energy Communities Repository of the European Commission [3], listed some cross-cutting barriers and relative cross-cutting action drivers which help promote an easier development of RECs. Among these barriers stands out above all the difficulty in designing and monitoring a clear and uniform legal definition of REC, a lack of public and private financing as well as a lack of awareness and trust. These factors are strictly linked to policy, regulations, and legislation that either support or undermine clarity and predictability to invest in RECs [3]. Among other important aspects to be considered, the lack in knowing the real availability of renewable energy sources and how they can be exploited with the right technology can act also as a barrier. This highlights the availability of a detailed mapping to understand how much potential can be achieved in a given locality. Despite of these barriers such collective energy systems are increasing in Europe but without providing thermal energy for heating and cooling purposes. Developing RECs in which sharing not only electricity but also thermal energy, is important since its use and sharing among consumers could drastically reduce households' natural gas consumptions and CO_2 emissions up to 50%; it also promotes social cohesion and environmentally friendly behaviors increasing welfare, awareness, communities' energy security and resilience [4].

A roadmap aimed at developing standardized methods focused on legal aspects and on the formulations of energy, environmental, economic, and social Key Performance Indicators (KPIs), is proposed by [5].

As widely discussed, the thermal sector is still responsible for 49% of the final energy consumption in Europe [2]. This percentage also includes cooling demand which is increasing since Europe's temperatures are rising more than twice as fast as the global average, and then the use of passive cooling solution is a key element for a sustainable production [6]. To this regard, geothermal energy may provide an important leverage for the green energy transition, but it still covers a minor niche corresponding to around 2% inside the heating and cooling sectors [2]. Based on a detailed analysis of a geothermal energy community, authors in [7] defined the advantage in sharing this kind of renewable source confirming that it allows reducing the 82% of primary energy and the 81.2% of CO_2 emissions than the traditional configuration.

Another important benefits in using geothermal energy both for electricity and thermal production for supplying energy communities, is the strong reduction of energy poverty in remote areas [8, 9], also ensuring food security and economic rise of communities [10].

This work deals with the exploitation of geothermal energy to be used for integrated the already existing or new RECs in Italy, being this source of energy that which ensures

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the most constant production than the other renewables as well as the less environmental impacts. In particular, the study wants to improve the current knowledge, doing a critical review of the available data aimed at evaluating the geothermal potential which can be needed to meet energy needs of a renewable energy community. After the Introduction, Section II introduces a developing energy Atlas that aimed at identifying more suitable areas for RECs in Italy. Section III describes the geothermal resources in Italy and Section IV explains how geothermal energy can be exploited to produce energy for the RECs, its social perception and its potential production.

II. AN ITALIAN ENERGY ATLAS FOR RECS

With the aim to exploit the available energy resources, an Italian energy atlas is under development to accelerate the energy transition allowing to achieve the energy and climate targets according to European Directives and international agreements [11]. The Italian energy system is strongly depended by abroad and by fossil fuels, then the more effective solution is the self-production by renewable energy sources (RES). This solution is possible in Italy thanks to very diversified territories rich in energy resources. This is a top-down atlas based on the use of Geographic Information System (GIS) information with a place-based approach [12]. Each territory will be involved in energy transition according with its specific potential, socio-economic conditions and environmental problems. One of the measures to achieve energy and climate targets in Italy is the creation of Renewable Energy Communities (RECs). RECs promote a more distributed and cleaner energy production system and the share of energy between members with economic and environmental benefits for all the community. The Italian atlas will identify the areas more suitable for RECs based on the spatial distribution of energy consumption, renewables' availability, clean energy production, territorial constrains and future potential production, the atlas will help stakeholders the self-produce energy.

TABLE I. DATABASES FOR RECS ATLAS

Source acronym	Data
ISTAT	Population and Housing Census (2011,2021), Industry and Services Census (2011), General Census of Agriculture (2010)
National Geoportal	Buildings, Infrastructure, Water Bodies, Woods, Agricultural field, Digital Terrain Model (DTM), Hydrogeological Risk Areas, Environmental and Landscape Constrained Areas
Copernicus	Corine Land Cover (2018) level IV: land cover and territorial constraints
Atlaimpianti GSE	July 2021: Power of RES plants/systems
PVGIS JRC	Solar irradiation, Diffuse/Global Ratio, Irradiance, Energy production by Photovoltaic
ISPRA	Municipal waste production (2022)
	Plan for the sustainable energy transition of suitable areas PiTESAI (Piano per la transizione energetica sostenibile delle aree idonee, in Italian): Territorial constrains
Global Wind Atlas	Wind-to-Energy Variables (Wind Speed, Capacity Factor, hourly profiles)
MASE	Geothermal zoning of Italian territory
TERNA	Electricity consumption at provincial scale by sector of use (2015-2022), Monthly electricity consumption profile industrial sector (2022)
ARERA	Domestic electricity consumption hourly profile (2021-22)
ENEA	ENEA Solar Atlas
	ENEA Biomass Atlas
	Non-domestic electricity consumption hourly profile (2018)
GSE - RSE	Municipal-scale electricity consumption by sector of use (2015), Regional-scale hours of use (2021), Provincial-scale hours of use for solar (2023)

A. Data collection and pre-processing

The information about the Italian territory and the availability of renewable sources is given by free databases mainly used by local, regional and national government bodies. Table I describes the main information used by the atlas to characterize the: socio-economic conditions of the population; built environment, presence of rivers, lakes, parks, woods, territorial constrains; presence of renewables and data about potential production; data about annual, monthly and hourly consumption by type of user.

B. Indicators-indexes

The suitability of Italian territory to organize RECs can be measures through different indicators and indexes to take into account the energy, economic, environmental and social benefits. Some of them are reported in Table II and these indicators and indexes can also be used to illustrate and identify the features of different future scenarios [13]. Usually, the RECs are recognized by their economic convenience in reducing the cost of energy. For island without connection to the electricity grid, the self-sufficiency could be a more effective index, as for cites the reduction of GHG emissions.

TABLE II. ENERGY, ECONOMIC, ENVIRONMENTAL AND SOCIAL INDICATORS AND INDEXES TO EVALUATE THE RECS

Energy	Economic	Environmental	Social
Self-Consumption	Economic savings	Share of RES	Energy poverty
Self-Consumption Index	Global cost	Diversification of RES	Social inclusion
Self-Sufficiency Index	Payback time	Reduction of GHG emission	Welfare services
Collective Self - Consumption	Cost-optimal priorities	Landscape quality	Involvement of stakeholders

C. Actual and future RECs scenarios

The atlas consists of three main sections relating to the consumption of electricity, the current production from renewable energy sources and the future potential production from the RES available on the territory. For each section, databases were created containing the information at regional, provincial and municipal scale, with annual, monthly, daily and hourly details. The spatio-temporal analysis is fundamental for the evaluation of future scenarios because we need the produce energy where and when there is an energy demand; especially with renewables that need large spaces and do not guarantee the continuity of energy production.

In Figure 1 the actual annual consumption of electricity is represented by province. This information is available at the building scale and with GIS can be aggregated in the required representation. It must be remembered that the current law provides that members of a REC can exchange energy in an area beneath a primary substation. It is possible to observe the higher consumptions in the provinces of large Italian cities such as Milan, Rome Naples and Turin.

Figure 2 represents the ratio between actual production (P_a) by RES and consumption by Italian zones: North-West, North-East, Center and South. This representation highlights the territories with high-RES production and low consumption that are the mountain areas and some territory in which the use of renewable energy is already exploited as the: Tuscany with geothermal plants and North Sardinia with wind farms and touristic areas. It is possible to observe also the variation in renewables from the North with high hydroelectric and biomass plants to the South with more wind and solar plants. This work is in progress to evaluate these quantities hourly.

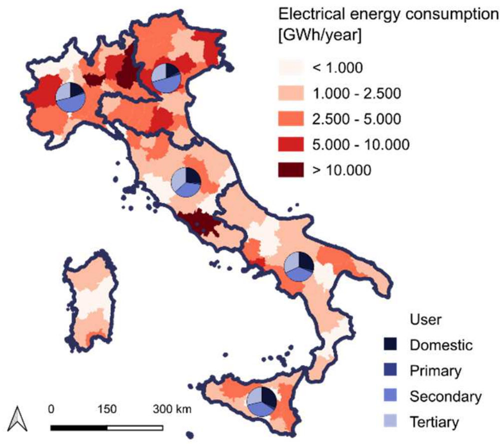

Fig. 1 Annual electricity consumption C by province and sector

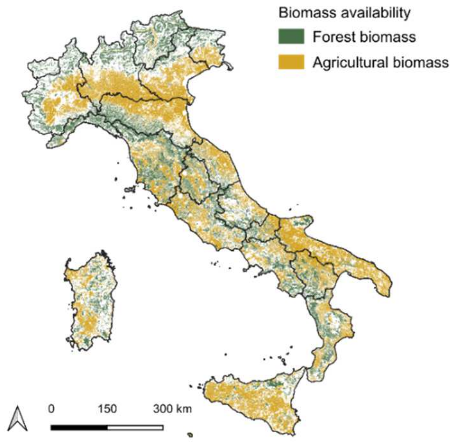

Fig. 3 Spatial distribution of annual available biomass

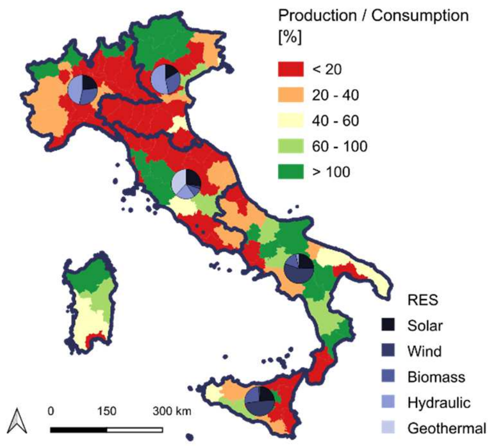

Fig. 2 Ratio between actual production by RES and annual consumption (P_a/C).

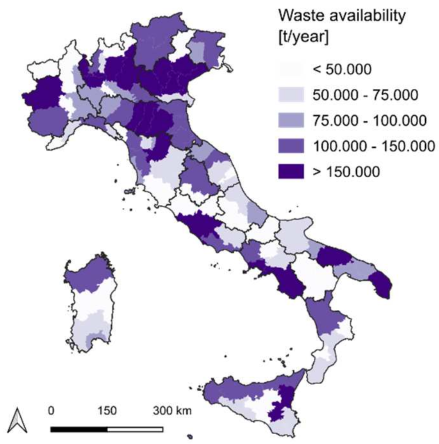

Fig. 4 Spatial distribution of annual available biomass by waste

An example of availability of RES is represented in Figures 3 and 4 with the agricultural, forest and waste biomass. These maps consent to observe that in all territories there is an availability of biomass to be exploited: in the mountains and hills forestry biomass, agricultural biomass in the plains and waste in the cities.

Then, before the analysis about the use of biomass to produce energy, the analysis of territorial constraints was carried out. Different constraints can affect the producibility of electricity. These constraints may limit the withdrawal of the resource or the availability of areas suitable for the installation of the plants. Among to the constraints considered, technical, environmental and economic ones can be indicated. Table III describes the main constraints.

TABLE III. MAIN TERRITORIAL CONSTRAINTS THAT LIMIT THE PRODUCTION BY RES

Technical	Environmental	Economic
Resource availability	Landslide and flood risk sites	Investment cost
Resource accessibility	UNESCO World Heritage sites, Code of the Cultural and Landscape Heritage sites (ex-Galasso Law)	Access to incentives
Availability of space for plants installation	Natura 2000 sites, Important Bird Areas, Ramsar convention areas, protected natural areas	
	Noise pollution	
	Air quality plans	

To evaluate the future potential production (P_f) of energy from the availability of resources, the use of some technologies with their conversion efficiencies should be considered. For biomass plants, it has been hypothesized the use of medium plants with a conversion efficiency of 25%.

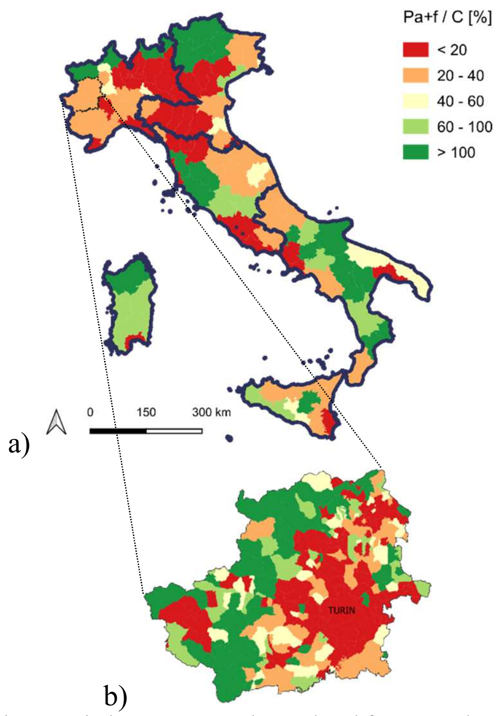

Fig. 5 Ratio between annual actual and future production by biomass and actual consumption (P_{a+f}/C).

Figure 5 illustrates the ratio between actual and future production (P_{a+f}) and the consumption (C) of electricity considering the potential use of biomass and different levels of aggregation: a) provincial and b) municipal. The city of

Turin has very high consumptions and P_{a+f}/C of 0.11 but considering the provincial aggregation P_{a+f}/C can reach 0.32. Big cities have critical energy indicators because of the high energy intensity and the low renewable resources. Joint energy production with neighboring territories can improve self-sufficiency of cities; on the other hand, cities can provide secondary services (e.g., hospitals, healthcare, high schools, universities, sports facilities, theaters, museums) to neighboring territories. The presented analysis is annual, but the platform will evaluate hourly consumption, production and future production.

III. GEOTHERMAL RESOURCES IN THE ITALIAN TERRITORY

A. Geothermal resources and their applications

Geothermal energy is a renewable, sustainable, and clean source of energy coming from the subsoil at different depths. Its potential mainly depends on the geological, hydrogeological, and thermophysical properties of the ground. It is available all year round and at all times of the day. Different geothermal resources can be exploited for power generation, as well as for heating and cooling buildings [14]. The utilization mode strictly depends on the temperature (or exergy content) and on the depth of the geothermal resource, for which different technologies can be used to produce and store energy (Figure 6).

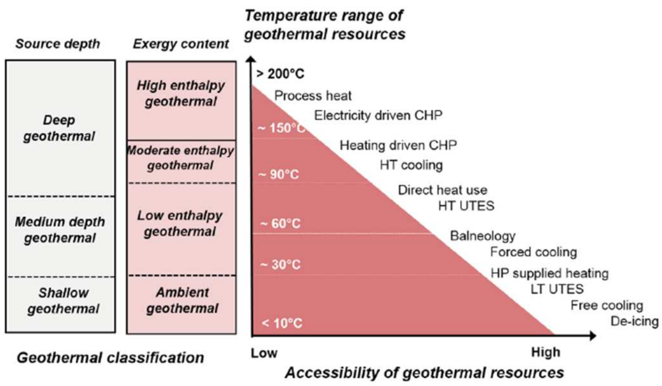

Fig. 6 Geothermal resources classification and their accessibility (modified after [2]). Keys: CHP means combined heat and power, HT and LT UTES are high and low temperature underground thermal energy storage systems.

As shown in Figure 6, the accessibility of geothermal resources significantly increases with lowered supply temperature. In general: i) low temperature resources (< 90°C) can be found anywhere at depth typically below 300 m, and the energy extracted can be used only for thermal energy production through ground source heat pumps (GSHPs); ii) medium temperature resources (90-150 °C, up to 2000 m) can be used directly for heating and cooling purposes or be harnessed to generate clean electricity, through for example combined heat and power facilities; iii) high temperature resources (> 150 °C, up to over 2000 m depth), mostly found at tectonically and volcanic areas, are mainly used to produce clean electricity through binary, flash or dry steam power plants; iv) finally, deep geopressured (> 200 °C) and super-hot geothermal systems (> 400 °C) represent unconventional geothermal systems [15].

B. Current utilization of geothermal energy in Italy

Geothermal energy is not impacted upon by climate conditions or by the difference between day and night like the other renewables such as solar and wind energies, and it is not geographically limited like hydropower. This means a constant production and availability which represent two important features to meet base and peak loads of an energy community, not only in the short but also in the long term. Among other important benefits it does not require large spaces unlike the wind turbines and photovoltaic panels, especially for the thermal energy production for which borehole heat exchangers are buried underground, avoiding problem of space. Geothermal energy is the third renewable energy source in Italy, providing at about 2% of the whole renewable energy consumption [14]. As reported by Enel Green Power managing the current facilities as the only geo-electricity producer [16], Italy has a geothermal potential resource to be exploited which corresponds at between 5,800 and 116,000 TW/h of energy. This means that a small fraction of that energy would only be necessary to fully satisfy the full domestic energy demand. Despite Italy is one of the main producers of geothermal energy in the world, this source of energy still plays a very marginal role in the whole energy mix of the Country. Tuscany, with 34 power plants in operation represents the better geothermal site in Italy where there is the largest geothermal plant in Europe. This big resource is in the historical localities of Larderello, Travale-Radicondoli, and Monte Amiata for which the heat extracted derives from the intrusion of a magmatic pluton beneath the volcanic system of Mount Amiata [14,16, 17]. Other Italian regions where there is a rich geothermal heritage not fully exploited are the Veneto region (Euganei hills near Padua), the Friuli-Venezia Giulia (Grado and neighboring areas), the Campania region (area around Naples between Campi Flegrei and the island of Ischia), Sicily (Alcamo, Sciacca, the Aeolian Islands and Pantelleria), and Emilia Romagna (Casaglia in the province of Ferrara). In this last it has been assessed by [18], that the fluid contained in the geothermal reservoir of the Casaglia area, is exploited with a flow rate of 400 m^3/h, providing a renewable thermal energy power of about 14 MWth.

C. Potential energy production in Italy

Aimed at estimating the use of the geothermal energy and its potential for a possible integration in renewable energy communities, clean energy atlas has been taken into account. The first document is the "Zonazione Geotermica del Territorio Italiano" of the Italian Environmental Ministry (MASE) [19]. This document provides a zonation of the Italian territory, developed on municipal basis, that allows the identification of the areas of geothermal interest on which starting further investigations. It consists of maps representing temperatures at different depths and the map of the shallow heat flux (Figure 7).

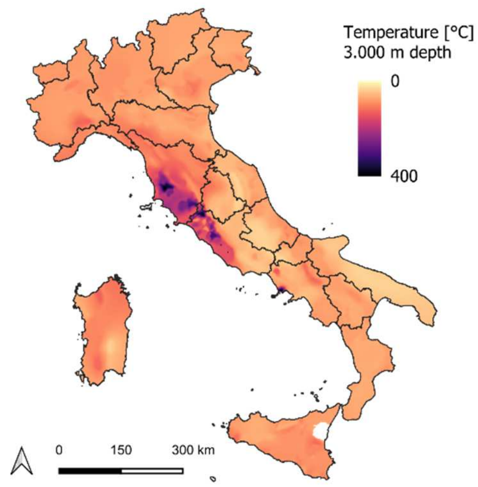

Figure 7. Map with temperature at -3000 m depth

Figure 7 shows the map with temperatures at 3000 m depth in which yellow and red colours in Tuscany and at the border with Latium region, clearly represent the area with the highest geothermal potential for power generation (temperatures ranging from 180 and up to over 400°C). Even if in a restricted area, the same temperature values are detected around Naples (Campania region). In these areas stands out again how the geothermal potential is very high, as represented inf Figure 8, in which isotherms at -2000 m depth are shown.

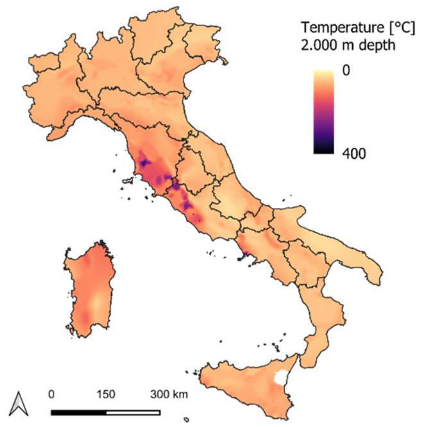

Figure 8 Map with temperatures at -2000 m depth

Another important source of information is the VIGOR project by the National Research Council (CNR) [20]. It consists of a detailed study about temperatures and geothermal potential of four regions in Southern Italy (Calabria, Campania, Puglia, Sicilia). The main information is about the geo-exchange for closed loop and open loop circuit systems, and on the geothermal potential.

A similar project by CNR is the Geothopica project which combines data from the VIGOR project with those of the National Geothermal Database and the Geothermal Resource Inventory. All these data are represented in maps that can be viewed through a webGIS tool, for a total of 9 regions in Southern Italy (https://geothopica.igg.cnr.it/index.php/it/).

Based on the available information and taking into account the electricity production, the most common technologies include [15]: i) dry steam geothermal power plants, using steam directly from the subsoil to run a turbine, ranging in size from 8 to 140 MW; ii) flash steam geothermal power plants, that operate with high temperature and pressure fluids up to 180 °C; part of this fluid evaporates into steam used to run a turbine, ranging with a different size from 0.2 up to 150 MW depending on the kind of evaporation or "flash"; iii) Binary cycle plants, characterized by a heat transfer from a primary to a secondary fluid with a lower boiling point, in a heat exchanger. These fluids can be a mixture of water and ammonia (Kalina cycles) or hydrocarbons (Organic Rankine cycles). These plants range in size from 0.1 to 50 MW.

D. Legal aspects and territorial constraints

Concerning environmental constraints, the Legislative Decree 152/2006 is the most important to be taken into account: it aims to ensure the compatibility of human activity with the environment for a sustainable development. Based on this Decree, geothermal power plants projects are subjected to specific environmental procedures such as the « Environmental Impact Assessment » (V.I.A.) and the « V.I.A. Screening ». These procedures allow detecting and assessing possible effects of a given project on the environment. Dealing with the realization of power plants for electricity generation, the required licenses for the exploration and exploitation of geothermal resources, are released only after the above-mentioned procedures [21]. In particular, high temperature energy sources which ensure a total supplied power of at least 20 MW, are considered of National Interest and declared as a National Heritage of the State. These geothermal resources are mainly regulated by the Legislative Decree 22/2010 which has been integrated with the Law 17/2022 and are also regulated by the Royal Decree 1443/1927 for which they are considered mining resources. In addition, the National Energy and Climate Plan (PNIEC) recently released, further regulates geothermal resources and their applications based on European Directives.

As detailed described in [21], licenses to be produced ranging from the exploration permit (to determine the geothermal resources), and the Mining Lease, which allows the exploration on a specific area. In detail, the exploration permit can cover a maximum area of 300 km^2 and has a duration of 4 years, while the Mining Lease can last 30 years. Furthermore, landscape and territorial constraints could be taken into account and mainly depend on the Regional Laws of the area of interest.

IV. INTEGRATING GEOTHERMAL ENERGY IN RENEWABLE ENERGY COMMUNITIES: WHAT IS THE SOCIAL PERCEPTION?

As widely discussed, Italy has a large geothermal potential to be exploited and it could meet the whole energy needs of the Country. In recent years the interest in geothermal energy has been grown since it is considered a strategic and sustainable energy resource. Its use allows avoiding combustion process emitting carbon dioxide (CO_2), it enables reduction of utility bills and taxes, as well as increased employment. Besides these aspects, a good knowledge about the potential of this source of energy is still lacking.

Most of the people think about geothermal energy as the energy coming only from volcanoes, natural emissions such as geysers or thermal spring, without knowing its real potential and technologies and its implication for the society. Results from a questionnaire in Southern Italy [22], show as solar and wind energies are considered as valid alternatives to fossil fuels and thus for the energy supply while, an opposite trend, has been perceived for nuclear. When speaking about geothermal, a greater percentage of people do not know to give an answer, highlighting the high level of uncertainty due to a lack of knowledge [9, 22, 23]. In addition, the economic investments are surely onerous especially for the realization of geothermal power plants. In this case, the energy management can be significative, and it is often perceived as politicized, causing a lack of trust in the public administrations and thus in the social acceptance of certain projects. This highlights the need of a communication action strategy to engage citizen's participation in dissemination and feasibility projects [7, 22]. Besides these factors, the social perception of geothermal energy is also often link to environmental issues related to water contamination and potential micro-seismicity [9], as also highlighted after an interview in the Province of Viterbo (Central Italy) [24]. A method probably useful in increasing social acceptance of certain projects, is the use of the Lindal Diagram [25]. It is a representation of the local geothermal resource use, and defines the cascade use to enhance the feasibility of geothermal projects, finding solutions to design the geothermal system according to the local climate, quality of resources and market demand. As reported in [26], all these characteristics are of paramount importance to indicate the benefits of geothermal energy local utilisation, and thus increasing confidence though people. In this case, the role of communities is centric and when geothermal resources are introduced to the local economic system, this can result in generating energy for the community's own purposes as an example of a self-sufficient local economic system [9, 26]. This also highlights the importance in using local energy sources, leading to energy independence that needs to be supported by specific national policies. To date, in Italy, a simulation of a geothermal-based energy community has been done for the Pisciarelli district of Pozzuoli, located in the geothermal area of Phlegraean Fields (South Italy) [7]. It includes an economic analysis based on energy incentives and social acceptance. Main findings of this work show that the index relative to self-consumption and self-sufficiency is equal to 85% and 89% respectively, allowing for a reduction of the 81.2% of CO_2 emissions. These very interesting results should be widely disseminated to increase awareness and confidence in using geothermal energy and to integrate it in RECs, both for electricity and thermal energy production.

V. CONCLUSIONS

The main findings of this work allowed understanding how Italy is rich in energy resources, which could guarantee the energy independence avoiding the use of fossil fuels. A developing top-down energy atlas based on a GIS tool, has been analysed evaluating the most suitable areas for renewable energy communities (REC). This atlas highlights how the production is higher than consumption in some areas with a greater hydroelectric production in northern Italy and an increased use of wind and solar energies in the South; at the same time, it allows observing how a great amount of biomass is also available to be exploited for energy purposes. On the other hand, an increased exploitation of geothermal resources should be done since it is still covering a minor niche. Available geothermal maps show as Italy has a large geothermal potential to be exploited in some areas and this energy could be integrated in RECs, also in combination with other renewables through specific technologies for power generation. Anyway, environmental and territorial constrains may often limit the retrieval of the resource or the availability of suitable areas for the installation of power plants. In addition, the lack of knowledge on benefits which can be derived from using clean energies such as geothermal, sometimes cause a wrong social perception. Future investigations will also focus on the areas with a lower geothermal potential, assuming the production and sharing of thermal energy inside RECs for space heating-cooling and for domestic hot water in buildings, since it represents an important step to be done towards a faster energy transition.

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