ENERGY PUMPED STORAGE: ITALIAN EXPERIENCE(*)

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1. INTRODUCTION

The last few years have been characterized by extreme drought phenomena in the main Italian regions, particularly in the Southern part of the country, with heavy consequences on valuable agricultural productions and diffused alarms on the capacity of existing drinking water supply systems.

Meantime, extreme alluvial events are multiplying in several geographical areas of the national territory, interested by exceptional rainfall intensities.

These phenomena occur in parallel with a tendential increase of the atmospheric temperatures, with evident undesirable climatic changes.

(*) *Stockage d'énergie par pompage: l'expérience italienne*
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In order to contrast this drift, Italy has made international commitments already at the Earth Summit held in Rio de Janeiro in 1992, renewed with the signing of the Paris Agreement on Climate Change at COP 21 in 2015, to contribute to maintain the rise of temperature below 2 °C compared to pre-industrial levels.

At the end of 2019, after a broad consultation with the social, economic and political parties, the National Energy and Climate Plan (NECP) was launched jointly by the Ministries of the Economic Development, of the Environment and of the Infrastructure and Transport, based on the recommendations of the European Commission.

The NECP configures a gradual decarbonisation of the Italian energy system, with an impulse to the development of renewable energies in particular in the Central and Southern regions, which are suitable for their climate, made convenient by the simultaneous creation of storage capacity through electrochemical battery systems and hydroelectric pumped plants.

The latter should enhance with a multiple use some of the existing artificial reservoirs, at present exploited for irrigation, through interconnection or, in the absence of valid combinations, with the construction in coupling of specific impounds of convenient elevation and distance.

2. NATIONAL ENERGY AND CLIMATE PLAN

During the 2019, based on the indication of the European Commission, every Member State has prepared its own National Energy and Climate Plan (NECP), in which the expected targets and actions for the containment of the climate change in the next decades are specified.

In particular, Italy intends to adopt specific tools in order to ensure in the medium-long term the availability of the necessary capacity of the electricity system by providing CO_2 emission limits per unit of energy supplied, thus promoting low environmental impact plants and renewables, excluding coal plants. This implies, in the electricity sector, a commitment to move from a percentage of the renewables estimated in 2020 of about 36% to 55% in 2030.

In this context, the development of storage capacities will be gradually, but increasingly, aimed to limit the phenomenon of overgeneration and to promote the achievement of renewable energy consumption targets. Among the storage technologies, the hydroelectric storage systems are today the most mature option. The strong penetration of renewables will first of all require an increase, thanks also to the planned energy network supports, in the use of existing pumped plants in the Northern Italy, in addition to the construction of new plants of the same type.

Beyond the optimal management of the existing pumped storage systems, new storage systems for almost 1000 MW in production, between hydroelectric and electrochemical, have been estimated to be necessary already in the medium term (around 2023). For 2030, preliminary estimations indicate a need, also functional to contain the overgeneration from renewables, of around 1 TWh, equal to about 6000 MW between pumped and electrochemical at centralized level.

In summary, the targets for the energy security of the electricity system and related quantifications are:

- increase of the resilience and flexibility of the system privileging the use of solutions for the management and control of networks parameters technologically innovative;
- implementation of new capacity market mechanisms, aimed to ensure the adequacy of the system in a consistent way with the decarbonisation objectives and with the targets fixed for the development of renewables and energy efficiency;
- increase in the use of existing pumped plants for a number of hours per year equal to about the 70% more than the current ones and installation of new pumped plants for at least 3 GW within 2030;
- development of electrochemical storage for both distributed and centralized level;
- reduction of the overgeneration phenomenon within values of around 1 TWh by 2030, through the strengthening of the network and an increasing and more efficient use of storage systems;
- planning and development of the grid and of the relative mesh in line with the planning modalities of the development of renewable energy plants, in order to make more efficient the transit of energy flows from the South to the North;
- increase in the resilience of the grids even to extreme weather phenomena, with the adoption and implementation of specific intervention plans starting from the areas more at risk, for the protection of the continuity of supplies and for the safety of people and things;
- simplification and speeding of the authorization procedures for the execution of the structures related to the previous points, strengthening the consultation and the information of the stakeholders, as well as the awareness of local populations.

3. PREROGATIVES OF THE HYDROELECTRIC PUMPED PLANTS

The pumped plants present today technical characteristics that are complementary to the renewable plants because:

- they constitute the only available resource for the energy storage in big scale, with the possibility of absorption in the solar hours or in windy conditions;
- they have high characteristics of flexibility, due to the capability of modifying in very fast periods production and absorption, also through functioning transitions, from which the possibility to furnish prompt supply service and balancing derives;
- they are provided of significant capability of frequency and tension regulation.

They are also part of defence systems for the mitigation of the impact of relevant events that may affect the electricity system and also support the restarting of the system given the possibility to provide the black start service[2].

The pumped plants, being equipped with a greater (more prolonged) energy storage capacity than electrochemical storage systems, can offer a contribution for:

- the management of overgeneration periods, in which renewable energy production exceeds the requirement and must therefore be stored in order to avoid its loss;
- the management of the ramps of the so-called residual load (difference between demand and production from non-programmable sources), which will be increasingly severe, especially in the evening, due to the strong penetration of photovoltaics;
- the reduction in the electrical system of regulating capacity (in terms of voltage, frequency, contribution to inertia and short-circuit power) due to the less presence in service of programmable plants;
- the adequacy of the system, in the hours of lower availability of natural resources and greater energy needs.

4. PRESENT SITUATION IN ITALY

After the economic crisis of 2009, the demand of power generation on the Italian network has stabilized, decreasing, around 290 TWh, while the contribution of renewables has gradually increased in 7 years from about 50 TWh up to a maximum of 121 TWh in 2014, thanks to a national incentives policy, reaching around 110 TWh in recent years (Fig. 1).

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[2] Autonomous start-up even with related grid voltage equal to zero - black out condition

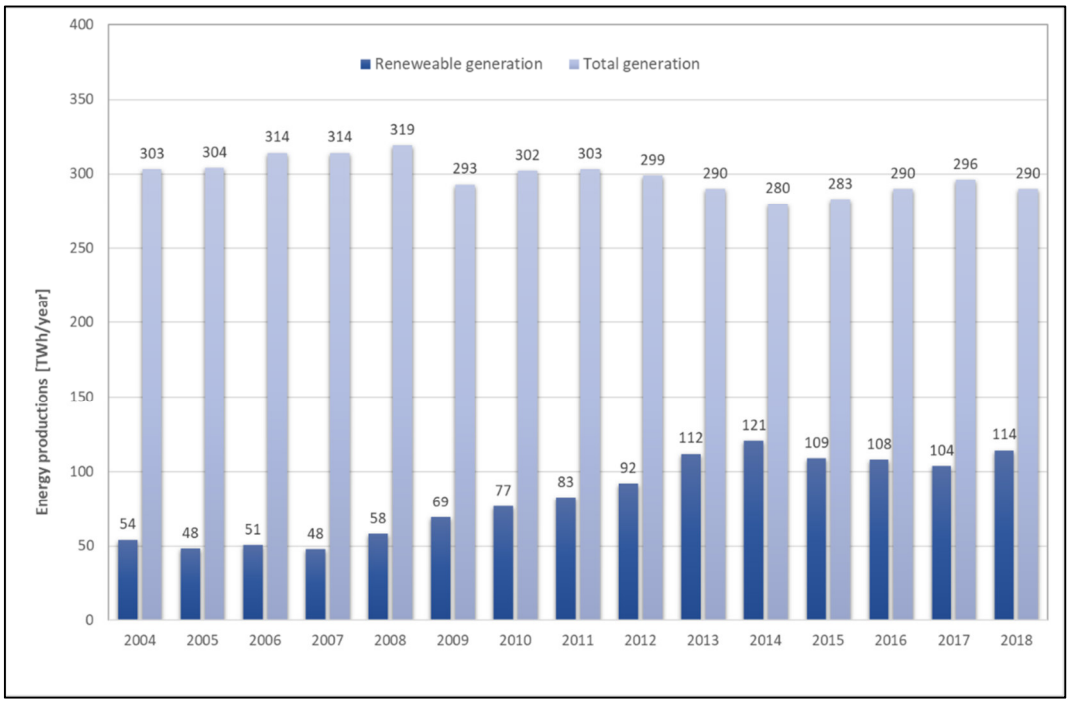

Fig. 1
Renewable and total generation in Italy for the period 2004-2018 (GSE source)
Production renouvelable et totale en Italie pour la période 2004-2018 (source GSE)

The hydropower generation, steadily above 70% until 2007, in the following years gradually decreased up to 50% in 2014, and then recently settled at around 45% of the total national renewable generation (Fig. 2).

This progressive reduction of the percentage of hydropower generation undoubtedly derives from the increase of the other renewable sources, but also from an aging process of the plants that would require rehabilitation and improvement interventions, delayed also by the postponed renews of the Hydroelectric Concessions.

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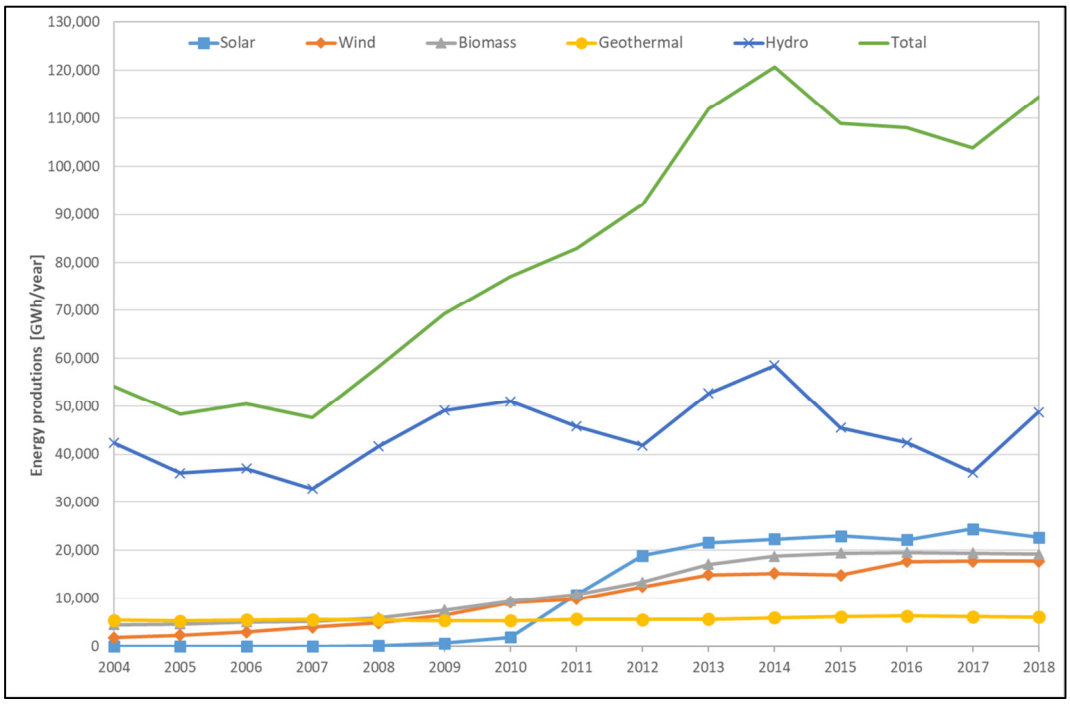

Fig. 2
Generation from different renewable energies in Italy for the period 2004-2018 (GSE source)
Production de différentes énergies renouvelables en Italie pour la période 2004-2018 (source GSE)

The progressive growth of non-programmable renewable energy sources and the simultaneous accelerated closure process of coal-fired power plants tend to create serious difficulties to the electricity network operator for the load balancing. This leads to a growing need for energy storage systems to manage the difficult relationship between availability and demand, in order to stabilize the frequency of the grid and ensure continuity of service.

Even if the pumped hydropower plants have the advantage of being able to perform this function more efficiently and cheaply than other storage systems, it can be ascertained in Fig. 3 how the pumped generation in Italy in the last decade has drastically decreased until it stabilized below 2 TWh per year, compared to previous about 8 TWh per year.

This highlights an already consolidated problem of insufficient remuneration of the service, as its costs are not covered by the operation under the current tariff regime.

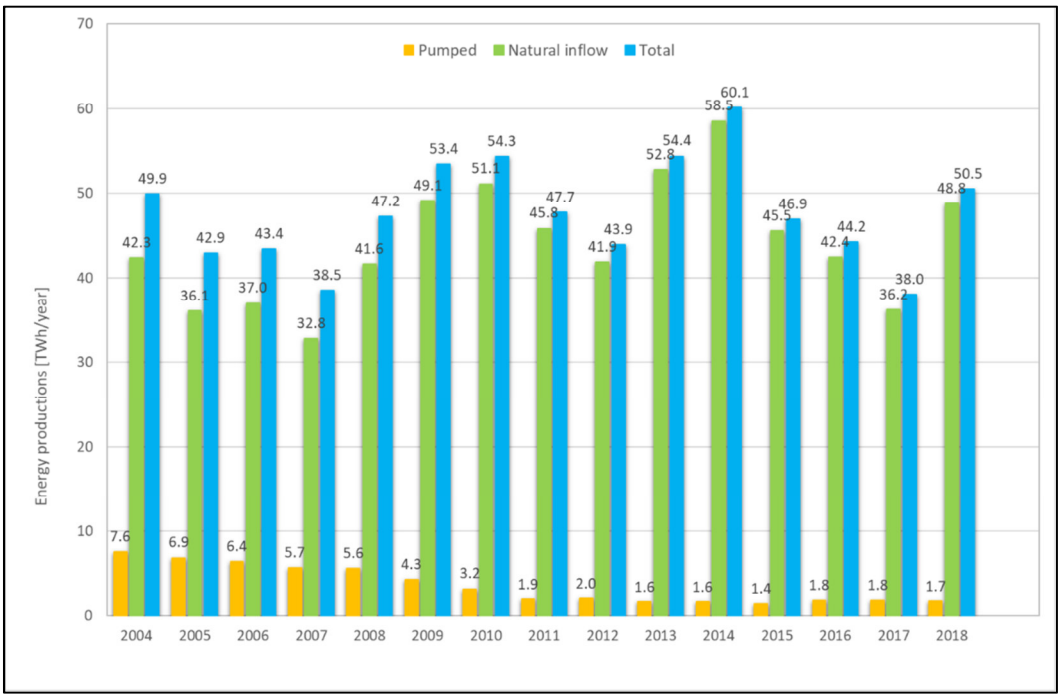

Fig. 3
Pumped and natural inflow generation in Italy for the period 2004-2018 (GSE source)
Génération de flux pompés et naturels en Italie pour la période 2004-2018 (source GSE)

5. EXISTING HYDROELECTRIC PUMPED PLANTS IN ITALY

Currently 22 main plants are operating in Italy, with a maximum capacity of about 6.5 GW in absorption and 7.6 GW in production. Of these, the largest 6 exceed a capacity of 500 MW for a total of about 5240 MW.

The overall geographic distribution is of 5090.3 MW (66.9 %) in the North of Italy, 1702.0 MW (22.3 %) in the Central and Southern regions and 820.0 MW (10.8 %) in Sicily and Sardinia.

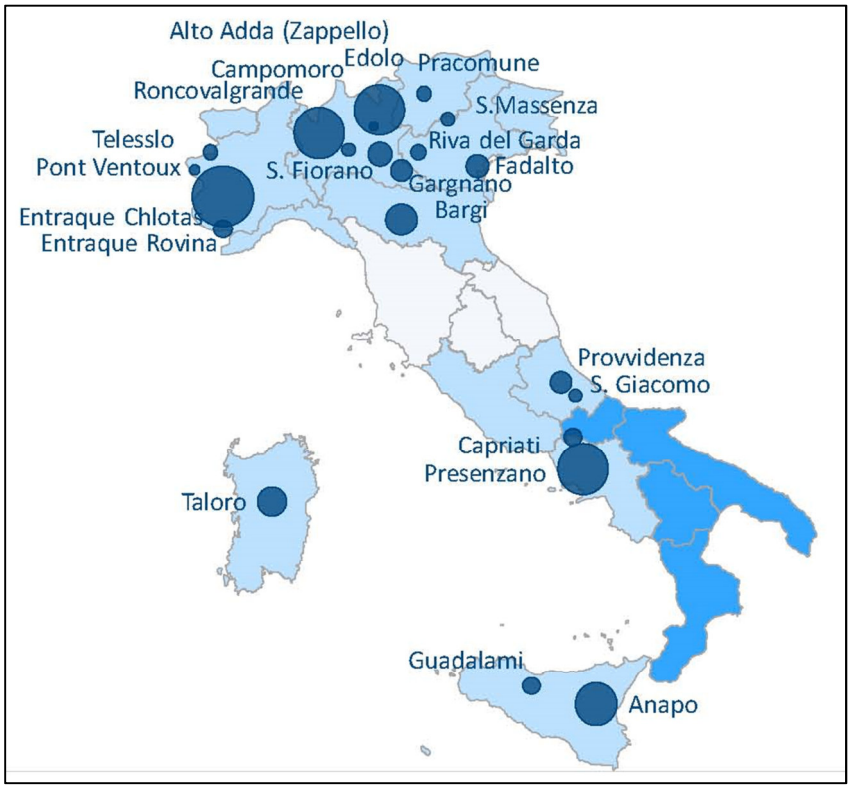

Fig. 4

Location of existing hydroelectric pumped plants in Italy

Localisation des aménagements hydroélectriques de pompage existants en Italie

Pumped hydro plant name – Place (Province)	**Plant Capacity [MW]**	**Pumped hydro plant name – Place (Province)**	**Plant Capacity [MW]**
Anapo - Priolo Gargallo (SR)	500.00	Telessio - Locana (TO)	34.00
Alto Adda – Zappello (SO)	11.00	Pont Ventoux - Susa (TO)	78.50
Bargi - Camugnano (BO)	300.00	Pracomune – Ultimo (BZ)	42.00
Campo Moro - Lanzada (SO)	36.50	Presenzano (CE)	1000.00
Capriati-Capriati Volturno (CE)	113.00	Provvidenza - L'Aquila (AQ)	141.00
Edolo (BS)	977.55	Riva del Garda (TN)	115.00
Entracque (CN)	1190.00	Roncovalgrande - Maccagno (VA)	1000.00
Fadalto - Vittorio Veneto (CN)	210.00	S. Giacomo - Fano Adriano (TE)	448.00
Fontana Bianca - Ultimo (BZ)	10.20	S. Fiorano - Sellero (BS)	570.85
Gargnano (BS)	137.20	S. Massenza - Vezzano (TN)	377.50
Guadalami - Piana degli Albanesi (PA)	80.00	Taloro - Ovodda (NU)	240.00
Total		**7612.3**	

Table 1

Location and installed capacity of the existing hydroelectric pumped plants in Italy

Localisation et capacité installée des aménagements hydroélectriques de pompage existants en Italie

6. NEW PLANTS REALIZATION POTENTIALITY

The location mainly in the North of the pumped plants limits their use for the resolution of system and overgeneration criticalities generated by non-programmable renewable plants.

The latter, in fact, are located in sites meteorologically suitable for wind or solar production, namely in the South of the country and in the Islands, where the grid meshing is historically less developed. This situation has determined the so-called “local” congestions.

Furthermore, in perspective, the progressive growth of intermittent renewable plants increases the need of resources in reserve, in the hours of maximum production from wind or solar, and of balancing, in the hours characterized by high discontinuity of production of the same (e.g. coverage of the evening peak).

The Italian territory, due to its geomorphological characteristics, has important reservoirs in all the regions, which are suitable for hosting new hydroelectric storage plants.

These reservoirs, currently used for the water supplying for civil, irrigation and industrial uses, could be equipped, at least in part, with pumped plants to exploit residual capacities, for example through the creation of a reservoir upstream or downstream of the existing one with adequate elevation drop, or by the connection of two existing impounds with different water level through a conduit or a tunnel.

Indeed, many reservoirs are today under-used, due to limitations of the operating parameters for the progressive deterioration of the safety conditions for the delay or lack of investments, which could be indeed turned on by the additional destination.

In particular, with reference to the pumped plants, on the basis of an ISMES study cited by Terna, the potentiality in the areas mentioned above and represented in Fig. 5 was already identified in 2010.

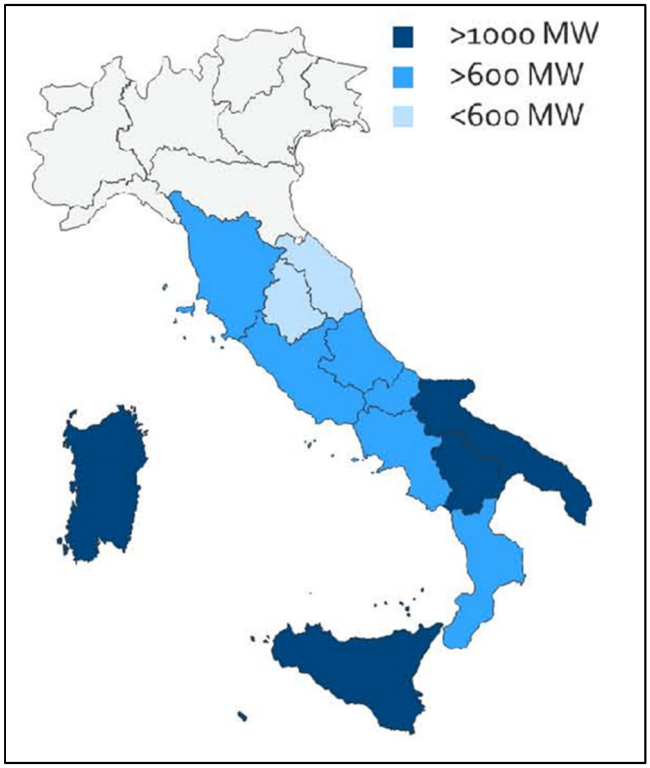

Fig. 5
Energy storage potential through new pumped hydroelectric plants
Potentiel de stockage d'énergie par nouveaux aménagements hydroélectriques de pompage

In the following years, preliminary studies for both fresh water and sea water pumped hydro plants were developed by RSE, operating in a GIS environment.

Firstly, the Italian territory has been analysed in order to identify suitable areas, within a distance of 10 km from existing reservoirs, to build an upper or a lower reservoir with a minimum head of 100 m, excluding the protected areas.

Then, with similar methodology, the shoreline has been scanned in order to identify roughly flat areas, within a distance of 1 km from the sea, to build an upper reservoir with a minimum head of 100 m.

Finally, the application of a methodology for the assessment of the nationwide storage potential for underground hydroelectric pumped plants has been developed.

In this way it was assessed that the additional possible total storage capacity could easily overcome the whole solar and wind Italian generation, with specific investment costs between 1.0 and 1.5 Millions of €/MW.

7. TERRITORIAL ANALYSIS FOR THE RESEARCH OF NEW HYDROELECTRIC PUMPED PLANTS

Since 2018 the Italian electricity network operator has commissioned a series of Surveys, partly still in progress, aimed to verify in the Southern regions and in the main Islands, the possibility and convenience of using a portion of the capacity of existing reservoirs, connecting themselves or in combination with a new suitable impound, in order to create new hydroelectric pumped plants.

As a first step, 41 artificial agricultural reservoirs of Concessionaires members of the National Irrigation Reclamation Association (ANBI) and distributed in the regions Campania, Molise, Calabria, Basilicata, Puglia and Sicily have been analysed, collecting technical and administrative data and establishing a ranking of interest based on elements of different nature.

An analogous Survey has been then carried out on 38 reservoirs in Sicily and is continuing on Sardinia and Southern regions reservoirs.

8. IDENTIFICATION OF SUITABLE SITES

Once the residual water availability of an existing reservoir has been ascertained, the research for suitable areas to locate a new impound in combination for hydroelectric pumping can be carried out with the support of IT tools. They can be implemented in a GIS environment and managed through the common functions of geographic information systems, which allow the spatial representation of georeferenced databases of specific interest (e.g. topographic, geological, geomorphological, hydrogeological, instability, land use, environmental constraints digital maps, etc.).

The approach used for the GIS analysis considers that, in the context of a circular search area with a defined radius centred on the existing dam (generally 10 or 20 km), the parts of territory subject to environmental constraints (e.g. National Parks, Protected Natural Areas, Wetlands, urbanized areas, industrial areas, areas of agricultural development, etc.), as well as those with a high ground slope (e.g. slopes with an inclination> 30°), or affected by hydraulic risk (flooding), geomorphological (landslides), seismic hazards (e.g. presence of capable faults) have to be initially excluded.

Removing within the circular area of research the zones affected by the above-mentioned constraints, it is possible to identify, by difference, the areas considered "suitable" for the location of a new reservoir (Fig. 6).

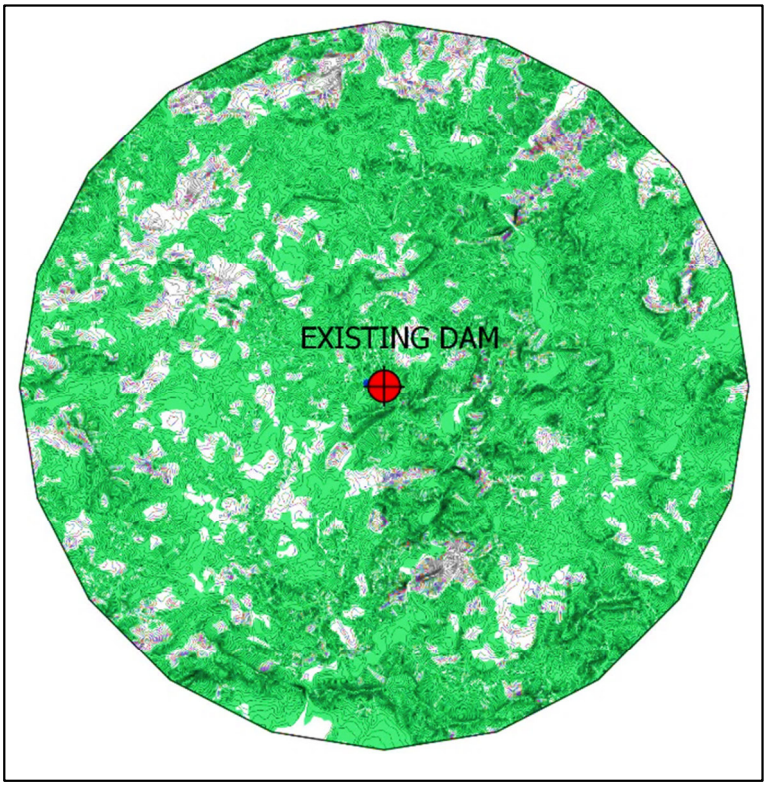

Fig. 6
Example of representation of “suitable” areas (green) for the location of a new impound in combination with an existing dam
Exemple de représentation des zones «convenables» (vert) pour l'emplacement d'un nouveau bassin en combinaison avec un barrage existant

The possible locations of a new pumped reservoir are then subsequently researched within the above-mentioned "suitable" areas.

For this purpose, a raster base is developed for the research area consisting of a grid of points (pixels) each characterized by a value of the ratio elevation drop/distance (Δ/D) with respect to the existing dam. The best locations of the new impound are then selected coinciding with the points having the maximum values of this index.

In this way, the possible “optimal” positions of the new reservoir which allow, in combination with an existing dam, to create a pumped system that maximizes the ratio between the producible energy and the construction costs can be selected.

The construction, by successive steps, of such a raster base, indispensable to set up the research according to the above described criteria, requires the elaboration of maps of elevation drop and distance of each cell (pixel), with respect to the plane-altimetric position of the existing reference dam (Fig. 7),

through the GIS functions that perform mathematical operations among the rasters of the terrain topography.

For this purpose, the digital terrain model provided by NASA (STRM Shuttle Radar Topography Mission), consisting of a regular mesh of elementary cells extending 3"x 3" of arc (indicatively corresponding to 90 mx 90 m cells), or even higher resolution DEM models, can be used as a topographical database.

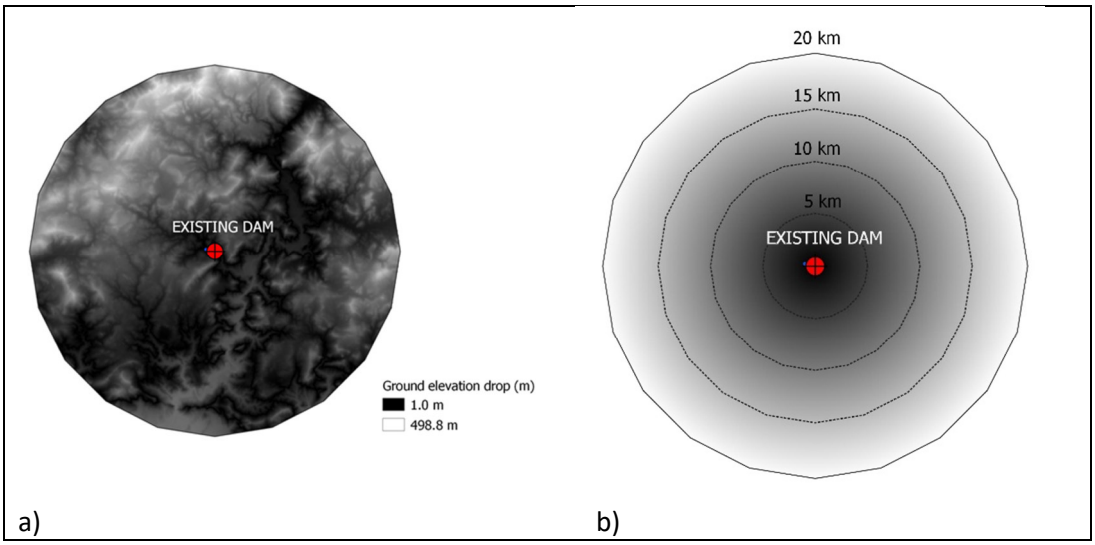

Fig. 7
Raster maps realized to represent a) the ground elevation drop Δ and b) the distance D from the existing dam
Cartes raster réalisées pour représenter a) la différence de niveau Δ et b) la distance D du barrage existant

In addition, it is necessary to exclude from the research the suitable areas that present an elevation, referred to an existing dam, lower than a given limit value (usually ± 100 m), generally considered as a minimum value of acceptability for sustainability purposes and interest of an hydroelectric pumped plant.

As an example, Fig. 8 illustrates the final processed map showing the elevation drop / distance ratio Δ/D in relation to an existing reservoir, processed considering only elevation drop values > 100 m.

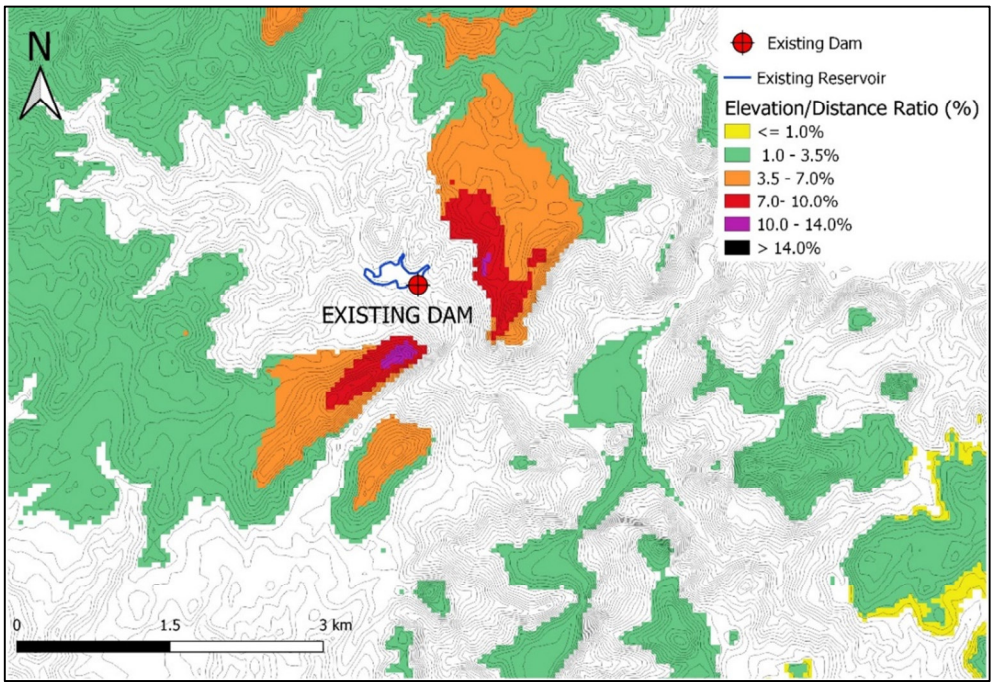

Fig. 8
Example of raster map processing, with representation of the ratio Δ/D evaluated in relation to an existing reservoir
Exemple de traitement de carte raster, avec représentation du rapport Δ / D évalué se référant à un réservoir existant

Of course, the interest focuses on the positions where the ratio is maximum, even if also the distance and other factors affect the classification.

9. UNSOLVED CRITICALITIES AND POSSIBLE DEVELOPMENTS

In the Italian market, parallel to a recognized necessity of development of new hydroelectric pumped plants, it is evident a growing delay of the national Regulatory Authorities to define a tariff policy that provides an economic remuneration for the role of strategic reserve and regulator instrument of the electricity grid which is attributed to such systems.

For this purpose, the introduction of a sort of "capacity market" would seem necessary, to allow the recovery of the investments and of at least part of the energetic gap between production and pumping, but such measure is debated because it could introduce distorting effects on the competition.

On the other hand, in Italy the long-standing problem of renewing the expiring (and in part already expired) hydroelectric concessions has not yet found

a solution and the Regions are called to shortly legislate, with the State in a role of regulator and possible takeover in case of default, about this subject.

There is no doubt that the time would be mature for one or more tenders aimed to promote and at least partially financing new hydroelectric pumped plants in areas of the country particularly at risk of energy deficiencies following the abandonment of coal and / or of overgeneration from non-programmable renewables.

In consideration of the urgency of having a growing electricity storage capacity between 2023 and 2030, the launch of a specific legislation that rationalizes and simplifies the authorization procedures and timelines also plays a fundamental role to be able to achieve this goal.

10. REFERENCES

[1] BALDOVIN E. (2019). Piano Nazionale Integrato per l'Energia ed il Clima (PNIEC), Decarbonizzazione, Capacità di accumulo idroelettrico. Seminario Dighe e Territorio nel contesto siciliano – Palermo.

[2] BALDOVIN E., DE PAOLA A., MORELLI G.L:, MURA M. (2021). Applications for the sustainable use of water resources. *Proceedings XXVII CNG Conference – Cosenza*.

[3] GSE - Statistiche sulle fonti rinnovabili in Italia. Reports for the years 2004-2018

[4] MEGHELLA M., FRIGERIO (2013). Assessing the residual hydropower storage capacity in Italy. A new challenge toward the achievement of 2020 European energy targets. *Proceedings 9th ICOLD European Club Symposium – Venezia*.

[5] MINISTERO SVILUPPO ECONOMICO, MINISTERO AMBIENTE, MINISTERO INFRATRUTTURE E TRASPORTI (2019). Piano Nazionale Integrato per l'Energia ed il Clima (PNIEC)

[6] TERNA S.P.A (2019). Piano di sviluppo della rete di trasmissione nazionale

SUMMARY:

The undersigned appointments at European level to accelerate the decarbonisation process and increase the diffusion of renewable energy plants, in order to contrast the climate global heating trend, commit Italy to important and rapid transformations in the transmission electrical network and to create energy pumped storages in areas of the Country up to now less involved in such process.

In particular the National Energy and Climate Plan (NECP), launched at the end of 2019 on the basis of the recommendations of the European Commission, implies, in the electricity sector, a target to move from a percentage of the renewables estimated of about 36% in 2020 to 55% in 2030 and to realize new storage systems for almost 1000 MW in production, between hydroelectric and electrochemical, in the medium term (around 2023) and of around 1 TWh, equal to about 6000 MW between pumped and electrochemical systems, for 2030.

After a short exposition of the hydroelectric pumped plants prerogatives in an electricity system characterized by the decarbonisation and an increasing percentage of renewables, the current energetic situation of Italy is presented.

A potentiality for the realization of new energy storage plants, introducing a multiple use operation of artificial hydric basins at the moment mainly exploited for irrigation purposes, exists in the Italian Southern regions and major islands, where the meteoric conditions are favourable for a worthwhile development of the non-programmable photovoltaic and wind installations.

That could be obtained connecting two close reservoirs at different elevation or coupling an existing reservoir and a proximity hydric basin with adequate drop to be built.

Surveys of estimation and enhancement of existing opportunities commissioned by the Italian electricity network operator are in progress since 2018, in order to identify possible opportunities to submit to investors through dedicated tenders. Concerning this point, a methodology implemented in GIS environment for the identification and classification of suitable sites is illustrated.

Finally some unsolved criticalities and possible developments are outlined.

RESUME:

Les engagements soussignés au niveau Européen d'accélérer le procès de décarbonisation et d'augmenter la diffusion des aménagements d'énergie renouvelable, afin de contraster la tendance au chauffage global du climat, poussent l'Italie vers transformations importantes et rapides dans le réseau électrique de transmission et à réaliser stockages d'énergie par pompage hydroélectrique dans zones du Pays jusqu'ici moins concernées.

En particulier le Plan National Intégré en Matière d'Energie et Climat (PNEC), lancé à la fin de 2019 sur la base des recommandations de la Commission Européenne, implique, dans le secteur électrique, un objectif de passer d'un pourcentage des renouvelables estimé d'environ 36 % en 2020 à 55% en 2030 et de réaliser nouveaux systèmes de stockage pour presque 1000 MW en production, entre hydroélectrique et électrochimique, dans le moyen terme (autour de 2023) et d'à peu près 1 TWh, égal à presque 6000 MW, entre systèmes hydroélectriques et électrochimiques, pour le 2030.

Après une brève exposition des prérogatives des aménagements hydroélectriques de pompage dans un système d'électricité caractérisé par la décarbonisation et un pourcentage croissant de renouvelables, on présente la situation énergique courante d'Italie.

Une potentialité pour la réalisation de nouveaux aménagements d'accumulation par pompage, en introduisant une exploitation multiple de bassins hydriques artificiels jusqu'au moment utilisés principalement pour l'irrigation, existe dans les régions de l'Italie du Sud et les îles majeures, où les conditions météoriques sont favorables pour un développement payant des installations photovoltaïques et éoliennes non programmables.

Cela pourrait être obtenu en reliant deux réservoirs proches à altitudes différentes ou accouplant un réservoir existant et un bassin hydrique de proximité, avec une chute convenable, à construire.

Etudes d'évaluation et valorisation des possibilités existantes commissionnées par l'opérateur du réseau électrique Italien sont en cours dès 2018 pour identifier opportunités convenables à soumettre aux investisseurs à travers appels d'offre dédiés.

A cet égard, une méthodologie implémentée en environnement SIG (système d'information géographique) pour l'identification et la classification de sites convenables est illustrée.

Enfin quelques criticités non résolues et développements envisageables sont exposés.