The evolution of the Italian power system in 2030 to support more than 55% of renewables on electricity consumption

Fabio Lanati
Energy System Development department
RSE – Ricerca sul sistema Energetico
Milan, Italy
fabio.lanati@rse-web.it

Alberto Gelmini
Energy System Development department
RSE – Ricerca sul sistema Energetico
Milan, Italy
alberto.gelmini@rse-web.it

Giacomo Viganò
Energy System Development department
RSE – Ricerca sul sistema Energetico
Milan, Italy
giacomo.vigano@rse-web.it

***Abstract* - On 31 December 2018, the draft of National Energy Climate Plan (NECP) was sent by the Italian Government to the European Commission. In the NECP, electricity production from RES reaches a share, in 2030, more than 55% of the gross domestic consumption of electricity (GDC-E). In this paper we present the impact assessment of the achievement of such target on the development and on the operation of the power system with a focus on the need of new storage infrastructures. The analysis started from an energy scenario developed with a TIMES based energy model. Then, using a mid-term power system simulator (sMTSIM by RSE), the main criticalities (congestion, overgeneration, energy not supplied, etc.) have been identified and quantified. The technical and regulatory measures to mitigate the impact of such critical issues, have been evaluated based on a cost/benefit analysis. Finally, the amount of investments needed have been estimated.**

Keywords - Climate and energy policy, power system simulation, renewable generation, storage, flexibility, 2030

I. INTRODUCTION

In June 2018, the European Council, European Commission and European Parliament reached an agreement to increase European climate-energy targets for the year 2030 [1]:

- share of renewable energy consumption: from 27% to at least 32%;
- energy savings: from 27% to at least 32.5% compared with the business-as-usual scenario.

On 31 December 2018, the draft of National Energy Climate Plan (NECP [2]) was sent by the Italian government to the European Commission; the final version will be sent by the end of 2019. This document defines actions and priorities for achieving the objectives that Italy intends to pursue in terms of reducing greenhouse gas emissions and increasing renewable energy and energy efficiency by 2030, taking into account the targets set by the EU climate-energy policy and Paris Agreement.

The "NECP" scenario, accompanying the document, is outlined on the achievement of the main policy objectives of the plan:

- annual energy consumption reduction of 0.8% per year in the period 2021-2030 with respect to the energy consumed on average in the 2016-2018 period, excluding the transport sector, according to the new directive on energy efficiency [3];
- total phase-out of coal in electricity generation by 2025;
- a 30% share of Renewable Energy Sources in the 2030 Gross Final Consumption, with a 55.4% share of RES in the electricity sector.

Member States should take additional measures in the event that the share of renewable energy at Union level does not meet the Union trajectory towards the renewable energy target of at least 32 % as indicated in the new RES directive [4].

II. OBJECTIVE OF THE STUDY

In this paper we present the impact assessment of the achievement of RES target, in Italy, on the development and on the operation of the power system, to determine the necessary investments on infrastructures and flexible plants by means of a cost-benefit analysis based on simulations and to estimate the effects on the electricity price.

One of the main objectives of NECP is to trace a path to sustainable growth of renewable energy sources (RES), leading, as above mentioned, to a share of at least 30% of gross final consumption in 2030. In the electricity sector there is a significant residual potential for production, technically and economically exploitable. This, together with the expected reduction of investment costs of technologies, especially for photovoltaic and wind power, means that a significant development is expected. In the NECP scenario, electricity production from RES reaches a share, in 2030, more than 55% of the gross domestic consumption of electricity (GDC-E). This very strong growth of renewable sources, mainly intermittent, which today enjoy dispatching priority, requires the acceleration of measures aimed primarily at their integration into the power system, such as the development of infrastructures and plants that will ensure adequacy and flexibility. An immediate consequence is the reduction of the production of conventional generation plants, the only ones that currently provide the reserve and balancing services essential to guarantee the secure operation of the Italian power system. The high penetration of distributed generation also leads to a gradual transformation of the distribution networks from passive to active ones, making it increasingly necessary to evolve towards a "smart grid" perspective [5].

The methodology followed a hierarchical approach: a scenario analysis for the overall Italian energy system has

978-8-8872-3745-0 ©2019 AEIT

been carried out with a TIMES [1] based national energy model, [6] thus setting the boundary conditions for a detailed study of the impact on the Italian power system carried with a specific simulation model (sMTSIM [7][8][9]).

III. FROM THE ITALIAN 2030 OVERALL ENERGY SCENARIO TO THE POWER SYSTEM SIMULATION

Using the TIMES model of the Italian energy system, we identified the mix of energy sources and technologies capable of meeting the demand for energy services expected till 2030 and to achieve the goal of reducing CO_2 emissions at minimum cost, defining the "NECP" scenario. We also outlined a reference scenario, which defines the trends followed by the Italian energy system without the additional measures required to achieve the de-carbonization objectives in 2030, called "BASE" scenario.

The "NECP" scenario is characterized by a strong development of electricity from renewable sources (RES-E) with a production, in 2030, by more than 75% higher than in 2017. This development is mainly due to intermittent (non-programmable) renewable sources, which today have dispatching priority. It also shows a significant growth of high-efficiency cogeneration plants, characterized by a low operational flexibility and that have dispatching priority today, too. The result is a further reduction of the residual demand covered by the dispatchable generation plants, the only ones currently able to provide the reserve and balancing services[2] essential to ensure a secure operation of the system, that are more and more necessary considering the increasing level of uncertainty introduced by renewable sources.

TABLE I. shows the different sources contributions at the gross domestic electricity consumption (GDC-E) in 2017 and in the 2030 "BASE" and "NECP" scenarios. The table also shows the percentage of RES-E production on the overall production and on GDC-E.

While the share of non-dispatchable generation (intermittent renewable sources and cogeneration) shows such a significant increase, the electricity demand (network losses included), on the contrary, shows a quite moderate growth in the "NECP" scenario, with a value in 2030 (equal to 330 TWh) higher than the one of 2017 (equal to 314 TWh) by only about 3% (TABLE II.). A new hourly load profile for 2030 has been made considering the main differences amongst the major electric final use for 2030 and the currently ones (heat pumps, and electric vehicles in particular).

[1] The TIMES (The Integrated MARKAL-EFOM System) model generator was developed as part of the IEA-ETSAP (Energy Technology Systems Analysis Program), an international community which uses long term energy scenarios to conduct in-depth energy and environmental analyses.

[2] Except for a large experimentation on virtual aggregated unit (aggregated of DG, demands, batteries)

TABLE I. ELECTRICITY GROSS PRODCTION AND GDC-E IN ITALY IN 2017 AND IN THE 2030 "BASE" AND "NECP" SCENARIOS [TWH]

Source	Statistic Data	**"BASE" Scenario**	**"NECP" Scenario**
	2017	***2030***	***2030***
Natural Gas	143	142	118
Coal	33	34	0
Oil and others	16	7	7
RES	**104**	**132**	**187**
Photovoltaic	*24*	*34*	*72*
Concentrated Solar Power	*-*	*0.7*	*3*
Onshore wind	*18*	*25*	*37*
Offshore wind	*-*	*0.3*	*3*
Geothermal	*6*	*7*	*7*
Hydroelectric	*36*	*51*	*49*
Bioenergies	*19*	*14*	*16*
Total production	**296**	**314**	**312**
Net Import	*37.8*	*28.5*	*28.5*
Gross Domestic Consumption	**332**	**341**	**338**
% RES-E/Total Production	**35%**	**42%**	**60%**
% RES-E/GDC-E	**31%**	**39%**	**55.4%**

TABLE II. ELECTRICITY DEMAND IN ITALY IN 2017 AND IN THE 2030 "BASE" AND "NECP" SCENARIOS [TWH]

	Statistic Data	**"BASE" Scenario**	**"NECP" Scenario**
	2017	***2030***	***2030***
Final electricity consumption	302	311	310
Network losses	19	20	20
Electricity demand	**320.5**	**331**	**330**

As above mentioned, these are the boundary conditions we took as a reference for an in-depth analysis of the main criticalities that would affect the Italian power system and of the measures to tackle with them.

In such a scenario, significant problems arise in terms of network congestion, excess production by non-programmable sources at certain times and, more in general, a low flexibility of the generation set no longer sufficient to ensure system security.

IV. METHODOLOGY

The starting point of the analysis was the set of results of the "NECP" energy system scenario, developed with the TIMES national energy model, relevant to the power system (annual electricity demand, renewable energy and cogeneration production, dispatchable conventional installed capacity).

Then through various simulations of the power system and the electricity market in 2030, the main criticalities for the secure operation of the power system have been identified and quantified, together with the required actions (such as upgrading the network infrastructure and increasing the flexibility of the generation set) to mitigate the impact of such critical issues.

We proceeded as follows:

- the annual electricity demand, as well as renewable energy and cogeneration production were allocated to the different market zones and profiled on an hourly basis, together with net imports;
- the set of dispatchable conventional generators, with their specific characteristics in terms of minimum/

maximum power, consumption curve, flexibility and availability rates were configured;

- the reserve margins for each market zone required for the secure operation of the system were calculated with a specific algorithm built by RSE [10], taking into account load, photovoltaic and wind generation typical forecasting errors and thermal units failure rates;
- based on the above-mentioned information, using sMTSIM, simulations of power system operation were carried out in order to highlight and quantify the main critical issues;
- then, different measures to address the detected criticalities were progressively introduced, quantifying them with specific simulations able to determine their cost/benefit ratio;
- finally, the total benefit arising from the overall implementation of all the considered measures was evaluated and their impact on the price of electricity in the day-ahead market was estimated.

V. sMTSIM

sMTSIM (*Stochastic Medium Term SIMulator*) is a zonal[3] electricity market simulator able to determine the hourly dispatching of the generation set and the clearing of the day ahead market over an annual time horizon, calculating the hourly marginal price for each market zone, fuel consumption and cost for each thermal power plant, emissions of CO_2 (and of other pollutants) and related costs for emissions allowances, revenues, variable profits and market shares of the modelled generation companies, as well as power flows on the interconnections between market zones. sMTSIM can provide also information about the level of inter-zonal congestion, the amount of overgeneration, of energy not supplied and the lack of available reserve capacity.

VI. Problems and Solutions

The large development of non-programmable renewables and cogeneration (i.e. non-dispatchable generation), along with a very limited growth of electricity demand, significantly reduces the share of dispatchable generation, able to provide dispatching services. The simulation of the Italian day-ahead market (MGP[4]) shows, for the "NECP" scenario, an overgeneration level that amount to 3.7 TWh. Also, the higher demand for pumped storage hydro plants highlights the need for flexibility in the generation system.

The reduction of CO_2 emissions compared to the "BASE" scenario is determined by the increased renewable production and by the phase-out of coal plants in the "NECP" scenario. TABLE III. shows the comparison between the electricity balance of the "BASE" and "NECP" scenarios in terms of dispatchable thermoelectric production, pumped storage consumption, overgeneration levels, and CO_2 emissions. The delta expresses the variations in the "NECP" scenario with respect to the "BASE" one.

TABLE III. ELECTRICITY BALANCE IN THE 2030 "BASE" AND "NECP" SCENARIOS, MARKET SIMULATION

Electricity Balance	Unit	NECP	BASE	Delta
Thermoelectric production	TWh	*97.8*	*148.6*	*-50.8*
Pumped storage (consumption)	TWh	*5.5*	*0.3*	*+5.2*
Overgeneration	TWh	*3.7*	*<0.05*	*+3.7*
CO_2 emissions	$MtCO_2$	-	-	*-35.5*

However, the market simulation does not consider many of the technical constraints of the power system. In the "NECP_RSV" simulation, the reserve constraints, calculated with a specific algorithm [10], are added to have a simulation closer to the actual operation of the power system and, consequently, providing more precise results on the adequacy/security of the system itself.

In the simulation with the reserve constraints (power system simulation - TABLE IV.) the difficulties of the power system to operate in a secure way begin to emerge, in particular the RES overgeneration increases over 10 TWh despite the greater use of pumped storage. The need to have always a minimum share of thermoelectric generation available to guarantee the power reserve leads to an increase of thermoelectric production over 10 TWh. The results also show a lack of reserve availability in certain periods of the year.

The results of the simulations also show significant inter-zonal network congestions between Center-North and North and/or between Center-South and Center-North. Moreover, there are non-negligible overgeneration phenomena due to the high levels of non-dispatchable generation, to low demand and to the limited flexibility of thermal power plants. The high penetration of distributed generation (more than 24 GW of FV in low voltage grids) causes also a significant impact on the operation of distribution networks.

TABLE IV. ELECTRICITY BALANCE IN THE 2030 "NECP" AND "NECP_RSV" SCENARIOS, POWER SYSTEM SIMULATION

Electricity Balance	Unit	NECP	NECP_RSV
Thermoelectric production	TWh	*97.8*	*109.0*
Pumped storage (consumption)	TWh	*5.5*	*9.2*
Overgeneration	TWh	*3.7*	*10.8*
Reserve Not Available	TWh	*0*	*0.1*
CO_2 emissions	$MtCO_2$	-	-

The possible solutions, based on a cost/benefit analyses, are described below, specifying also the required investment costs.

The first mitigation intervention analysed is the further development of the national transmission grid to allow a greater flow of renewable electricity towards north to obtain the following benefits:

- closer zonal prices;
- reduction of overgeneration;
- greater number of thermoelectric plants turned on in areas with lower reserve availability.

[3] The Italian electricity market is composed of six zones, i.e. NO: North, CN: Center-North, CS: Center-South, SU: South, SA: Sardinia, SI: Sicily.
[4] MGP: Mercato del Giorno Prima, i.e. Day Ahead Market

In the "BASE" scenario, for the development of electricity transmission capacity to 2030, the full implementation of the 2017 Transmission Network Development Plan proposed by the Italian TSO Terna is assumed [11] (investment: 7.8 billion €).

For the "NECP" scenario, the analysis highlighted the need to further develop the transport capacity between the center-south and the center-north and north market zones of about 1000 MW (additional investment: 2.0 billion €), in order to reduce the level of congestion that occurs on these interconnections. This intervention is already substantially envisaged in Terna's 2018 Transmission Network Development Plan [12].

In addition to the transmission network, a number of interventions related to the increasing penetration of distributed generation (GD), are also required for the distribution networks: development and improvement of primary and secondary substations, of operations centers and of metering systems, as well as deployment of a fast charging infrastructure for electric vehicles, which are one of the main measures to increase efficiency in the transport sector. In the "BASE" scenario the estimated cumulated investment (2017-2030) is 21.4 billion € while in the "NECP" is 25.7 billion € (additional investment: 4.3 billion €). Unlike the transmission network, these interventions are not inserted directly into the sMTSIM model, but are the results of an exogenous evaluation.

In order to be more effective in reducing overgeneration and providing greater reserve availability, flexible dispatching resources need to be increased. The analysis shows the need to install about 6 GW of new storage systems in the "NECP" scenario, located in the center-south, south, Sicily and Sardinia market zones (investment: 10.0 billion €). A focus on these solutions is reported in the next section.

However, the development of new electricity infrastructures is not enough. The involvement of new resources for the provision of reserve services, traditionally provided by dispatchable thermoelectric groups, has long been foreseen or desired [13][14][15] and has begun to see the first implementations [16] [17]. This regulatory interventions were explored by RSE, considering in this study the possible participation in the services markets both of demand side resources (in particular for electric vehicles) and supply side resources (the participation of RES plants in the ancillary services market - MSD[5]).

VII. FOCUS ON STORAGE SOLUTIONS

Storage solutions are very effective in reducing overgeneration and providing greater reserve availability. In our analysis we considered:

- new hydroelectric pumping plants (pSTG): with a capacity/power ratio of 10 hours, which also contribute to the reserve supply, in particular the tertiary reserve (RR[6]);
- electrochemical storage systems (eSTG): with capacity / power ratio = 8 hours, exercises at 60% of capacity (in order to leave a guaranteed margin for reserve services) operating on the network and located in areas with greater overgeneration (mainly South, Sicily and Sardinia); they also contribute to the secondary reserve (aFRR[7]).

The analysis carried out on the power system has indicated a need for about 6 GW of new storage systems in Southern Italy: from a sensitivity analysis emerged that at least 50% of these should be new pumping plants. These are additional to the existing power plants (more than 7 GW) which are concentred in the Alpine region (Northern Italy).

We considered two scenarios, with a different storage mix, but that lead to the same results; this was made to analyse less optimistic scenarios regarding the possibility of installing new pumping systems:

a) "NECP_RSV_A": 1,5 GW of eSTG and 4,5 GW of pSTG
b) "NECP_RSV_B": 3 GW of eSTG and 3 GW of pSTG

The contingent of new storage systems determined is that necessary to limit the need of RES curtailment to guarantee the respect of the % of RES share in the scenario.

For the potential and the location of new pumping plants, the results of a working group on storage, established in 2018 by the Italian Ministry of Economic Development and which saw the collaboration between RSE and TERNA, were used.

The study, whose results are described in [18], allowed the identification of 5.8 GW of new pumping plants on lake basins and about 0.9 GW of new marine pumping systems in the southern regions of Italy for a total new pumping power of about 6.7 GW (TABLE V.).

TABLE V. POTENTIAL AND LOCATION OF NEW PUMPING POWER PLANTS IN ITALY [GW]

Type	Market zones	Pumping Power (GW)
Marine	South	0.50
	Sardinia	0.25
	Sicily	0.15
	Total	**0.9**
Lake	Center-South	0.4
	South	2.8
	Sardinia	1.8
	Sicily	0.8
	Total	**5.8**

Total investment costs are estimated in almost 10 billion euros for the "NECP" scenario. With regard to the cost of electrochemical storage systems the average investment cost in 2030 would be around 250 €/kWh as indicated by the results of the Technical Working Group "*Decarbonizzazione dell'economia Italiana*" set up in 2016 at the Italian Presidency of the Council of Ministries [19][20]. With

[5] MSD: Mercato Servizi Dispacciamento, i.e. Dispatching Services Market.
[6] RR: 'Replacement Reserve
[7] aFRR: Automatic Frequency Restoration Reserve

regard to the cost of pumping systems, 1000 €/kW were assumed for the new plants for which a feasibility study was carried out by RSE [21], and 1900 €/kW for additional pumping systems. These investments will be borne by market operators and should be facilitated in the presence of a capacity market mechanism.

VIII. RESULTS

By introducing all the planned interventions into the power system (transmission grid expansion, new storage systems and regulatory solutions) we reduce the overgeneration and the lack of reserve availability till acceptable levels as shown in TABLE VI. The results are shown for the two scenarios ("NECP_RSV_A" and "NECP_RSV_B") characterized by a different mix of storage systems and compared with the scenario without interventions "NECP_RSV". In TABLE VII. the results of the market simulation before and after the implementation of the foreseen measures are reported (zonal selling prices[8] and PUN[9] are shown inside each box in €/MWh) in comparison with the "BASE" scenario.

In 2017 the average value of PUN was 53.9 €/MWh: the "BASE" scenario shows an increase of 40% of PUN in 2030 determined mainly by the assumption on fuel prices evolution in the scenarios. In particular, the increase of natural gas price from 24 to 32 €/MWh and even higher increases in the price of CO_2 (from 7 to 33.5 €/t). In the "NECP" scenario there is a reduction of electricity prices of around 9 €/MWh compared to the "BASE" scenario due to the increase of RES production.

Observing the "NECP" scenario, before and after the interventions, two considerations can be made:

1) the interventions allow to reduce the spread among zonal prices and the number of hours of congestion;
2) the interventions for further development of the grid have been evaluated mainly for the two most congested sections (CS-CN and CN-NO) which constitute a "bottleneck". These capacity increases allow a greater flow of renewable energy towards the North, reducing the price in the northern area.

TABLE VI. ELECTRICITY BALANCE IN THE 2030 "NECP_RSV" AND "NECP_RSV_FINAL" SCENARIOS, POWER SYSTEM SIMULATION

Electricity Balance	Unit	NECP_RSV	NECP_RSV_A	NECP_RSV_B
Thermoelectric production	TWh	*109.0*	*96.3*	*96.3*
Pumped storage (consumption)	TWh	*9.2*	*11.1*	*11.0*
Overgeneration	TWh	*10.8*	*1.2*	*1.2*
Reserve Not Available	TWh	*0.1*	*<0.05*	*<0.05*

[8] Zonal Selling Price: clearing Price in each of the Italian electricity market zones:
[9] National Single Purchase Price (PUN): average of Zonal Prices in the Day-Ahead Market, weighted for total purchases and net of purchases for Pumped-Storage Units and of purchases by Neighbouring Countries' Zones.

TABLE VII. 2030 ZONAL SELLING PRICES AND PUN OF THE DAY AHEAD MARKET IN THE "BASE" AND "NECP" SCENARIOS, MARKET SIMULATION

	BASE	NECP	NECP_A	NECP_B
PUN	74.9	65.8	68.9	68.7
NO	75.8	69.3	69.6	69.5
CN	73.7	59.7	66.1	65.8
CS	72.4	59.3	66.2	65.9
SU	72.3	58.7	65.0	64.7
SI	72.8	58.2	65.0	64.7
SA	71.8	58.3	65.7	65.2

IX. CONCLUSIONS

Realizing in Italy the "NECP" scenario in line with the objectives of the European climate and energy policy for 2030, means a significant shift in the mix of energy sources from fossil fuels to renewable sources). The analysis, carried out with the mid-term power system simulator sMTSIM, highlighted significant critical issues, such as overgenerations, congestions and lack of reserve margins. To solve the criticalities a set of measures (either technological and regulatory) were identified. In particular, the need to introduce more flexibility into the power system emerged.

The analysis has indicated a need for new storage systems of approximately 6 GW:

- of these, at least 50% should be new pumping systems;
- total investment costs would be almost 10 billion €;
- the contingent of new storage systems determined is that necessary to limit the value of the residual overgeneration to guarantee the respect of the % of RES share in the scenario;
- in addition to the reduction of overgeneration, other expected benefits are the reduction of the zonal price spread between the north and southern areas and the reduction of thermoelectric production.

The results of the analysis show the effectiveness of the interventions considered and the related investments required. These interventions will require large investments especially for TSO and DSOs whose remuneration in the electricity bill will partially counteract the reduction of the day-ahead market price determined by the large share of production from renewable sources.

Lastly, it is also necessary to rethink the rules of the electricity markets to extend, for example, a very large participation of renewables and demand sources in the ancillary services market and to encourage operators to invest in new storage systems.

REFERENCES

[1] European Council, "*Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources*",10308/18, Brussels, 21 June 2018.

[2] Ministero dello Sviluppo Economico (MiSE), "*Proposta di Piano Nazionale Integrato per l'Energia e il Clima*", December 2018, in italian

[3] Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable

[4] Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency

[5] G. Viganò, M. Rossi, D. Moneta, "*Comparing control systems performance in increasing the Hosting Capacity of distribution networks",* 2018, AEIT International Annual Conference

[6] F. Lanati, M. Gaeta, A. Gelmini, A. Gatti, L. Mazzocchi "*Studi a supporto della Governance del sistema elettrico ed energetico nazionale"* RSE, Rapporto RDS n° 18007604, 2019, in italian

[7] D. Siface, M.T. Vespucci. A. Gelmini, "*Solution of the mixed integer large scale unit commitment problem by means of a continuous Stochastic linear programming model*", Energy Systems, No 2013, DOI 10.1007/s12667-013-0107-z.

[8] D. Siface, A. Gelmini, M.T. Vespucci, "*Development of the stochastic medium-term market simulation model s-MTSIM*", Proceedings of PMAPS 2012, Istanbul, Turkey, June 10-14, 2012.

[9] D. Siface, A. Gelmini, M. Benini, M. T. Vespucci, "*Assessment of the impact of RES uncertainty on the Italian power system in a 2020 scenario by means of stochastic programming*", 25th European Conference on Operational Research, Vilnius, Lithuania, 8-11 July, 2012.

[10] A. Iaria, E. Gaglioti: "*Valutazione dei requisiti di riserva terziaria di sostituzione a salire nel Sistema Elettrico italiano: un approccio probabilistico*", L'Energia Elettrica, n° 4, vol. 90, 2013, in Italian.

[11] TERNA, "*National Electricity Transmission Grid Development Plan*", 2017, in Italian.

[12] TERNA, "*National Electricity Transmission Grid Development Plan*", 2018, in Italian.

[13] Documento di consultazione: DCO 354/2013, ARERA, 2013, in italian.

[14] Documento di consultazione: DCO 557/2013, ARERA, 2013, in italian.

[15] Documento di consultazione: DCO 298/2016, ARERA, 2016, in italian.

[16] Delibera: 300/2017/R/eel, ARERA, 2017, in italian.

[17] G. Viganò, M. Rossi, D. Moneta, M.T. Vespucci, "*Fast estimation of equivalent capability for active distribution networks*", 2017, 24th International Conference & Exhibition on Electricity Distribution (CIRED)

[18] F. Lanati e A. Gelmini, "*Studi di scenario per l'evoluzione delle infrastrutture del mercato elettrico*" RSE, Rapporto RDS n° 18007679, 2019, in italian.

[19] RSE, ENEA, FEEEM, ISPRA, Politecnico di Milano "*Decarbonizzazione dell'economia italiana – Scenari di sviluppo del sistema energetico nazionale*", Pubblicazione RSE Colloquia, IV Volume 2017, in italian.

[20] Monografia ENEA, "*Decarbonizzazione dell'economia italiana: Il Catalogo delle tecnologie energetiche*", 2017, in italian.

[21] A. Frigerio, M. Meghella e G. Bruno, "*Valutazione del potenziale dei sistemi di accumulo di energia mediante centrali di pompaggio idroelettrico per il sistema idroelettrico italiano*" RSE, Rapporto RDS n° 1200959,2012, in italian.