CO_2-Reduced Energy Scenarios in Italy: Combined Modelling of Renewable Energy Sources, CCS and Hydrogen Penetration in the End-User Uses

Greta Magnolia*, Michela Vellini and Marco Gambini
Dept. of Industrial Engineering, University of Rome Tor Vergata, Italy

Keywords: EnergyPlan, Italian NECP, Decarbonisation, Energy Scenarios, Hydrogen, IRES, CCS.

Abstract: Climate change and greenhouse emissions are becoming an important issue to be solved. Europe and the whole world continuously set new targets on the CO_2 emitting sectors to accelerate the contribution of the different States in maintaining the global temperature at acceptable values. The Italian Government has stated challenging objectives to be achieved on energy and climate matter by 2030. The installation of intermittent renewable energy systems (IRES), implementation of carbon capture and sequestration (CCS) on existing power plants and hydrogen penetration in the end-user uses could be important technologies to reach these objectives. This paper analyses future energy scenarios to occur by 2030 through the modelling of the Italian future energy system in the software EnergyPlan. Results show that the simultaneous demonstration of the Italian CO_2 emissions target and low values of electricity curtailments could be obtained through the diversification of the technologies and the combined modelling of an increase of IRES plants installation, CCS and hydrogen use as a novel energy vector in different sectors.

1 INTRODUCTION

In November 2014, the Intergovernmental Panel on Climate Change (i.e. IPCC) released the Fifth Assessment Report updating the studies on climate change and highlighting the important role played by humans concerning this issue (IPCC, 2014). In the perspective of reducing this impact on the environment, in 2015, the historic Paris Agreement (i.e. COP21) was the first universal and legally binding agreement on climate change and it established to limit the global average temperature increase at 1.5 °C above pre-industrial levels (European Commission, 2016). During these years, the European Union has established a series of energetic and environmental pledges aimed at defining a European Strategy for the meeting of the EU's Paris Agreement commitments. In 2019, the “Clean Energy for all Europeans package” (i.e. CEP) was published (European Commission, 2017) and, among the other requests, it also established the Member States to draw up 10-year National Integrated Energy and Climate Plans (i.e. NECPs) aimed at defining the representative national tools for the achievement of the EU climate objectives and targets.

According to these directives, in 2019, the Italian Government published the so-called “National Energy and Climate Plan” defining the roadmap in terms of energy transition. The main objectives to be reached by 2030 are very challenging (Ministero dello Sviluppo Economico, 2019):

1) reduction of CO_2 emissions in non-emission trading systems (i.e. non-ETS) sectors of 40% compared with 1990;
2) decrease of the primary energy requirement by 43%;
3) coal phase-out in the electricity production by 2025.

M.Vellini et al. (Vellini et al., 2020) proposed different configurations for the 2030 Italian electricity sector achieving the desired environmental performance. Results highlighted how energy efficiency is a primary necessity for pursuing the environmental objectives in a cost-effective way. D.Sofia et al. (Sofia et al., 2020) validated the

* Corresponding Author

Magnolia, G., Vellini, M. and Gambini, M.
CO2-Reduced Energy Scenarios in Italy: Combined Modelling of Renewable Energy Sources, CCS and Hydrogen Penetration in the End-User Uses.
DOI: 10.5220/0011902800003536
In *Proceedings of the 3rd International Symposium on Water, Ecology and Environment (ISWEE 2022)*, pages 71-76
ISBN: 978-989-758-639-2; ISSN: 2975-9439

decarbonization scenario expected for Italy in 2030 in terms of environmental and social benefits by using a Cost-Benefit Analysis (i.e. CBA). The results showed that, in all the sectors, total health co-benefits are higher than the mitigation cost of achieving the specific target.

In November 2020, the Italian Government also published the so-called "National Hydrogen Strategy -Preliminary Guidelines" (i.e. NHS-PG). This document aims to define the vision of the Italian Government on the role that hydrogen can play in the national decarbonisation pathway. The main objectives to be reached by 2030 are (Ministero dello Sviluppo Economico, 2020):

1) 5 GW of installed capacity of electrolyzers;
2) 2% of penetration of hydrogen in the final energy demand.

Different studies have been executed on the future energy scenarios in Italy. The majority of these studies in literature forecasts the reduction of the greenhouse gases (i.e. GHG) emissions through the combination of renewable energy sources (i.e. RES) penetration in the energy production sector and an electrification of the end-user uses. S.Bellocchi et al.(Bellocchi et al., 2020) modelled the electrification of transport and residential heating sectors in support of renewable penetration. They found out that CO_2 emissions could be reduced down to approximately 70/75% compared to the 2017 level with a penetration of IRES of around 65% of the national electricity demand. E. Bompard et al. (Bompard et al., 2020) proposed the so-called "electricity triangle" involving electricity generation from Renewable Energy Sources, exploitation of electricity as the main energy vector, and electrification of the final energy uses in all sectors for the evaluation of the Italian energy scenario in 2050. According to their study, the electricity triangle would allow the 68% reduction in CO_2 emissions in 2050 compared to 2020 levels. Colbertaldo et al. (Colbertaldo et al., 2018) modelled the Italian 2030 and 2050 energy scenarios considering the interaction between power and transport sectors through power-to-gas systems for hydrogen production from excess electricity for fuel cell vehicles. The results of this study outlined a not sufficient reduction of GHG emissions even with a high coverage of hydrogen mobility demand by clean production.

As for the authors knowledge, in literature there is not a study which evaluates the meeting of the NECP targets through the combined modelling of Carbon Capture and Sequestration and hydrogen penetration in the different sectors. This work aims at defining the future CO_2-reduced 2030 Italian energy scenario through the integration of CCS in power plants and hydrogen production in a power to gas system for electricity curtailment reduction using the EnergyPlan software tool.

The first part of the study concerns the model validation through the simulation of the 2019 Italian reference energy scenario. The core of the study follows with the simulation of the 2030 Italian energy scenarios. A first expected 2030 energy scenario in Italy is modelled considering to maintain the proportions of the 2019 energy scenario in the allocation of primary energy sources and implementing the NECP estimates concerning RES penetration, coal phase-out in energy production sector, total final energy consumptions of the different sectors and electrification of the end-user uses. The outputs of this model outline high values of curtailment of electricity and CO_2 emissions. To solve these issues, a second energy scenario is forecasted starting from the first one and modelling the combined integration of post-combustion CCS applied to the gas exhausts from power plants and the 2% of penetration of hydrogen in the end-user uses. This scenario meets the NECP target on CO_2 emissions with low values of electricity curtailment, but the sequestration of 20 Mt of CO_2 is an important issue to consider.

2 METHODS

The Italian energy system is modelled through the use of EnergyPlan tool (*EnergyPLAN*, 2022). This software is an input/output model. Inputs are demands, renewable energy sources, energy plant capacities, costs and different simulation strategies defining import/export and excess of electricity production. Since EnergyPlan simulates energy scenarios on an hourly basis, additional inputs are hourly power distributions, defined as the ratio between power demand at a particular hour and its yearly peak value, of electricity, heating, cooling and transport demands. Outputs are given by energy balances, annual productions, fuel consumption, import/exports and total costs. The basis of the simulations is the minimization of the output from fossil fuel power plants to reduce both primary energy consumption and CO_2 emissions and thus to optimize the system operation from a technical and/or economic perspective.

2.1 Validation of EnergyPlan Tool

The validation of EnergyPlan tool for the modelling of the Italian energy scenario has been addressed through the simulation of the 2019 reference Italian energy scenario according to the demand, supply and storage data provided by TERNA (the Italian electric transmission system operator) and GSE (i.e. Gestore dei Servizi Energetici), the agency responsible for managing energy services in Italy. The difference between the model outputs and real data as provided by IEA (IEA, 2019) (IEA, 2021) has shown acceptable values, below 3%.

3 2030 NATIONAL ENERGY SCENARIOS

Two different Italian energy scenarios by 2030 are modelled starting from the 2019 energy scenario with the aim to reach the main targets of the Italian NECP. The modelling of these energy scenarios in EnergyPlan is executed maintaining the hourly power distributions of electricity, heating, cooling and transport demands and the efficiencies/SPFs/COPs of the different devices equal to the 2019 energy scenario.

3.1 First 2030 Energy Scenario

3.1.1 Inputs

The first energy scenario is simulated considering the Italian NECP estimates of increase RES penetration in the generation mix (i.e. around +40 GW of IRES plants), coal phase-out in energy production sector, total final energy consumptions of the different sectors and electrification of the end-user uses. The remaining inputs are evaluated as follows. The individual heating demand is simulated assuming that heat pumps will be the only electric devices which will be used in this sector in 2030, while oil, natural gas and biomass boilers exploitation is modelled considering the total final energy consumption for civil uses as defined in the Italian NECP and maintaining the proportions of the 2019 scenario for the allocation of the different sources. The annual energy demand for space cooling is set at 43 TWh/year (Zebra Datamapper, 2020). As for industry, primary energy consumption divided by fuel is taken from the Terna-Snam combined scenario (Terna, Snam, 2019) considering not to use coal in industry in 2030. The transport energy demand divided by fuel is modelled considering the total final energy consumption for transport uses as defined in the Italian NECP and maintaining the proportions of the scenario 2019 for the allocation of the different sources.

Primary energy consumption of power supply systems is modelled assuming not to use oil for the powering of these systems and a 23% of biomass-fired CHP in 2030.

3.1.2 Outputs

The Italian NECP sets the target of 247.18 Mt of total CO_2 emissions by 2030 (Mancuso, 2010), this first modelling of the 2030 energy scenario outlines around +7% of total emitted CO_2 compared to this target. Another important output of this first simulation is a critical exportable excess of electricity production (i.e. CEEP), related to the overgeneration of energy production plants, equal of around +25 TWh/year compared to the 5 TWh/year forecasted in Terna-Snam combined scenario (Terna, Snam, 2019).

3.2 Second 2030 Energy Scenario

3.2.1 Inputs

A second 2030 energy scenario in Italy is modelled in this paragraph starting from the first energy scenario and meeting the NECP target of CO_2 through the planning of a post-combustion Carbon Capture and Sequestration (i.e. CCS) to the gas exhausts of the power plants (i.e. PP) (Gambini & Vellini, 2003, 2009; Budinis et al., 2018). The process implies a chemical absorption of the CO_2 from the flue gases of the power plants using a chemical solvent, which generally is an aqueous amine solution. The electricity consumption per unit of captured CO_2 is set equal to 0.40 MWh/tCO_2 and it is given by the sum of the consumptions for the chemical absorption solvent regeneration process, fluids circulation in the CO_2 chemical absorption system and CO_2 compression and liquefaction (Gambini & Vellini, 2003; Vellini & Gambini, 2015; Feron, 2016).

3.2.2 Outputs

The CCS allows the meeting of the Italian NECP CO_2 emissions target by 2030, but the CEEP still remains very high. This value of CEEP can be properly reduced at acceptable values, below 5 TWh/year and in line with Terna and SNAM estimates for the 2030 energy scenario (Terna, Snam, 2019), with the use of this overgeneration for the production of the amount of hydrogen (Walker et al., 2016) estimated by the

NHS-PG and, consequently, with an installed capacity of electrolysers in line with SNAM estimates (SNAM, 2019).

4 RESULTS AND DISCUSSION

The first simulated 2030 energy scenario is implemented with the Italian objective of coal phase-out in the electricity production by 2025 and considering the input data stated in the NECP document (when defined). Additionally, a trend in continuity with the 2019 tendencies for the other inputs required by EnergyPlan (e.g. efficiency of the devices, proportions of used sources in transport and boilers etc.) is modelled. The demonstration of this scenario outlines a high value of CO_2 emissions compared to the Italian NECP target. In fact, the total emitted CO_2 of this energy scenario is around 265 Mt per year, almost +7% of total emitted CO_2 compared to the NECP target in terms of GHG emissions. Transport and production sectors are the main responsible of this phenomenon, covering more than the 60% of global CO_2 emissions in the atmosphere, as shown in Figure 1. The high penetration of IRES, modelled in the generation mix of this scenario, also produces a high value of CEEP. This energy would be produced in those periods of high availability of the renewable source and low demand (e.g. at midday for the solar energy source), thus it would not be used by the load and a curtailment of the production would be executed. This phenomenon has a peak value in June and its trend in this month is shown in Figure 2. It is necessary to lower as much as possible the value of the CEEP to reduce the wasted energy and not to stress the Italian power supply with overgeneration events.

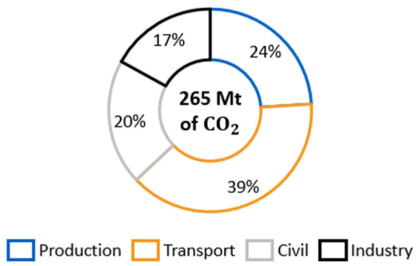

Figure 1: CO2 emissions by different sectors in 2030 - First scenario.

The second simulated energy scenario is characterized by the coupling of hydrogen penetration in the end-user uses and CCS.

Hydrogen implementation in the end-user uses allows the reduction of electricity curtailment throughout the year. Figure 3 shows the reduction of the peak value of this phenomenon compared to the first energy scenario.

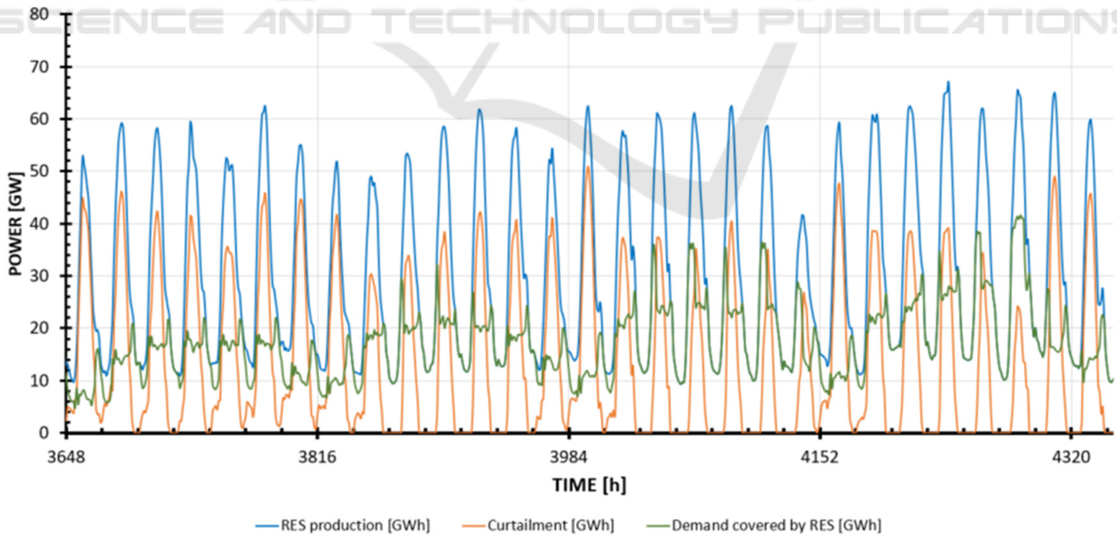

Figure 2: Power generation and demand in June - First 2030 energy scenario.

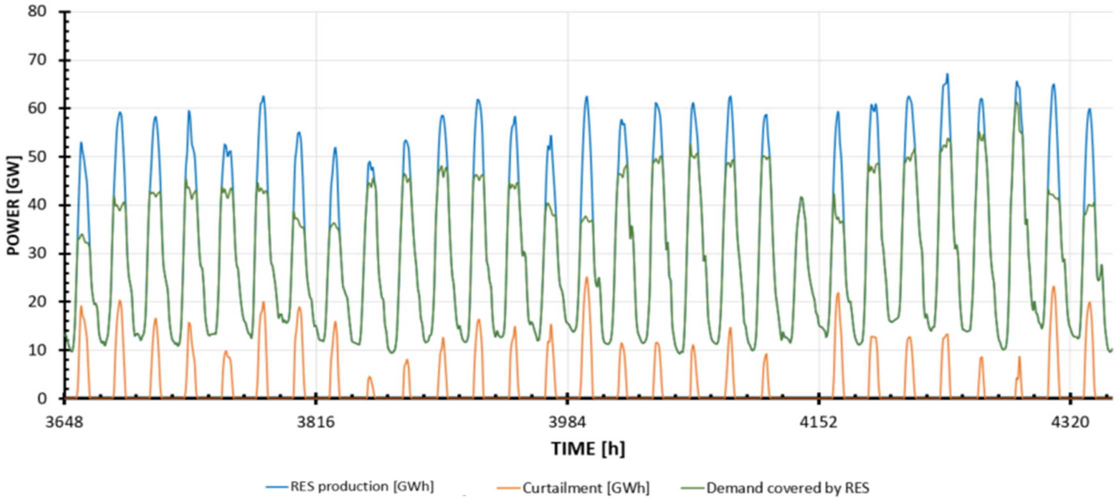

Figure 3: Power generation and demand in June - Second 2030 energy scenario.

The modelling of CCS to the flue gases of existing power plants produces the partial decarbonization of the energy production sector, reducing its contribution to CO_2 emissions into the atmosphere by 3% compared to the first 2030 simulated scenario.

The total emitted CO_2 in this second energy scenario is around 244 Mt per year, allocated between the different sectors as shown in Figure 4.

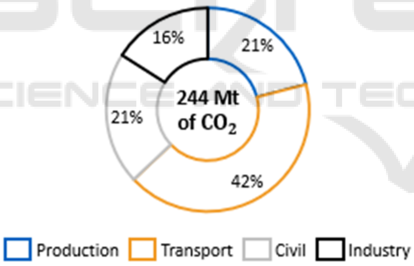

Figure 4: CO2 emissions by different sectors in 2030 - Second scenario.

However, this energy scenario has the important issue of sequestration of CO_2 in a safe and permanent way (Alcalde et al., 2018).

5 CONCLUSIONS

The paper shows the importance of diversification of the different technologies for the future 2030 Italian energy scenario. The simultaneous modelling of CCS to existing power plants and around +40 GW of IRES plants compared to the 2019 energy scenario allows the meeting of the Italian NECP target on CO_2 emissions. Furthermore, a combined installation of electrolysers, exploiting electricity overgeneration for hydrogen penetration as a novel energy vector in the end-user uses, allows to maintain electricity curtailment at acceptable values.

Further studies are ongoing implementing a cost-analysis of the different scenarios and varying the amount of captured CO_2 or IRES and hydrogen penetration in the energy production mix and the end-user uses respectively. Additionally, considering the current European and Global situation of the energy sector (e.g. gas crisis, ambitious emissions targets etc.), the authors are evaluating possible uses of other energy sources in Italy, such as the nuclear energy.

REFERENCES

Alcalde, J., Flude, S., Wilkinson, M., Johnson, G., Edlmann, K., Bond, C. E., Scott, V., Gilfillan, S. M. V., Ogaya, X., & Haszeldine, R. S. (2018). Estimating geological CO2 storage security to deliver on climate mitigation. *Nature Communications*, *9*(1).

Bellocchi, S., Manno, M., Noussan, M., Prina, M. G., & Vellini, M. (2020). Electrification of transport and residential heating sectors in support of renewable penetration: Scenarios for the Italian energy system. *Energy*, *196.*

Bompard, E., Botterud, A., Corgnati, S., Huang, T., Jafari, M., Leone, P., Mauro, S., Montesano, G., Papa, C., & Profumo, F. (2020). An electricity triangle for energy transition: Application to Italy. *Applied Energy*, *277*, 115525.

Budinis, S., Krevor, S., Dowell, N. M., Brandon, N., & Hawkes, A. (2018). An assessment of CCS costs, barriers and potential. *Energy Strategy Reviews*, *22*, 61–81.

Colbertaldo, P., Guandalini, G., & Campanari, S. (2018). Modelling the integrated power and transport energy system: The role of power-to-gas and hydrogen in long-term scenarios for Italy. *Energy*, *154*, 592–601.

EnergyPLAN. (2022). EnergyPLAN. https://www.energyplan.eu/

European Commission. (2016, November 23). *Paris Agreement* [Text]. Climate Action - European Commission.

European Commission. (2017, October 20). *Clean energy for all Europeans package* [Text]. Energy - European Commission.

Feron, P. H. M. (Ed.). (2016). Related titles. In *Absorption-Based Post-combustion Capture of Carbon Dioxide* (p. ii). Woodhead Publishing.

Gambini, M., & Vellini, M. (2003). *CO2 emission abatement from fossil fuel power plants by exhaust gas treatment*. *125*(1), 365–373.

Gambini, M., & Vellini, M. (2009). *Conventional Power Plants Equipped With Systems for CO2 Emission Abatement*. 859–867. h

IEA. (2019). *Data tables – Data & Statistics—Electricity—2019*. IEA.

IEA. (2021). *Key World Energy Statistics 2021 – Analysis*. IEA.

IPCC. (2014). *2014—IPCC*. https://www.ipcc.ch/2014/

Mancuso. (2010). *Inventario annuale delle emissioni di gas serra su scala regionale*.

Ministero dello Sviluppo Economico. (2019). *Energia Clima 2030*.

Ministero dello Sviluppo Economico. (2020). *Strategia_Nazionale_Idrogeno_Linee_guida_preliminari_nov20.pdf*.

SNAM. (2019). *The-H2-challenge-Position-Paper.pdf*.

Sofia, D., Gioiella, F., Lotrecchiano, N., & Giuliano, A. (2020). Cost-benefit analysis to support decarbonization scenario for 2030: A case study in Italy. *Energy Policy*, *137*, 111137.

Terna, Snam. (2019). *Scenari, Terna-Snam.pdf*.

Vellini, M., Bellocchi, S., Gambini, M., Manno, M., & Stilo, T. (2020). Impact and costs of proposed scenarios for power sector decarbonisation: An Italian case study. *Journal of Cleaner Production*, *274*, 123667.

Vellini, M., & Gambini, M. (2015). CO2 capture in advanced power plants fed by coal and equipped with OTM. *International Journal of Greenhouse Gas Control*, *36*, 144–152.

Walker, S. B., Mukherjee, U., Fowler, M., & Elkamel, A. (2016). Benchmarking and selection of Power-to-Gas utilizing electrolytic hydrogen as an energy storage alternative. *International Journal of Hydrogen Energy*, *41*(19), 7717–7731.

Zebra Datamapper. (2020). *Zebra2020 Datamapper—Scenarios of the market transition to nZEBs*.