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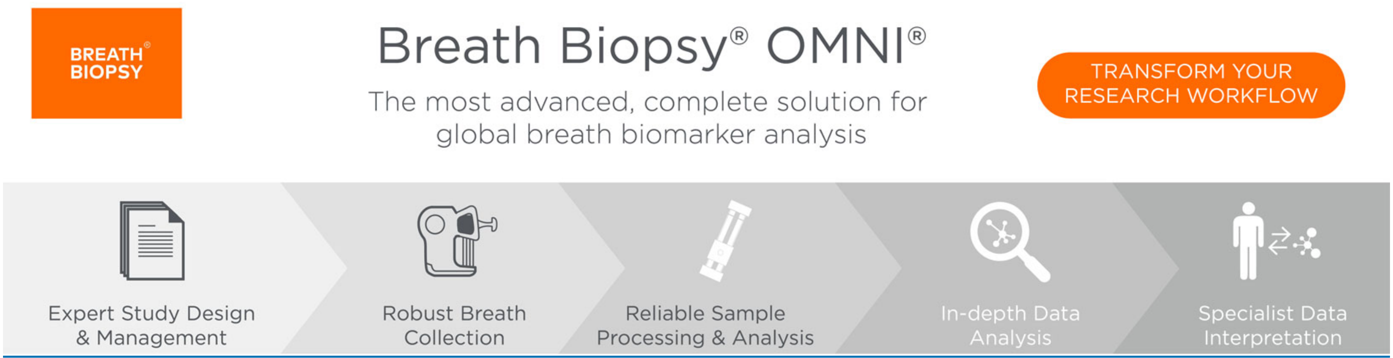

How Power-to-Gas strategy could reduce national Natural Gas consumption over the energy crisis period

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Abstract. Europe is facing an energy crisis caused by the dramatic rise in gas prices. This situation is damaging the European economy and urgent measures to reduce gas consumption are crucial in the short term. This paper aims to analyse the potential contribution of the Power-to-Gas strategy to reduce the Italian consumption of Natural Gas (NG) in the context of the current energy crisis. To do so, the Italian energy system has been modelled by means the EnergyPLAN software. The electrolysers' installation in the Italian energy systems has been simulated in combination with different levels of additional RES installation. The hydrogen production and the NG abatement potential have been calculated in each simulated scenario. Furthermore, the Natural Gas Abatement Cost (NGAC) has been assessed. By installing 1.5 GW of electrolysers, along with an additional 25 GW of renewables, about 140 ktonH2/year can be produced only by exploiting the RES excess. The total NG reduction due to both the RES generation and the hydrogen injection is more than 60 TWh/year. The NG abatement cost varies between 45 and 54 €/MWh. At current gas prices, it is therefore extremely cheaper to invest in a drastic reduction of natural gas than to buy the same amount of gas on the wholesale market. Therefore, the current energy crisis can be an opportunity to accelerate the energy transition process. The proposed solutions allow a substantial reduction in gas consumption with the consequent reduction in emissions and the country's energy dependency.

1. Introduction

Europe is facing an energy crisis caused by the dramatic rise in gas prices. In recent months, this price has reached unprecedented levels. Moreover, many countries base their electricity price formation mechanism on natural gas (NG). Therefore, the cost of energy has risen dramatically and does not seem to slow down in the near future.

This situation is damaging the European economy and causing serious problems for European companies and families. Moreover, this price increase is increasing the number of households in energy poverty and widening inequalities in European countries [1].

The Title Transfer Facility (TTF) is the reference wholesale market of NG exchange for several countries of continental Europe, including Italy, Germany and France.

The gas price has been rising since the end of last year. Since October 2021, the average monthly gas price has never fallen below €80/MWh. In Figure 1, the monthly average from 2015 and the 5-years average of TFF have been depicted.

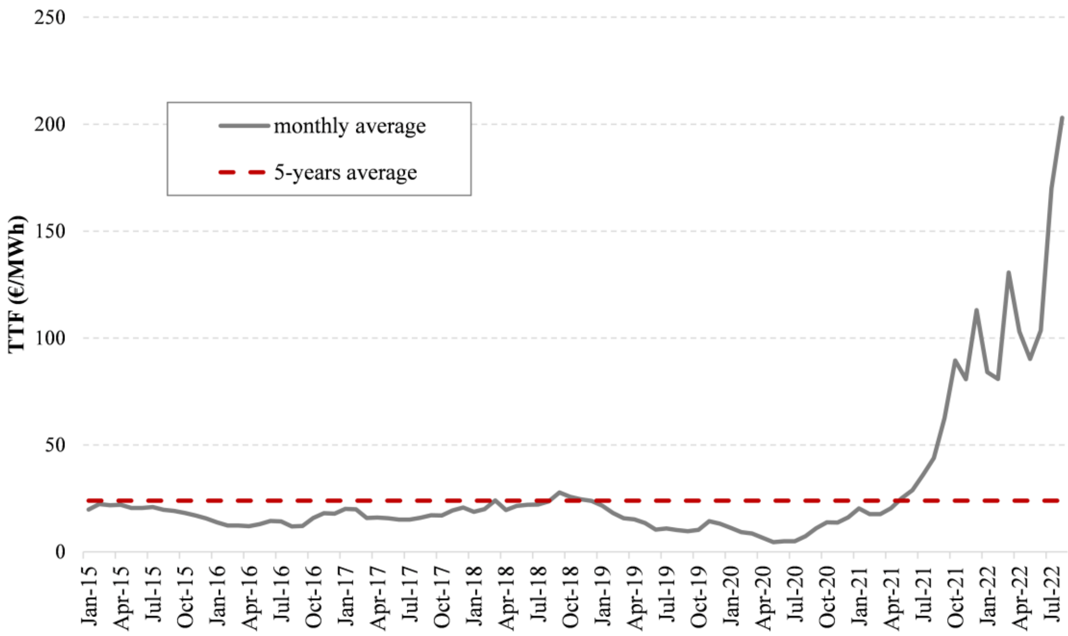

Figure 1. Monthly average and 5-years average price of gas on the TTF market [2]

Europe imports about 90% of its gas consumption and about 45% of this comes from Russia. The current geopolitical crisis is showing the vulnerability of the European energy supply system and how dependent the EU and its economy are on imported fossil fuels.

In the near future, many countries are speeding up a policy of import diversification. However, that cannot be the only solution, as it temporarily curbs the problem, but does not solve it.

Furthermore, the gas infrastructure expansion, whether through regasification plants or new pipelines, is a long-term investment [3]. These infrastructures normally have a functional lifetime of several decades and their construction risks tying Europe to the massive import of a fossil energy source, delaying or hindering the spread of renewable technologies [4].

Moreover, such investments risk being stranded assets, which may slow down national investments for the energy transition [5].

Conversely, the reduction of gas consumption can be rapidly achieved through the energy system decarbonisation [6]. In countries like Italy, which base most of their electricity production on natural gas, the installation of renewable energy sources (RES) allows a direct reduction in national gas consumption.

The cost of generating electricity from renewable sources is, even before the recent energy crisis, lower than that of thermoelectric plants [7]. Therefore, the RES deployment can reduce both national gas consumption and the electricity price for consumers.

The deployment of alternative fuels is a much discussed solution in national strategies and scientific literature [8]. However, they are characterised by very high production costs that limit their uptake. Nevertheless, the current energy crisis can make the production of such fuels worthwhile and speed up their deployment [9].

Green hydrogen can be a key vector in the energy decarbonisation process [10,11]. Several countries have developed their own national hydrogen strategies and set targets for the installation of electrolysers [12]. This will speed up the learning process of hydrogen technologies in order to deploy this vector in the medium term [13].

Hydrogen can be injected directly into the gas network at low volumetric fractions without significant changes in the network [14]. In this way, natural gas can be directly replaced by hydrogen. This solution is especially suitable in the first phase of the deployment of Power-to-Gas (PtG) technologies [15].

Indeed, it overcomes the problems of storing and transporting hydrogen without the need for a dedicated infrastructure [16].

Hydrogen injection thus enables the decarbonisation of the gas network and natural gas end-uses [17,18]. This makes it possible to reduce consumption and emissions in the residential sector without investments for end users [19]. Furthermore, Power-to-Gas strategies are also suitable in residential communities to integrate non-programmable renewable generation [20].

The aim of this work is to investigate the potential role of hydrogen for reducing the natural gas consumption. The aim is to assess and quantify the impact of national Power-to-Gas strategies along with the RES installation in energy and economic terms. The main goal is to calculate an abatement cost of natural gas consumption in order to compare such cost with the price for purchasing the same amount of gas.

2. Methodology

The present work analyses the impact of PtG strategies along with the rapid deployment of renewable plants in the Italian energy systems for reducing the national NG consumption in the short term.

The Italian energy system has been modelled by means the EnergyPLAN software. The electrolysers' installation in the Italian energy systems has been simulated in combination with different levels of additional RES installation.

Four scenarios of electrolysers, corresponding to an overall capacity installation equal to 0.5, 1 and 1.5 GW, have been taken in consideration. Furthermore, additional RES installation levels have been simulated in combination with the electrolysers. The additional RES capacity has been considered up to 25 GW, setting a ratio between PV and Wind capacity equal to 1.5. Therefore, the scenario characterised by the highest level of renewable installation provides for an additional capacity of 15 GW and 10 GW for PV and Wind, respectively.

The electrolysers are operated as a storage system for the system's electricity surplus. In this way, the energy from renewable sources is used to meet the electricity demand and only the RES excess feeds the electrolysers.

The hydrogen production and the NG abatement potential have been calculated in each simulated scenario. Furthermore, the Natural Gas Abatement Cost (NGAC) has been assessed.

2.1. EnergyPLAN and MAT4EnergyPLAN

EnergyPLAN is a computer tool for modelling energy systems characterised by high renewable generation levels [21]. It is a deterministic input/output tool, which allows to simulate the energy system at hourly resolution over a whole year. In recent years, EnergyPLAN has been applied for the analysis of energy systems at different scales. Numerous works have used this software for national energy planning [22,23].

Recently, the MATLAB toolbox for EnergyPLAN (MaT4EnergyPLAN) has been developed [24], which allows to manage EnergyPLAN in the MATLAB environment. In such a way, several simulations can be performed easily.

In the present work, that tool has been applied to simulate several scenarios of the Italian energy system, by combining the different implementation levels of the proposed strategies.

2.2. Natural Gas Abatement Cost

The NGAC is an indicator proposed in order to analyse the abatement cost of NG. The NGAC, expressed in €/MWh, is the average cost for abating one MWh of NG. It can be calculated according to Equation 1:

$$NGAC = \frac{\sum_j (CAPEX_j \cdot crf_j + OPEX_j)}{NG_{Avd,y}} \tag{1}$$

Here, CAPEX is the CAPital EXpenditure, OPEX is the OPerating EXpenditure, $NG_{Avd,y}$ is the annual NG abatement potential and crf is the capital recovery factor. The latter can be computed according to Equation 2:

$$crf = \frac{i \cdot (1+i)^{\tau}}{(1+i)^{\tau}-1} \qquad (2)$$

Where, i is the interest rate of investments and τ is the lifetime.

2.3. EnergyPLAN model and economic assumptions

The Italian energy system model applied in the present work has been built and validated in Ref. [6]. In Table 1, the comparison between EnergyPLAN model and actual data has been reported.

Table 1. Comparison between EnergyPLAN model and actual data

Value	Unit	Actual data	EnergyPLAN model	Discrepancy %
Annual CO_{2eq} emissions	Mt_{CO2}/yr	321.59	321.76	+0.05%
Natural Gas	TWh/yr	708.92	708.69	-0.03%
Oil and petroleum products (excluding LPG)	TWh/yr	570.31	569.56	-0.13%
LPG	TWh/yr	27.34	27.30	-0.15%
Solid fuels	TWh/yr	75.37	75.56	+0.25%
Non-renewable Waste	TWh/yr	12.03	12.02	-0.05%

Furthermore, the main economic assumptions regarding costs and lifetime of the technologies applied in the present work have been summarised in Table 2.

Table 2. Economic assumptions

Technology	Unit	Investment (€/unit)	Lifetime (Years)	Fixed O&M (% of INV)	Ref.
Wind	kW_e	1,558	25	1.3	[7]
PV utility	kW_e	703	25	2.2	[7]
PV residential	kW_e	1,221	25	2.2	[7]
Electrolyser	kW_e	810	15	1.5	[25]
Mixer	Nm^3_{H2}	177	15	2.0	[26]

3. Results and discussion

The Italian Energy system has been simulated in the different electrolysers' installation scenarios by implementing different levels of additional RES capacity. In Figure 2, the total hydrogen production versus additional RES installation in the different scenarios of electrolysers' capacity has been depicted.

Furthermore, in Figure 3, the same values have been represented in terms of NG avoided by means the hydrogen injection into the gas grid.

The RES excess in the current Italian energy system configuration is extremely low. Therefore, the installation of electrolysers without a considerable implementation of renewable capacity is inefficient.

As additional RES capacity increases, hydrogen production increases more than proportionally. This is due to the increased electricity excess once high levels of renewables penetration in the system are achieved.

By installing 1.5 GW of electrolysers, along with an additional 25 GW of renewables, about 140 $kton_{H2}$/year can be produced only by exploiting the RES excess. Thus, if hydrogen is fed into the gas grid, a reduction of about 4.7 TWh of NG consumption can be achieved.

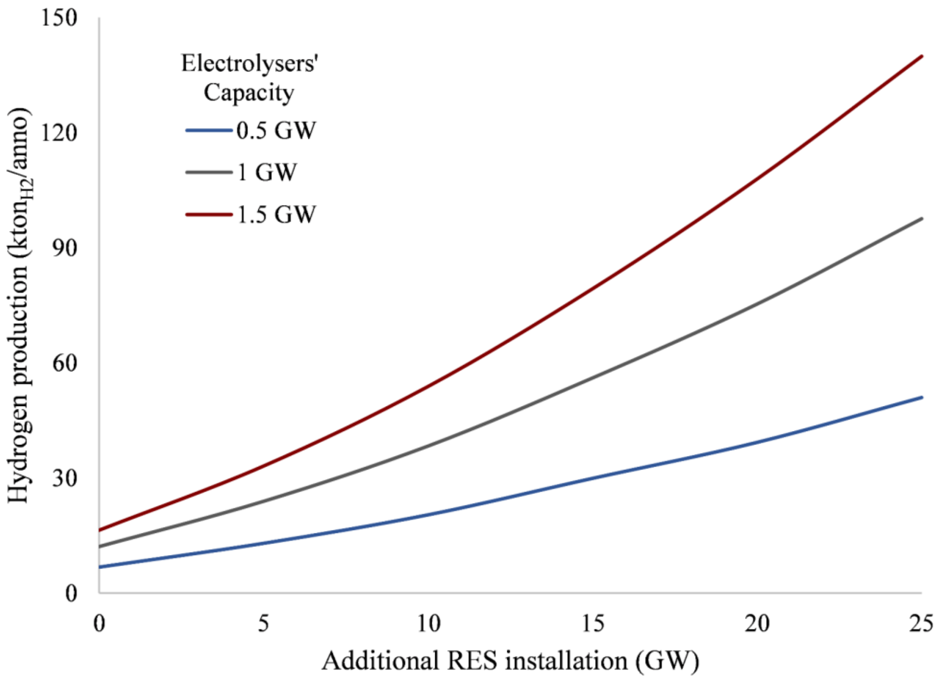

Figure 2. Hydrogen production versus additional RES installation in the different scenarios of electrolysers' capacity

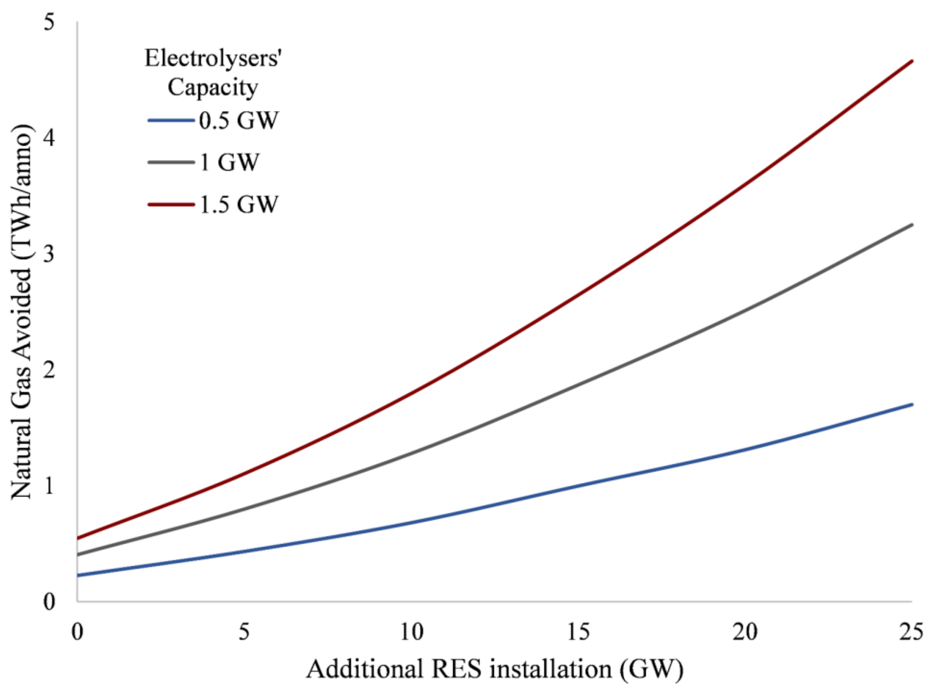

Figure 3. Natural gas avoided by means hydrogen injection versus additional RES installation in the different scenarios of electrolysers' capacity

In Figure 4, the total amount of natural gas avoided by means hydrogen injection and RES generation in the different configuration has been depicted.

As can be seen from the graph, more than 60 TWh/year can be reduced by installing 25 GW of renewables and 1.5 GW of electrolysers. Therefore, the reduction of NG consumption depends mainly on the amount of electricity demand covered by renewable generation.

Nevertheless, the high-RES penetration in the energy system results in a significant excess of renewable generation that can be efficiently used for hydrogen production. In such scenarios, the reduction in NG consumption due to hydrogen injection is quantitatively significant.

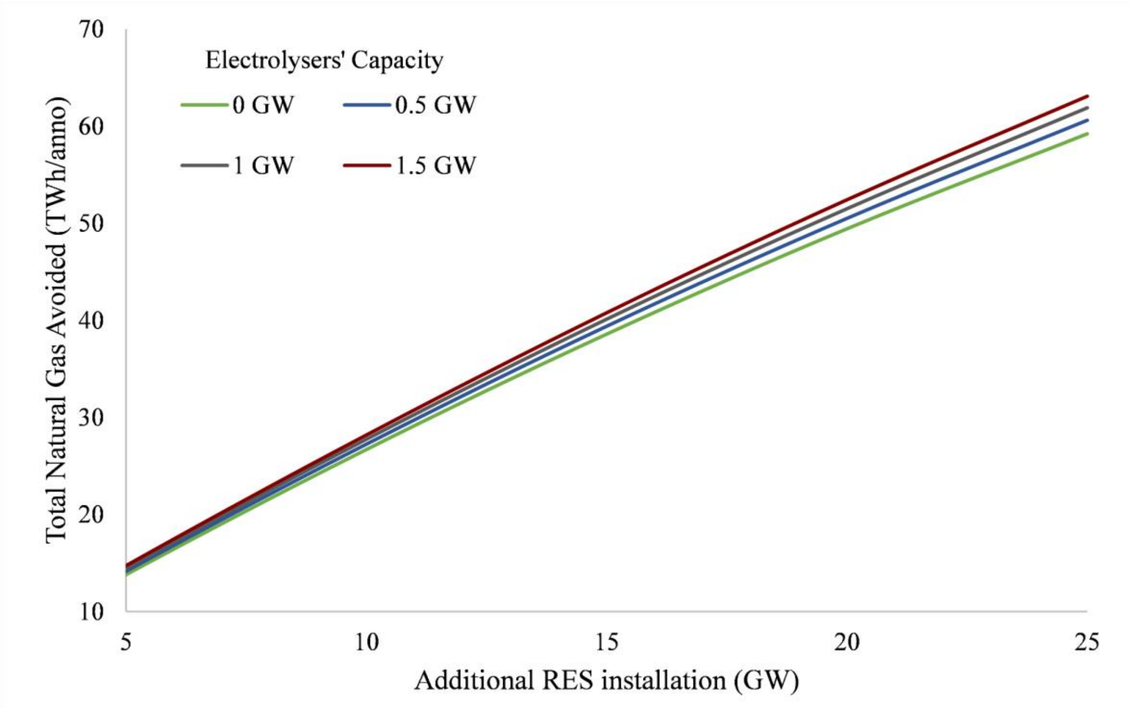

Figure 4. Total amount of natural gas avoided versus additional RES installation in the different scenarios of electrolysers' capacity

In Figure 5, the NGAC versus additional RES installation in the different scenarios of electrolysers' capacity has been depicted. Without the electrolysers' installation, higher the additional RES capacity, higher the NGAC is.

This is due to the system excess, which reduces the useful full load hours and thus the levelized cost of electricity. When electrolysis capacity is installed in the power system, NGAC decreases for low additional RES capacity, then reaches a minimum and, above 10 GW, increases.

At high-RES penetration levels, the difference in NGAC in the electrolyser scenarios is lower. This is due to the fact that in such scenarios as the overall size of the electrolysers increases, the equivalent hours remain similar.

The NGAC values obtained in the different scenarios are very significant. As shown in Figure 5, the NG abatement cost varies between 45 and 54 €/MWh. Comparing these costs with the European reference market spot prices, they are much higher than the gas price until the first half of 2021. On the contrary, since October 2021, the gas price has always been above 80 €/MWh.

At current gas prices, it is therefore extremely cheaper to invest in a drastic reduction of natural gas than to buy the same amount of gas on the wholesale market.

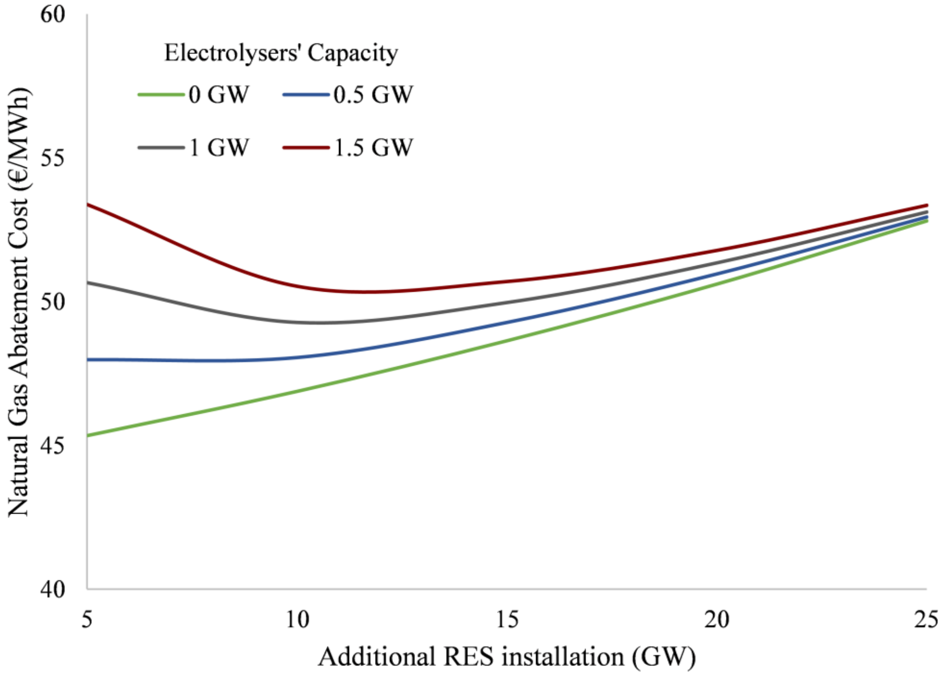

Figure 5. Natural Gas Abatement Cost versus additional RES installation in the different scenarios of electrolysers' capacity

It must be emphasised that this comparison must be made not with the current price, but with the average NG price in the coming years. Indeed, it is not possible to predict how long the current energy crisis will last and how long gas prices will remain at these values.

The longer the spot price remains at current values, the higher the average price will be in the coming years. Therefore, the cost-effectiveness of such reduction measures compared to buying gas also depends on how quickly they will be implemented.

In addition, there are further advantages in the immediate implementation of such measures. The expected gas reduction in the scenario of maximum implementation of the strategies allows for a reduction in emissions equal to 12 $Mton_{CO2}$/year.

Furthermore, the reduction in gas consumption makes it possible to decrease the country's dependence on fossil fuels and to be less subject to the high volatility of their prices.

4. Conclusion

The aim of this work is to investigate the potential role of hydrogen for reducing the natural gas consumption. To do so, the Italian energy system has been modelled by means the EnergyPLAN software. The electrolysers' installation in the Italian energy systems has been simulated in combination with different levels of additional RES installation. The hydrogen production and the NG abatement potential have been calculated in each simulated scenario. Furthermore, the Natural Gas Abatement Cost has been assessed.

The main findings can be summarised as follows:

- The RES excess in the current Italian energy system configuration is extremely low. Therefore, the installation of electrolysers without a considerable implementation of renewable capacity is inefficient.
- As additional RES capacity increases, hydrogen production increases more than proportionally. This is due to the increased electricity excess once high levels of renewables penetration in the system are achieved.

- By installing 1.5 GW of electrolysers, along with an additional 25 GW of renewables, about 140 ktonH2/year can be produced only by exploiting the RES excess. Thus, if hydrogen is fed into the gas grid, a reduction of about 4.7 TWh of NG consumption can be achieved. In that strategy, the total NG reduction due to both the RES generation and the hydrogen injection is more than 60 TWh/year.
- Without the electrolysers' installation, higher the additional RES capacity, higher the NGAC is. This is due to the system excess, which reduces the useful full load hours and thus the levelized cost of electricity.
- At high-RES penetration levels, the difference in NGAC in the electrolyser scenarios is lower. This is due to the fact that in such scenarios as the overall size of the electrolysers increases, the equivalent hours remain similar.
- The NG abatement cost varies between 45 and 54 €/MWh. At current gas prices, it is therefore extremely cheaper to invest in a drastic reduction of natural gas than to buy the same amount of gas on the wholesale market.

In conclusion, the current energy crisis can be an opportunity to accelerate the energy transition process. The proposed solutions allow a substantial reduction in gas consumption with the consequent reduction in emissions and the country's energy dependency.

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