Utilising the full potential of Italy's renewable energy future

How to reduce costs and curtailment by introducing more flexibility

BUSINESS WHITE PAPER

In the National Energy and Climate Plan, NECP, Italy sets forward its roadmap how to meet the energy and climate targets set by the EU. Achieving these targets requires actions of all sectors in the society, increasing renewable energy in transport, heating, electricity etc. These targets include among others having 32% of final energy consumption of renewable origin and reducing CO_2 emissions by 40% compared to 1990 levels by 2030.

The National Energy and Climate Plan (NECP) sets ambitious targets for Italy to further increase the share of renewable energy sources in the power system. PLEXOS power system optimisation tool was used to model Italian power system and analyse several scenarios to optimise and increase flexibility in the system by 2030. The results show a clear value for flexibility: adding 5-7 GW of flexible gas generation enables better integration and utilisation of renewable energy sources. Fast start and stop of flexible gas generation enables the operation of the units only when needed, yet fully supporting intermittent renewable generation. Better utilisation of renewable energy and non-spinning reserve provision enables 400 MEUR savings in annual system costs as well as increased renewable energy penetration and reduced CO_2 emissions.

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1. Development of the Italian power system until 2030

The development plan for the Italian power system and the capacity mix is focusing on renewable energy sources and reducing emissions. Coal will be phased-out by 2025, significantly cutting the CO_2 emissions and providing a notable step towards reaching the target.

The development plan, which is outlined in Figure 1, is also very ambitious in terms of developing renewable energy sources. Italy's target is to double the wind power generation and triple the solar power generation compared to current status in 2019. In addition, 5 GW of additional energy storage capacity is envisioned to come online to provide frequency regulation and time shifting of renewable energy.

Gas is still seen to have an important role to play in the Italian system, and the overall capacity should reach 50 GW, a net increase of 4 GW. However, the role of gas will be very different. Gas-fired generation will move away from baseload generation towards peaking generation that is supporting renewable generation. This aspect of flexible gas and the value of flexibility will be assessed in more detail in this paper.

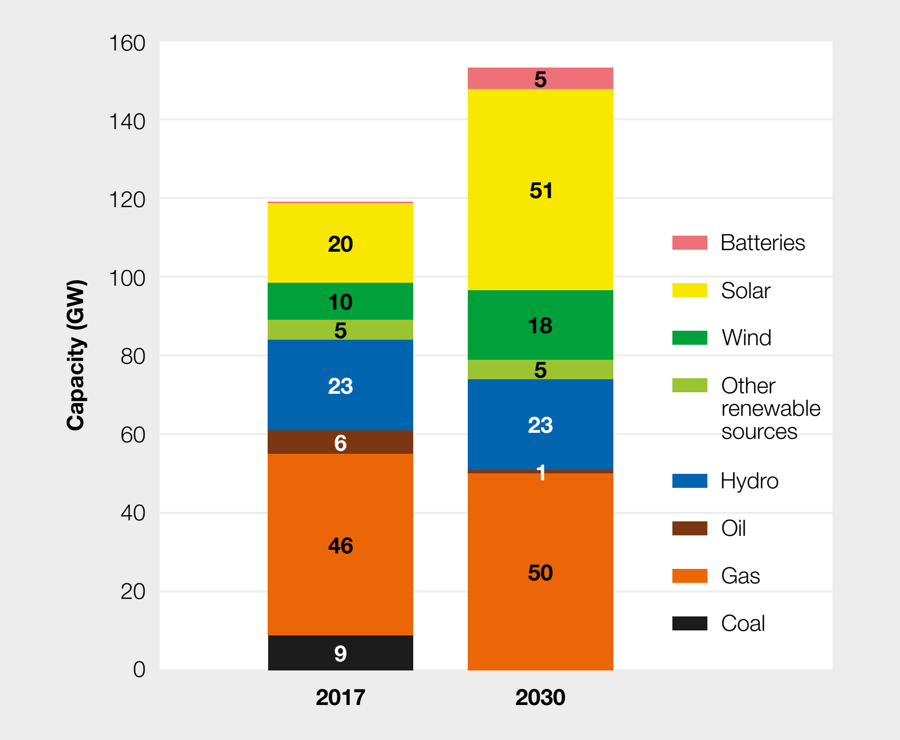

Figure 1. Italian power system development plan until 2030

2. Italian power system model

Wärtsilä is the global leader in smart technologies that enable a transition to more sustainable societies. Wärtsilä has done an analysis of more than 60 power systems globally to identify the optimal system design that would support integration of renewables and reduce the system operational cost and emissions.

The development of the Italian power system poses a great challenge in terms of renewable integration, curtailment reduction and providing the Italian people with affordable and reliable electricity. Our hypothesis is that with the proposed additions of wind and solar generation the system requires more flexibility than what is now planned. Therefore, our objective is to derive the optimal amount of flexible generation in the system and from an economical point of view show how the power system can be further optimised from commercial and environmental perspective. Our analysis has been done with the power system optimisation tool PLEXOS.

2.1. POWER SYSTEM MODELLING TOOL PLEXOS

The optimisation software PLEXOS is developed by the Australian software company Energy Exemplar. PLEXOS is widely used by Transmission System Operators (TSO), consultants and utilities among others to optimise the dispatch of power plants, the utilisation of transmission systems, long-term development planning, etc.

In PLEXOS detailed models of power plants, transmission systems, power system reserves, power markets, etc. can be analysed. By running different scenarios based on the model, one can assess what happens in the system in various situations. The outcome being, for example, optimised dispatch or plans for future capacity additions.

The target for the solver is to find a solution with the lowest cost while fulfilling all boundary constraints, such as dynamic parameters of plants, load profile, etc. The optimisation process used in this study is based on Mixed Integer Programming (MIP) and chronological optimisation, namely, each hour is optimised.

2.2. INPUTS

The following section presents some of the assumptions and explanations regarding the input values for the model. In general, the PLEXOS model has been built based on current power plant data available on public databases with the additions and decommissioning presented in section 1.

Reserves

Power system reserves are defined as a fixed percentage of actual load and variable renewable energy (VRE) generation, and hence changes from hour to hour. Load risk properties are taken into account in both Primary and Secondary reserves, whereas the Secondary reserve includes also a factor on reserving capacity for sudden changes in VRE output, i.e. forecast errors.

Type of reserve	Hourly demand
Primary	3% of load
Secondary	9% of load + 20% of VRE generation

Table 1. Reserves considered in the model

Fuels and emissions

There is always a high uncertainty related to future prices for fuels. In this study fuel prices have been fixed to 2018 levels. However, as the planned generation capacity for year 2030 shows, natural gas is the most significant fuel being used, and therefore sensitivity analysis with different natural gas prices are advisable on further studies. In this study it is assumed that oil is only being used on islands and in captive or emergency plants. Furthermore, biomass-fired power plants are assumed to operate in a fixed baseload profile.

Another important parameter, from an environmental point of view, is the CO_2 production rate from different fuels. In the model, CO_2 is accounted for and requires European Emission Allowances (EUA). The price of CO_2 allowances is 34 EUR/tonne CO_2 and is based on Bloomberg New Energy Finance (BNEF) estimates of EUA price at year 2030.

Fuel	Price	CO_2 emissions
Natural gas	25.2 EUR/MWh	56.1 $kgCO_2$/GJfuel
Biomass	13.3 EUR/MWh	0 $kgCO_2$/GJfuel

Table 2. Fuel prices and CO_2 emission factors utilised

Interconnectors

Transmission connections to neighbouring countries can be vital to the power system of any country. In this study it has been assumed that interconnector capacities remain constant until 2030. Interconnectors can be a significant source of flexibility in both importing power when more generation is needed and exporting excess generation e.g. at times of high renewable output. To model the effect of increasing amounts of VRE capacity in the Italian (and most probably in neighbouring countries') power system, the price paid for importing electricity and price received for exporting electricity is based on realised hourly day-ahead prices from 2018. However, prices have been increased by 10% when importing and lowered by 40% when exporting power.

Interconnector capacities included in the model can be seen in Table 3 and 4.

Import	Winter (MW)	Summer (MW)
France	3,150	2,700
Switzerland	4,240	3,420
Austria	315	270
Slovenia	730	515
Greece	500	500

Export	Winter (MW)	Summer (MW)
France	995	870
Switzerland	1,810	1,440
Austria	100	80
Slovenia	660	620
Greece	500	500

Tables 3 and 4. Transmissions capacities for interconnectors to neighbouring countries

Hydropower
The model includes three types on hydropower plants: run-of-river, reservoir and pumped-storage. To take into consideration seasonal differences in availability as well as limitations in dynamic capabilities, hydrological conditions are modelled to represent the year 2018. Annual generation of hydropower plants depends very much on hydrological conditions, and sensitivity on different conditions is advisable on further studies.

Renewable energy and battery storage
Operating profiles of wind and solar generation are based on actual aggregated profiles from the Italian power system in 2018. The profiles are used in the model on an hourly level, and they include realised variations on daily, weekly and seasonal levels. Battery energy storage systems (BESS) are introduced to the system as planned in the NECP and are assumed to be units of 1 MW / 4 MWh. Operation (charging and discharging) of battery storages is optimised by PLEXOS in accordance to requirements of the total system.

The cost of renewables and BESS are based on yearly cost estimates by BNEF. This study focuses on the Italian power system after the year 2030 when the planned wind and solar additions are completed. The total installed generation capacity of wind power is 18 GW and that of solar power 51 GW. Installed capacity of BESS is 5 GW.

	Wind (EUR/MWh)	Solar (EUR/MWh)	BESS (EUR/kW)
2020	60.3	55.3	1,011
2021	57.2	50.9	930
2022	56.0	48.8	861
2023	54.9	46.7	797
2024	53.8	44.5	743
2025	52.9	42.4	696
2026	51.9	40.6	655
2027	51.2	39.2	617
2028	50.4	37.8	581
2029	49.6	36.5	548
2030	48.7	35.4	516

Table 5. Cost estimates for wind, solar and battery energy storage systems

Financial parameters

A significant part of this study is to evaluate benefits of investing into flexible generation capacity to the whole Italian power system, hence investment cost for installing new capacity is accounted for in the model. Cost of wind and solar power are based on installed capacity and the total cost is paid even if VRE capacity is curtailed to maintain stability in the power system at times.

Financial figures used in this study are presented in Table 6.

	Flexible gas	Wind	Solar	BESS
WACC	8%	8%	8%	8%
EPC price	700 EUR/kW	Based on yearly LCOE	Based on yearly LCOE	Based on yearly estimates
Economical lifetime	20 years	20 years	20 years	10 years

Table 6. Financial parameters for new capacity investments

3. Results

This study takes a high-level view on the Italian power system. Due to the planned wind and solar generation capacity additions, the study assesses whether the power system requires additional flexibility to maintain stability and cost efficiency and whether the country can make full use of their investments to the renewable energy without curtailments. The study is conducted by modelling the Italian power system on an hourly level, focusing on the year 2030, when the planned capacity additions in renewable generation and energy storage are in place and operational.

Operation and dispatch of the power system is optimised with the PLEXOS software, hour-by-hour for the full year. The Base scenario corresponds to the NECP, i.e. with only wind, solar and BESS additions. In the following flexibility analyses flexible gas generation capacity is incrementally added to the Base scenario, while optimising the power system in each step.

Annualised investment costs for all added capacity, as well as all dynamic parameters of different technologies while optimising dispatch of the power system, are taken into account. In the following sections the results of the optimisation are analysed and explained.

3.1. OPTIMAL SHARE OF FLEXIBILITY

A total of 12 optimisation rounds were conducted and compared to each other on basis of total cost of operating the Italian power system. As expected, additional flexible generation capacity is a key feature in optimising the total system, by allowing better utilisation of renewable energy sources and providing non-spinning reserves without burning fossil fuels. Each incremental addition of flexible gas capacity increases renewables utilisation by lowering curtailment. However, after a certain threshold, the investment costs of additional flexible capacity outweigh the acquired operational savings. Figure 2 shows total cost of operating the Italian power system in different scenarios. Each scenario represents an amount of additional installed flexible gas generation capacity in GW, with 0 GW representing the Base scenario. The graph also shows the lowering levels of wind and solar power curtailment when flexibility is added into the system.

The results show that while installing the planned capacities of wind, solar and battery energy storage, the Italian power system requires further flexibility and is in its optimal state with 5–7 GW of additional flexible gas-fired power generation capacity. The lowest system cost is achieved with 6 GW of new flexible capacity. This scenario is referred to as the Flexible scenario in the following sections. The total system savings are on a level of 400 MEUR annually, which equals 2.5% of total system cost. The savings are based on better utilisation of installed renewable energy capacity as well as providing non-spinning stability reserves to the system, resulting in fuel savings.

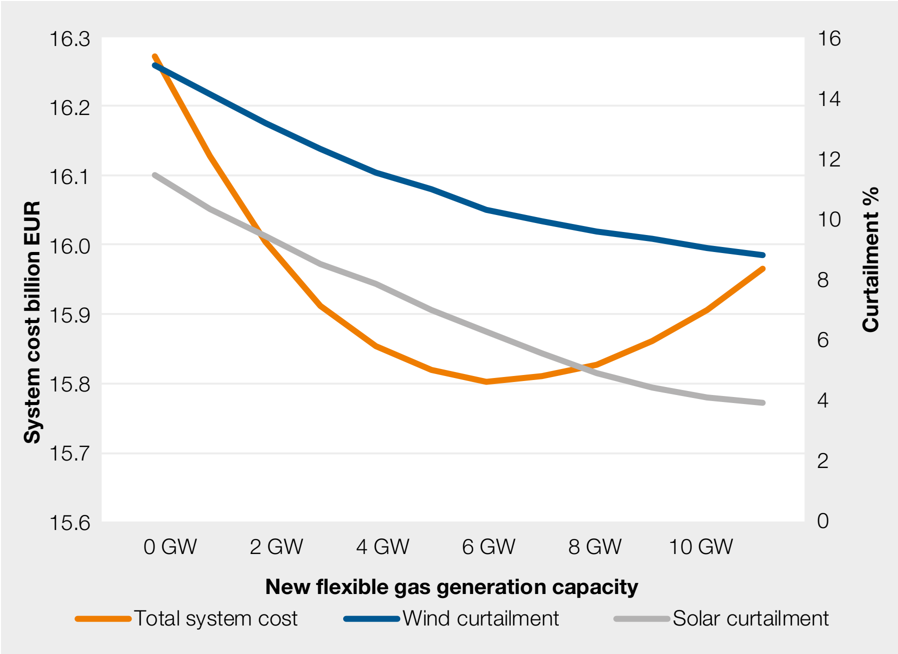

Figure 2. Total system cost and curtailment of renewable energy, 0 GW represents the Base scenario

3.2. DISPATCH

This study has been conducted by optimising dispatch of the Italian power system for the year 2030, hour-by-hour. Optimisation inputs include actual hourly profiles for wind and solar output as well as electricity consumption so that variability in the generation demand could be fully examined. Figure 3 shows dispatch for week 37 for both Base scenario and Flexible scenario (6 GW of new flexible capacity). In the graph, load includes charging batteries, pumping of pumped hydro storage and export energy as well as the native load of consumption itself.

Most flexibility from the system is required during daytime with intensive solar generation, and during evening peaks, which take place after sunset. All other technologies try to minimise generation during peak output of solar power, after which they ramp up to meet the demand of the evening peak. This has to be managed while accounting for constraints such as start-up times, reserve needs, etc.

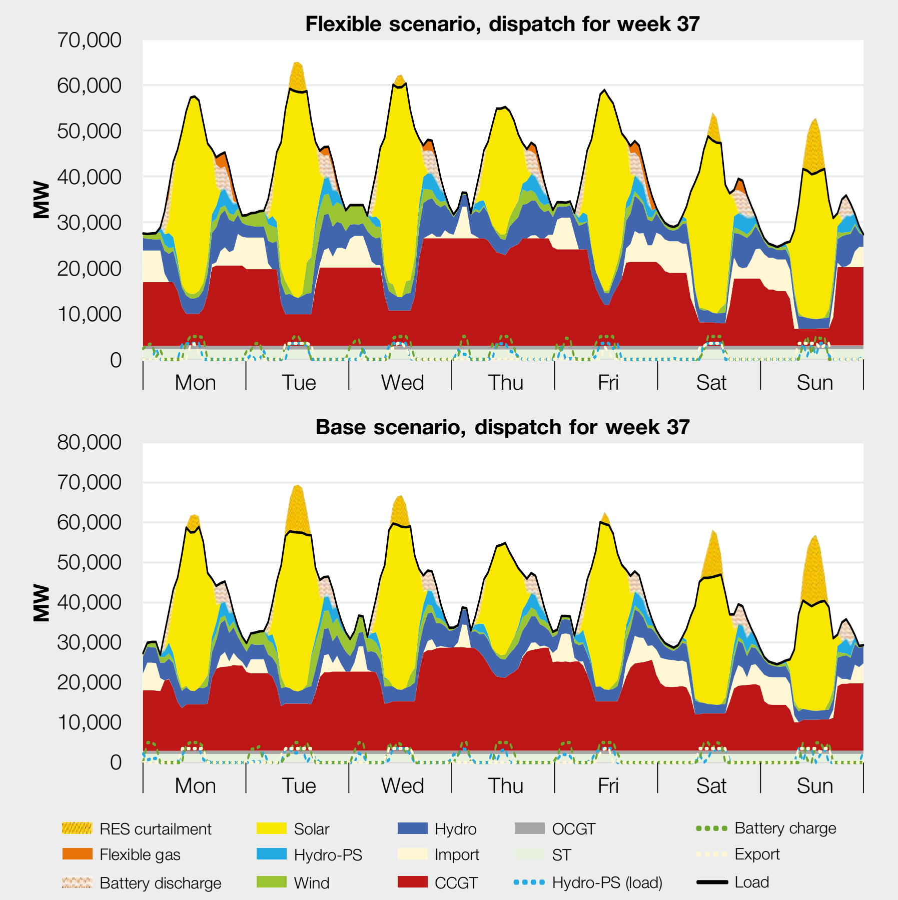

Figure 3. Power system dispatch comparison between flexible and base scenario. Example week in 2030

Much of the required flexibility is provided by the large share of flexible hydropower and pumped hydro storage in the Italian power system. However, the Flexible scenario still shows a need for additional flexible generation especially during the evening peak, when the solar output is reduced and demand increases. Also notable is the lower curtailment of renewable energy in the Flexible scenario. The lower curtailment is enabled by non-spinning reserves provided by the flexible gas capacity with extremely fast start-up time. Furthermore, the new flexible gas generation capacity optimises operation of the entire Italian power system, allowing for a more stable operating profile also for the combined cycle gas turbines providing baseload generation.

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It must be noted that in both scenarios there is heavy utilisation of cross-border interconnectors in form of import and export of power. Renewable generation, mainly solar, which cannot be utilised in the Italian system, is exported to neighbouring countries almost daily. In the night, there are considerable amounts of available imports from neighbouring systems. It is advisable that sensitivity analysis on the availability and cost of importing and exporting power is conducted in further studies.

3.3. CURTAILMENT

The power system flexibility analysis shows that each incremental addition of flexible gas generation capacity lowers curtailment of both wind and solar capacity. In the Base scenario, which represents the NECP, 14.9% of wind and 11.8% of solar power is curtailed. When the system is optimised with 11 GW of flexible capacity, curtailment of wind and solar can be reduced to 9.5% and 4.4% respectively. However, in this scenario the investment costs of flexible capacity outweigh the operational savings acquired by utilising more renewable energy.

The Flexible scenario with 6 GW of flexible capacity optimises the overall system cost to a minimum level, balancing between operational savings and investment costs. In the Flexible scenario curtailment of wind and solar is 10.8% and 6.7% respectively. On an annual level, there is 38% more curtailment of wind and 76% more curtailment of solar in the Base scenario compared to the Flexible scenario.

Figure 4 shows the dispatch for 24 hours of Sunday 16th of September 2030. Curtailment of renewable generation is 74% higher in the inflexible Base scenario. The reason is that thermal and hydro plants must provide reserves and cannot further reduce their load. The Flexible scenario shows how generation units with fast start-up time can provide reserves in non-spinning mode, maximising utilisation of renewable energy. Furthermore, in both scenarios the battery storage is fully charged during daytime and cannot absorb more renewable energy.

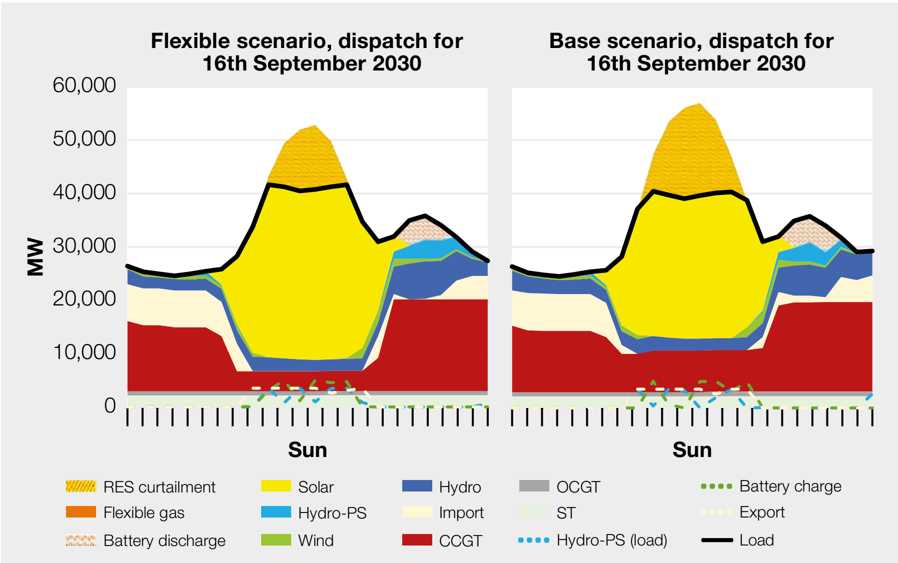

Figure 4. Power system dispatch comparison between Flexible and Base scenario. Example day in 2030

Figure 5 shows how flexible gas technology with a fast start-up time and efficient operation on low minimum loads optimises power system reserve provision.

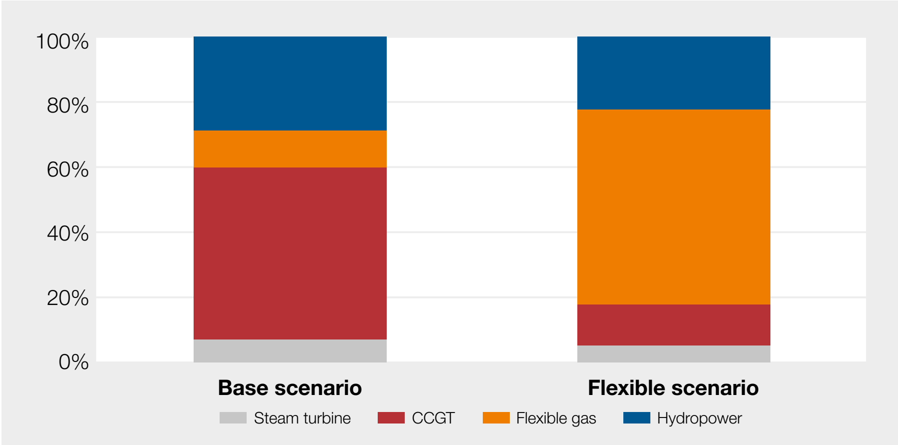

Figure 5. Reserve provision

3.4. SHARE OF RENEWABLES AND CO_2 EMISSIONS

The analysis shows a noticeable increase in renewable energy utilisation in the Italian system as flexible gas capacity is added. As shown in Figure 2, the utilisation of wind and solar capacity is 5.5% higher, reaching approximately 37% in total, in the Flexible scenario compared to the Base scenario. Wind and solar utilisation could be increased by as much as 7.7%, if 11 GW of new flexible capacity was installed in the system. However, this would not be cost optimal on a total system level. The total CO_2 free generation, i.e. wind, solar, hydro, geothermal and biomass, is 3.7% higher in the Flexible scenario compared to the Base scenario, totalling approximately 55% of total generation.

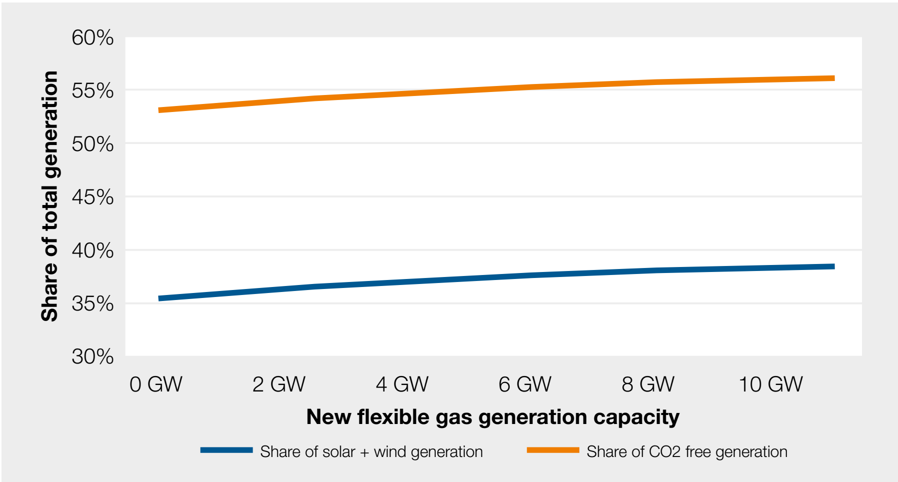

Figure 6. Share of renewable generation in the Italian energy mix

Carbon intensity is, naturally, linked to the utilisation of renewable and carbon neutral energy sources. As is shown in Figure 3, carbon intensity of the Italian power system can be reduced from 162 g/kWhel in the Base scenario to 143 g/kWhel in the Flexible scenario, which corresponds to a 12% reduction. It must be noted that imported electricity is considered carbon neutral regardless of the source of electricity.

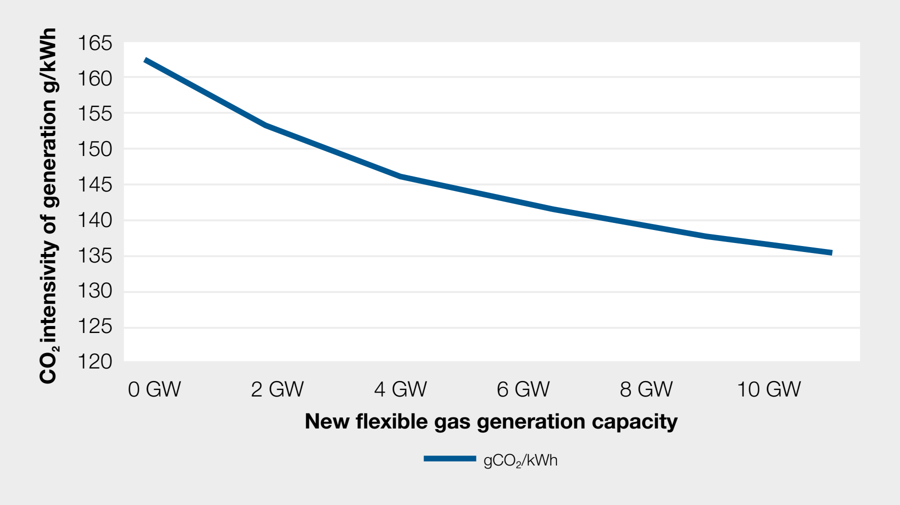

Figure 7. CO_2 intensity of the Italian power system

3.5. SUMMARY AND NEXT STEPS

Sustainable, reliable and affordable power is a key concern in many countries, especially as the world is fighting to keep the global warming below 1.5 degrees Celsius. Italy, with already more than 35% of electricity coming from renewable sources, is one of the leading countries in the transition towards renewable power systems. With the new National Energy and Climate Plan Italy sets new ambitious targets to further increase the share of renewable electricity.

This study has taken a high-level view on the Italian power system to assess the situation from a flexibility point of view, because the current plan does not include other flexibility additions than energy storage. By modelling the Italian power system with PLEXOS, it is possible to analyse several flexibility scenarios and determine the capacity of flexibility required in the system by 2030.

The results show a clear value for flexibility in the Italian system. By adding 5-7 GW of flexible gas generation, renewable energy sources can be better integrated and utilised in the system. As implied, flexible gas generation can be started and stopped very fast, currently in even less than 2 minutes. This feature allows the units to be operated only when needed, and yet fully supporting intermittent renewable generation. The results indicate a 400 MEUR annual system cost reduction, which mainly comes from better utilisation of renewable energy and non-spinning reserve provision.

These high-level results indicate that it is possible to further optimise the Italian system and national plan to increase renewable energy penetration, reduce CO_2 emissions and save costs. We are aware that this model still lacks certain constraints and details, such as internal transmission system bottlenecks, that may have an impact on the study results. This paper is the preliminary high-level study and we will incorporate more scenarios and sensitivity analyses and continue modelling the Italian power system in a more detailed manner.

WÄRTSILÄ ENERGY BUSINESS IN BRIEF

Wärtsilä Energy Business is leading the transition towards a 100% renewable energy future. As an energy system integrator, we understand, design, build and serve optimal power systems for future generations. Wärtsilä's solutions provide the needed flexibility to integrate renewables and secure power system reliability. Our offering comprises engine-based flexible power plants – including liquid gas systems – hybrid solar power plants, energy management systems and storage and integration solutions. We support our customers over the lifecycle of their installations with services that enable increased efficiency and guaranteed performance. Wärtsilä has 70 GW of installed power plant capacity in 177 countries around the world.

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