FONDAZIONE ENI ENRICO MATTEI

# A Strategic Co-optimization on the Italian Day-Ahead and Ancillary Services Markets

Implications for the phase out of coal and for the path towards carbon neutrality

Milan, 15-12-2021

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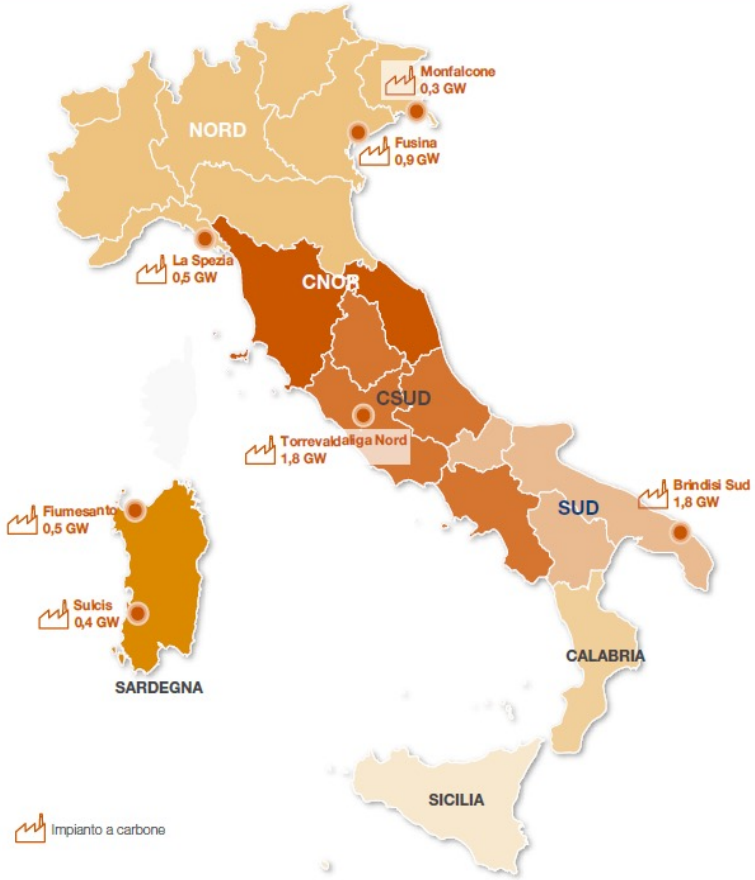



- Power systems must lead the way towards the full decarbonisation of the energy sector
- Conversely, installed renewable capacity (solar and wind) will achieve 45 GW in 2025 and 71 GW in 2030
- By 2025 (2028 including Sardinia), Italy will be among the first countries in the World to ban coal from its generation mix. According to Terna, Italy will phase-out 6 GW of coal capacity
- Phasing-out coal will have important consequences both on the day-ahead market as well as on the ancillary services market
- The Italian coal phase-out has been coupled with the introduction of a capacity-based mechanism, which will preserve security margins

https://download.terna.it/terna/Terna_Rapporto_Adeguatezza_Italia_2021_8d9a51d27ad741c.pdf

## 1.2 Rationale and Research Question

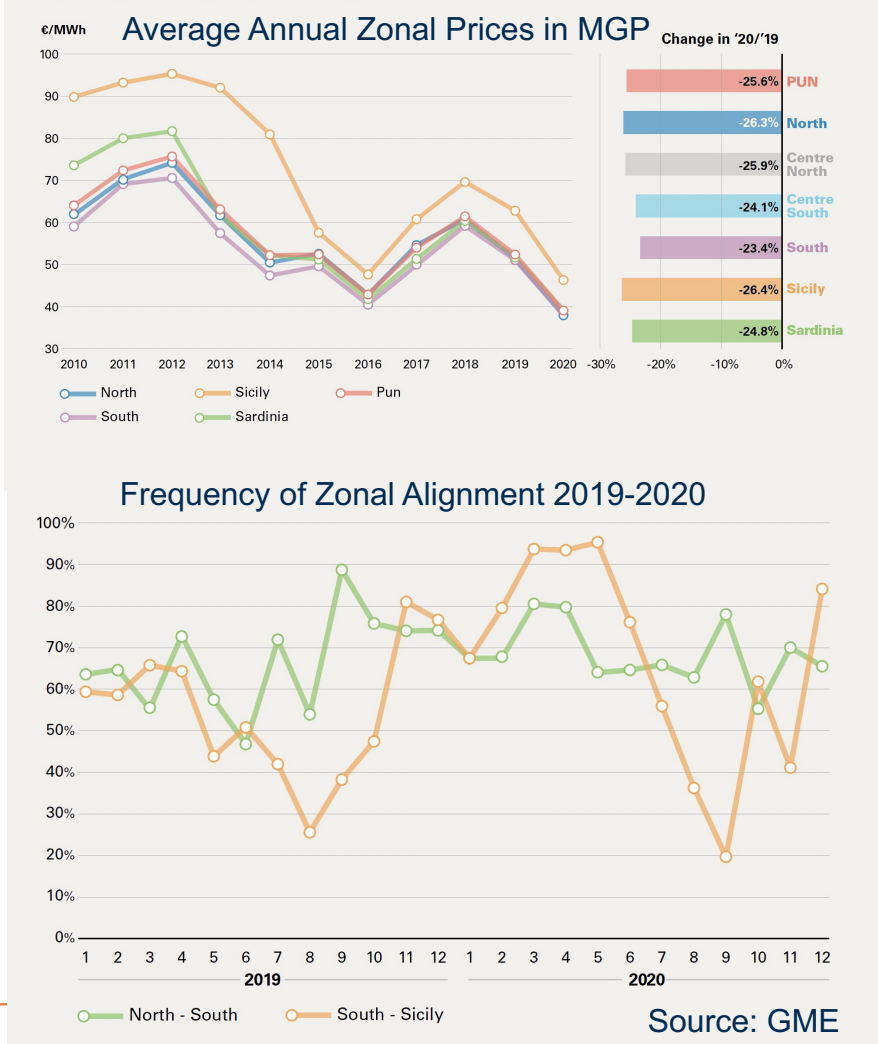
- Relying on Plexos, we develop a comprehensive model that simulates the hourly equilibrium (price-quantity) of the Italian day-ahead market and the MSD ex-ante
  - The model is calibrated on 2021 market outcomes
- The model is employed to analyze the Italian Power System in target year 2025
- The aim of the paper is to understand:
  - *What are the impacts of the phase out of coal on prices, generation mix, reserves and strategic behavior?*
  - *What are the fuel prices and ETS costs that would have naturally driven coal out of the market?*

# 2.1 The Italian Power System – Market Zones

Evolution of Italian Market Zones

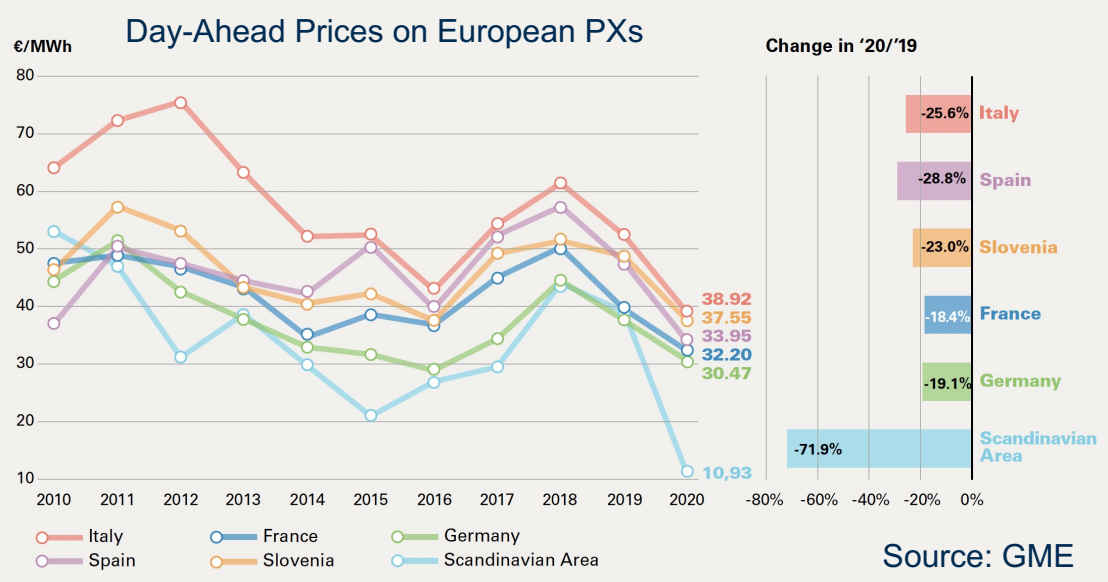

- A Market Zone is defined as portion of the power grid where, for system security purposes, there are physical limits to transfers of electricity to/from other Geographical Zones (Market Splitting)
- Market Zones are constantly changing due to investments in transmission de-bottlenecking and increased exchange capacity with bordering countries
- The Italian day-ahead System Marginal Price (PUN – Prezzo Unico Nazionale) is the weighted average of the prices of Market Zones

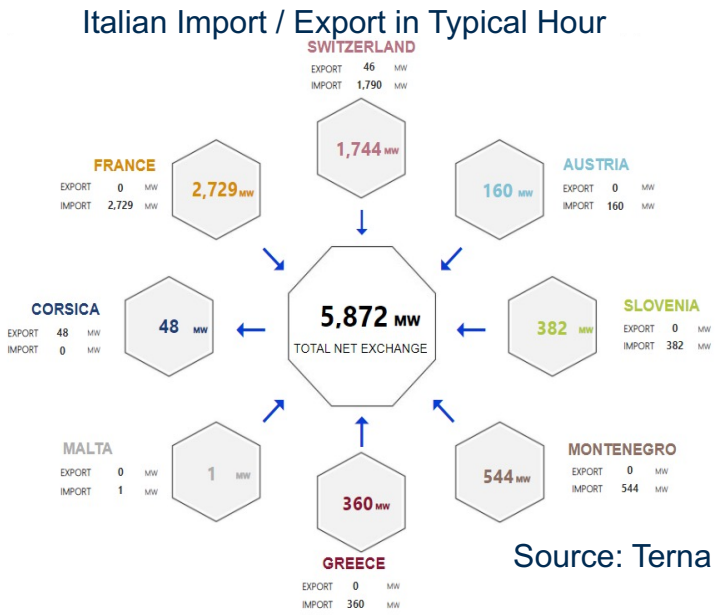
# 2.2 The Italian Power System – Zonal Prices




- Historically, Zonal Prices tend to diverge, especially in insular or isolated portions of the transmission grid, such as Sicily or Sardinia
- An isolated Market Zone allows the exercise of local market power, as well as the collection of infra-marginal rent for inefficient generation
- When transmission congestions are not present, electricity physical flows compensate areas with higher Zonal Prices >>> alignment towards the PUN
- Recently, thanks to the de-bottlenecking effort, Zonal Prices have been aligning
- Still, congestions and bottleneck are present along the North-South direction
  - The North is more connected to foreign power systems
  - The South features a higher penetration of renewables

# 2.3 The Italian Power System – Import and Export

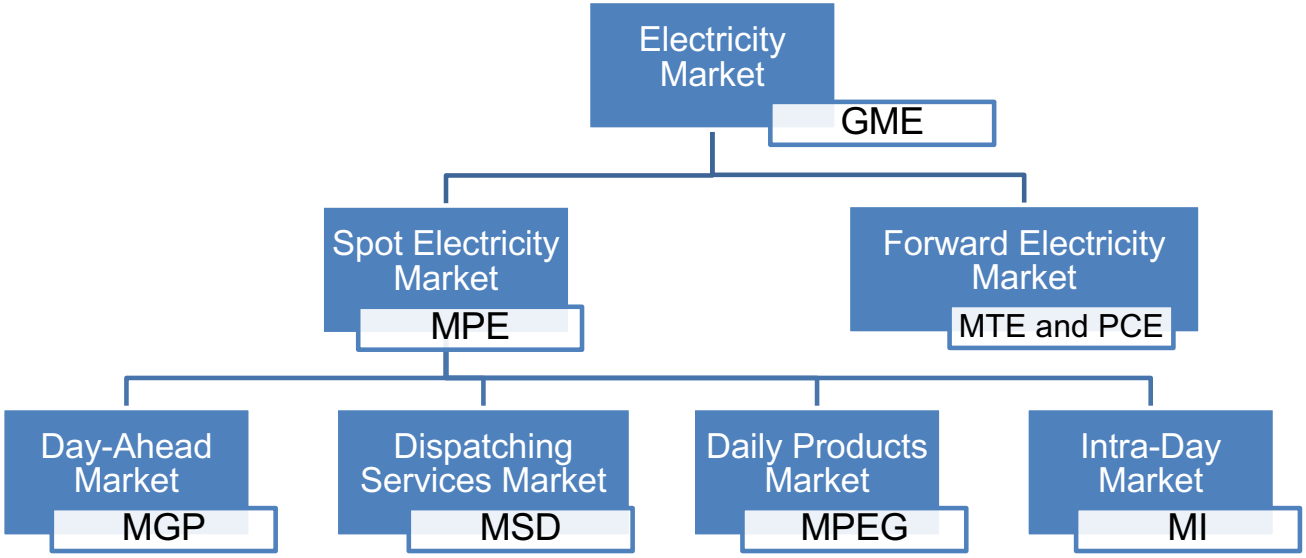



- Italy is electrically connected with France, Switzerland, Austria, Slovenia, Montenegro, Malta and Greece through 25 interconnection lines
- Historically, Italian electricity spot prices are above the European average, because of higher reliance on gas-based thermal generation vs coal and/or nuclear options
- In recent years, prices have aligned, thanks to de-bottlenecking, enhanced cross-border trade (Market Coupling), introduction of renewables, and phase-out of coal and/or nuclear

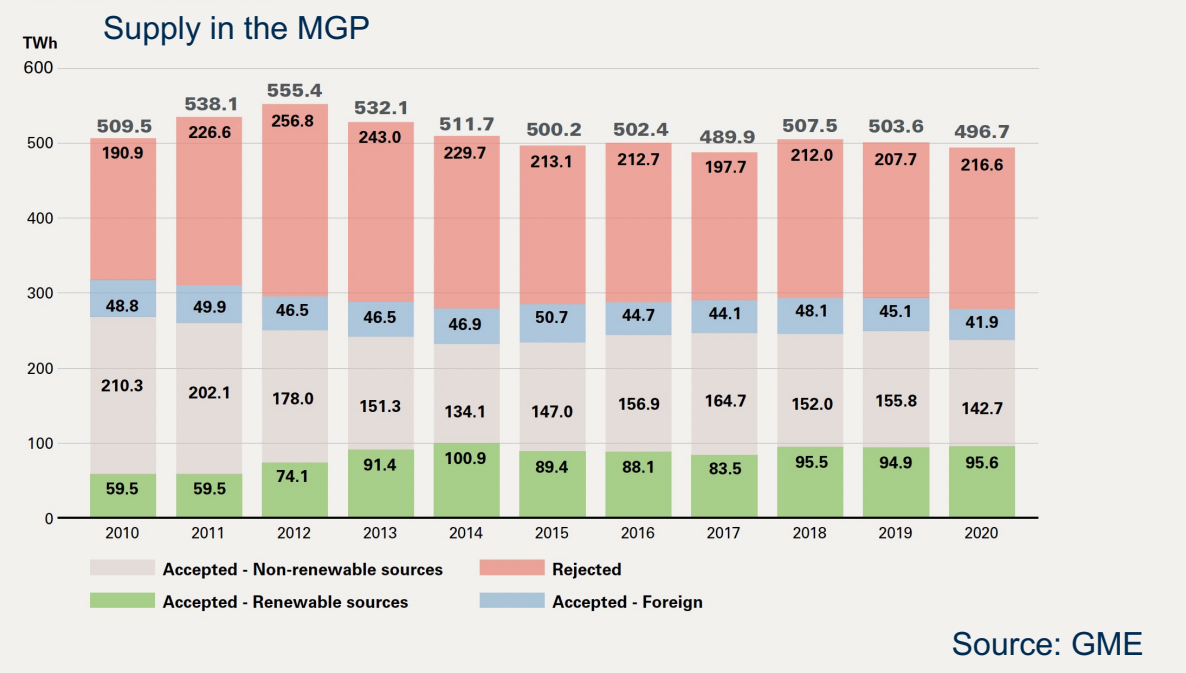
3.1

# The Italian Power Exchange – Market Segments




- the Spot Energy Market (MPE), is divided into the Day-Ahead Market (MGP), the Intra-day Market (MI) and the Daily Products Market (MPEG)
- the Forward Energy Market (MTE) and the Forward Energy Accounts Platform (PCE) allow for the recording of forward electricity purchase and sale contracts concluded outside the market system
- the Dispatching Services Market (MSD), concerning the procurement of resources for the dispatching service (ancillary services) and whose economic management is the responsibility of the TSO Terna

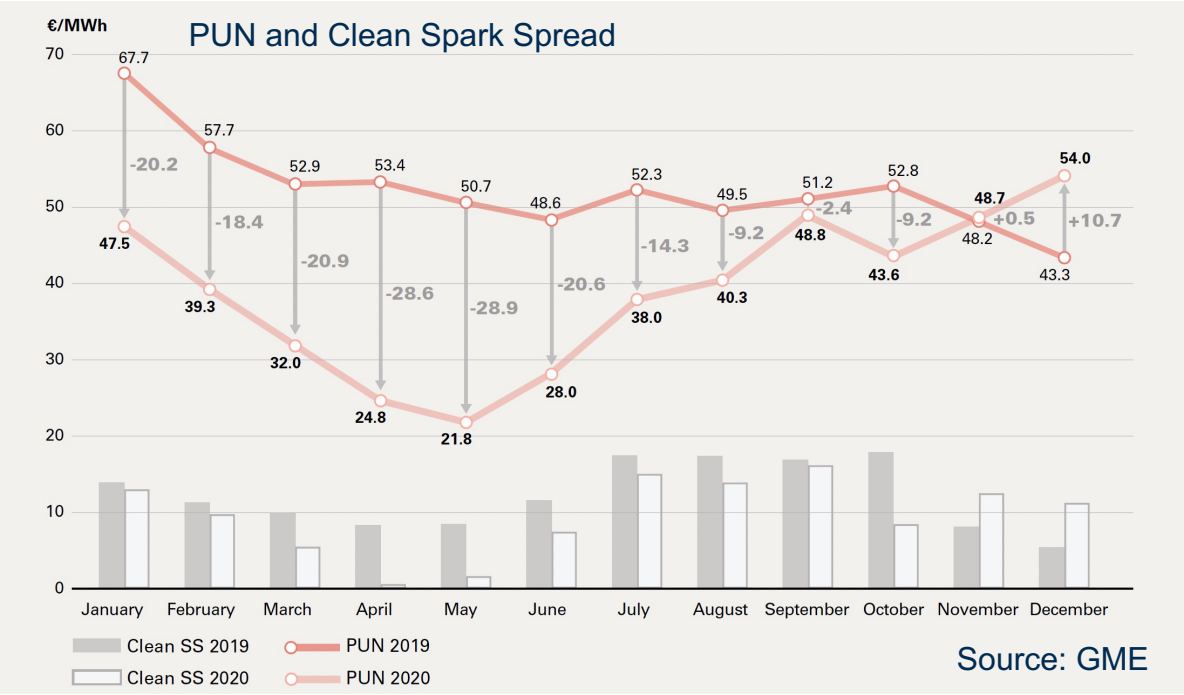
# 3.2 The Italian Power Exchange – Market Liquidity




Source: GME

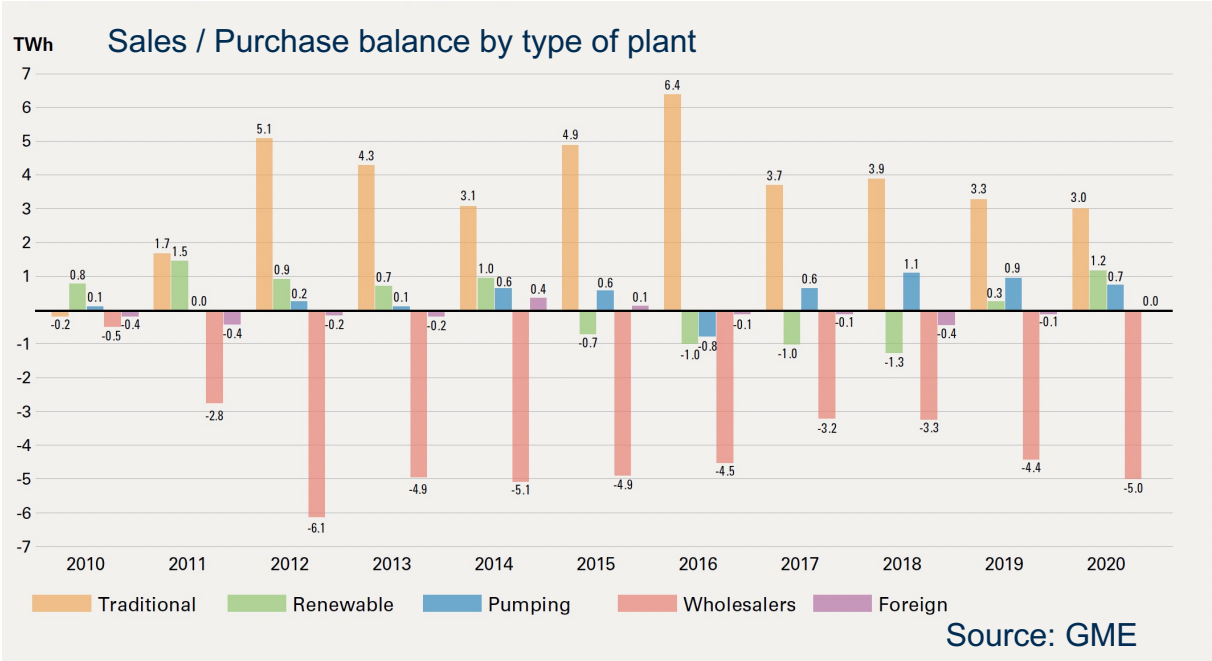
- The Day-Ahead segment of the IPEX is a very liquid market
- Presence of 280 registered market participants in 2020
- 280 TWh of electricity were traded in 2020, a 5% decrease compared to the previous year
- 216 TWh were offered but not accepted via the merit order algorithm in 2020, equal to 77% of the traded electricity
- Renewables represented 44% of the total accepted bids in 2020

# 3.3 The Italian Power Exchange – PUN and Clean Spark Spread

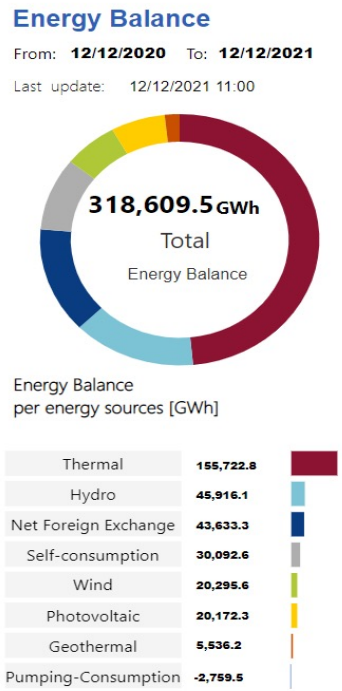



- The Clean Spark Spread is the difference between the wholesale market price of electricity and its cost of production using natural gas, minus the ETS prices of carbon emissions
- This metric presents high volatility, given by fluctuations in PUN and in ETS carbon prices
- With the phase-out of coal plants, the majority of the Italian baseload capacity will be represented by CCGT plants

# 3.4 The Italian Power Exchange – Evolution of Trading



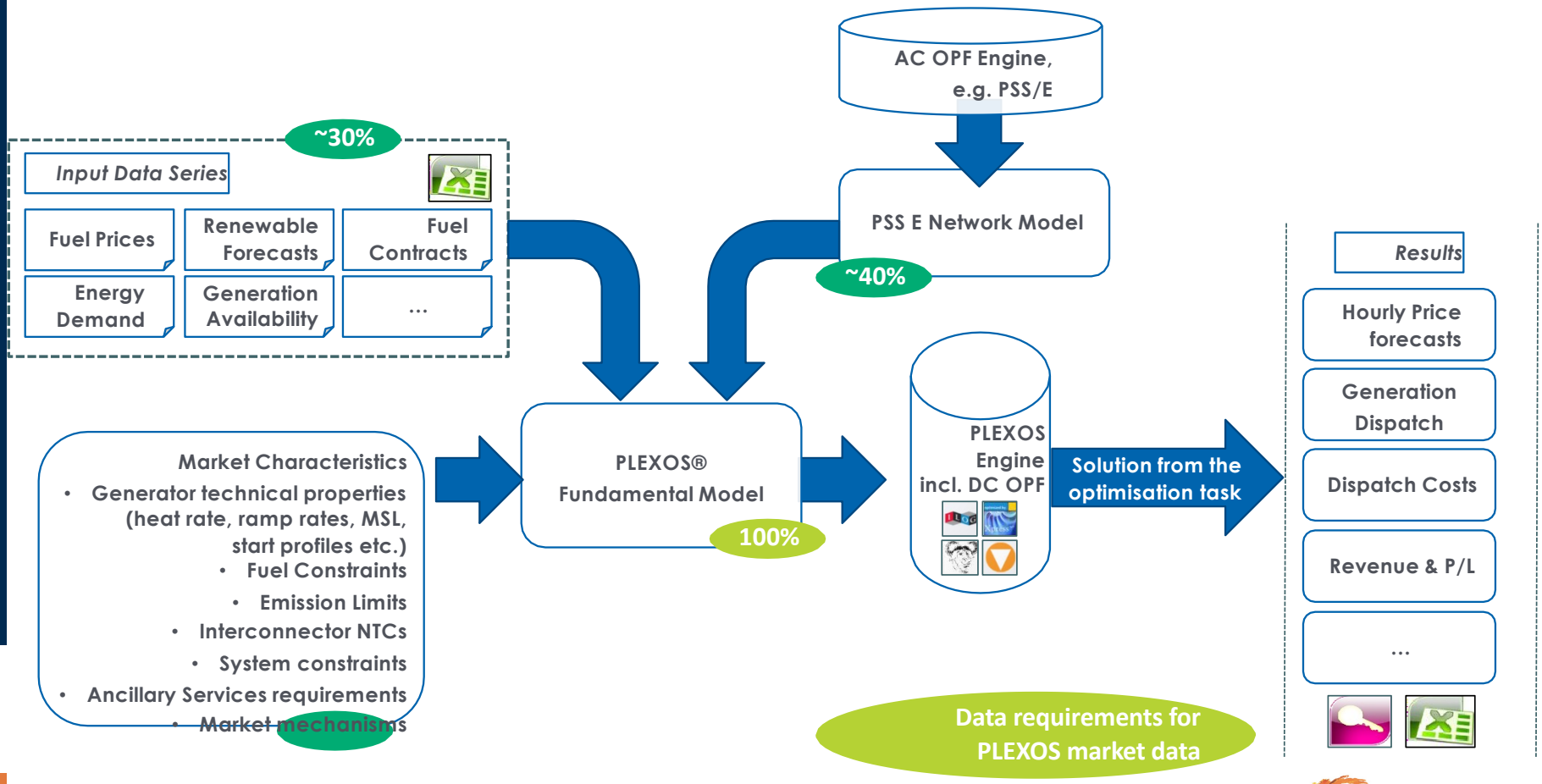

Source: GME




Source: Terna

- The balance of energy traded on the IPEX has evolved throughout the years
- Traditional (thermal) generation presents a declining profile, in line with the decommissioning of capacity and the increased competition from priority dispatching renewables
- Consistently, pumping storage is being activated on the sales side, as a back-up solution for an ever increasing share of intermittent renewables

# 4.1 Methodology – PLEXOS Data and Output

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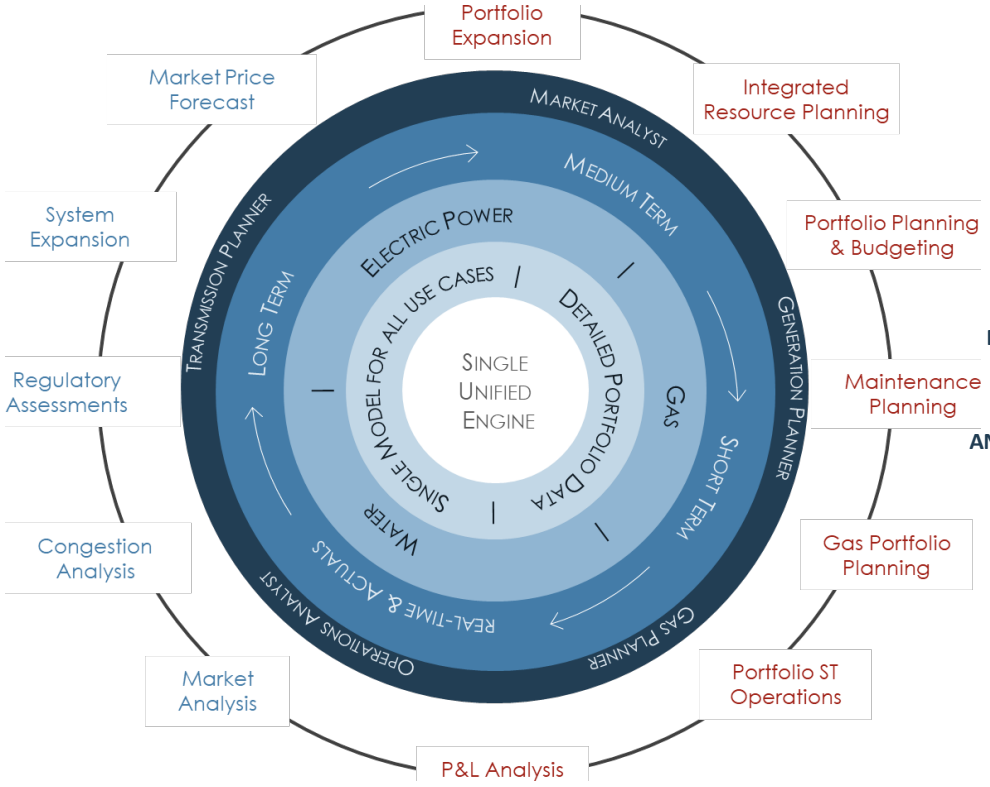
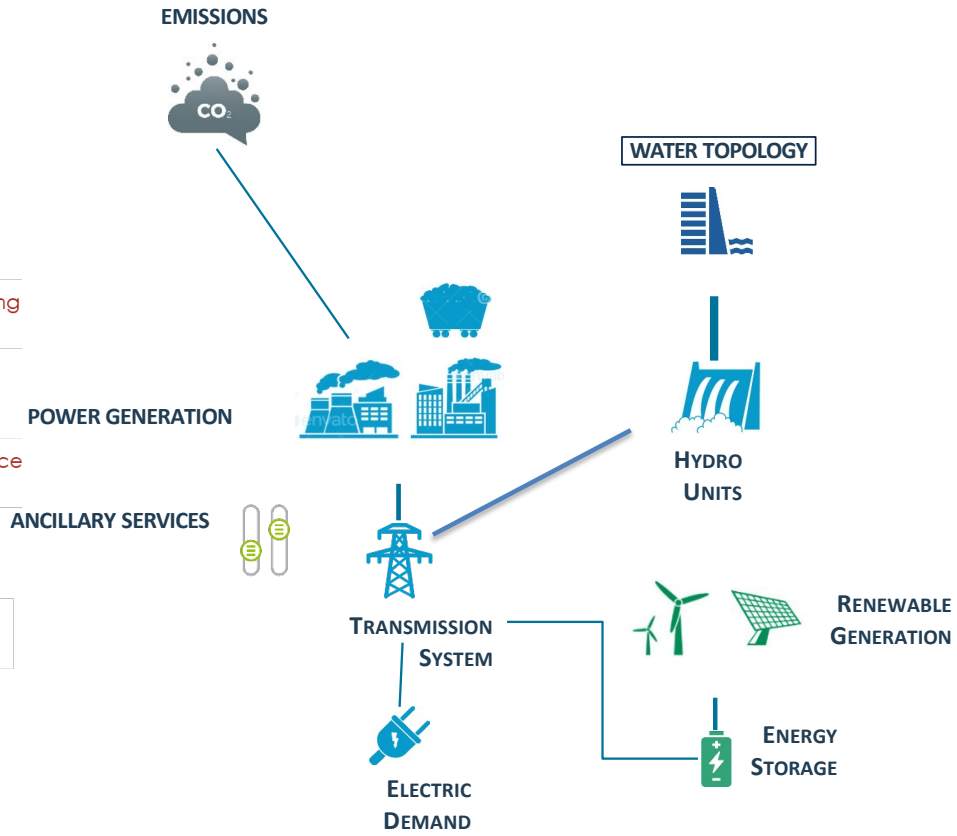
# 4.2 Methodology – PLEXOS Range of Analysis

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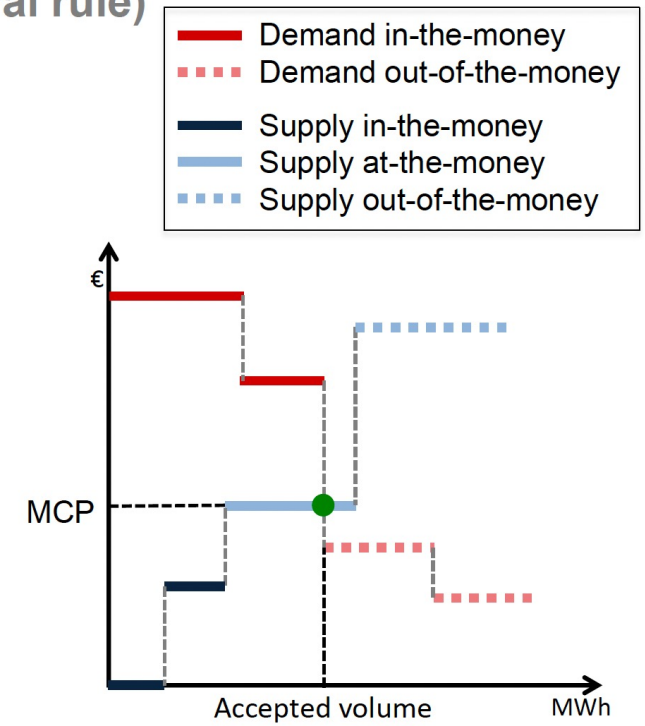
## 4.3 Methodology – PLEXOS Algorithm

- The simulator reproduces the iterative market splitting logic and the hourly equilibrium for the day-ahead and the provision of primary, secondary, and tertiary reserves as prescribed by ENTSO-E and Terna
- Plexos has an algorithm that replicates EUPEHMIA, the European algorithm that has been developed to solve the Day-Ahead European Market Coupling problem.
  - EUPHEMIA matches energy demand and supply for all the periods of a single day at once while taking into account the market and network constraints. The main objective of EUPHEMIA is to maximize the social welfare, i.e. the total market value of the Day-Ahead auction expressed as a function of the consumer surplus, the supplier surplus, and the congestion rent
- Within our simulation, we add a level of complexity: maximization entails the optimal provisions of ancillary services, hence some capacity cannot be offered on the day-ahead market, as it is needed for security

# 4.4 Methodology – PLEXOS – EUPHEMIA for the Day-Ahead

## HOURLY STEP ORDERS (general rule)

- Hourly step orders are defined by
  - A type (buy or sell)
  - A volume
  - A limit price
- EUPHEMIA provides solutions such that
  - Orders in-the-money are fully accepted
    - Supply at price < MCP
    - Demand at price > MCP
  - Orders out-of-the-money are fully rejected
    - Supply at price > MCP
    - Demand at price < MCP
  - Orders at-the-money can be curtailed




OMIE, APX, Belpex, GME and OTE use this kind of orders.

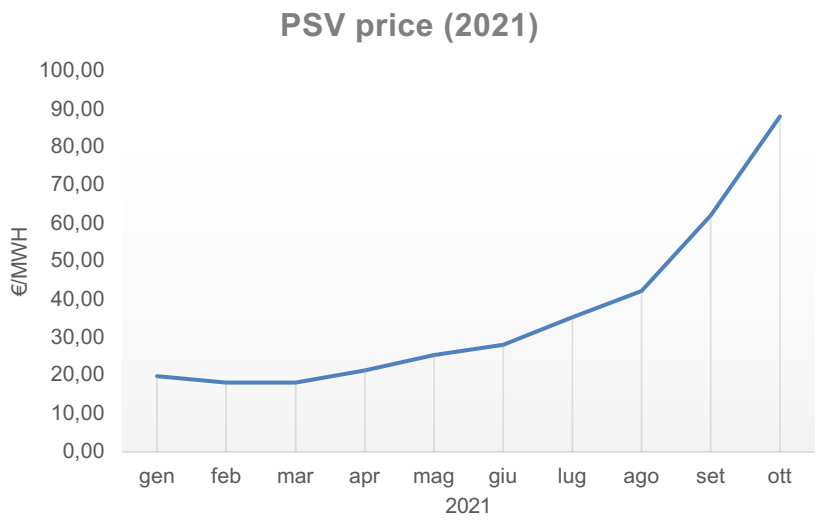
## 4.5 Methodology – Modelling Strategic Behaviour

- With Plexos is possible to model strategic behaviour
  - Companies can compete with each other and aim at maximizing their profits, hence they can bid at a price higher than their marginal costs
  - Moreover, they can co-optimize their strategy by deciding whether to offer their capacity on the day-ahead market or on the ancillary service market
- In our simulations, we develop a simple Bertrand setting, that allows companies to offer at a price which is an epsilon lower than the marginal cost of their closest competitor
- The iterative bidding allows companies to estimate rivals' marginal costs

5.1

# Modelling Year 2021 @Oct 2021 – Assumptions

- ETS price: 52 €/ton
- Gas price: Monthly prices 2021
- Essential power plants as per Terna list*




| Generators | Italian zone | Max Capacity (MW) | Fuel type |
|---|---|---|---|
| Assemini | Sardegna | 150 | Gas |
| Montemartini | Lazio | 80 | Gas |
| Porcari | Toscana | 102 | Gas |
| Porto Empedocle 1 | Sicilia | 64 | Gas |
| Porto Empedocle 3 | Sicilia | 76 | Gas |
| Rosen Rosignano | Toscana | 180 | Gas |
| Brindisi Sud | Puglia | 2420 | Coal |
| Fiumesanto | Sardegna | 534 | Coal |
| Sulcis 2 | Sardegna | 250 | Coal |
| Sulcis 3 | Sardegna | 182 | Coal |
| Ottana | Sardegna | 80 | Oil |
| San Filippo del Mela 1 | Sicilia | 145 | Oil |
| San Filippo del Mela 2 | Sicilia | 145 | Oil |
| San Filippo del Mela 5 | Sicilia | 288 | Oil |
| San Filippo del Mela 6 | Sicilia | 288 | Oil |

*Terna elenco impianti essenziali per la sicurezza del sistema elettrico https://download.terna.it/terna/Allegato_A27%20-%20anno%202021_8d88f9569156833.pdf

5.2

# Modelling Year 2021 @Oct 2021 – Results summary

| Yearly data @Oct2021 | GME/Terna | No reserves PC | Reserves PC | No reserves Bertrand | Reserves Bertrand |
|---|---|---|---|---|---|
| Price (€/MWh) | 99,27 | 94,28 | 96,59 | 94,72 | 98,72 |
| Quantity (GWh) | 229.319,00 | 227.429,45 | 226.977,62 | 227.362,72 | 226.852,14 |
| Emissions (tonnes) | 62.777.340,94 | 65.361.673,35 | 65.355.427,68 | 64.176.519,63 | 64.182.954,41 |

| Delta vs GME/Terna | No reserves PC | Reserves PC | No reserves Bertrand | Reserves Bertrand |
|---|---|---|---|---|
| Price | -5,0% | -2,7% | -4,6% | -0,5% |
| Quantity | -0,8% | -1,0% | -0,9% | -1,1% |
| Emissions | 4,1% | 4,1% | 2,2% | 2,2% |

- NO reserve PC: Plexos default model (no modelling of ancillary services, NO manual mark-up; Perfect Competition);
- NO reserve BT: Plexos default model (no modelling of ancillary services, NO manual mark-up; Bertrand Competition);
- Reserves BT: Plexos default model + ancillary services modelling + NO manual mark-up + Bertrand Competition + essential power plants.
- Reserves PC: Plexos default model + ancillary services modelling + NO manual mark-up + Perfect Competition + essential power plants.

*source: Terna https://www.terna.it/it/sistema-elettrico/pubblicazioni/rapporto-mesile

5.3

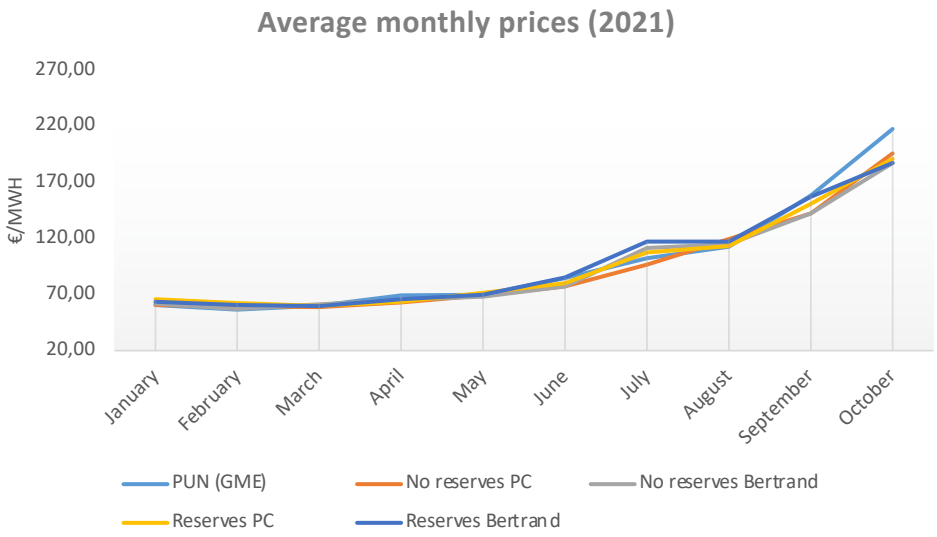
# Modelling Year 2021 @Oct 2021 – Prices

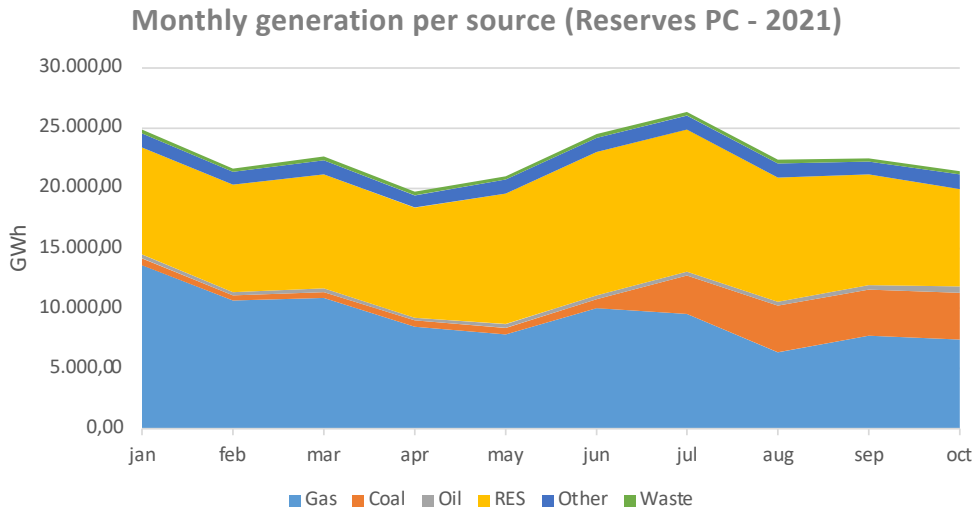
| Correlation Index GME and Plexos (daily prices) | | | |
|---|---|---|---|
| No reserves PC | No reserves Bertrand | Reserves PC | Reserves Bertrand |
| 0,95 | 0,92 | 0,94 | 0,93 |

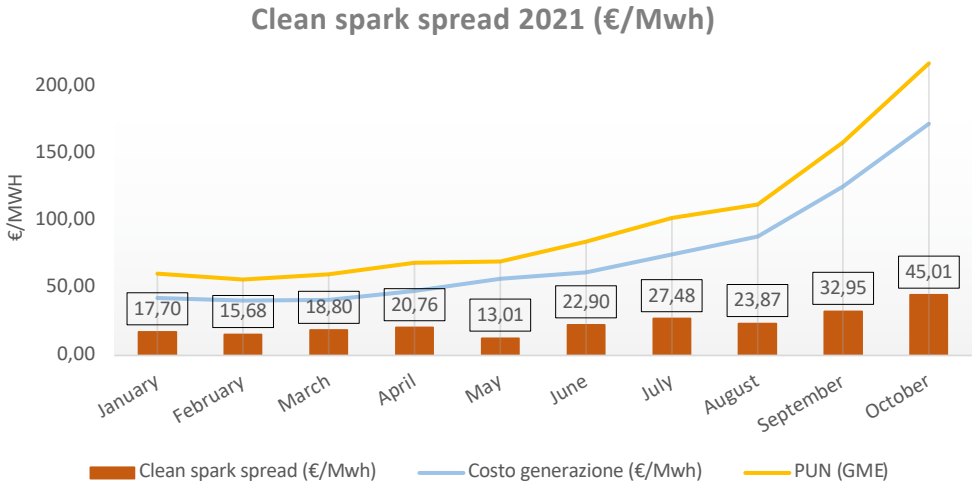
| Delta in % vs PUN | No reserves PC | No reserves Bertrand | Reserves PC | Reserves Bertrand |
|---|---|---|---|---|
| < 1% | 6,3% | 4,3% | 4,6% | 5,6% |
| < 5% | 23,7% | 22,0% | 19,1% | 24,0% |
| < 10% | 41,4% | 42,4% | 40,8% | 44,4% |
| < 15% | 60,9% | 61,2% | 56,9% | 61,5% |
| < 20% | 77,3% | 76,3% | 73,7% | 74,0% |
| < 30% | 92,4% | 92,8% | 91,4% | 88,2% |

- All models are quite close to PUN.

# 5.4 Modelling Year 2021 @Oct 2021 – Prices, generation, Spark spread




- All models are close to PUN;
- Increasing trend in prices in year 2021 in line with gas price increase.

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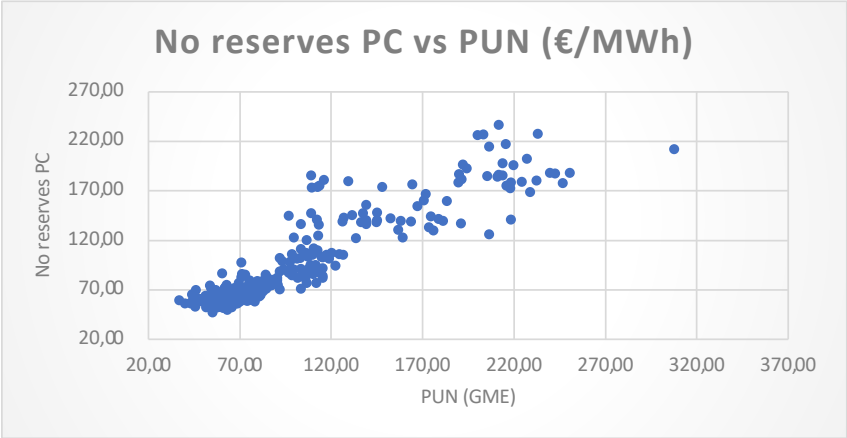
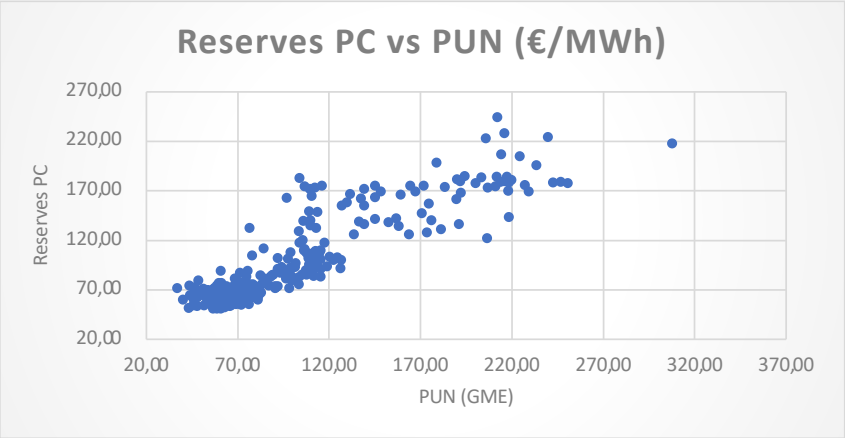
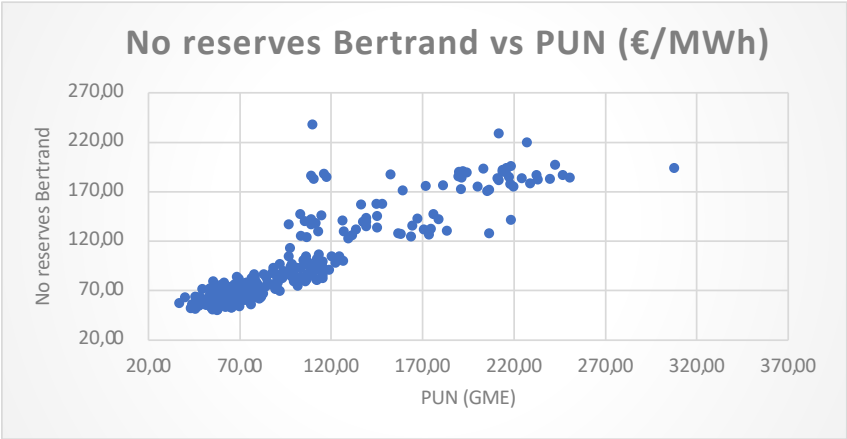
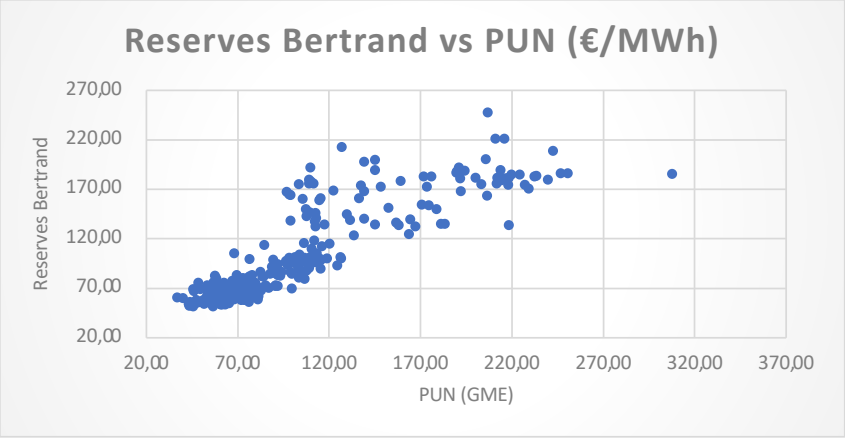
5.5

# Modelling Year 2021 @Oct 2021 – Daily prices



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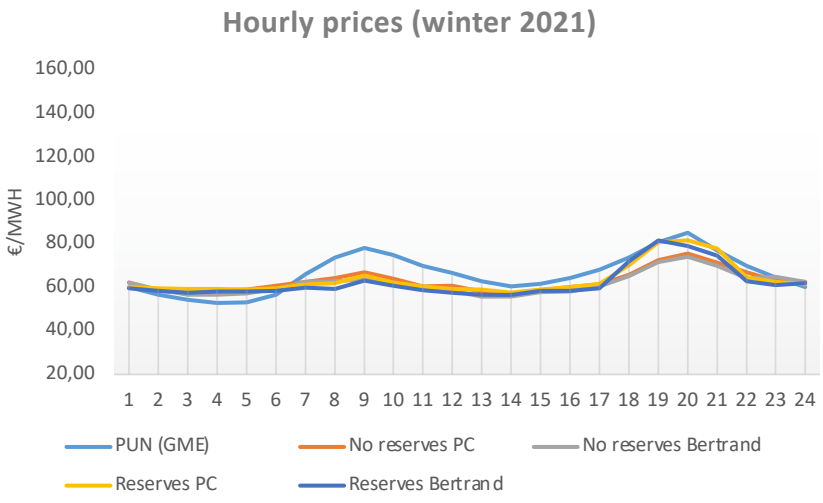
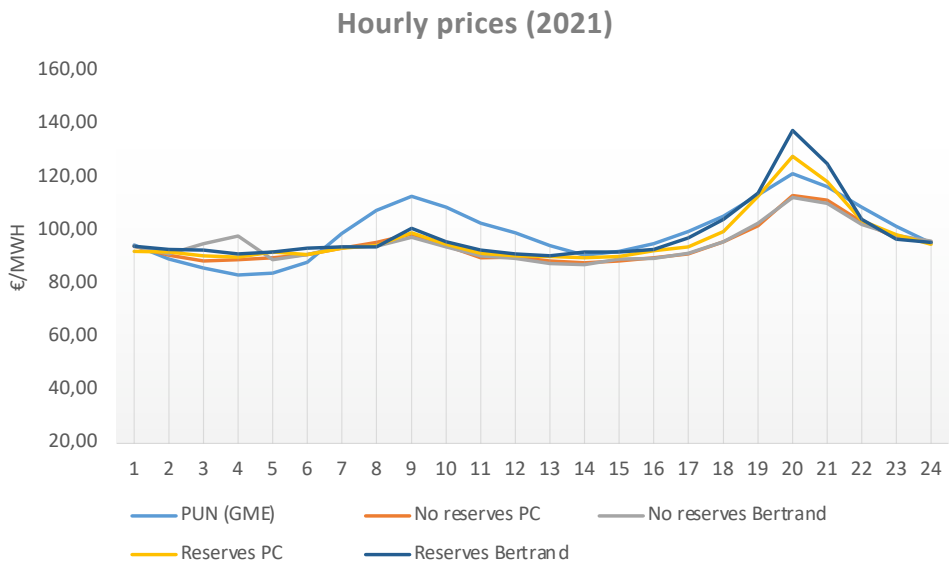
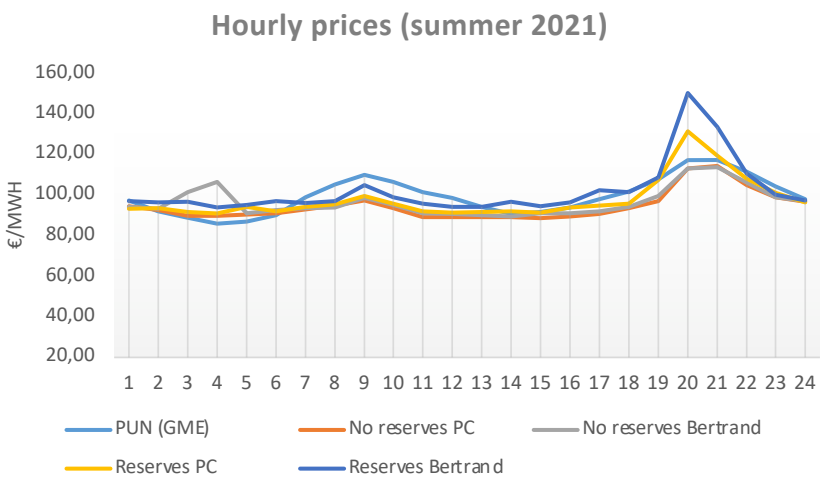
5.6

# Modelling Year 2021 @Oct 2021 – Hourly prices




- Calculations of hourly prices are close to PUN.

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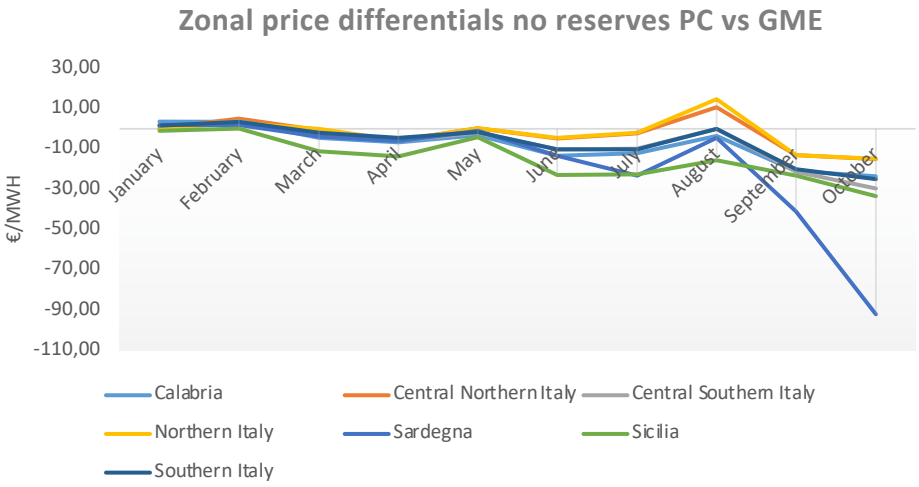
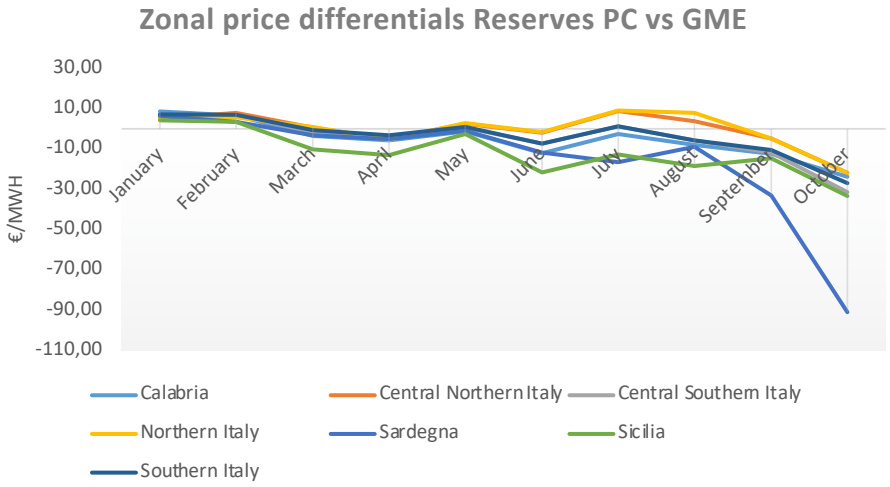
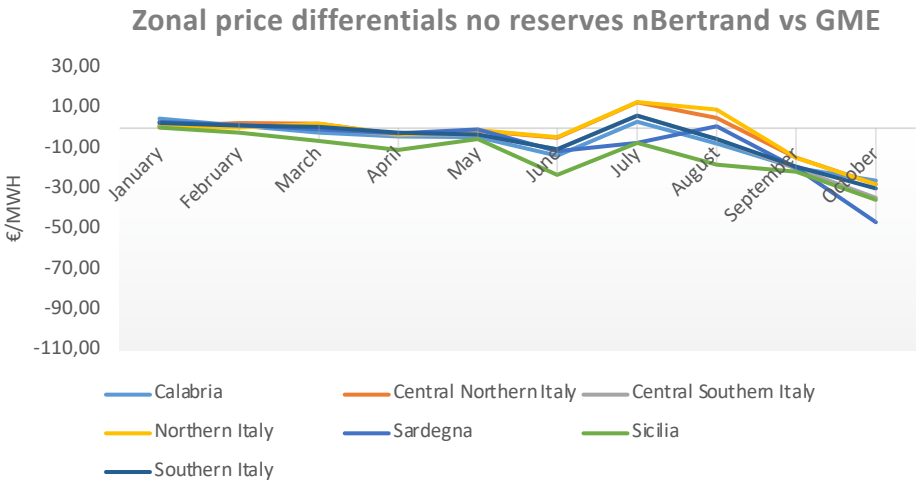
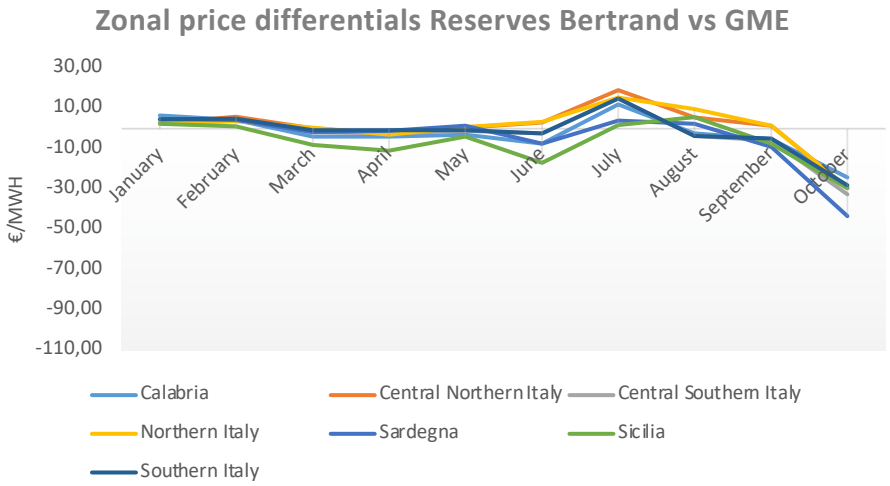
5.7

# Modelling Year 2021 @Oct 2021 - Zonal Prices



5.8

# Modelling Year 2021 @Oct 2021 - Emissions

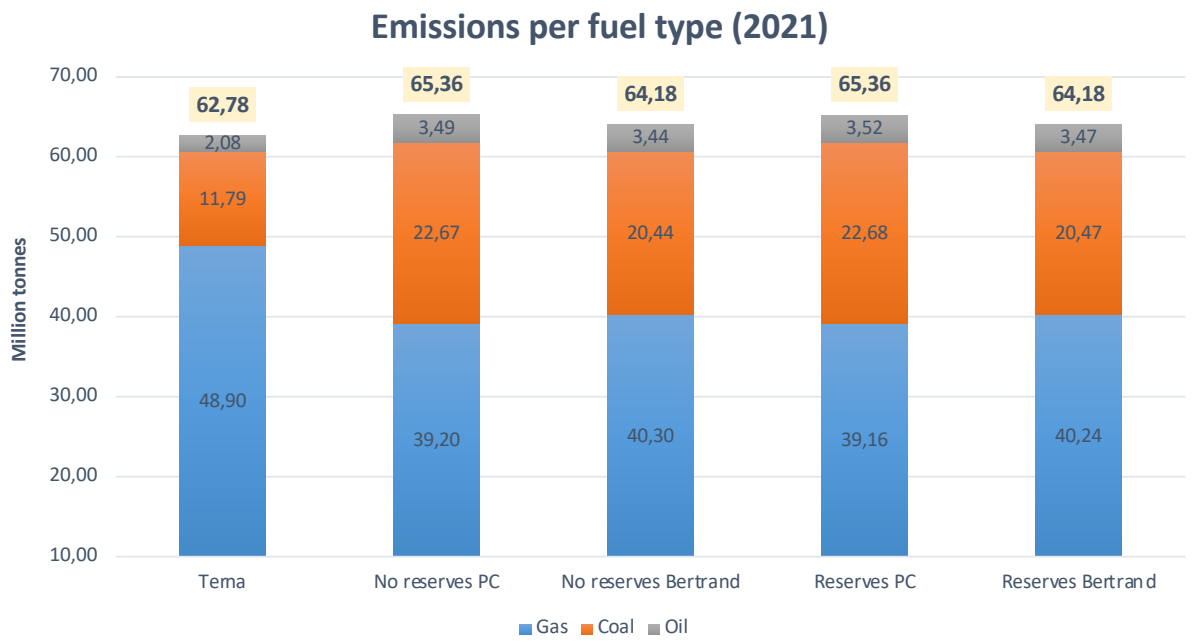
| Yearly emissions (tonnes) | Terna | Plexos | Delta (plexos - Terna) | % delta vs Terna |
|---|---|---|---|---|
| No reserves PC | 62.777.341 | 65.361.673,35 | 2.584.332,41 | 4,12% |
| Reserves PC | 62.777.341 | 65.355.427,68 | 2.578.086,74 | 4,11% |
| No reserves Bertrand | 62.777.341 | 64.176.519,63 | 1.399.178,69 | 2,23% |
| Reserves Bertrand | 62.777.341 | 64.182.954,41 | 1.405.613,47 | 2,24% |

- In general, greater emission level in Plexos compared to Terna data.

→ Need to model emissions per generator instead of only emissions per fuel type

5.9

# Modelling Year 2021 @Oct 2021 – Emissions per fuel type




- Perfect competition has the highest level of emissions and coal and oil use.



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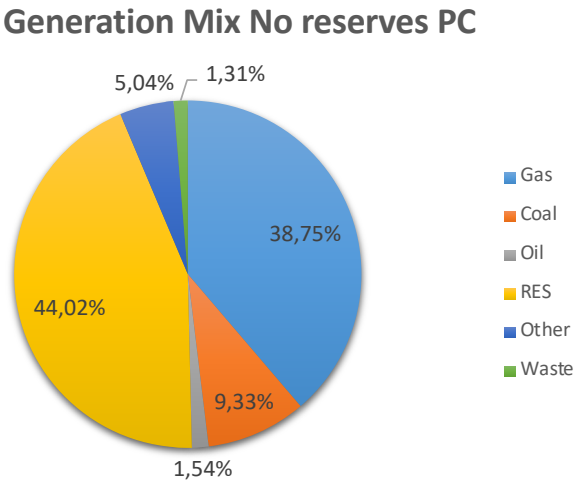
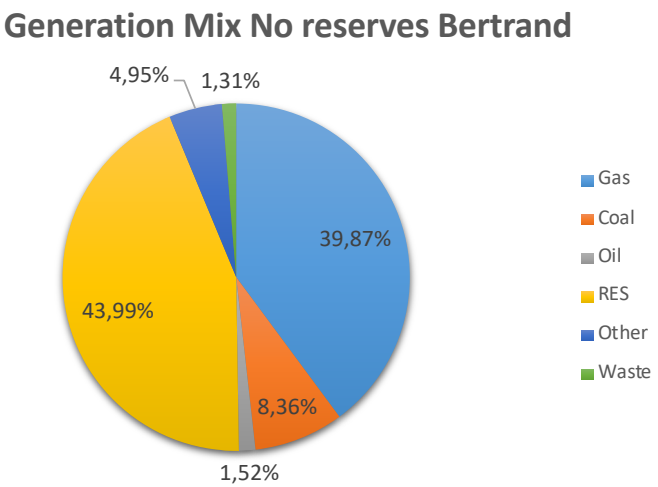
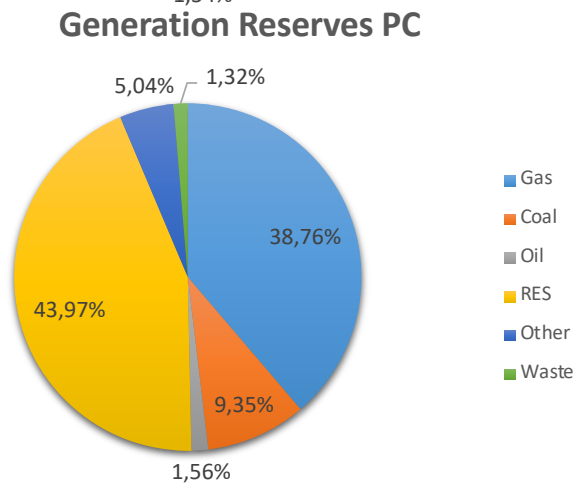
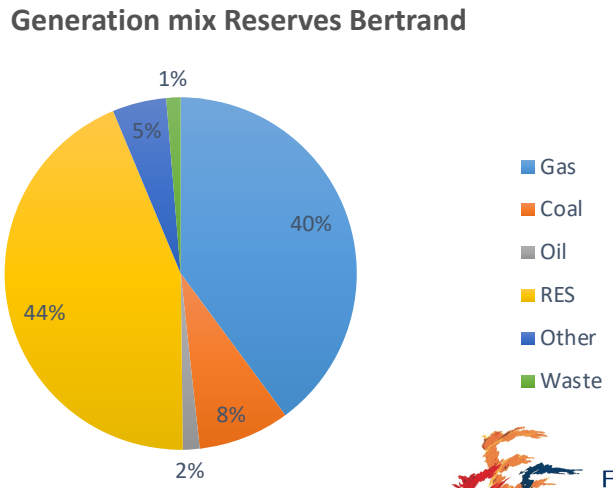
5.10

# Modelling Year 2021 @Oct 2021 - Generation mix




*2021 Terna data are only published for RES and Thermal as a total
https://www.terna.it/it/sistema-elettrico/transparency-report/actual-generation



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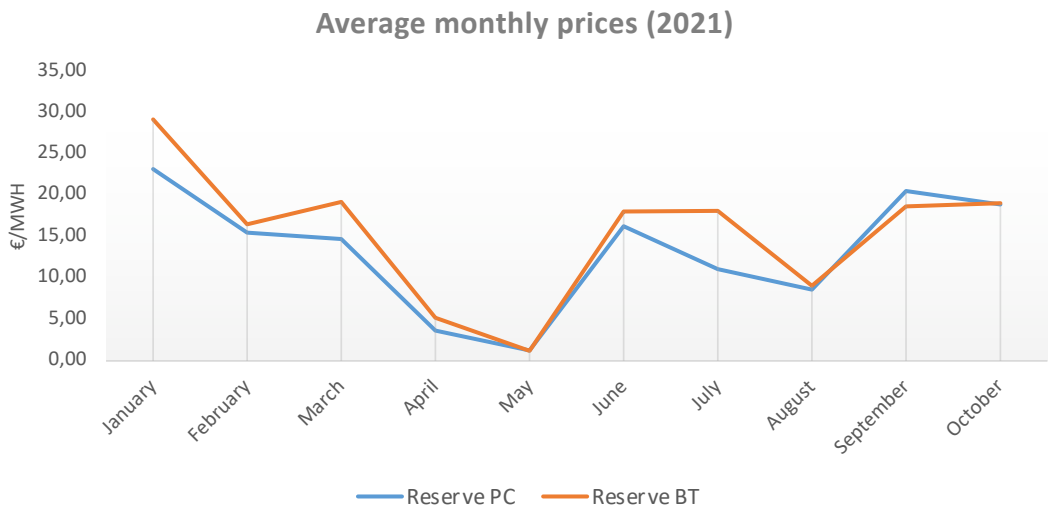
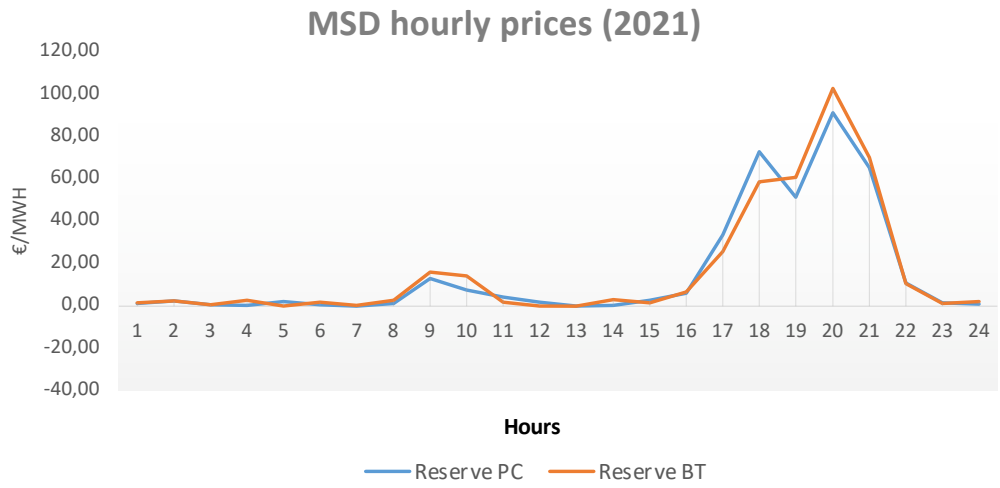
5.11

# Modelling Year 2021 @Oct 2021 – MSD Prices



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# 6.1 ETS, Gas and Coal prices: can market dynamics only phase-out coal?

| Coal | ETS | Gas 20 | 40 | 60 | 80 | 100 |
|---|---|---|---|---|---|---|
| 50 | 40 | 0,44 | - 35,93 | - 72,29 | - 108,65 | - 145,02 |
| | 60 | 10,54 | - 25,83 | - 62,19 | - 98,55 | - 134,92 |
| | 80 | 20,64 | - 15,73 | - 52,09 | - 88,45 | - 124,82 |
| | 100 | 30,74 | - 5,63 | - 41,99 | - 78,35 | - 114,72 |
| 100 | 40 | 17,04 | - 19,32 | - 55,69 | - 92,05 | - 128,42 |
| | 60 | 27,14 | - 9,22 | - 45,59 | - 81,95 | - 118,32 |
| | 80 | 37,24 | 0,88 | - 35,49 | - 71,85 | - 108,22 |
| | 100 | 47,34 | 10,98 | - 25,39 | - 61,75 | - 98,12 |
| 150 | 40 | 33,64 | - 2,72 | - 39,09 | - 75,45 | - 111,81 |
| | 60 | 43,74 | 7,38 | - 28,99 | - 65,35 | - 101,71 |
| | 80 | 53,84 | 17,48 | - 18,89 | - 55,25 | - 91,61 |
| | 100 | 63,94 | 27,58 | - 8,79 | - 45,15 | - 81,51 |
| 200 | 40 | 50,24 | 13,88 | - 22,49 | - 58,85 | - 95,21 |
| | 60 | 60,34 | 23,98 | - 12,39 | - 48,75 | - 85,11 |
| | 80 | 70,44 | 34,08 | - 2,29 | - 38,65 | - 75,01 |
| | 100 | 80,54 | 44,18 | 7,81 | - 28,55 | - 64,91 |
| 250 | 40 | 66,84 | 30,48 | - 5,88 | - 42,25 | - 78,61 |
| | 60 | 76,94 | 40,58 | 4,22 | - 32,15 | - 68,51 |
| | 80 | 87,04 | 50,68 | 14,32 | - 22,05 | - 58,41 |
| | 100 | 97,14 | 60,78 | 24,42 | - 11,95 | - 48,31 |

- Efficiency gas 55%
- Efficiency coal 37%
- Emission gas 0.36 ton/MWh
- Emission coal 0.87 ton/MWh

- ETS prices in €/ton
- Coal prices in €/ton
- Gas prices in €/MWh
- Spread = Coal price – Gas price
- **If >0 then gas is cheaper**

- Gas prices consistently above 40 €/MWh make the phasing out of coal more expensive in terms of opportunity costs
- Conversely, the elasticity of the Spread vs ETS prices is lower

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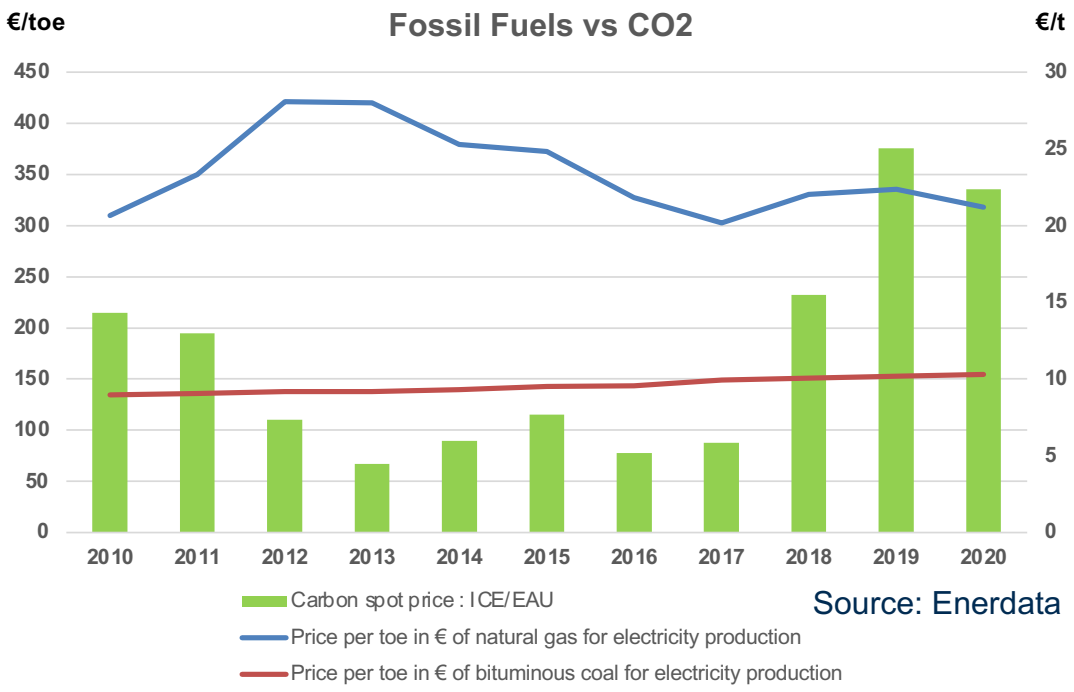
# 6.2 ETS, Gas and Coal Prices: can market dynamics only phase-out coal?




Source: Enerdata

- Gas and ETS prices present a higher degree of volatility
- Coal prices are linked to regional markets (e.g. Europe, China, Australia) and less volatile
- There is no apparent correlation between the price of fuel commodities and the ETS price
- The impact of ETS and fuel commodity price fluctuations are reverted on energy prices via the Spark and Dark Spreads (marginal costs to generation)

7.1

# Modelling Year 2025 – Assumptions

- Electricity demand: 298,6 TWh (+14% vs 2019);
- Phase out of coal power plants in 2025 (Sardinia in 2028);

**Scenario ETNT**

- ETS price: 56 €/ton
- Entso-E gas price*: 23,5 €/MWh
- Coal price: 13,64 €/MWh

**Scenario Bloomberg**

- ETS price: 56 €/ton
- Bloomberg gas price**: 35 €/MWh
- Coal price: 13,64 €/MWh

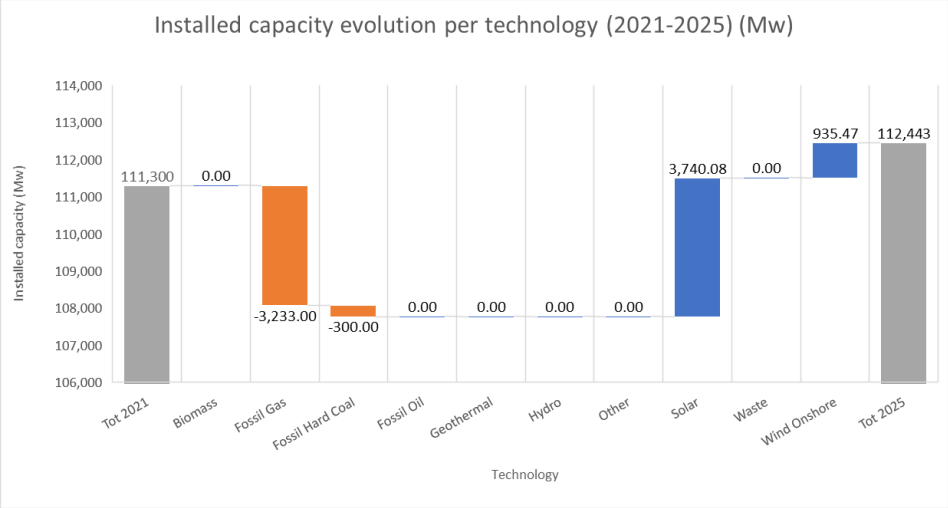
Essential Power plants only for Sicily

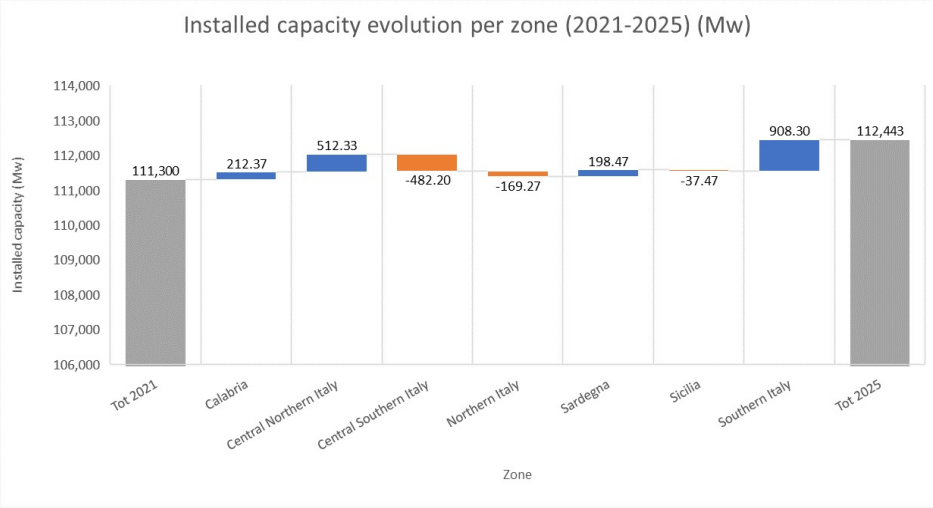
| Generators | Italian zone | Max Capacity (MW) | Fuel type |
|---|---|---|---|
| Porto Empedocle 1 | Sicilia | 64 | Gas |
| Porto Empedocle 3 | Sicilia | 76 | Gas |
| San Filippo del Mela 1 | Sicilia | 145 | Oil |
| San Filippo del Mela 2 | Sicilia | 145 | Oil |
| San Filippo del Mela 5 | Sicilia | 288 | Oil |
| San Filippo del Mela 6 | Sicilia | 288 | Oil |

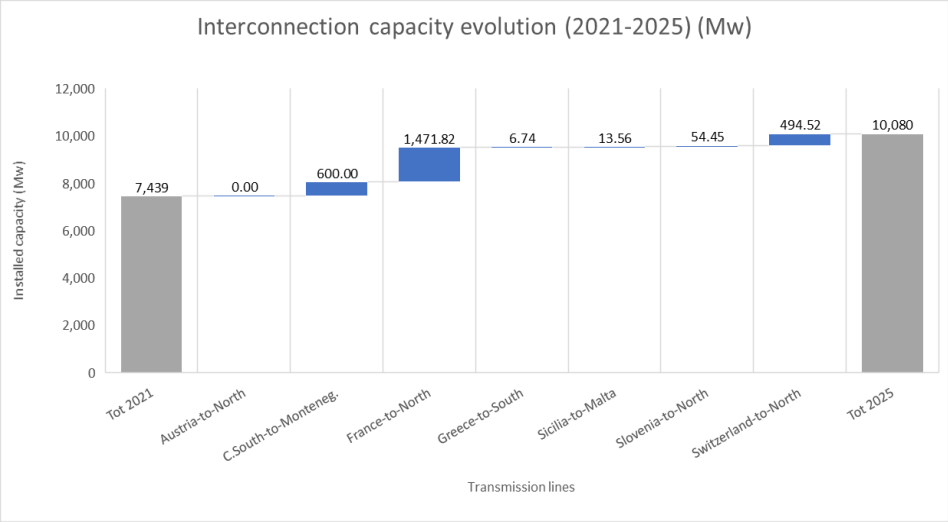
*Entso-E TYDP 2020 Scenario Report; Page 48; TYNDP 2020 Scenario Report – Final Report, June 2020 (azureedge.net)

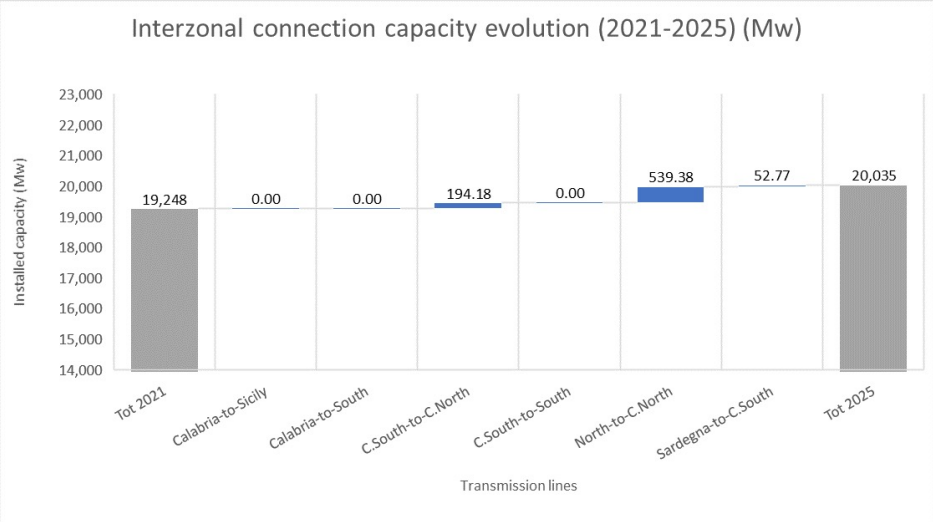
**Bloomberg; 2021 Bloomberg Finance L.P.

# 7.2 Modelling Year 2025 – Assumptions



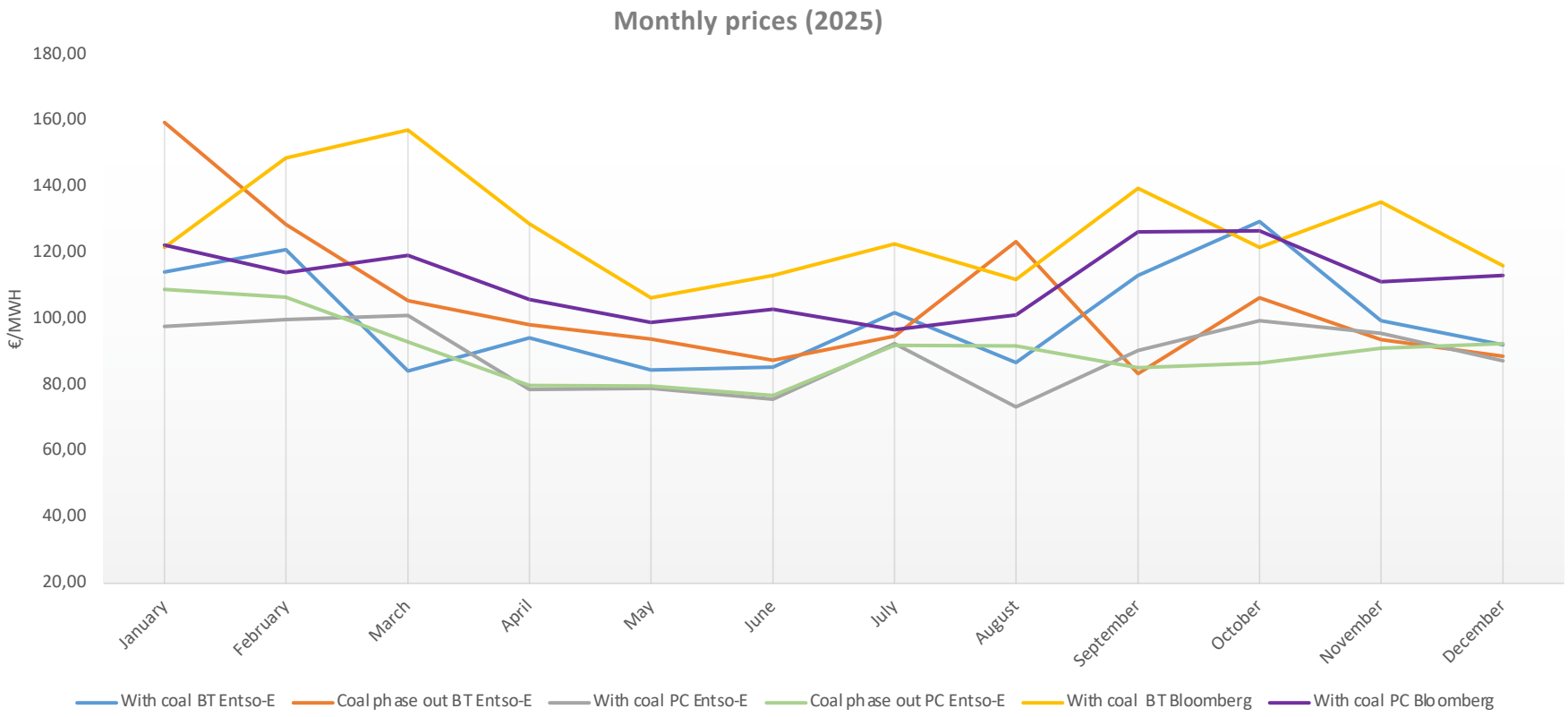
# 7.3 Modelling Year 2025 – Results summary

| | 2025 with coal | | | | 2025 coal phase-out | |
|---|---|---|---|---|---|---|
| **Yearly data 2025** | **With coal BT Entso-E** | **With coal PC Entso-E** | **With coal BT Bloomberg** | **With coal PC Bloomberg** | **Coal phase out BT Entso-E** | **Coal phase out PC Entso-E** |
| **Price (€/MWh)** | 100,47 | 89,24 | 126,81 | 111,61 | 105,34 | 90,38 |
| **Quantity (GWh)** | 289.139,79 | 289.148,81 | 288796,47 | 288841,49 | 289.134,69 | 289.143,32 |
| **Emissions (tonnes)** | 52.204.325,60 | 52.222.918,05 | 52.154.628,69 | 52.129.846,37 | 52.224.868,59 | 52.237.719,44 |

- The coal phase-out induces higher electricity prices (+5% vs coal scenario)

- With coal PC Entso-E: Plexos default model + ancillary services modelling + NO manual mark-up + Sicily essencial power plants; Entso-E prices; Perfect competition
- With/without coal BT Entso-E: Plexos default model + ancillary services modelling + NO manual mark-up + Sicily essencial power plants; Entso-E prices; Bertrand competition
- With coal PC Bloomberg: Plexos default model + ancillary services modelling + NO manual mark-up + Sicily essencial power plants; Bloomberg prices; Perfect competition
- With/without coal BT Bloomberg: Plexos default model + ancillary services modelling + NO manual mark-up + Sicily essencial power plants; Bloomberg prices; Bertrand competition

# 7.4 Modelling Year 2025 – Monthly Prices



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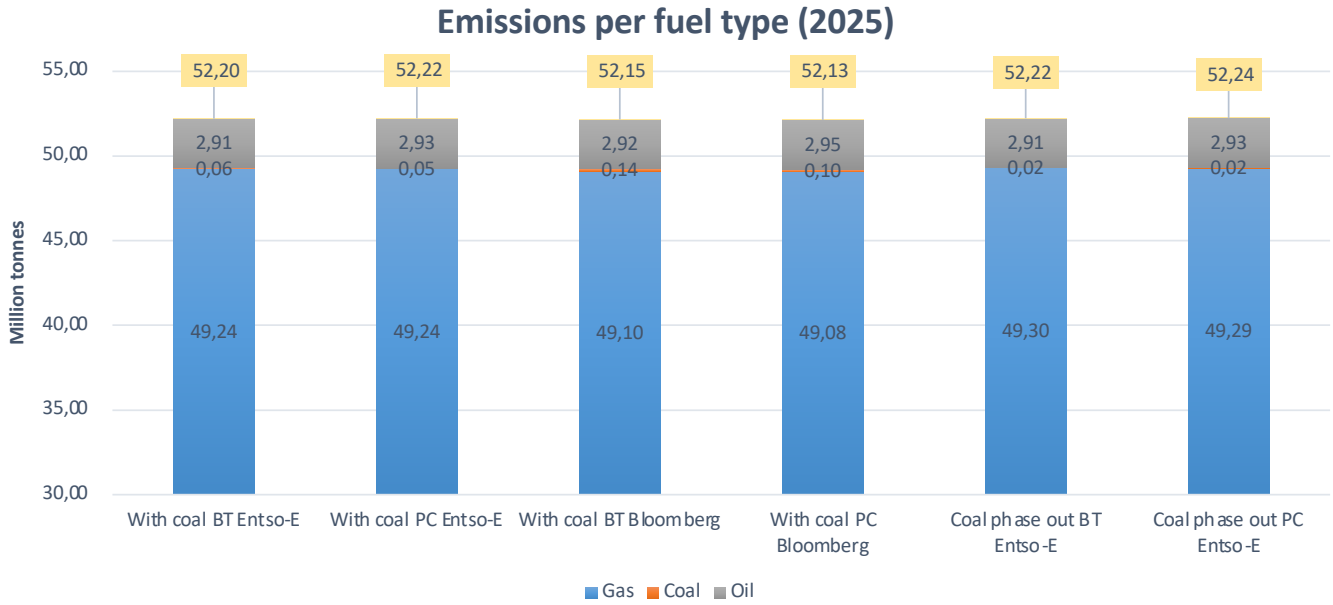
# 7.5 Modelling Year 2025 - Emissions




- Gas plants are replacing the coal generation ones.



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7.6

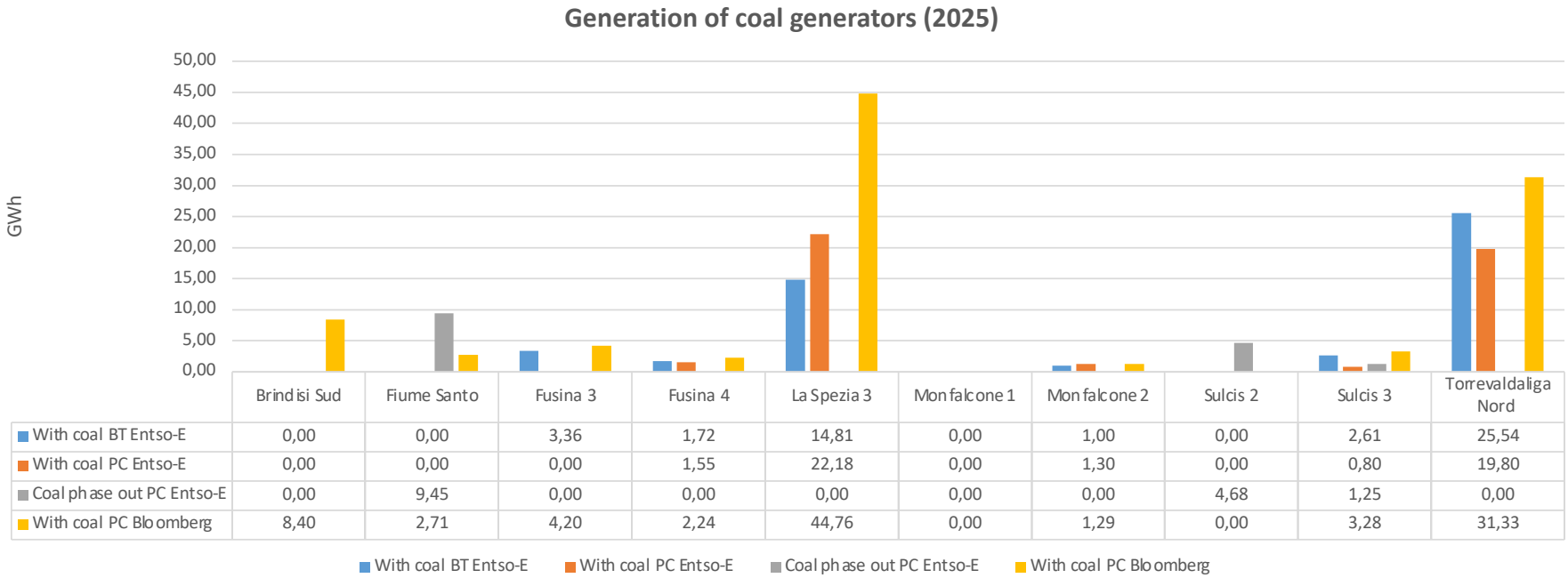
# Modelling Year 2025 - Coal power plants' detail

| Generators | Italian zone | Date from | Max Capacity (MW) | Date to (phase-out) |
|---|---|---|---|---|
| Monfalcone 1 | Northern Italy | 2008 | 153 | 31/12/2024 |
| Monfalcone 2 | Northern Italy | 2008 | 162 | 31/12/2024 |
| Brindisi Sud | Southern Italy | 1991 | 2,420 | 1 unit 31/01/2021 |
| Fusina 1 | Northern Italy | 1970 | 145 | 17/08/2021 |
| Fusina 2 | Northern Italy | 1970 | 155 | 17/08/2021 |
| Fusina 3 | Northern Italy | 1972 | 280 | 31/12/2024 |
| Fusina 4 | Northern Italy | 1972 | 280 | 31/12/2024 |
| La Spezia 3 | Northern Italy | 1991 | 520 | 31/12/2024 |
| Sulcis 2 | Sardegna | 2005 | 250 | 31/12/2027 |
| Sulcis 3 | Sardegna | 1986 | 182 | 31/12/2027 |
| Torrevaldaliga Nord | Central Southern Italy | 2009 | 1,845 | 31/12/2024 |
| Fiume Santo | Sardegna | 1993 | 534 | 31/12/2027 |

Sardinia is the last Italian region to relinquish the coal power plants

7.7

# Modelling Year 2025 - Coal power plants' detail (Generation)




| | Brindisi Sud | Fiume Santo | Fusina 3 | Fusina 4 | La Spezia 3 | Monfalcone 1 | Monfalcone 2 | Sulcis 2 | Sulcis 3 | Torrevaldaliga Nord |
|---|---|---|---|---|---|---|---|---|---|---|
| With coal BT Entso-E | 0,00 | 0,00 | 3,36 | 1,72 | 14,81 | 0,00 | 1,00 | 0,00 | 2,61 | 25,54 |
| With coal PC Entso-E | 0,00 | 0,00 | 0,00 | 1,55 | 22,18 | 0,00 | 1,30 | 0,00 | 0,80 | 19,80 |
| Coal phase out PC Entso-E | 0,00 | 9,45 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 4,68 | 1,25 | 0,00 |
| With coal PC Bloomberg | 8,40 | 2,71 | 4,20 | 2,24 | 44,76 | 0,00 | 1,29 | 0,00 | 3,28 | 31,33 |

- Coal generators in Sardinia stop producing in 2028 in phase-out scenario;
- Fiumesanto and Sulcis 2 generators increase their generation in the coal phase-out scenario compared to with coal scenario.



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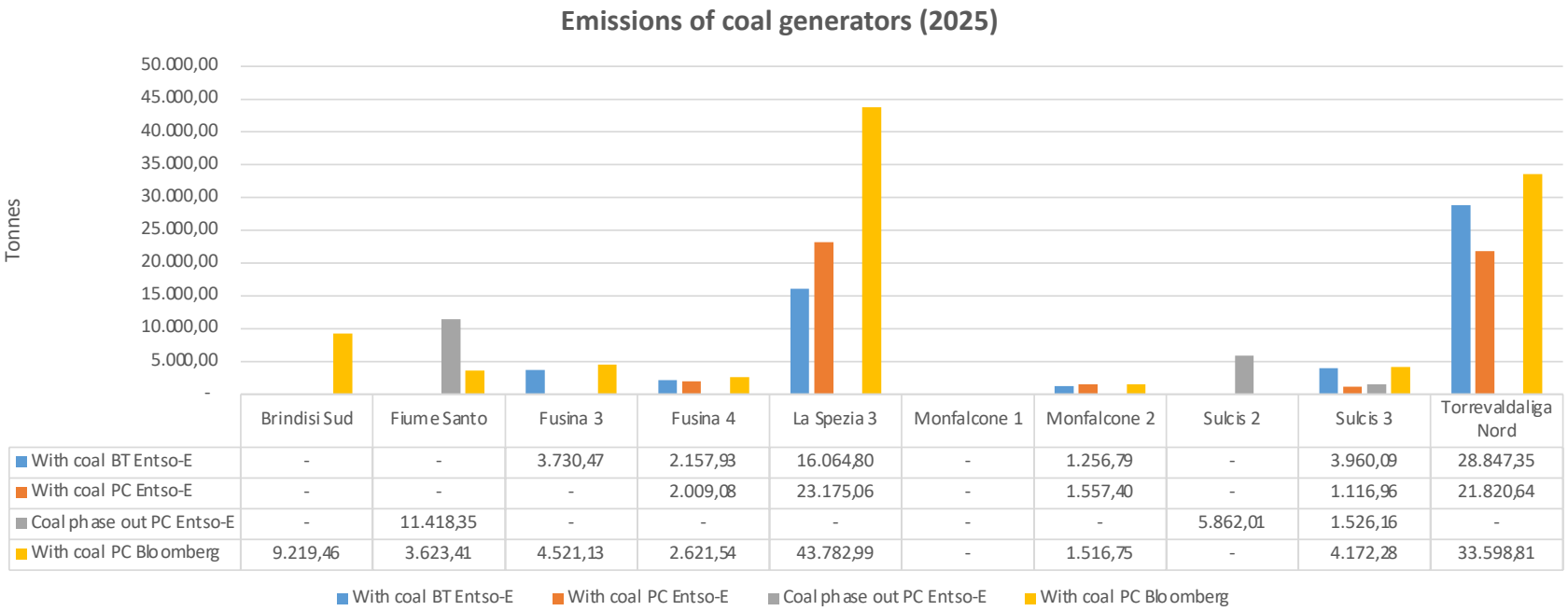
# 7.8 Modelling Year 2025 - Coal power plants' detail (Emissions)




| | Brindisi Sud | Fiume Santo | Fusina 3 | Fusina 4 | La Spezia 3 | Monfalcone 1 | Monfalcone 2 | Sulcis 2 | Sulcis 3 | Torrevaldaliga Nord |
|---|---|---|---|---|---|---|---|---|---|---|
| With coal BT Entso-E | - | - | 3.730,47 | 2.157,93 | 16.064,80 | - | 1.256,79 | - | 3.960,09 | 28.847,35 |
| With coal PC Entso-E | - | - | - | 2.009,08 | 23.175,06 | - | 1.557,40 | - | 1.116,96 | 21.820,64 |
| Coal phase out PC Entso-E | - | 11.418,35 | - | - | - | - | - | 5.862,01 | 1.526,16 | - |
| With coal PC Bloomberg | 9.219,46 | 3.623,41 | 4.521,13 | 2.621,54 | 43.782,99 | - | 1.516,75 | - | 4.172,28 | 33.598,81 |

- Fiumesanto and Sulcis 2 generators increase their emissions in the coal phase-out scenario compared to with coal scenario due to higher generation.



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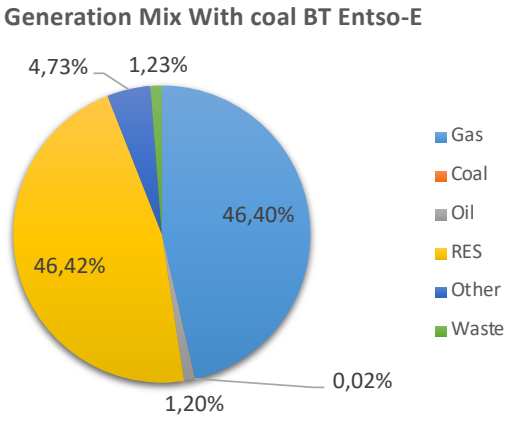
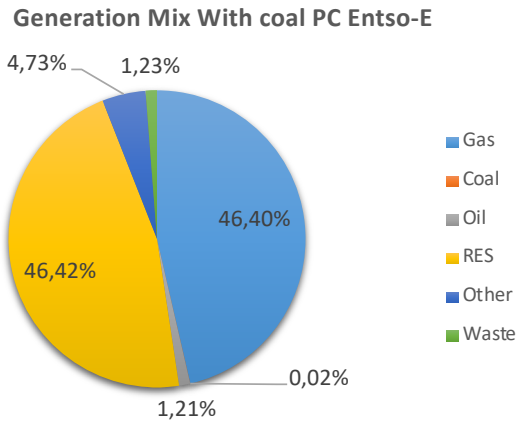
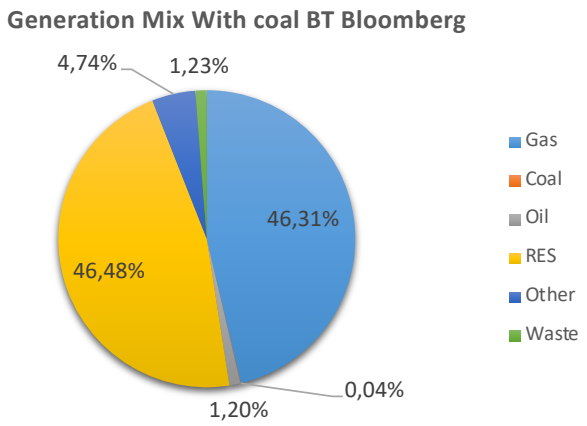
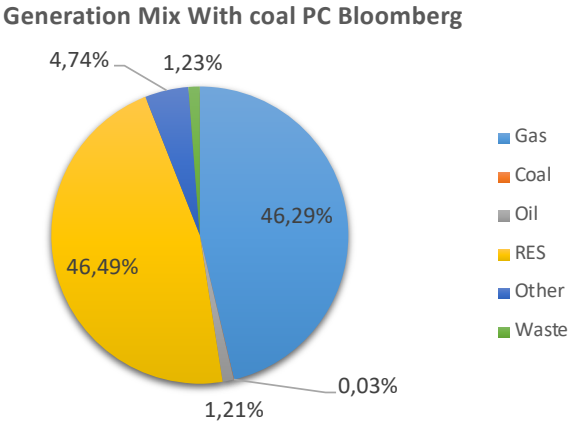
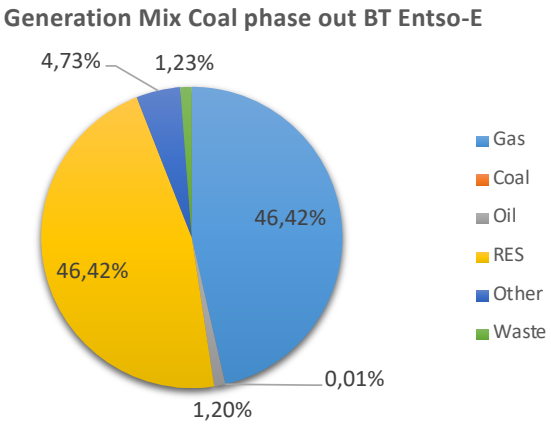
# 7.9 Generation mix comparison

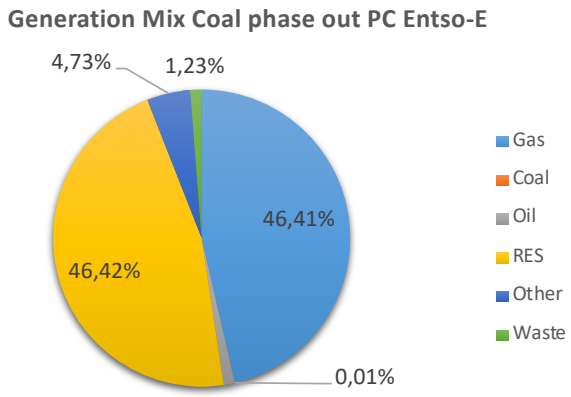


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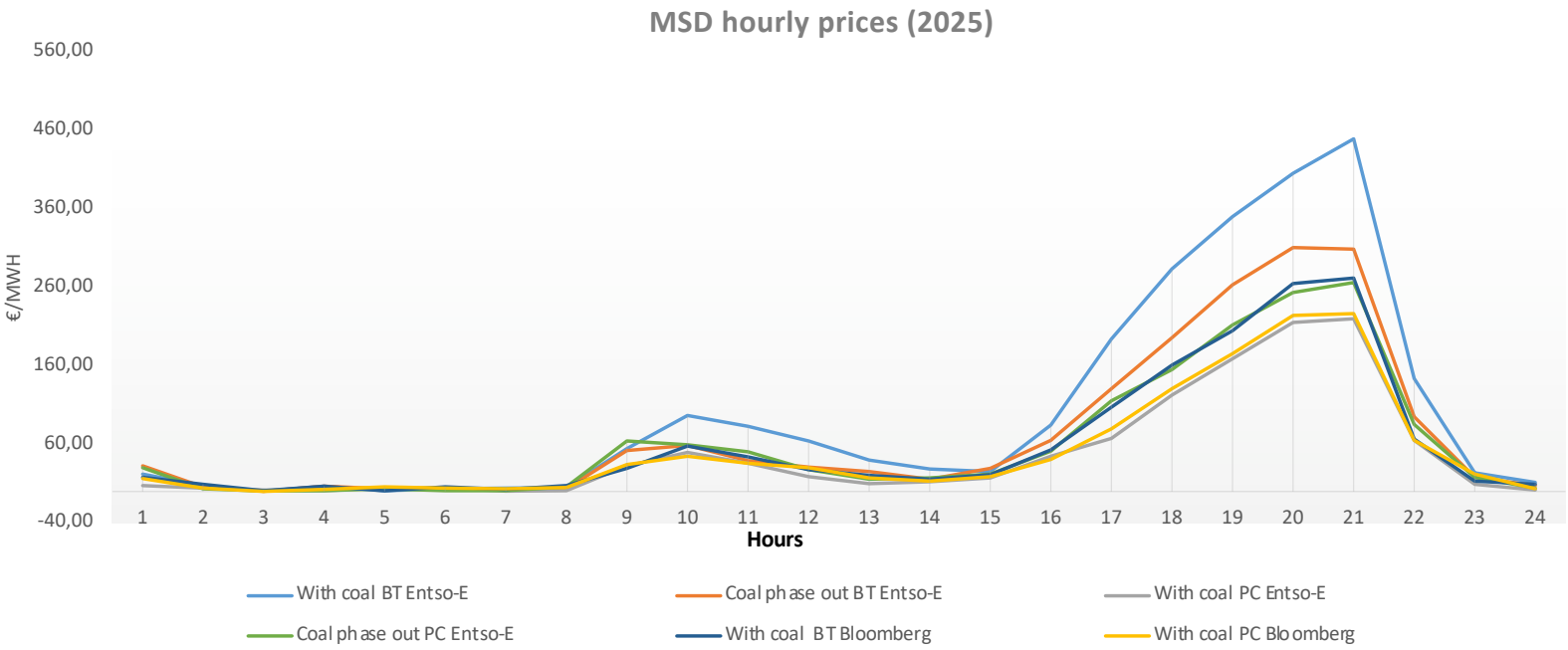
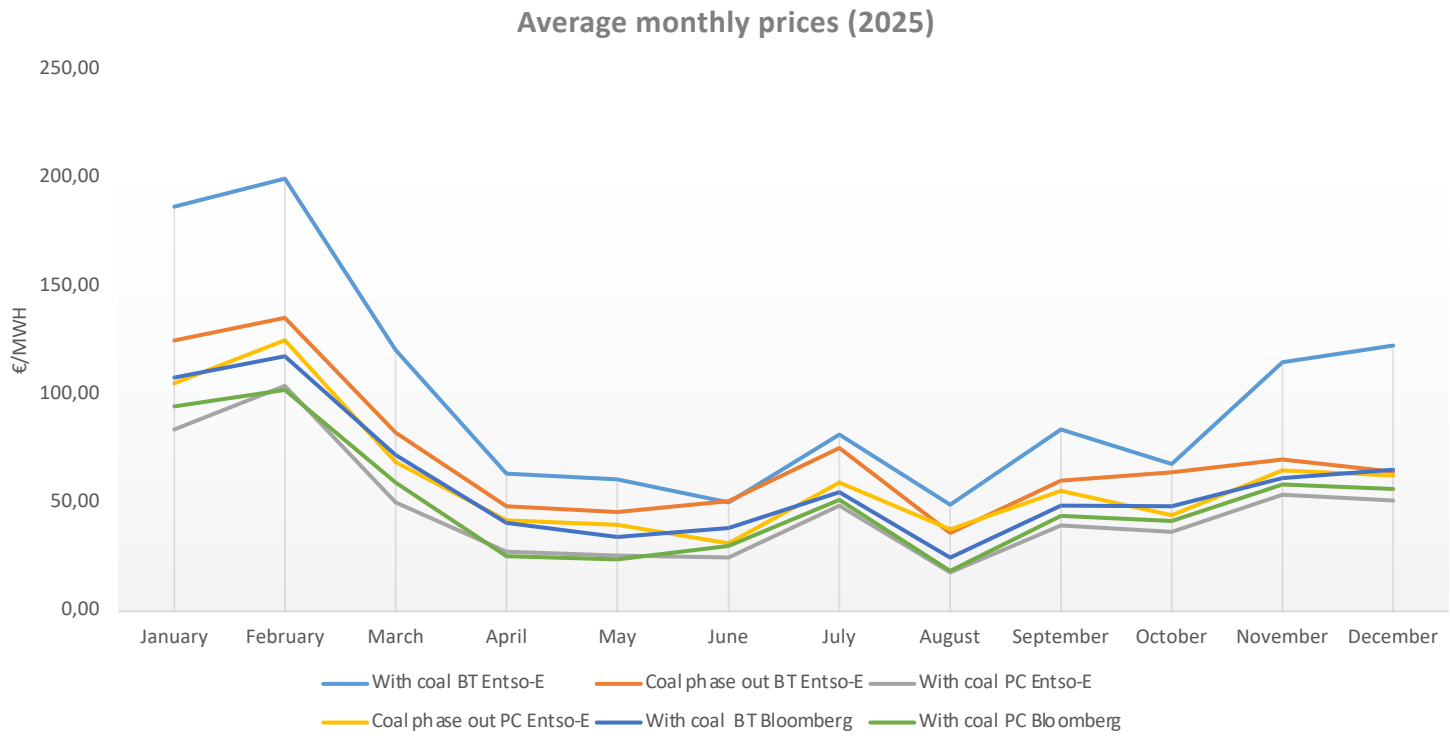
# 7.10 Modelling Year 2025 – MSD Hourly prices



7.11

# Modelling Year 2025 – MSD Monthly prices



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8.1

# Final comments

PRICES

- Co-optimization leads to better fitting of the models and it results necessary to precisely approximate PUN real results.
- On annual basis, the delta prices between Plexos and GME of Reserve Bertrand scenario are close to 1% for year 2021.
- Considering year 2025, coal phase-out leads on average to higher prices.
- Perfect competition leads on average to lower prices compared to Bertrand competition.
- MSD prices reflects the greater needs for ancillary services in 2025 due to the higher presence of RES in the generation mix
- In both 2025 scenarios (coal and coal phase-out) coal power plants remain economically disadvantageus due to sufficiently high ETS prices (both in Bloomberg and Entso-E scenarios).

EMISSIONS

- Considering year 2025, coal phase-out leads Sardinanian power plants to increse their generation.
- While PC is beneficial in terms of lower prices, market power leads to lower emission quantities (bertrand competition)

QUANTITIES

- Additional investigations on generation capacity, company ownership and portfolio's analysis will be part of the next work.
- An old and highly emitting generating park of oil power plants remains active in all the scenarios