GAT|WAT SuperP2G event

Allocation, size and operation of P2G in the future energy system

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This project has received funding in the framework of the joint programming initiative ERA-Net Smart Energy Systems' focus initiative integrated, Regional Energy Systems, with support from the European Union's Horizon 2020 research and innovation programme under grant agreement No 775970

AGENDA

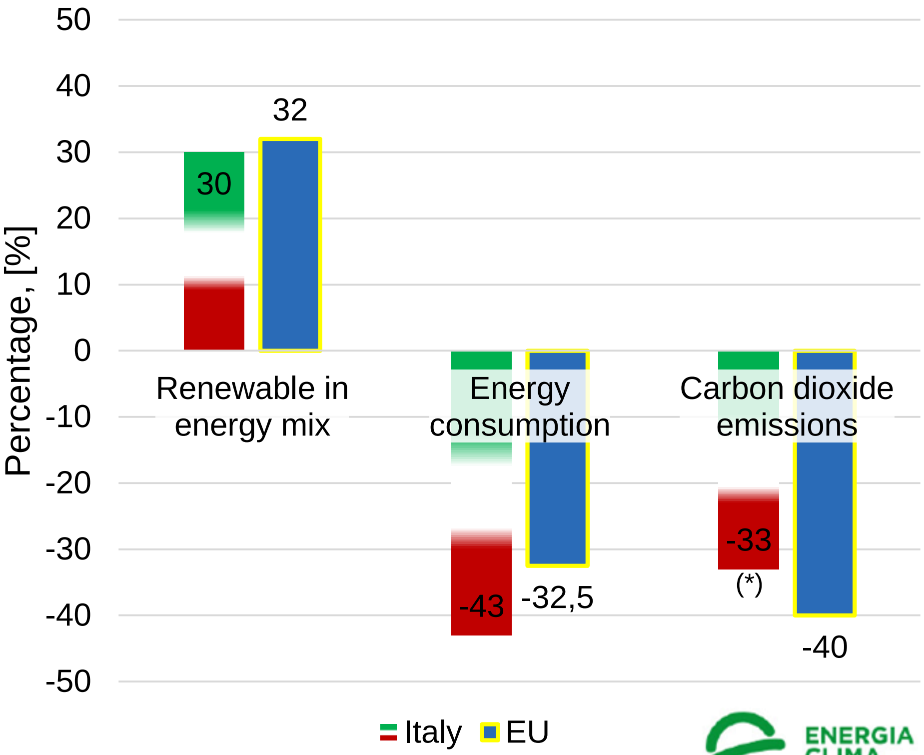
- OVERVIEW AND GENERAL CONTEXT
- THE SUPERP2G – ITALY PROJECT
- THE SUPERP2G – ITALY PROJECT: FIRST RESULTS
- CONCLUSIONS AND FUTURE DEVELOPMENTS

OVERVIEW AND GENERAL CONTEXT

To reach EU global ambitious, **the Italian Energy and Climate plan (PNIEC)** was presented to the Commission at the end of 2019.

The plan follows three main EU targets to be reached by 2030:

1. **Increase of renewables in final energy consumption**
2. **Increase of efficiency in energy utilisation**
3. **Carbon Dioxide emissions reduction compared to 1990**



(*) PNIEC doesn't give indications about the global CO2 emission reduction respect to 1990 but identify a target for not ETS sectors (-33% compared to 2005)

OVERVIEW AND GENERAL CONTEXT

The Italian «**Hydrogen strategy**» (2020) defines 6 targets of the national green hydrogen economy at 2030

5 GW of electrolysis capacity installed

-8 Mton/year CO2eq. emissions

10 billion euros of investment

2% of the final energy consumption

GDP ↑ (27 billion €)

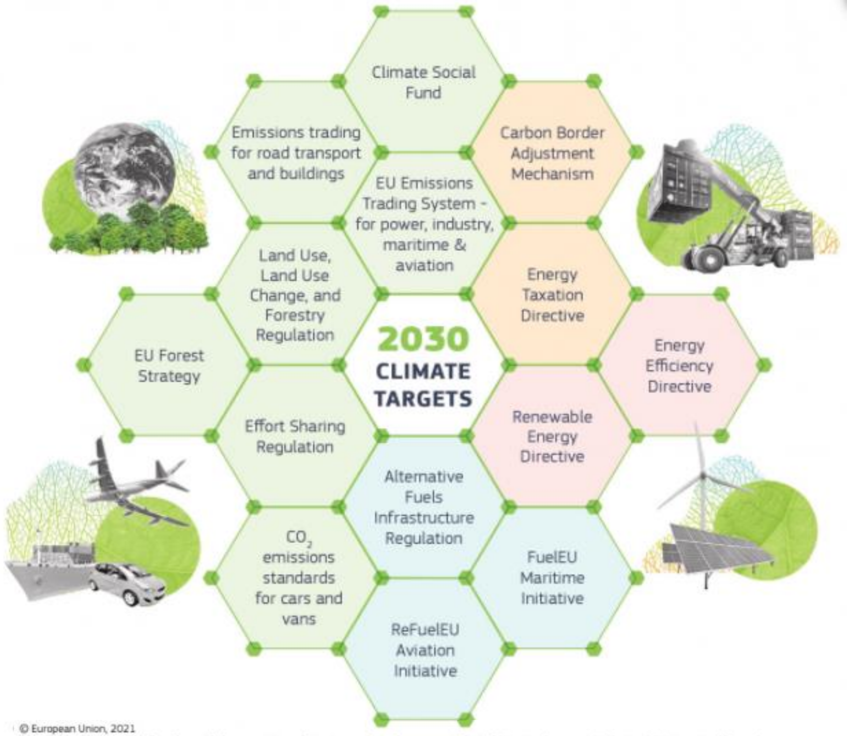
200k & 10k new temporary and fixed jobs

Source: MISE (2020)

More challenging targets by 2030 were presented by the European Commission in July 2021.

The so called «***Fit for 55***» proposals aim:

1. **To increase renewable in the EU energy mix up to 40% (vs 32%)**
2. **To reduce by 9% the EU energy consumption (compared to the baseline projections)**
3. **To reduce the EU CO2 emissions by 55% compared to 1990 (vs 40%)**



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THE SUPERP2G – ITALY PROJECT

The SuperP2G - ITALY **partners**:

The **CNR-ITAE** is the **leading partner**.
CNR-ITAE has a long experience in thermal storage, electric storage, renewable energy conversion and integration, hydrogen production and storage, biofuels and high efficiency energy buildings.

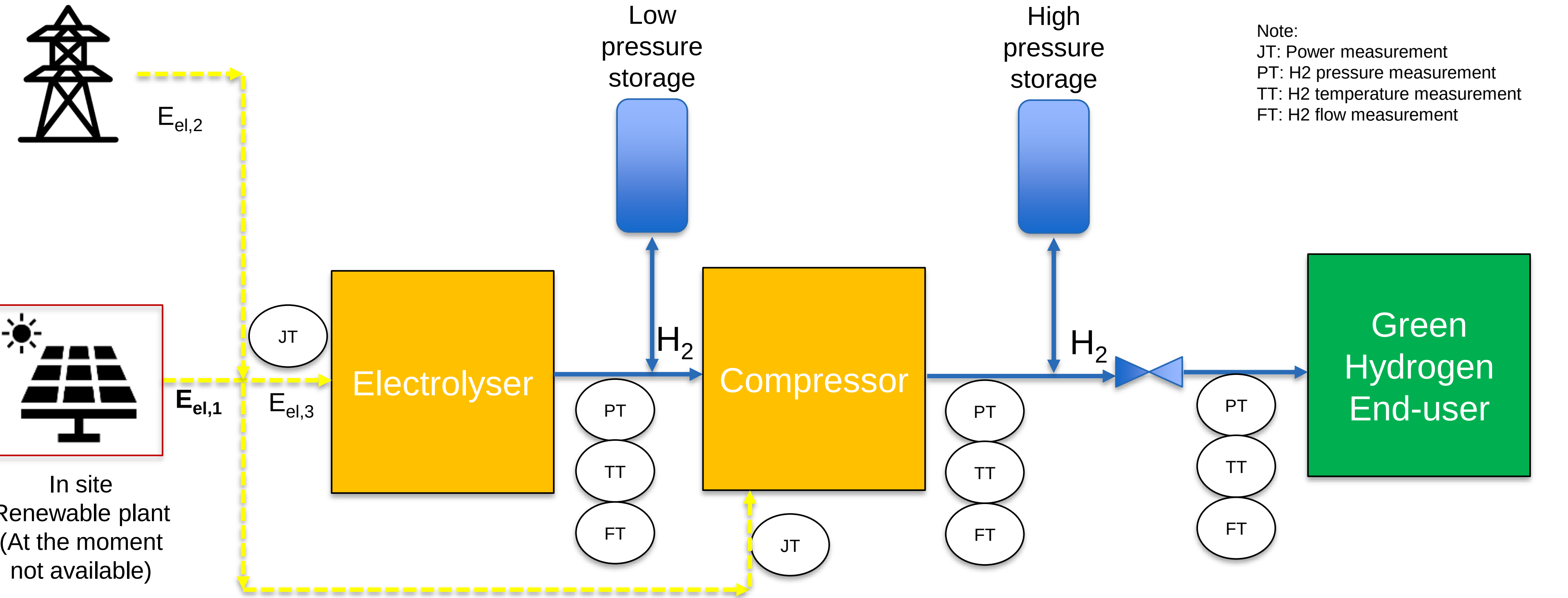
The research team of the **University of Bologna (UNIBO)** has a long experience in renewable plant engineering (design, construction and operation) and **a hydrogen experimental laboratory**.

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
DIPARTIMENTO DI INGEGNERIA INDUSTRIALE

Industrial stakeholders were also involved as interested observers of the research activities

THE SUPERP2G – ITALY PROJECT

The UNIBO hydrogen lab Process Flow Diagram (PFD):



The UNIBO hydrogen lab:

THE SUPERP2G – ITALY PROJECT

The UNIBO hydrogen lab:

The UNIBO hydrogen lab:

THE SUPERP2G – ITALY PROJECT

The SuperP2G – ITALY project **objectives**:

- To develop an **open source WEB-GIS tool for the optimization of P2G plants' size and location**
- To validate the WEB-GIS tool and Optiflow & H2Index tools in the Apulia region case study

WEB GIS TOOL DEVELOPMENT PHASES

The WEB-GIS tool is based on complex algorithms:

Cost Function

$$\underbrace{\sum_{j\in D}\sum_{i\in F} d_j c_{ij} x_{ij}}_{\text{Cost related to the demand side}} + \underbrace{\sum_{k\in R}\sum_{i\in F} o_k c'_{ik} x'_{ik}}_{\text{Cost related to the energy source side}} + \underbrace{\sum_{i\in F} f_i(s_i) y_i}_{\text{Opening cost (size dependent)}}$$

Opening cost (size dependent)

Size may be chosen among a discrete set of values

Cost related to the demand side

Cost related to the energy source side

- d_j = consumer demand ≥ 0 with j ϵ D (set of consumer)
- c_{ij} = unit cost ≥ 0 to serve consumer j from P2G plant i
- xij = demand fraction of consumer j served from P2G plant i (with 0 ≤ xij ≤ 1)
- o_k = production source offer ≥ 0 with k ϵ R (set of production font)
- c'_{ik} = unit cost ≥ 0 to serve P2G plant i from production source k
- x'_{ik} = capacity (si) fraction of P2G plant i served from production source k (with $0 \leq x'_{ik} \leq 1$)
- f_i = cost ≥ 0 to open a P2G plant in i, which depends on size (s_i)
- y_i = open factor for P2G plant in i (it is binary, 0 = no plant, 1 = plant present in i)

In the matrices representing the costs are present the infrastructures and transport costs, efficiencies, the connection costs and so on...

<u>Note</u>: these information are strictly confidential and reserved since they are going to be published.

THE SUPERP2G – ITALY PROJECT

Several data and information are required as input by the algorithms to run the optimization procedure:

- Renewable energy power plants’ nominal capacity and location
- Hydrogen demand by the end users in terms of amount, purity and location
- P2G plant’s CAPEX and OPEX as a function of P2G plant layout, capacity and other factors. For example, P2G plants dedicated to blending have different sections compared to plants dedicated to refuelling.
- CAPEX and OPEX linked to hydrogen and electricity transport and distribution
- Technologies’ performances

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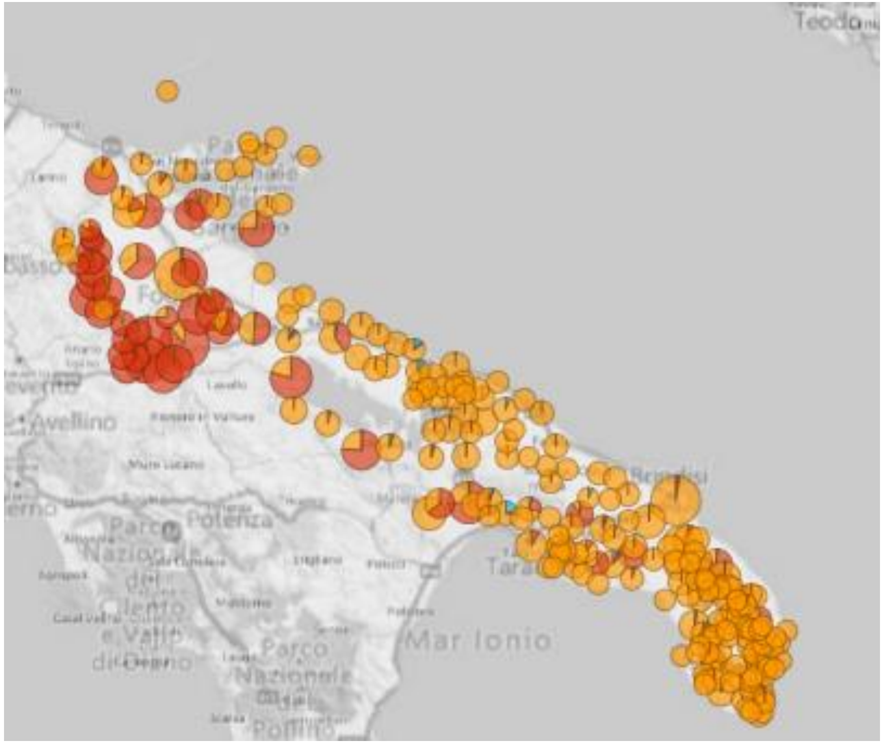
THE SUPERP2G – ITALY PROJECT: FIRST RESULTS

RENEWABLE ENERGY POWER PLANTS' NOMINAL CAPACITY AND LOCATION

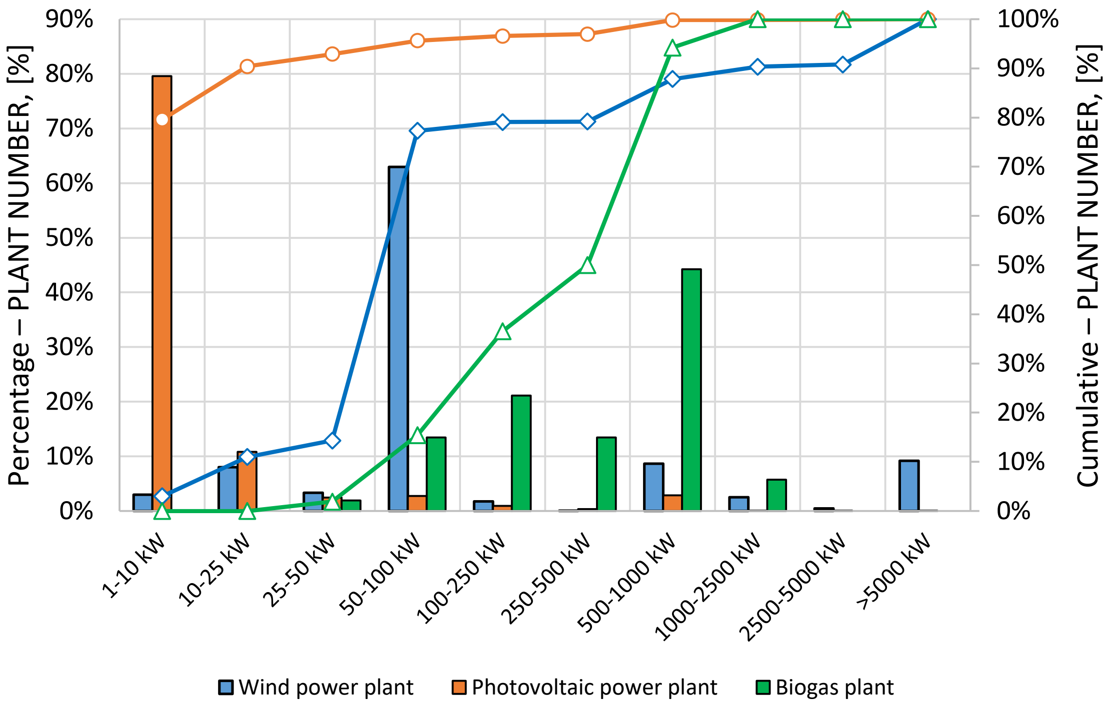


- WIND
- PV PLANTS
- BIOGAS PLANTS

More than **50.000 renewable plants** are installed in Apulia.
GSE gave the geographical coordinates to be implemented as input in the WEB-GIS tool

Source: GSE (2021)

RENEWABLE ENERGY POWER PLANTS' CHARACTERIZATION



PARETO ANALYSIS

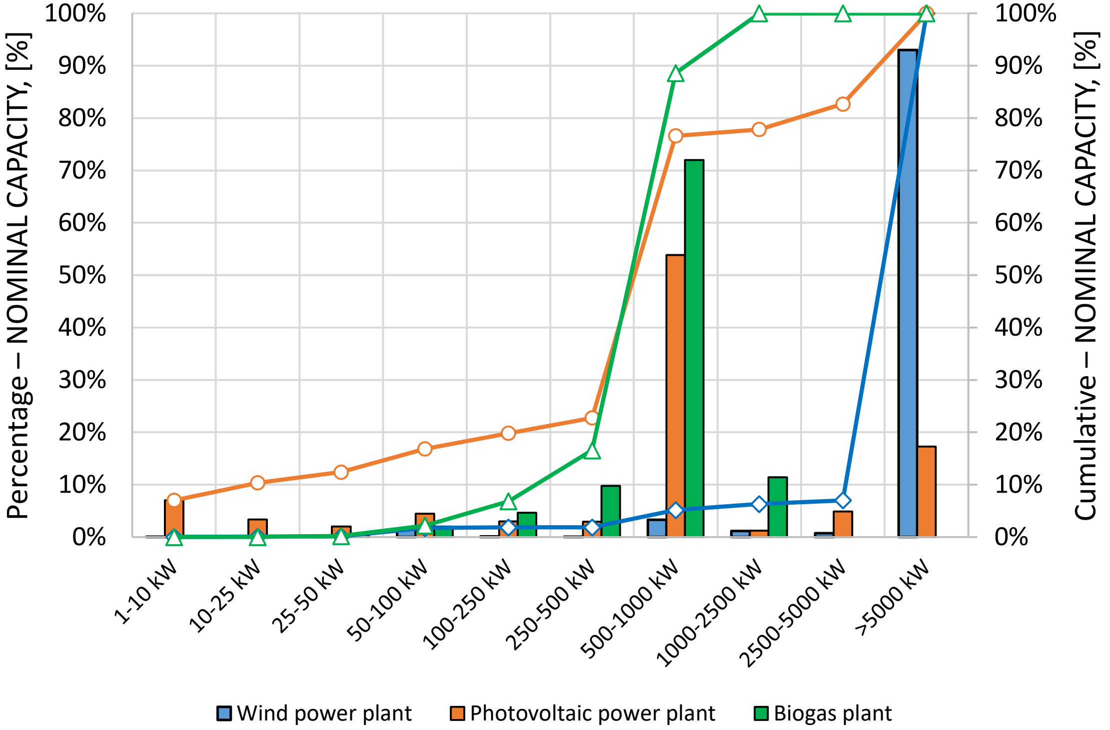
PV = 51385 PLANTS

WIND = 1072 PLANTS

BIOGAS = 52 PLANTS

Source: GSE (2021)

RENEWABLE ENERGY POWER PLANTS' CHARACTERIZATION



PARETO ANALYSIS

PV : P_{NOM} = 2,55 GW

WIND : P_{NOM} = 2,45 GW

BIOGAS : P_{NOM} = 26,7 MW

Source: GSE (2021)

THE SUPERP2G – ITALY PROJECT: FIRST RESULTS

RENEWABLE ELECTRIC ENERGY PRODUCTION: THE APULIA CASE

EQUIVALENT HOURS AT NOMINAL LOAD	2013	2014	2015	2016	2017	2018	2019	Average	Std. Dev	99% confidence (*)	
PHOTOVOLTAIC	1476	1401	1416	1327	1441	1302	1357	1389	58	**1332**	**1445**
WIND	1726	1837	1848	1964	2013	1819	2036	1892	106	**1789**	**1995**

(*) Calculated from GSE data

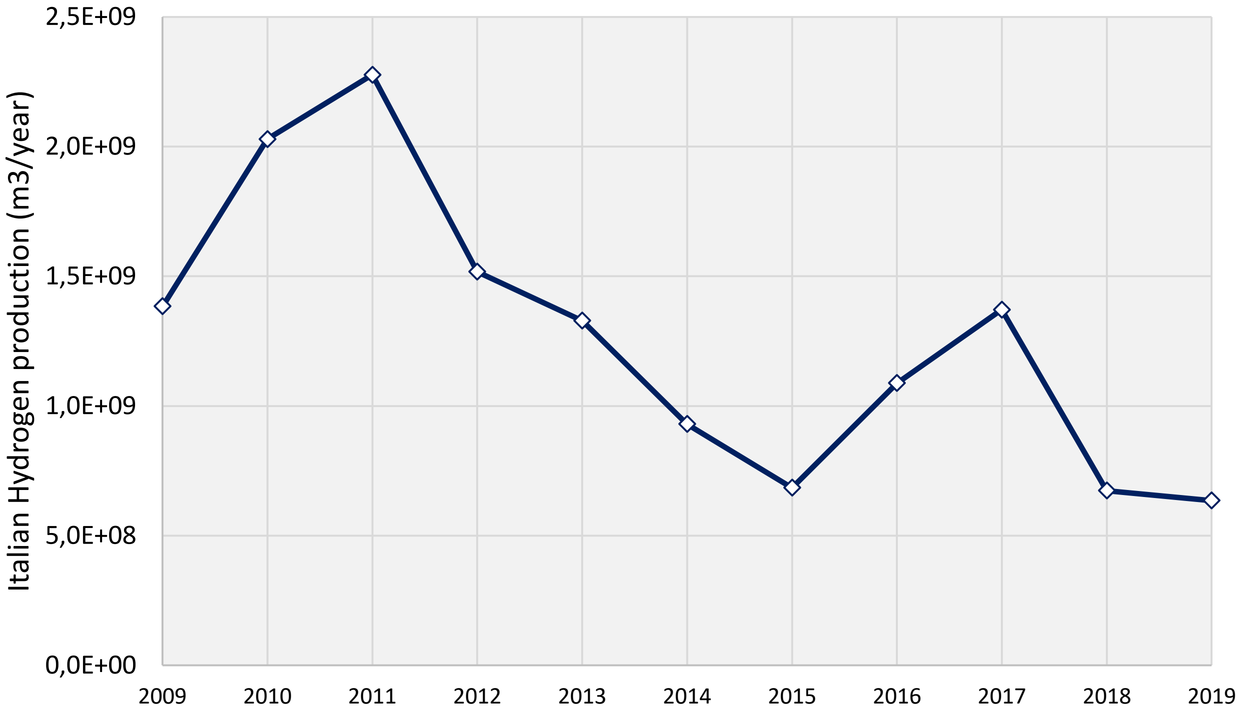
PV : P_{NOM} = 2,55 GW → $E_{el,PV}$ [3,40 GWh; 3,68 GWh]

WIND : P_{NOM} = 2,45 GW → $E_{el,PV}$ [4,38 GWh; 4,89 GWh]

The same approach to estimate annual renewable energy production in the WEB-GIS tool can be applied to each of the j-th renewable plant operated in Apulia

Source: data elaborated from available GSE documentation

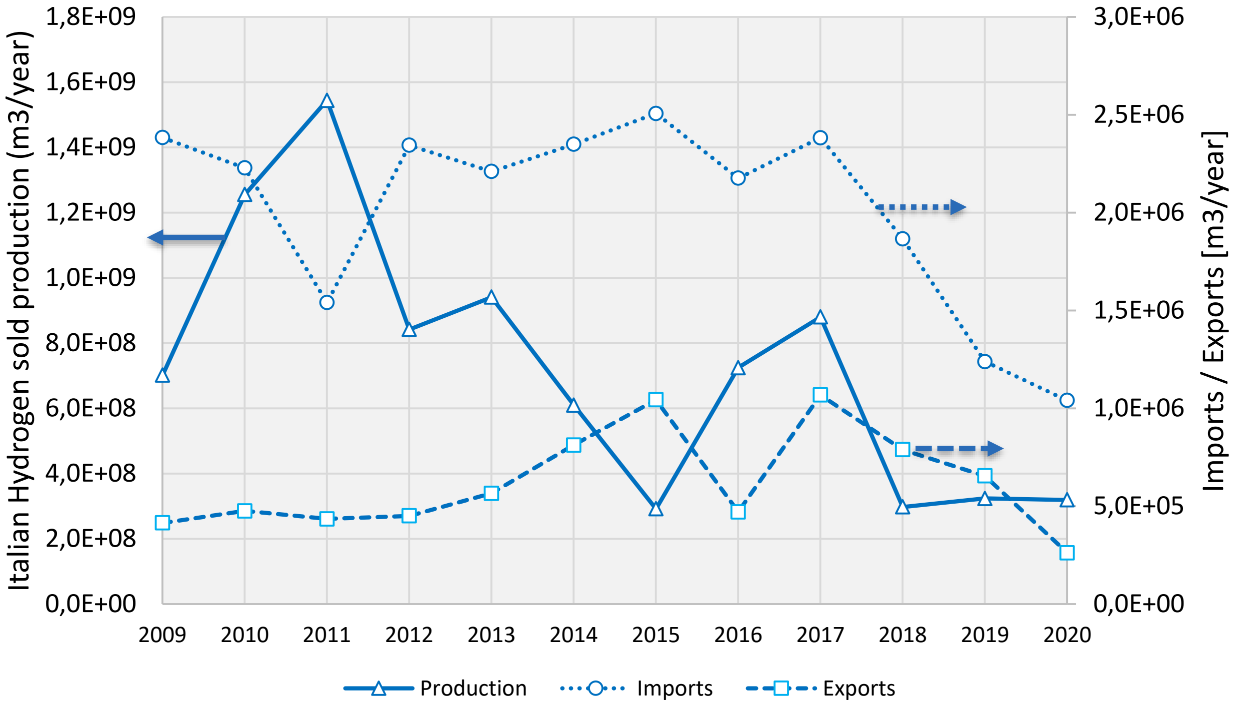
ITALIAN HYDROGEN DEMAND: TOTAL PRODUCTION



eurostat

Source: Eurostat (2019)

HYDROGEN DEMAND: SOLD PRODUCTION



Source: Eurostat (2019)

HYDROGEN DEMAND: CONSUMPTION

Hydrogen Demand, [Nm3]	2001	2006	2011	2016	2021
Refinery	3,7E+09	4,4E+09	4,0E+09	4,8E+09	5,2E+09
Chemical sector	5,4E+08	5,4E+08	5,4E+08	5,4E+08	5,4E+08
Others	5,4E+08	5,4E+08	5,4E+08	5,4E+08	5,4E+08
Total	**4,8E+09**	**5,5E+09**	**5,1E+09**	**5,8E+09**	**6,3E+09**

Source: H2IT (2020)

THE SUPERP2G – ITALY PROJECT: FIRST RESULTS

HYDROGEN DEMAND: OPEN ISSUES

Several issues have to be solved in order to develop the WEB-GIS tool:

- **A discrepancy exists between the data**. For example, Eurostat database indicates “m^3” as unit of measure. However, it is not specified in which condition (pressure and temperature) is defined. On the other hand, the methodology followed to estimate the quantity as reported by H2IT is not known

- **Only global data are available**. No detailed information about the distribution of the hydrogen demand in the Italian territory is available to the public

- **Hydrogen manufacturers consider P2G as a potential risk for their existing market**. Since P2G business could negatively impact their sales, technical gas manufacturers, traders and suppliers are not encouraged to give information about their clients

A very challenging activity has been started by Italian partners to fix these barriers

HYDROGEN DEMAND: APULIA CASE

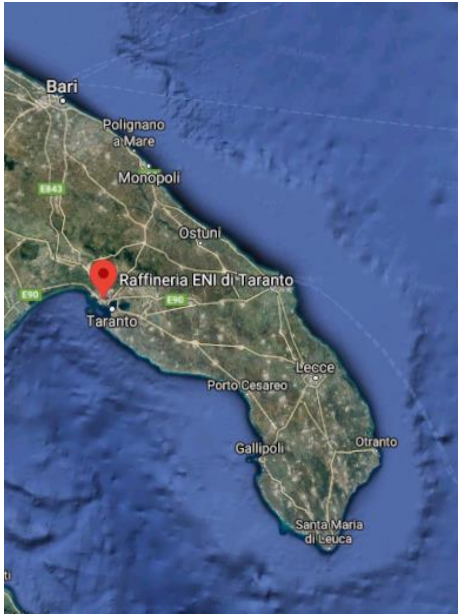
It is known, that hydrogen is consumed in the following sectors:

- Refinery
- Chemical
- Steelmaking
- Electronic components' manufacturing
- Ferrous metal production
- Non-ferrous metal production
- Glass production
- Jewelry manufacturing
- Food industry
- Mobility
- ….

VERY FEW DATA WERE RECEIVED BY SECTORS' ASSOCIATIONS

HYDROGEN DEMAND: APULIA CASE

The **ENI refinery in Taranto** elaborated 5,5 million of ton/year (2019). **A hydrogen nominal consumption in the range [24 kton/year, 30 kton/year] was calculated** and verified to the nominal capacity declared.



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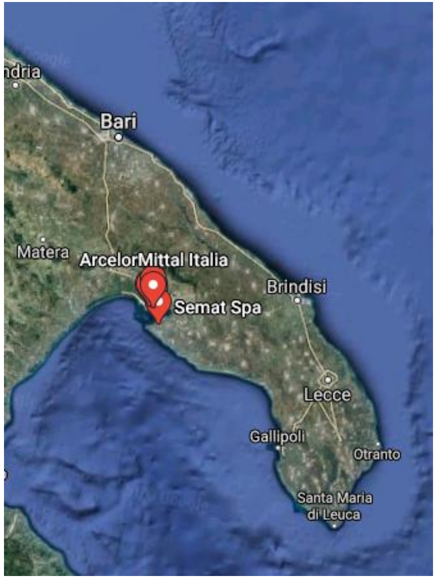
THE SUPERP2G – ITALY PROJECT: FIRST RESULTS

HYDROGEN DEMAND: APULIA CASE

The **ILVA steelmaking plant** could represent a significant end-user. Almost **2,740 ton/year of hydrogen** are estimated in case of hydrogen injection (10%vol) while **81,4 kg$_{H2}$ per tons of steel** is expected **in the case of the full process revamping**. It should be noted that the ILVA production is ≈ 3 million of tons per year.



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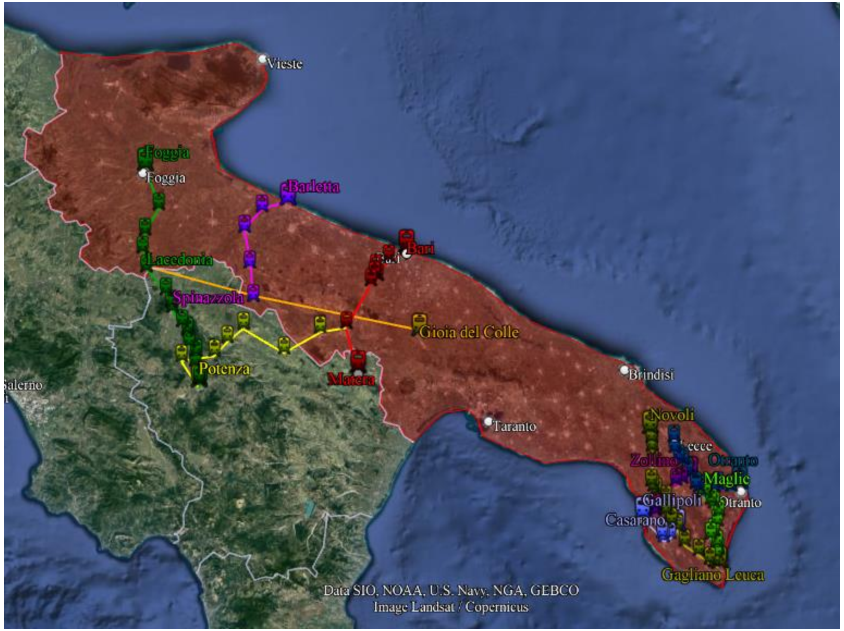
HYDROGEN DEMAND: APULIA CASE

All the unelectrified railways routes were identified in Apulia region.

- Three different operators currently operate **584 unelectrified kilometres in the region** (RFI, Ferrovie Appolo Lucane and Ferrovie del Sud Est).
- Since the total annual kilometres are not available in the database, the research team is calculating the annual hydrogen consumption potential for each routes .
- **A paper will be soon published dedicated to the topic**.



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THE SUPERP2G – ITALY PROJECT: FIRST RESULTS

SUPER P2G

P2G PLANTS: TECHNO-ECONOMIC ASSESSMENT

- The technical and economic performances of the P2G plant depends on the specific application.

- Different final applications result in different P2G plant layout:

  - Hydrogen direct use in the industrial processes
  - Refuelling station
  - Injection into the transportation gas network
  - Carbon dioxide methanation by Sabatier reaction
  - …

Note: these information are strictly confidential and reserved since they are going to be published.

THE SUPERP2G – ITALY PROJECT: FIRST RESULTS

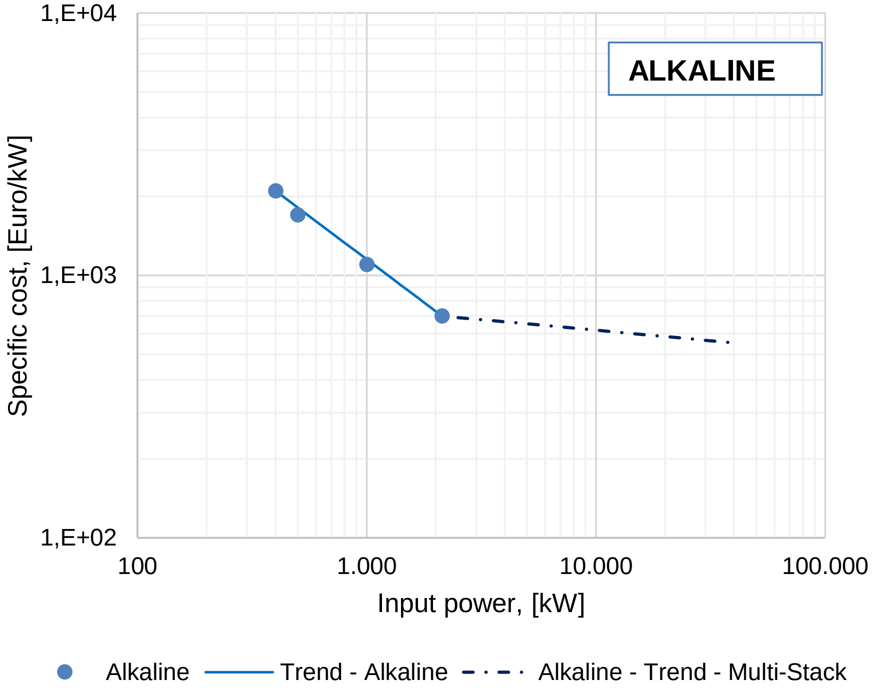
TECHNO-ECONOMIC ANALYSIS

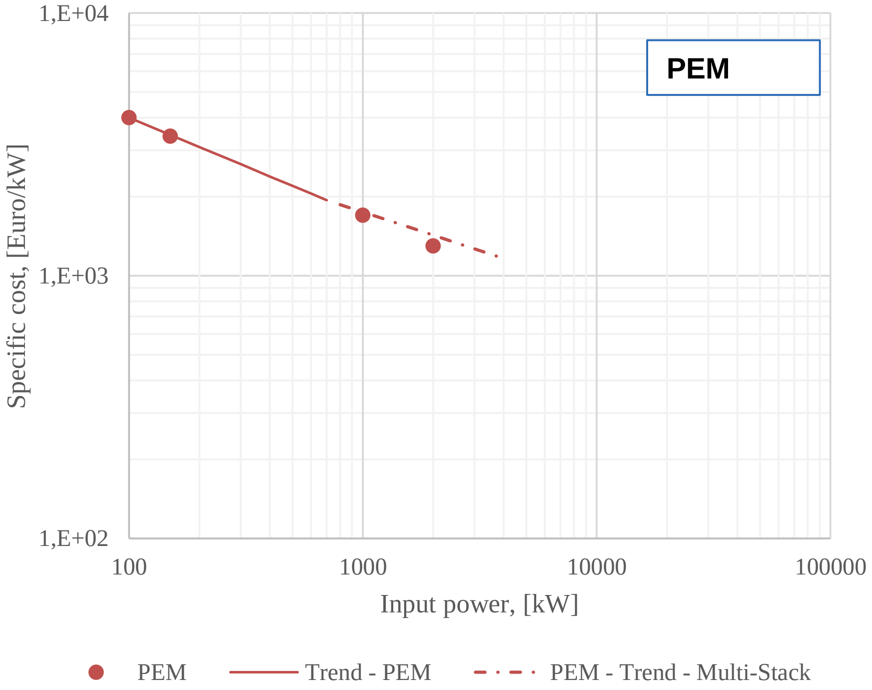
- $\text{CAPEX} = \text{CAPEX}_{\text{P2GPLANT}} + \text{CAPEX}_{\text{TRANSPORT}}$

- $\text{OPEX} = \text{OPEX}_{\text{P2GPLANT}} + \text{OPEX}_{\text{TRANSPORT}}$

THE SUPERP2G – ITALY PROJECT: FIRST RESULTS

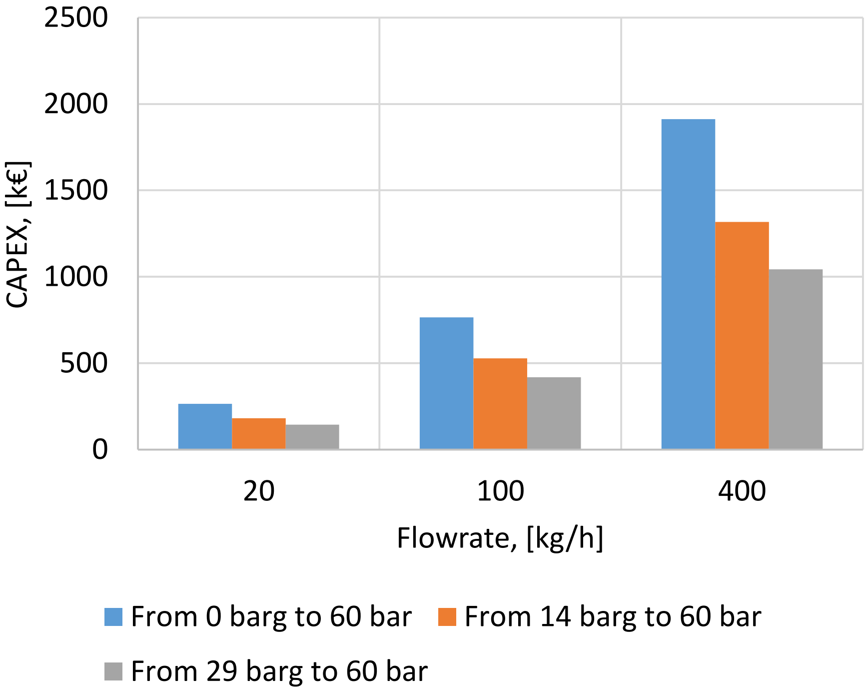
ELECTROLYZER CAPEX

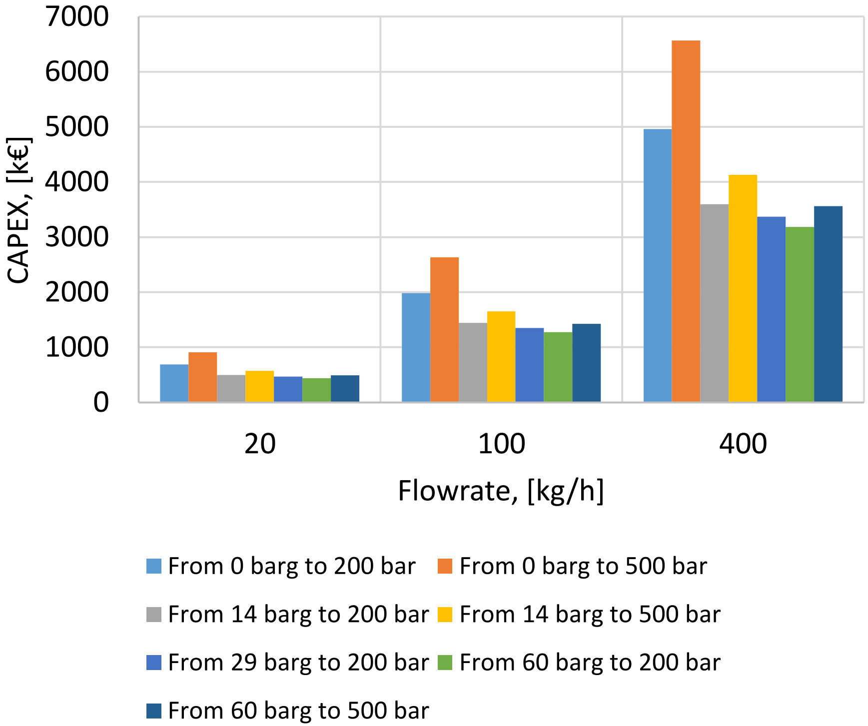




Source: Proost (2019)

COMPRESSOR CAPEX





Source: FCHJU (2017)

STORAGE CAPEX

Reference	Pressure, [bar]	Storage size, [m3]	CAPEX, [€/kg]
(vanLeeuwen and Zauner, 2018)	137	2856 m^3 (60 m^3 each)	560
	200	Different sizes	50-125-250-500
	Not specified	Not specified	790
	Not specified	Not specified	900
	Not specified	11,123	430
	173	3,337	1150
	432	1,557	1100
	500	5,000	450
	350	204	460
	1	85	5500
	414	Different sizes	190
	200	2,400	260
	141-552	556 – 13,793	260-2050
	350	3,337 – 156	1240-2200
	30	5 – 10,000	280-430
(Simbeck and Chang, 2002)	150 400 460 550	Not specified	530 820 1800 2600
(FCH JU, 2017)	50 (into tanks) 200 (into bundles) 350 (into bundles)	Not specified	470

THE SUPERP2G – ITALY PROJECT: FIRST RESULTS

SUPER P2G

INJECTION STATION CAPEX

Injection pressure, [bar]	CAPEX at 2017 [k€]	CAPEX at 2025 [k€]
60	700	560
10	600	480

Source: FCHJU (2017)

METHANATION PLANT CAPEX

Reference	Plant size, [MW]	CAPEX, [€/kW$_{SNG}$]
(van Leeuwen and Zauner, 2018)	-	190 - 550
	10 100	580 107
	5 30 110	300 160 110
	48	250
	1 3 6	1500 1000 750
	-	720
(Götz et al., 2016)	5 110	400 130
(Mors Friedemann et al., 2020)	1	3000
	0.2	7900
(Iaquaniello et al., 2018)	100	650
(Gorre et al., 2019)	-	600

Catalytic methanation

Reference	Plant size, [MW]	CAPEX, [€/kW$_{SNG}$]
(van Leeuwen and Zauner, 2018)	1 - 110	1200-340
	0.13-10	1150-100
	-	715
	-	700-1500
	0.2-1-2	320-120-90
	1	1,800
	5	490
	1	690
(Mors Friedemann et al., 2020)	0.3	3500

Biological methanation

OTHER COSTS OF P2G PLANTS

Several voice of costs are included in other costs:

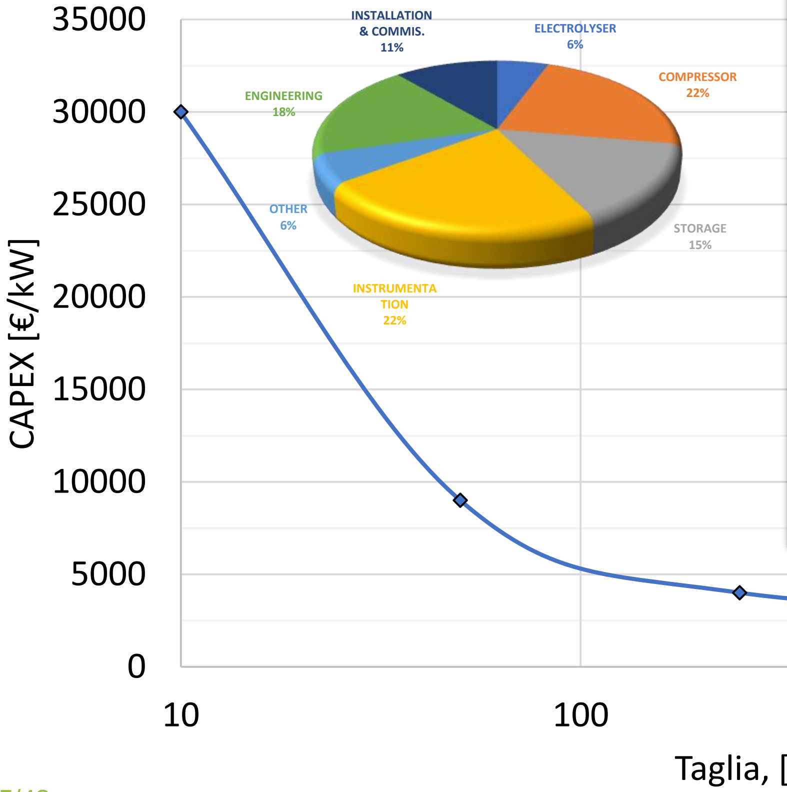
- *Civil works*. The civil works are related to the realization of foundation, of industrial building, the integration of the lighting and of the water supply, fencing and security. Civil works depends on the footprint of the plant.
- *Engineering costs*. They include all the costs related to architectural, engineering, studies, permitting, legal fees, and other pre and post construction expenses.
- *Distributed Control system (DCS) and Energy Management Unit (EMU)*. They are the components that ensure the correct operation of the plant.
- *Interconnection, commissioning and start-up costs*.

Other costs can be calculated:

$$\mathrm{OTHER\ COSTS} = 10\% \left(\frac{2.5}{\mathrm{P_{PROJECT}}[\mathrm{MW}]} \right) + 35\%$$

Source: FCHJU (2017)

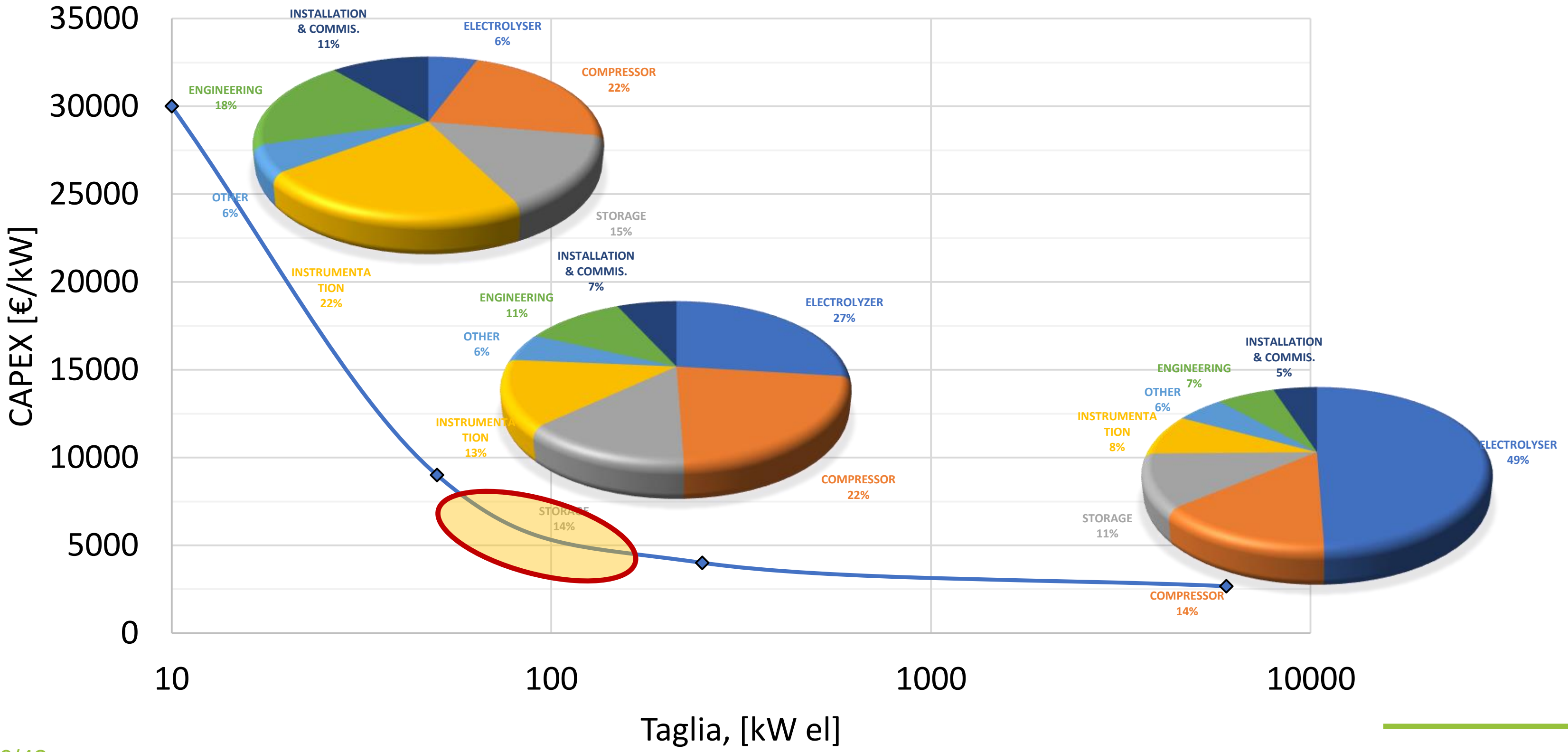
P2G PLANTS: CAPEX



UNIBO LABORATORY P2G PLANT (7 kW el.)

THE SUPERP2G – ITALY PROJECT: FIRST RESULTS

P2G PLANTS: CAPEX



HYDROGEN TRANSPORTATION COSTS: BY PIPELINE

In the case of transportation by pipeline, the connection cost C to the network is calculated in accordance to ARERA as follow:

$$C = \left(I - T \sum_{t=1}^{n} \frac{1}{(1+i)^t} \right) \times \alpha$$

Where:

- I is the initial investment [M€]. In the case of hydrogen, the typical values that are valid for the gas network are corrected, considering a safety factor between 10%-50% (ACER, 2021)
- T is the corresponding tariffs to be given to the TSO for the gas network utilization and calculated in accordance to ARERA rules [M€]
- i is the interest rate [%]
- n is the operative life (=50 years)
- α is a correction coefficient (=0,8)

HYDROGEN TRANSPORTATION COSTS: BY PIPELINE

For each route of the network, the transportation cost for the TSO is calculated as follow

$$CT = \frac{I \text{ x } (\delta + \beta + \gamma)}{Q_t}$$

Where:

- I is the investment [€/km]
- δ is the return on invested capital (assumed equal to 4,25%)
- β is the depreciation (2%/year)
- γ is the operative costs (assumed equal to 3% of the investment)
- Qt is the theoretical flowrate (Nm3/day)

<u>This correlation should be asked for confirmation to interested observers</u>.

HYDROGEN TRANSPORTATION COSTS: BY PIPELINE

An additional voice of cost is considered to take account of leakages.

Values for natural gas are reported below. A corrective factor between [1.3, 2.8] as defined by (Rigas&Amyotte,2013) is considered for high pressure pipelines transporting 100% hydrogen.

	P≥ 12 bar		p< 12 bar	
Leakage source	Emission factor	Unit of measure	Emission factor	Unit of measure
Pipeline	5290	Sm3/km/year	0,529	Sm3/km/year
node	16890	Sm3/source/year		
PIG station	10200	Sm3/source/year		
Control and pressure reduction station (R&R)	10810	Sm3/source/year		
Compression station	4018	Sm3/MW/year	[-]	[-]
Control, pressure reduction and measuring station (REMI)	2930	Sm3/source/year	290	Sm3/source/year
Leakage vents				
Pipeline, R&R, REMI	204	Sm3/km/year	20,45	Sm3/km/year
Other station	1521	Sm3/MW/year	[-]	[-]

Source: ARERA (2019)

HYDROGEN TRANSPORTATION COSTS: BY ROAD

The work of (Reuß et al., 2021) was considered as reference for the calculation. However, since the values reported in the paper are referred to Germany, a correction was required.

$$CAPEX = \frac{AF \times I_{Truck/Trailer}}{U} \times T_{Travel}$$

Where:

- I is the initial investment [€]
- U is the number of operative hours [h]
- T_{Travel} is the time required to cover the distance between the plant and the demand
- AF is the annuity factor calculated as below:

$$AF = \frac{\left(1 + WACC_{Truck/Trailer}\right)^{n_{Truck/Trailer}} \times WACC_{Truck/Trailer}}{\left(1 + WACC_{Truck/Trailer}\right)^{n_{Truck/Trailer}} - 1}$$

Where:

- n is the depreciation time (assumed equal to 5 both for truck and trailers in Italy)
- WACC is the weighted average cost of capital

Source: Reuß et al., 2021

HYDROGEN TRANSPORTATION COSTS: BY ROAD

Concerning OPEX the following was correlation is used.

$$OPEX = (Fuel \times C_{Fuel} + C_{Toll}) \times D_{Travel} + \left(O\&M \times \frac{I_{Truck}}{U} + C_{Driver} \times N_{Driver}\right) \times T_{Travel}$$

Where:

- Fuel is the fuel consumption [liter/km] assumed equal to 34,5 liter per 100 km
- C_{Fuel} is the cost of the fuel [€/liter] (equal to 1,029 €/liter in Italy)
- C_{Toll} is the toll cost [€/km] that is between [0.21387, 0.25167] €/km in Italy
- D_{Travel} is the distance [km]
- O&M are the maintenance costs respect to the initial investment [%]
- C_{Driver} is the cost of a driver [€/driver] that is assumed equal to 16,9 €/h in Italy
- N_{Driver} is the number of driver required to cover the distance [#]

Source: Reuß et al., 2021

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CONCLUSIONS AND FUTURE DEVELOPMENTS

A very challenging research activity was required to design a database containing the input information for the WEB-GIS tool of the SuperP2G – Italy project.

Particularly:

- **Available data about Italian hydrogen demand are very general and not useful as it for the WEB-GIS tool**. Furthermore, the detailed information (localization and demand characterization) are not easy to be accessed since hydrogen manufacturers see P2G plants as a market competitor. → **UNIBO and CNR-ITAE are working to cover this gap in Italy but the same should be performed also at European level to create a common and structured database**.

- **CAPEX and OPEX investigation requires a very big effort but it is necessary to give reliable input to the WEB-GIS tool**. However, many different P2G plants' layout exist. According to the idea to give a pre-feasibility indication to the end-users, only a list of potential P2G plants will be implemented in the WEB-GIS tool based on the feedback of the observer.

- **Techno-economic input data have to be continuously updated in the WEB-GIS tool**.

Thank very much for your attention

About ERA-Net Smart Energy Systems | www.eranet-smartenergysystems.eu
The transnational joint programming platform (JPP) ERA-Net SES unites 30 funding partners from European and associated countries. It functions as a network of owners and managers of national and regional public funding programs in the field of research, technical development and demonstration. It provides a sustainable and service-oriented joint programming platform to finance transnational RDD projects, developing technologies and solutions in thematic areas like smart power grids, integrated regional and local energy systems, heating and cooling networks, digital energy and smart services, etc.

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