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Energy Management & Carbon Footprint of a global manufacturing industry

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Contents

Abstract 5
1. Energy Management........ 7
1.1. Energy Management description and principal aspects........ 7
1.2. Continuous improvement cycle 7
1.3. Energy-intensive activities related to Nuovo Pignone business........ 9
1.4. Nuovo Pignone's management of energy balances........ 10
2. Cogeneration 17
2.1. Definition & operating principles........ 17
2.2. Nuovo Pignone CHP plant........ 18
2.3. CHP productivity vs consumption profiles........ 22
2.4. Contractual aspects of energy supply from CHP plant........ 24
2.5. Penalties related to energy supply 27
3. Electrical energy........ 33
3.1. The electricity market and its trend 33
3.2. Contractual aspects of energy supply from the national grid 36
4. Natural gas........ 41
4.1. The natural gas market and its trend........ 41
4.2. Contractual natural gas fixed term........ 44
5. The EU Emission Trading System 49
5.1. Operating policy 49
5.2. Phases 49
5.3. Thresholds........ 51
5.4. EU ETS in Nuovo Pignone's case 52
5.5. CO2 market........ 55
6. Water usage 61
6.1. World's water scarcity........ 61
6.2. Industrial and drinking water consumption 62
6.3. Improvements on water network 64
7. Actual Energy and Environmental World's scenario........ 67
7.1. United Nations Sustainable Development Goals........ 67

7.2. World's energy consumption ... 69
8. Baker Hughes's Decarbonization ... 77
8.1. Baker Hughes's focus on Climate and Energy ... 77
8.2. Nuovo Pignone's Carbon footprint ... 78
8.3. Decarbonization Performance Indicators ... 83
8.4. Target 2030 ... 85
9. Onsite photovoltaic power production ... 89
9.1. Investment opportunities on photovoltaic ... 90
9.2. Cashflow analysis of a photovoltaic investment ... 92
9.3. Power Purchase Agreements ... 94
10. LED Lighting installations ... 97
10.1. Investment on lighting technology ... 97
10.2. Energy Efficiency Incentives ... 100
Conclusions ... 103
Bibliography & Websites ... 105
Ringraziamenti ... 109

Abstract

This Master's thesis project is the result of the work done thanks to Baker Hughes company - Nuovo Pignone Srl in one of its major manufacturing Italian sites, in Florence. The work was developed in the global supply chain area and more precisely in the energy management one, which also gave me the opportunity to interface with other different business areas within the company.

The focus has been on energy in terms of electricity, natural gas and thermal energy, but also on water consumption with the joint goal of reducing both costs and the carbon footprint, which is strongly linked to climate changes, currently one of the priority topics on which global action is required.

The production and consumption characteristics of the plants have been examined as they are the main responsible for the energy supply expenditure and for greenhouse gas emissions. In order to meet the set scope, the performance of the main energy and environmental markets has been analyzed for continuous improvement in order to find the best contractual conditions necessary to minimize company's costs, compatibly with the needs and the expected work volumes.

Finally, energy efficiency and cost saving projects have been studied and developed, some of which have seen their actual implementation and execution and will contribute in the next future to the reduction of CO_2 emissions, both a company and a United Nations target for the years ahead. The obtained results have then been compared to the current worldwide situation, stressing the relevance of industry in the energy transition.

1. Energy Management

1.1. Energy Management description and principal aspects

In a large company such as Nuovo Pignone, where energy aspects and its related consumption are dealt with great attention, energy management plays a key role and as the term suggest it has the responsibility to manage everything related to energy within the plants, checking and forecasting consumption, optimizing and promoting projects and investments related to energy efficiency and to the use of renewable energy sources.

In Italy, when this topic is discussed, especially in relation to large industrial sites, the figure of reference is often the technician responsible for the conservation and the rational use of energy, a figure introduced in Italy by the Law 10/91 in order to promote the control of consumption and the diffusion of good practices on energy efficiency. The responsible for the conservation and rational use of energy is called "Energy Manager", although this term covers many more aspects. In fact, another function concerning this figure is the procurement of all energy sources, which in this case has the scope of reducing the purchase costs, promoting the proper management of loads and work volumes in order to avoid power peaks that lead to higher costs. A good and useful practice is to collaborate closely with the sourcing office both for energy purchases and for the acquisition of machines characterized by low energy consumption and therefore low operating costs, LCCA (Life Cycle Cost Analysis). [1]

1.2. Continuous improvement cycle [2]

Although Nuovo Pignone is not specifically certified by the ISO 50001, but considered as a future improvement, the internal process scheme is based on the model of the following management systems for which the company is certified: ISO 9001 regarding quality, ISO 14001 on environmental management systems and OHSAS 18001 regarding work safety. These models operate according to the so called PDCA (Plan - Do - Check - Act) or Deming cycle, illustrated in the figure below, which is at the basis of the continuous improvement philosophy and consists of four main parts:

- Plan: planning is necessary to identify the problem or objectives and propose strategies and goals;
- Do: implementation of planned actions;

- Check: verification by measuring and monitoring the actions taken to assess any deviations from the set objectives;
- Act: actions are adopted to further improve the achieved results.

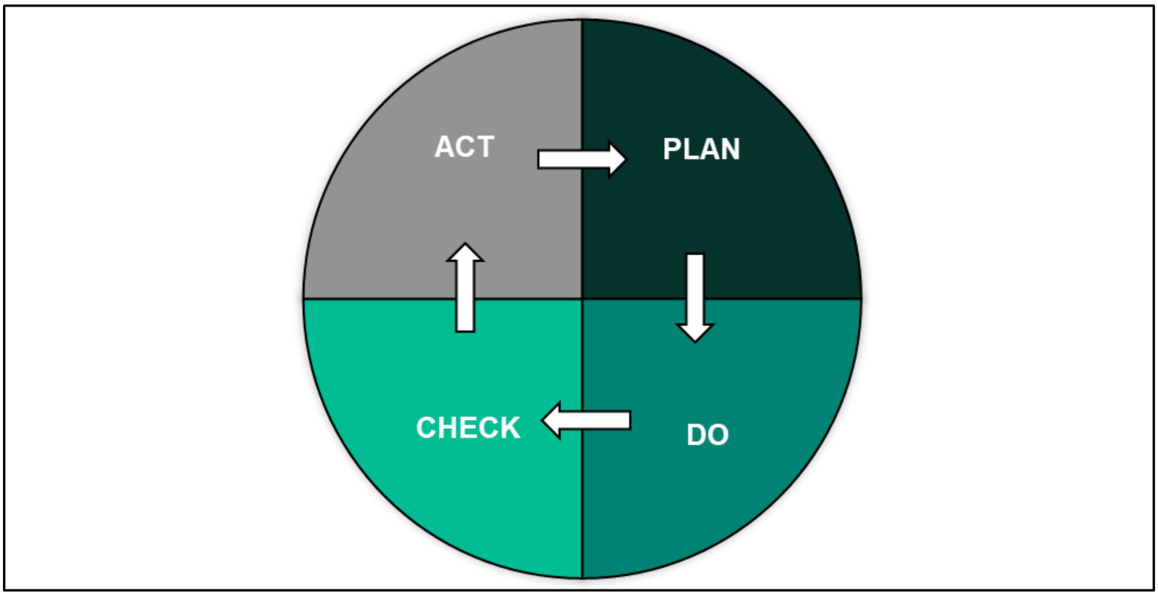

Figure 1.1: *PDCA Cycle. [2]*

The relationship between energy management and the planning phase of the cycle is fundamental, as it concerns the whole forecasting process related to the work and/or production volume and the expected results in terms of energy consumption generated by it. Therefore, the focus is on forecasting as accurately as possible what the consumption will be in order to optimize the use of equipment and set company budgets as targets to meet. The responsibility of the energy management area is focused on four main drivers, representative of the principal energy commodities: natural gas, electrical energy, thermal energy and water.

The second phase concerns the one in which the plan is implemented by running the process and collecting data from the previous phase in order to create charts or trends and to analyze and allocate them to the "Check" and e "Act" phases. The monitoring process is fundamental and in our company is helped by the so called Facility Monitoring System that permits to control in real time commodities' flows, to store the data related to them and to download trends and significant results useful for analytics and digital purposes, which in the future can permit to optimize the whole 4.0 digital industry.

In the third phase, called Check, the challenge is the test and control of the obtained results in the "Do" phase and the goal is to compare them with the expected results of the "Plan" in order to analyze and verify any variances.

The final step, also known as "Act" phase, concerns actions that aim to improve the overall process in order to correct significant differences between actual and expected results and to analyze these differences to determine the causes and where to apply the changes that allow to achieve the improvement of the process or product. Depending on the objective or type of process under investigation, the focus can be on different stages or on a single step of the process, considered to be more important than the others.

1.3. Energy-intensive activities related to Nuovo Pignone business

This paragraph is dedicated on the topic of energy management and its philosophy, applied to the company world with focus on its manufacturing Florence plant.

The Baker Hughes corporate is "*the first full-stream company in the oil & gas industry able to offer innovative equipment, services and digital solutions for the entire oil and gas value chain. Baker Hughes is made up of four main divisions: Oilfield Services, Oilfield Equipment, Turbomachinery and Process Solutions and Digital Solutions as well as other product segments and lines"*. The headquarter of Turbomachinery and Process Solutions (TPS) is based in Florence (Italy), but "*there are other six industrial plants and a construction site for the assembly of large industrial modules, combination of high technology and sophisticated environmental protection systems. In Italy, Baker Hughes operates mainly through Nuovo Pignone Srl that represents for the group an excellence in engineering and manufacturing skills, as well as a worldwide reference point for turbomachinery and applications in 4.0 industry. The Nuovo Pignone main business is the production and marketing of gas and steam turbines, centrifugal and alternative compressors and testing of these machines".* [3]

Company's production cycle and principal manufacturing activities regard:

- mechanical processing and heat treatment by machine tools;
- functional testing of installed parts and machine assembly;
- testing, which can be vacuum or thermodynamic, of gas and steam turbines, alternative and centrifugal compressors and full system;

- research and development analysis and related tests;
- additional processing and painting;
- warehouse's activities;
- spare parts production, maintenance and revision of the manufactured machines.

Other plant's activities are mainly related to maintenance of plants and facilities, specific machines intervention and office work.

These business' tasks require a very high energy consumption which is composed mainly of: natural gas, electricity, thermal energy, water and in small part of other fuels such as diesel and kerosene.

1.4. Nuovo Pignone's management of energy balances

Until the last quarter of 2018, date in which the CHP installation has been sold to an Energy Service Company (ESCO), the historical data highlight that the major consumption and consequently cost driver was the natural gas, with a range little less than 70% on the overall energy's expenditure. The second commodity that guides energy expenditure was the absorbed electricity from the national grid with a value around 30%, without considering the power produced by the CHP because it was auto produced and therefore has been considered in the natural gas term. While the cost related to water was around 2-3% as shown in the graph below.

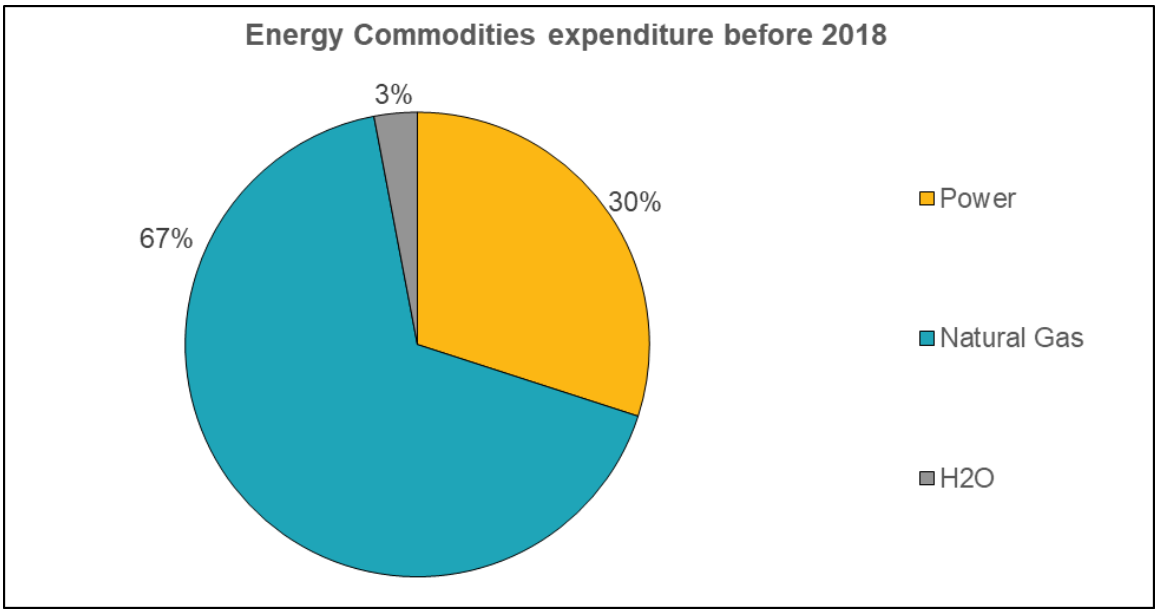

*Figure 1.2: **Historical energy commodities expenditure before 2018.***

In the abovementioned period, the thermal energy, as for the electrical energy from the cogeneration, was not considered as a cost because included and auto-produced by natural gas, while in the next period will be analyzed.

Special reference needs to be made to the CO_2 expenditure, which in this analysis is not included in the costs account because depends on natural gas consumption and on complex issues related to the EU ETS Directive, which will be examined in detail later.

As we have seen, from the end of 2018 onwards the subdivision of the main energy flows has changed and two new entries have been introduced: the thermal energy and the power supplied by the CHP, which is an additional term to the electrical energy slice. In this new scenario, the different energy commodities have changed their value strongly, as shown in the next figure.

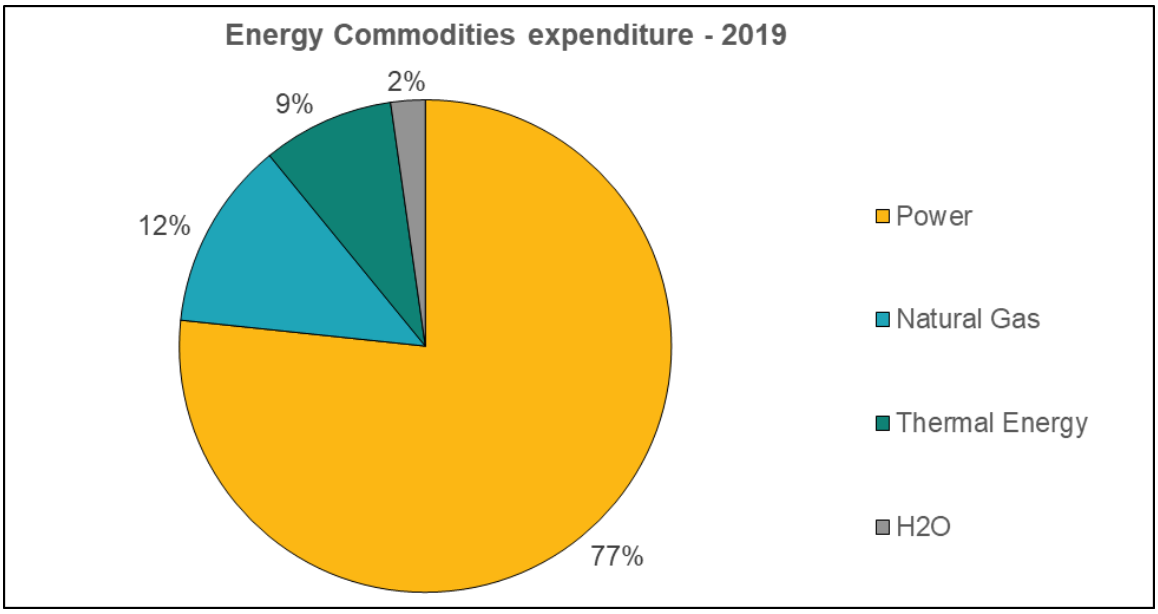

*Figure 1.3: **Energy commodities expenditure 2019.***

The comparison of the two scenarios highlights that:

- the contribution of natural gas, compared to the total value, is reduced of 80%;
- the electrical energy has more than doubled its previous value, recording a +120%, because the term related to the purchased electrical energy from the cogeneration is now added;
- the thermal energy is near the 10%, while in the first scenario it was absent;
- the water is decreased of 35%, but it’s hard to see it due to its little weight on the total.

These explained bullets are clearly visible in the graph below, figure 1.4.

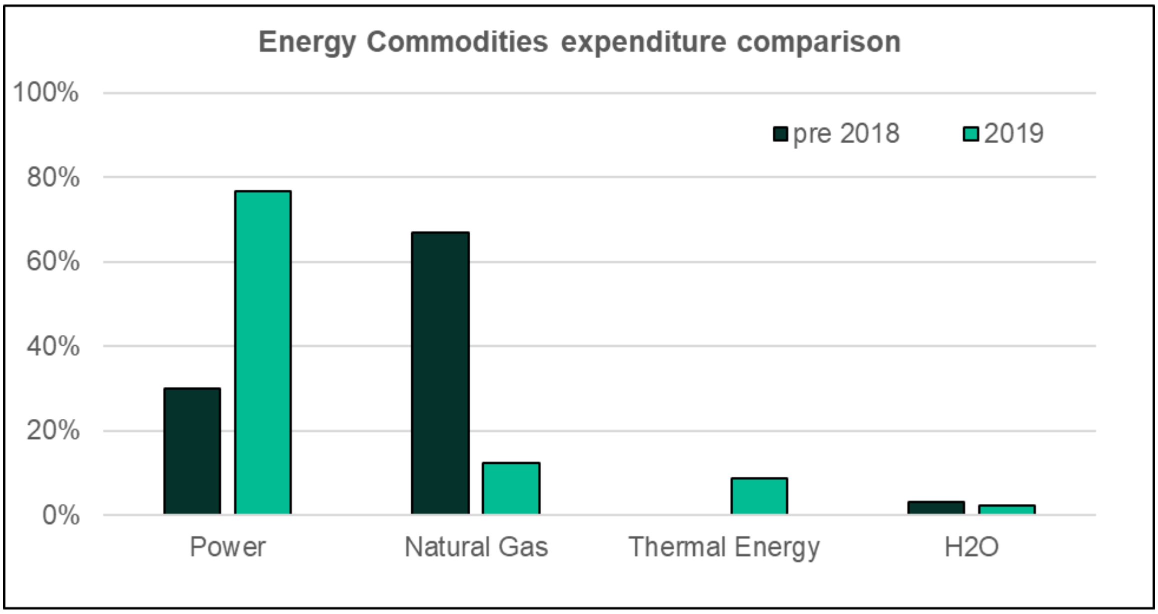

Figure 1.4: Energy commodities pre-2018 vs 2019.

Another very important result of the in-depth analysis is the fact that, despite the intense change of energy cost's allocation, the final use of these commodities remains almost unchanged over the years and we will now study them in detail.

First of all, the natural gas is used for the following scopes:

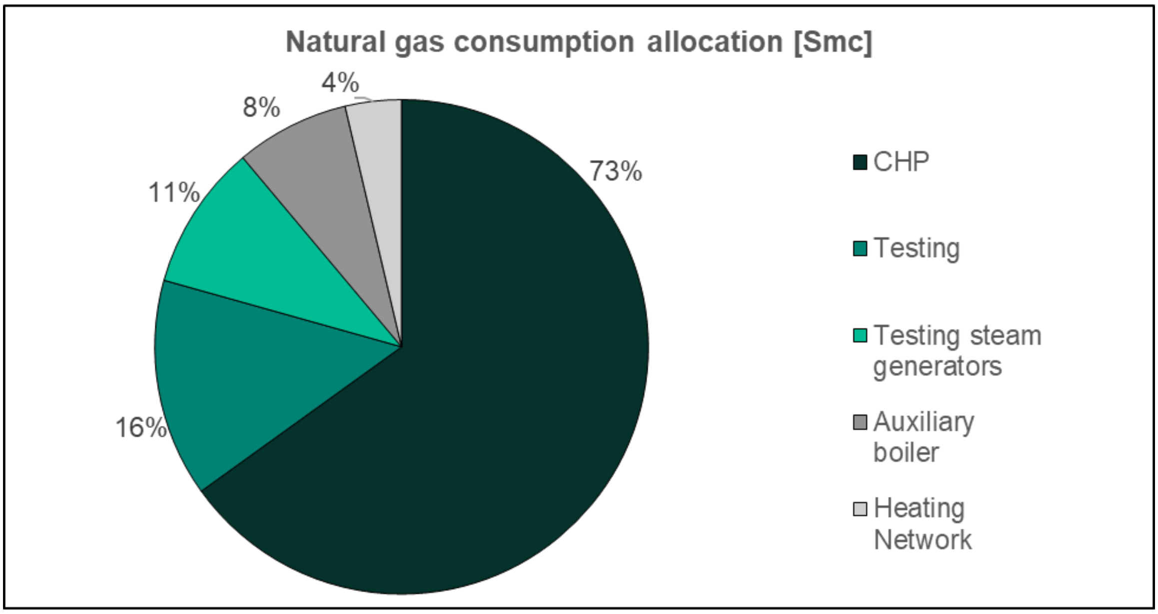

Figure 1.5: Natural gas consumption subdivision.

- more than 70% concerns the CHP power supply and it obviously depends on how much the installation works at full load;

- 15-20% in the last years regards the testing activity, which varies strongly during time;
- around 10% is used to power two steam generation boilers, which have a fluctuating trend during the year, another time caused by the testing purpose;
- 5-10% is used for the back-up boiler, whose performance strongly depends on seasonality and on CHP's workload;
- the remaining 5% feeds the heating network and its boilers. Also in this case, the predominant consumption occurs in the winter months and drops dramatically during summer.

The last two bullets, which have a trend proportional to the seasonality, are better visible in the figure 1.6 below.

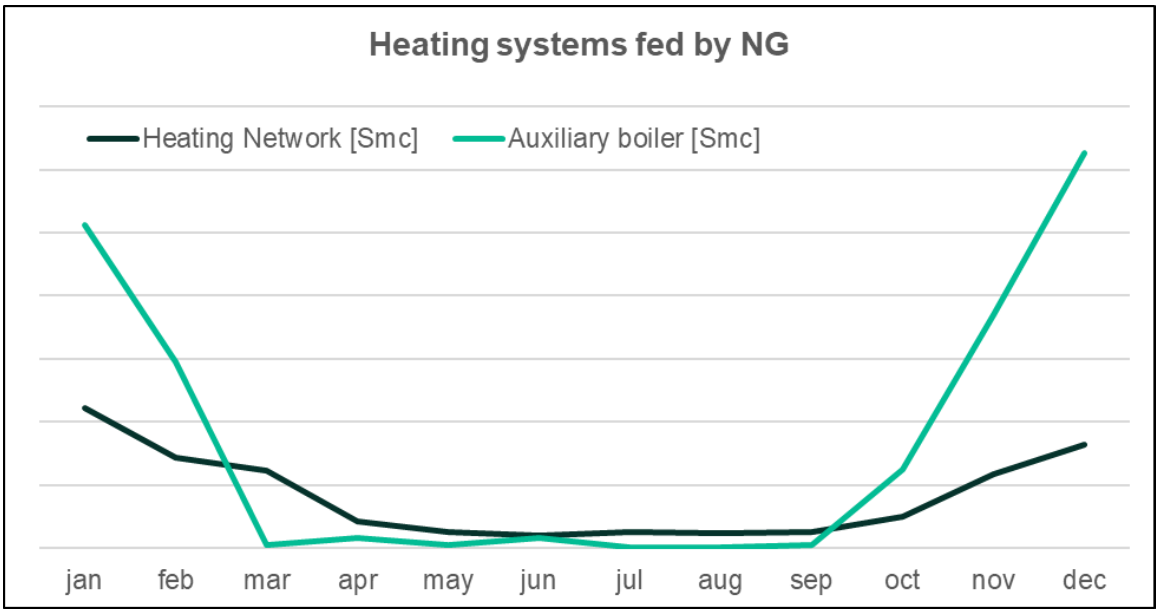

Figure 1.6: *Annual NG consumption for heating.*

As was done for natural gas, electrical energy consumption can also be divided according to its final use, during the last years:

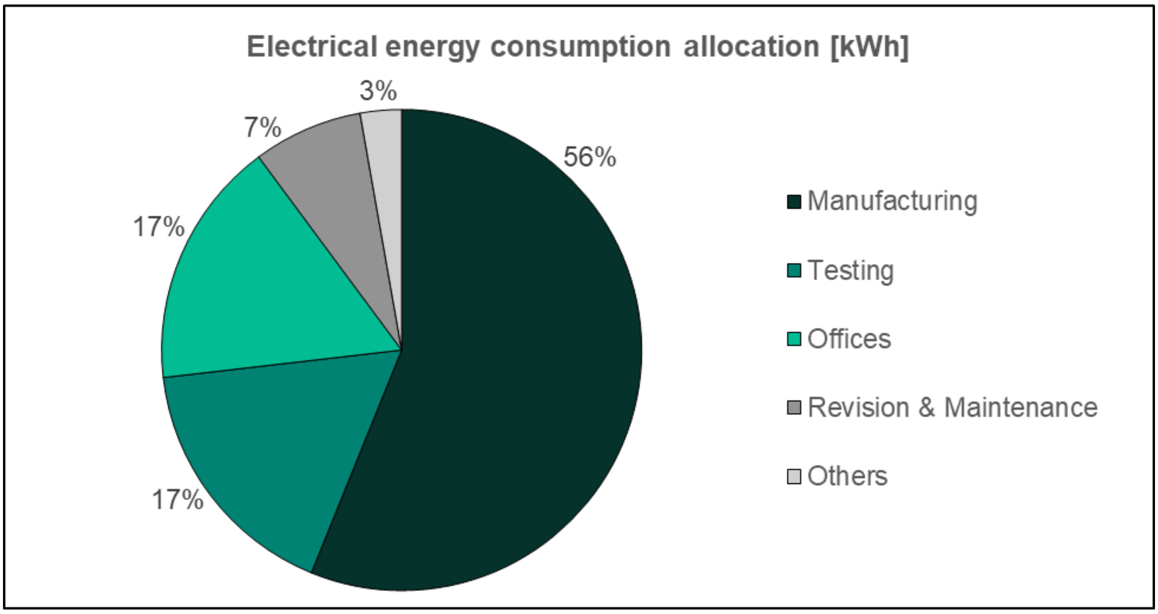

Figure 1.7: *Electricity consumption subdivision.*

- more than half of the electricity is used in the manufacturing area for production and processing's purposes;
- testing and offices activities contribution is around 17%, but while the first consumption and related expenditure varies greatly according to sales' demand and to the development of new machines, the second one has a flatter trend year over year;
- around 7% concerns revision and maintenance use;
- the remaining 3% can be categorized as "others", i.e. auxiliary plant and other campus buildings.

In conclusion, there are many aspects that have influenced the change in the allocation of energy consumption in recent years, e.g. price inflation, variation of work's volumes and production, contractual aspects, improvement projects, etc., but the most important one is definitively the sale of the CHP. This event has greatly affected the distribution and priority of consumptions and related expenses, despite the energy's need has not been turned upside-down over the years. For this reason, the CHP and all that concerns it will be dealt in a dedicated chapter below.

2. Cogeneration

2.1. Definition & operating principles [4]

"Cogeneration" also known as CHP (Combined Heat and Power) means the combined production of electrical (or mechanical) energy and thermal energy (or heat), which are obtained in specific installations fed by the same primary energy. This technology can lead to significant energy savings compared to the separate production: if a user requires both electricity and thermal energy at the same time, instead of installing a boiler and purchasing electricity from the grid, it is possible to take advantage of a thermodynamic cycle to produce electricity by exploiting the highest thermal levels, releasing the residual heat at a lower temperature in order to satisfy thermal requirements.

The following is an explicative diagram that compares cogeneration with separate production, giving an idea of the achievable savings in terms of primary energy:

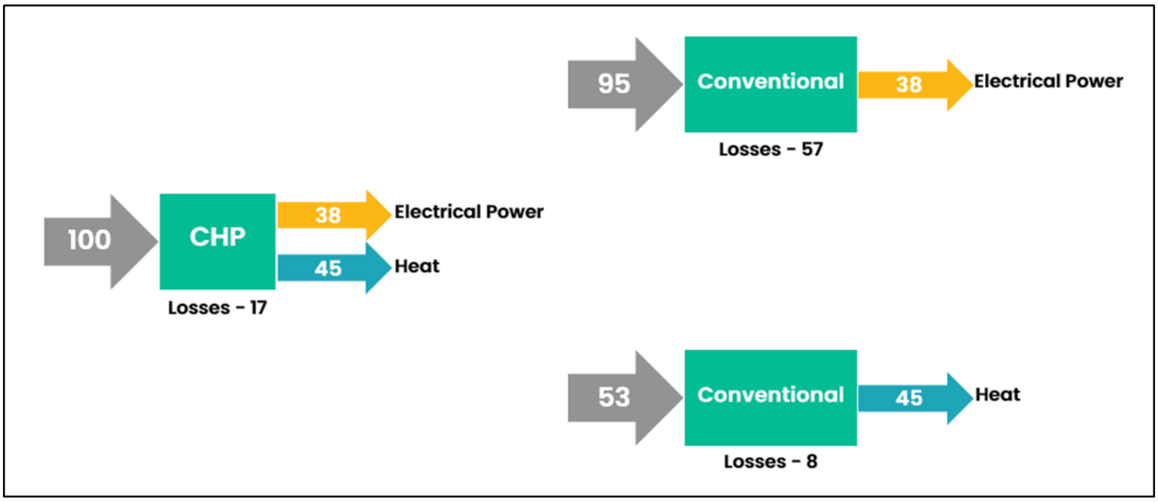

Figure 2.1: *CHP vs Separate Production.*

The most important aspect to highlight is the reduction of primary energy requirement. As can be seen from the figure 2.1, in the first case the primary energy consumption to obtain 38 of electricity and 45 of heat is supposed to be 100 units. In the case of separate production, however, to obtain the same result in terms of electricity and heat, the consumption increases by almost 50% with a value of 95 + 53 = 148 primary energy units. This result is mainly associated to economic and environmental savings since the fuel consumption is significantly reduced, but this is just one of the many positive aspects of CHP technology, other significant benefits are:

- lower environmental impact, resulting both from the reduction of emissions and the lower release of waste heat, meaning less air and thermal pollution;
- lower transmission and distribution losses for the national grid, due to the localization of these plants near the consumer areas or due to the self-consumption of produced energy;
- the replacement of less efficient and more polluting ways of supplying heat, such as boilers, which are characterized by a high environmental impact and less flexibility.

The most main users for cogeneration are those characterized by a constant demand over time of thermal energy and electricity, such as hospitals and care homes, swimming pools and sports centers as well as food industries, paper mills, oil refining and chemical industries. In the case of industrial applications, heat is generally produced at high temperature and pressure, but there are also situations in which heat is produced at different levels of temperature and pressure, especially in large industrial plants. In such cases, usually, the precious heat is used for processing, while the lower-temperature thermal energy is used to provide heating for workshops and offices.

In some industrial companies, CHP installations are already a well consolidated power generation option, which will be even more important in terms of contribution to national electricity demand and energy savings. Therefore, cogeneration is a very common practice in this sector, but in the last few years it has also expanded to the tertiary and residential sectors. An example of this is the expansion of small cogeneration plants, installed in utilities such as independent homes or apartment blocks. Even the district heating networks, which in Italy are mostly fed by heat produced by cogeneration, have recorded, in recent years, a constant increase both in terms of heated volumes and networks extension.

In addition, it is important to highlight that the exploitation of the useful heat produced by the CHP plants also for cooling, Tri-generation, allows to maximize utilization of the thermal energy, making profitable to use the plant for a greater number of hours per year.

2.2. Nuovo Pignone CHP plant

Nuovo Pignone Florence industrial plant is equipped with the following installations fed by natural gas:

- station for the superheated steam production supporting the steam turbine testing, consisting of two generators fed by natural gas with total capacity of 75 tons/h;
- 7 MW_{el} combined cycle cogeneration plant for electrical and thermal energy production and an auxiliary boiler;
- a series of boilers, which account for 5% of overall installed thermal capacity, mostly of condensing technology and used for space heating in several campus buildings.

We shall now focus on the second point, the CHP plant and its changes.

The current configuration of this system is a classic combined cycle for the electricity and heat production, consisting of a gas turbine, a heat recovery steam generator and a steam turbine, whose main components are the following:

- 4,7 MW_{el} gas turbine Nuovo Pignone PGT5;
- electric generator powered at one side by the gas turbine and at the other side by the steam turbine;
- 2 MW_{el} steam turbine Nuovo Pignone NG 25-20.

The steam turbine is fed by the steam at 50 bar pressure coming from the recovery steam generator and coupled in axis to the gas turbine.

As regards the gas turbine, its exhausts generated by the combustion of natural gas can be sent to the simple recovery system for the steam production and then vent, alternatively they are delivered to the by-pass chimney. A diverter system allows to automatically choose the operating configuration from the control panel: recovery configuration or simple cycle. The second option is the worst one and usually it's used for some hours or few days in case of fail or maintenance. As useful heat, it produces hot water to heat the workshops and some buildings in the plant by condensing the steam and recovering heat from the turbine exhaust. All the heat is then transported from the hot water fluid carrier by means of circulating pumps and is distributed to a series of radiant panels and in the plant's internal district heating network. The system is finally completed by an auxiliary boiler with reserve function to produce hot water.

Considering now the future CHP configuration, the following changes of the current layout are considered:

- installation of a new Nuovo Pignone LT5 5,35 MW_{el} gas turbine, exclusively fed by natural gas supplied from the national grid and equipped with a new generator;
- disconnection and disposal of the previous Nuovo Pignone PGT5 gas turbine, after more than 30 years operation;
- installation of a new heat recovery steam generator for the superheated steam production at 40 bar and 400 °C to feed the steam turbine, which remains unchanged as for its generator.

The thermal utility, consisting of the internal district heating circuit, will remain unchanged and the current back-up system, composed of the big auxiliary boiler, for the supply of heating will also not be modified.

In ISO conditions, the fact that the nominal electrical power of the new turbomachine is higher than before is due to the improved efficiency and lower specific fuel consumption. A detailed description of the new turbomachinery is given below.

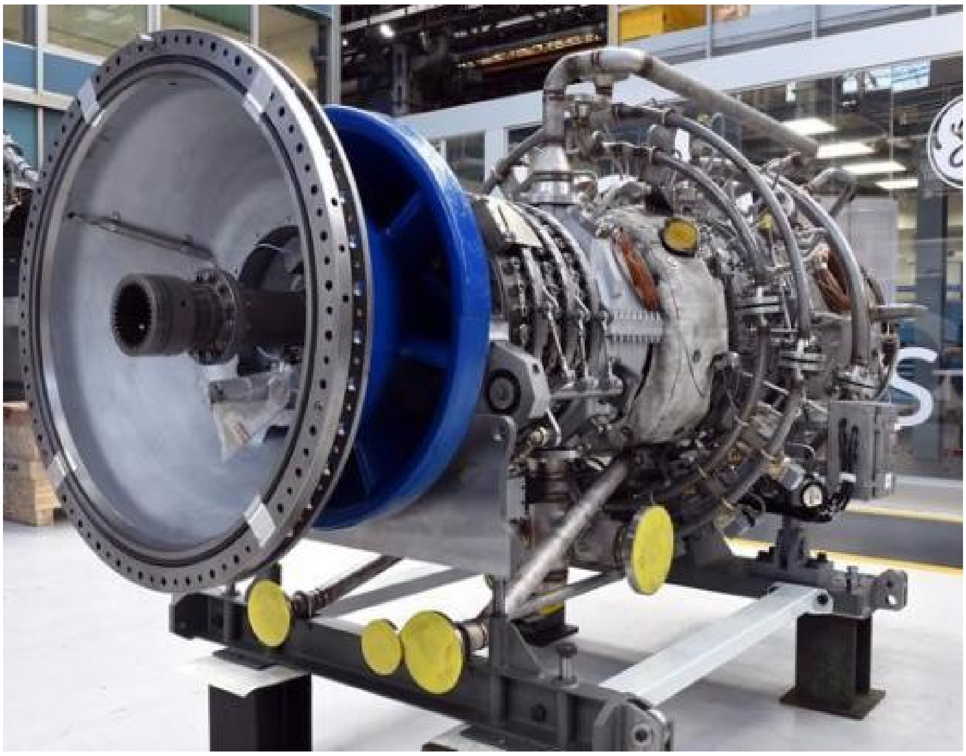

Figure 2.2: *NovaLT5, Baker Hughes' Gas Turbine.*

"Already proven in applications around the world, the new gas turbine NovaLT5 is a compact solution for a wide range of power generation, mechanical drive, and industrial applications. It is available in single-shaft and double-shaft configurations compactly designed, making

them ideal for operations with challenging footprint and height restrictions. Both have high efficiency, extended MTBM (Mean Time Between Maintenance) and significantly lower operating and maintenance costs. The high exhaust temperature of the single-shaft configuration is particularly advantageous for HRS (Heat Recovery System) operations". [5]

Below, are shown two tables, the first relating to the operating environmental conditions, while the second one comparing the machines in the two configurations, ante and post-operam:

Ambient reference conditions	
Ambient temperature	15 °C
Relative humidity	70%
Altitude	0 m
Ambient pressure	101,3 kPa

Table 2.1: *LT5 Ambient reference conditions.*

Nominal data	PGT5	LT5
Nominal Power [MW]	5,08	5,60
Electrical efficiency [%]	26,0	30,7
HTP speed [rpm]	11.140	16.630
Heat rate [kJ/kWel]	13.850	11.740
Exhaust temperature [°C]	543	574
Exhaust flow [kg/s]	25,8	19,6

Table 2.2: *LT5 vs PGT5 performance.*

Looking at the table above, table 2.2, the improvement achieved through the installation of the new turbomachine is related to:

- increased nominal power which means, with the same operational hours, a higher electrical producibility of the CHP and thus a reduction of cost for electrical energy consumption due to more advantageous contractual conditions and less purchase from the national grid;
- increased electrical efficiency and lower heat rate, so less primary energy needs, i.e. less natural gas consumption, which will reduce the carbon footprint of the plant and we will see how much this new turbomachine impacts in a dedicated paragraph;

2.3. CHP productivity vs consumption profiles

As we have seen in previous paragraphs, the Baker Hughes plant based in Florence was and still is served by a CHP installation, owned and operated by Nuovo Pignone until September 2018, which has now been sold to an Energy Service Company. In the best operational scenario, the size of the cogeneration permits to fulfill both thermal and electrical energy requirements during the off-peak hours with no absorption of power from the national grid, while in most of the cases the CHP is not sufficient to cover, at each moment, the consumption profile during the peaks. As an example, is reported in figure 2.3 a typical month, without any significative holiday periods, of the last year in which the CHP works continuously and without stops.

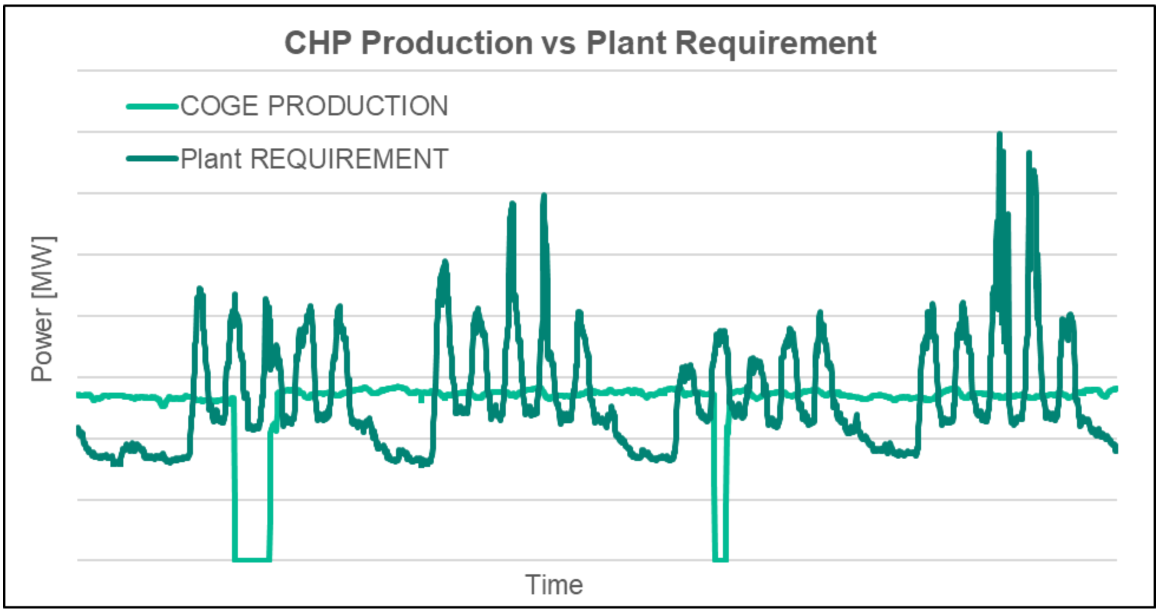

***Figure 2.3**: CHP production vs electrical need profiles.*

We can see that points characterized by a production lower than the electrical energy demand are periodically five, which indicate the hours of the five major working days. Vice-versa, the CHP's electrical load exceeds the consumption during off-peak periods, i.e. during weekends and at nighttime.

Now, if we analyze the monthly or annual data of the final balance, always assuming a good cogeneration's operation, appears that the availability of the cogeneration seems to be able to cover more than 90% of the electricity consumption. However, in the real scenario, characterized by peak loads during the working days, we see that a large amount of energy must be absorbed from the national grid. In fact, the 90% of electricity absorption concerns peak hours, i.e. Monday to Friday from 8 a.m. to 8 p.m., while demand is equally distributed between peaks and off-peak hours.

In fact, as shown in the following figure, during the five major working days we can see peaks of absorption, sometimes more evident than others but always greater than zero. Instead, the profile becomes zero during weekends and at night, which coincide with the areas where the CHP production exceeds requirements of the previous figure 2.3.

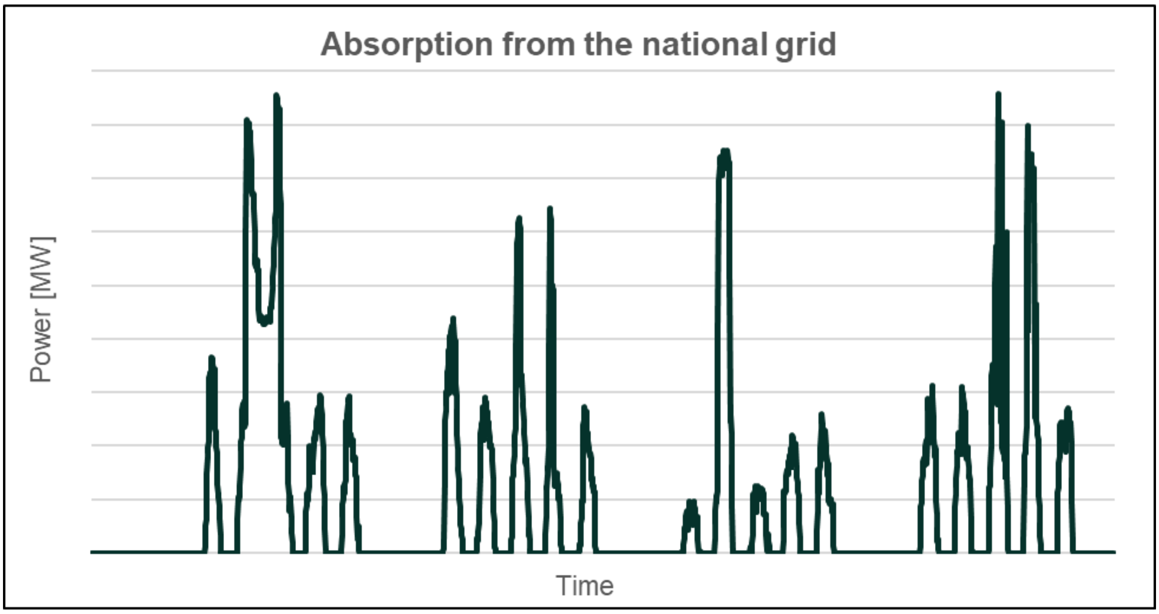

Figure 2.4: *Electrical energy absorbed profile.*

Consequently, the CHP is extremely important to meet the plant's requirements and obviously its relative purchase price of energy from the ESCO becomes the greater driver in the total computation of expenses. Regarding its importance in pursuing budgetary targets, the CHP's contractual aspects are discussed below, in a dedicated paragraph.

2.4. Contractual aspects of energy supply from CHP plant

As mentioned in the previous paragraph, since the last quarter of 2018, the CHP installation has been sold to an ESCO (Energy Service Company), which has become both a costumer and a supplier, the same as for our company and now it will be easier to understand what this means.

The ESCO becomes a customer since the plant mentioned above was sold in its current configuration and in addition the new gas turbine LT5, which will determine the future configuration of the plant, was manufactured and sold to the ESCO by Nuovo Pignone. At the same time, following the signing of a dedicated contract, this company has become a Baker Hughes's supplier of electricity and heat, as the new plant owner. From a commercial point of view the conclusion of this contract aims to be convenient for both companies, from the side of Nuovo Pignone the main benefits concern the sale of the new gas turbine, as mentioned, but also the purchase of energy at a cheaper price than those of the national grid, which means great and fundamental savings.

In the first period, corresponding to the current configuration, the supplier will provide to the costumer, Nuovo Pignone, electrical and thermal energy produced by the CHP following the contractual terms listed below:

$P_{EE,0}$ (€/MWh$_e$) is the reference price of electrical energy stipulated in 2018:

$$P_{EE,0} = XX + xx \cdot (1 - \frac{FT_{eff12m}}{FT_{ref}}) \quad (eq. 2.1)$$

where FT_{eff12m} is the annual thermal request related to the contractual year and FT_{ref} is a reference value, both are expressed in MWh$_t$.

$P_{EE,m}$ (€/MWh$_e$) is the monthly cost payed to the ESCO for the electricity supply:

$$P_{EE,m} = P_{EE,0} + k \cdot \left[\left(P_{gas,m} - P_{gas,0} \right) + \gamma \cdot (P_{CO_2,m} - P_{CO_2,0}) \right] \quad (eq. 2.2)$$

where $k = \frac{1}{(PCI_{gas \cdot \eta_e})}$ (kSm^3/MWh$_e$) is a representative coefficient of the production of electricity from natural gas considering the LHV (Lower Heating Value) of natural gas equal to 9,5 MWh/kSm^3 and the electrical efficiency of conversion. $P_{gas,m}$ and $P_{gas,0}$ are related to the natural gas price (€/kSm^3), the first is the monthly mean value of the TTF (Title Transfer

Facility), which represents the natural gas index in the Dutch market and the second one is a 2018 reference value. γ (ton_{CO2}/kSm^3) represents the CO_2 emission factor of the natural gas, while $P_{CO_2,m}$ and $P_{CO_2,0}$ (€/ton_{CO2}) are respectively the market price and 2018 reference CO_2 price.

$P_{ET,m}$ (€/MWht) is the monthly cost payed to the ESCO for the thermal supply:

$$P_{ET,m} = P_{ET,0} + k' \cdot \left[\left(P_{gas,m} - P_{gas,0}\right) + \gamma \cdot \left(P_{CO_2,m} - P_{CO_2,0}\right)\right] \quad (eq. 2.3)$$

where $k' = \frac{1}{(PCI_{gas} \cdot \eta_t)}$ (kSm^3/MWh_t) is equal to the previous coefficient, but in this case related to the production of thermal energy from natural gas, with its thermal efficiency. $P_{ET,0}$ (€/MWh_t) is the reference price of thermal energy stipulated in 2018, while the other terms remain constant.

Now, in order to forecast and calculate how much we will spend for electrical and thermal energy supply form the CHP system, owned by the ESCO, we have to consider the last two equations and in particular their variable terms such as $P_{gas,m}$ and $P_{CO_2,m}$ which follow the market trends, while the others are constant during the contractual year.

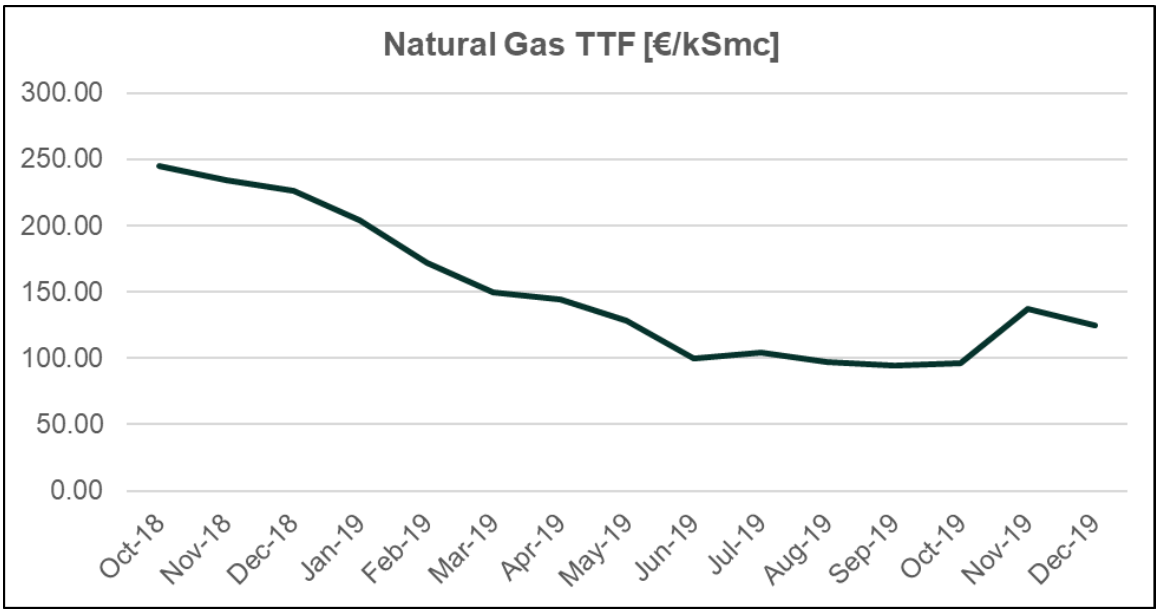

Figure 2.5: *TTF price trend [7].*

The natural gas index, shown in figure 2.5, coincides with $P_{gas,m}$ and is the variable that has the greatest influence on the prices of electricity and thermal energy supply. On the other hand, as far as CO_2 price is concerned, $P_{EE,m}$ and $P_{ET,m}$ are also affected, but in a less obvious way and with trends that are not directly proportional to those seen in the case of the TTF index. In fact, between October 2018 and December 2019 the general trend of $P_{gas,m}$ is decreasing, apart from two months and particularly November 2019, and therefore the same for the two contractual prices. Opposite evolution regarding the CO_2 price, which in the months considered has a fluctuating but generally upward trend. The considerations just made are clearly visible in the figures proposed below.

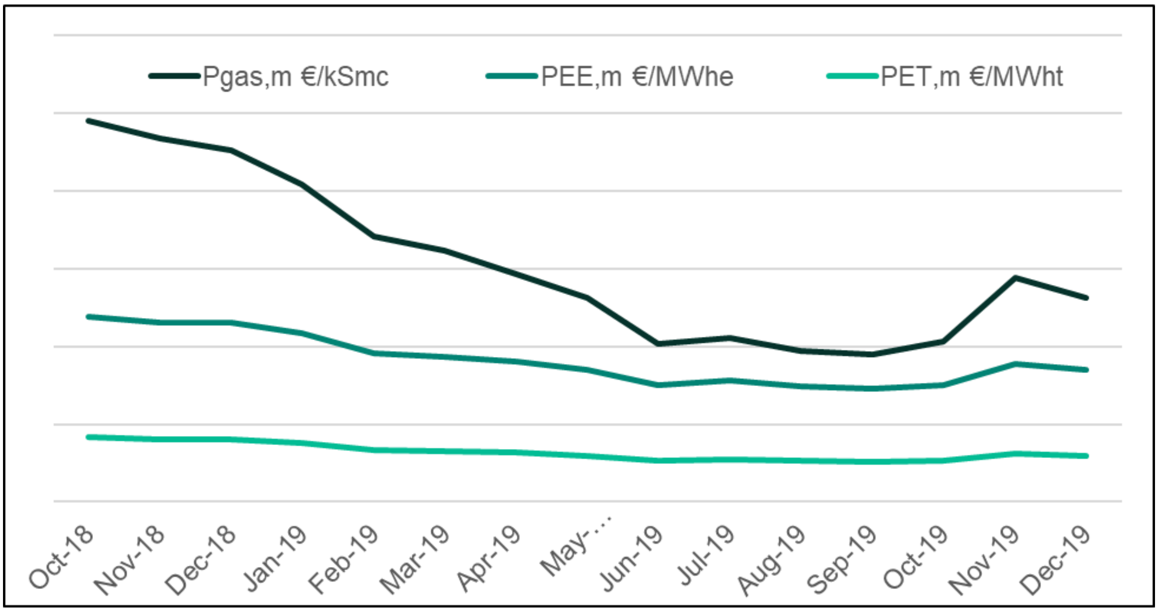

***Figure 2.6**: Comparison between P_{gas} and contractual prices.*

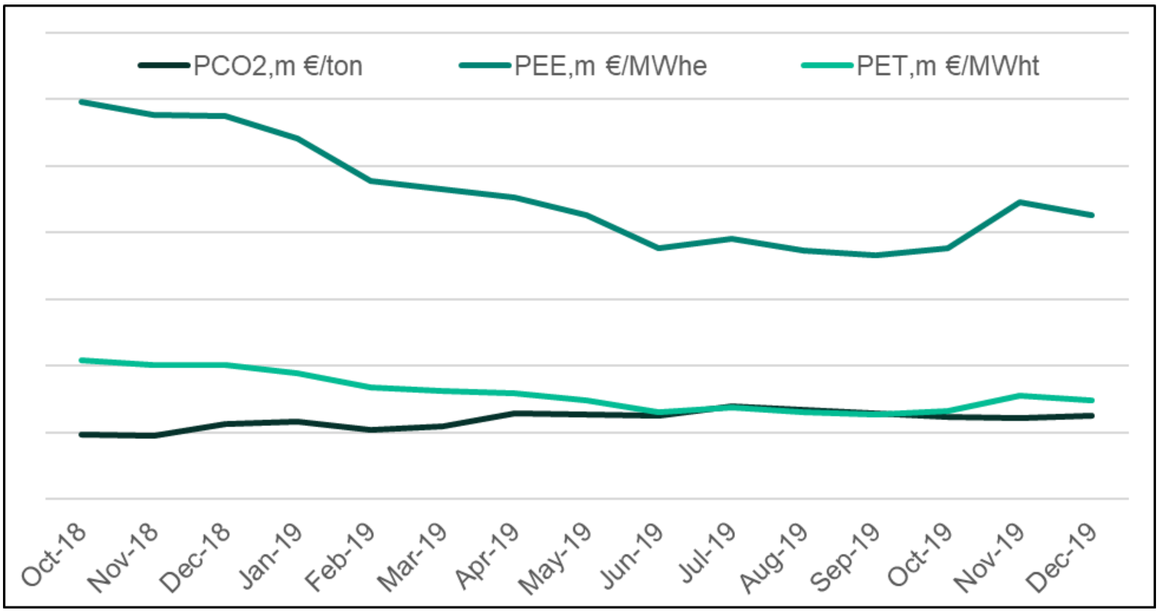

***Figure 2.7:** Comparison between P_{CO2} and contractual prices.*

These terms represent the company's expenditures for the electrical and thermal supply, but at the same time the supplier is required to ensure specific conditions. The most important is certainly the minimum CHP availability, also named Availability Guarantee, for both electrical and thermal energy.

In the case of electricity:

$$AG_{EE} = \frac{HEFF_{EE}}{HCOG_{EE}} > 80\% \quad (eq. 2.4)$$

where $HEFF_{EE}$ is the number of hours in which the gas turbine of the cogeneration system is effectively running and $HCOG_{EE}$ is the difference between the number of hours in which the costumer's requirement exceeds a certain value of power and the scheduled downtime for maintenance.

In the case of thermal energy:

$$AG_{ET} = \frac{HEFFINV_{ET}}{HINV_{ET}} > 98\% \quad (eq. 2.5)$$

where $HINV_{ET}$ is the total number of winter hours, for which the customer requests the thermal supply for space heating purpose and $HEFFINV_{ET}$ are the total hours during which the requested conditions are satisfied. During other periods of the year, different from the winter, the supplier is in any case required to ensure the thermal availability over 98%.

Another important aspect that must be guarantee by the supplier is related to the electrical power, in fact when the CHP installation is working the power output (PE_{EE}) must always be higher than the guaranteed power ($PGAR_{EE}$), which corresponds to the minimum value between the costumer's requirements ($PFABB_{EE}$) and the production capacity of the cogeneration (CP_{EE}), according to precise operating and climatic conditions.

2.5. Penalties related to energy supply

In some cases, due to the complexity of the CHP installation and its components, may happen that the contractual performances are not fulfilled. In this case the supplier is subject to certain penalties for which a special calculation model has been created and it will be dealt in detail below.

Power Penalty in the case in which the power output is lower than the guaranteed power with a 10% of tolerance:

$$Power\ Penalty\ [€] = (PGAR_{EE} \cdot 90\% - PE_{EE}) \cdot (PMarket - P_{EE,m}) \quad (eq. 2.6)$$

where PMarket is the sum of the PUN (Prezzo Unico Nazionale) and the general charges related to the variable components of the electricity bill, which follow the market's trend. In other words, PMarket corresponds to the price that would be paid for the electrical energy if it were absorbed by the national grid. The other terms are known and have already been defined previously.

Electrical Energy Availability Penalty in the case in which the electrical availability of the CHP is lower than AG_{EE}:

$$Availability\ Penalty\ EE\ [€] = PGAR_{EE} \cdot (HCOG_{EE} - HEFF_{EE}) \cdot (PMarket - P_{EE,m}) \quad (eq. 2.7)$$

Thermal Energy Availability Penalty in the case in which the thermal availability of the CHP is lower than AG_{ET}:

$$Availability\ Penalty\ ET\ [€] = PM_{ET} \cdot (HINV_{ET} - HEFFINV_{ET}) \cdot P_{ET,m} \quad (eq. 2.8)$$

where PM_{ET} is the costumer's reference thermal requirements, which has a fixed value in MW_t.

Thermal Energy Long Stop Penalty in the case in which the thermal requirement is not fulfilled for more than 3 consecutive days:

$$Long\ Stop\ Penalty\ ET\ [€] = 2 \cdot PM_{ET} \cdot (HINV_{ET} - HEFFINV_{ET}) \cdot P_{ET,m} \quad (eq. 2.9)$$

If this penalty is applicable the previous one is excluded and equal to zero.

The contract provides that in the future configuration of the CHP installation, i.e. when the new gas turbine LT5 is installed and working, some contractual constant values will change compared to the current state, in fact the electrical energy Availability Guarantee (AG_{EE}) will strongly increase, exceeding the current value, enlarging the applicability of penalties. Another change is related to Nuovo Pignone expenditure in terms of $P_{EE,m}$ which will decrease due to two aspects: the first is the growth of the electrical efficiency of conversion, the second is the lower value of the fixed terms XX and xx that determines a lower $P_{EE,0}$.

Contract modelling, useful to calculate the supply expenditures and any supplier's penalties, was carried out following a very precise procedure that now makes possible to obtain a table with the information needed to monitor contractual performance.

The first step regards the download of a monthly report, which contains data for every quarter of hour related to the power produced by the cogeneration system, absorbed by the grid and delivered to the grid, thanks to a sophisticated digital monitoring system. With these data available, a simple power balance equation allows to obtain the value of the plant's requirement as follows:

$$Requirement\ [MW] = Prod_{CHP} + Abs_{grid} - Deliv_{grid} \quad (eq. 2.10)$$

The figure below is an example of the report's download that has been described now.

	A	B	C	D	E	G	H	I
1	DATA	ORA	POTENZA EROGATA (MEDIA 15')	POTENZA ASSORBITA (MEDIA 15')	POTENZA PRODOTTA DALLA COGE (MEDIA 15')	POTENZA DI FABBISOGNO INTERNO (MEDIA 15')	UNITA DI MISURA	FASCIA ORARIA
23	1/7/2019	5:15:00					MW	OFF PEAK
24	1/7/2019	5:30:00					MW	OFF PEAK
25	1/7/2019	5:45:00					MW	OFF PEAK
26	1/7/2019	6:00:00					MW	OFF PEAK
27	1/7/2019	6:15:00					MW	OFF PEAK
28	1/7/2019	6:30:00					MW	OFF PEAK
29	1/7/2019	6:45:00					MW	OFF PEAK
30	1/7/2019	7:00:00					MW	OFF PEAK
31	1/7/2019	7:15:00					MW	OFF PEAK
32	1/7/2019	7:30:00					MW	OFF PEAK
33	1/7/2019	7:45:00					MW	OFF PEAK
34	1/7/2019	8:00:00					MW	PEAK
35	1/7/2019	8:15:00					MW	PEAK
36	1/7/2019	8:30:00					MW	PEAK
37	1/7/2019	8:45:00					MW	PEAK
38	1/7/2019	9:00:00					MW	PEAK
39	1/7/2019	9:15:00					MW	PEAK
40	1/7/2019	9:30:00					MW	PEAK
41	1/7/2019	9:45:00					MW	PEAK
42	1/7/2019	10:00:00					MW	PEAK
43	1/7/2019	10:15:00					MW	PEAK

Figure 2.8: *Report CHP Power data.*

The next step, which leads into the detailed contract modelling, consists in the calculation of parameters and contractual conditions necessary to obtain the final result, i.e. the calculation of penalties:

	PGAR,ee	DELTA_P	HFABB (MW)	PFABB> PEee	PEee < 0,9*PGAR	PENALE SI/NO	PENALE POTENZA [€]	PENALE ORARIAee [€/h]	PENALE DISPee [€]	HINVet [h]	HEFFINVet [h]	ΔHconsec	PENALE DISPet [€]	PENALE FERMOet [€]
23			FABB	SI	SI	Penale								-
24			FABB	SI	SI	Penale								-
25			FABB	SI	SI	Penale								-
26			FABB	SI	SI	Penale								-
27			FABB	SI	SI	Penale								-
28			FABB	SI	SI	Penale								-
29			FABB	SI	SI	Penale								-
30			FABB	SI	SI	Penale								-
31			FABB	SI	SI	Penale								-
32			FABB	SI	SI	Penale								-
33			FABB	SI	SI	Penale								-
34			FABB	SI	SI	Penale								-
35			FABB	SI	SI	Penale								-
36			FABB	SI	SI	Penale								-
37			FABB	SI	SI	Penale								-
38			FABB	SI	SI	Penale								-
39			FABB	SI	SI	Penale								-
40			FABB	SI	SI	Penale								-
41			FABB	SI	SI	Penale								-
42			FABB	SI	SI	Penale								-
43			FABB	SI	SI	Penale								-
44			FABB	SI	SI	Penale								-
45			FABB	SI	SI	Penale								-
46			FABB	SI	SI	Penale								-
47			FABB	SI	SI	Penale								-
48			FABB	SI	SI	Penale								-
49			FABB	SI	SI	Penale								-

Figure 2.9: Report Contractual Parameters.

Next, a new worksheet, linked to the previous one, has been created. At this point in addition to the data calculated before, the parameters related to the market prices are manually entered in special cells and the final result of monthly penalties is summarized, figure 2.10, in which the values entered have a consistent order of magnitude, despite being fictitious and simply for example purpose.

	B	C	D	E	F	G	H	I
2	1)							
3	2)							
4	3)							
6	NB	Prestare attenzione al mese analizzato:				WINTER?	YES	selezionare YES/NO dalla tendina
8	P MEDIA	3,8	MW	CONSTANT				
10	CP EE	5,4	MW	CALC				
12	PET,m	45,00	€/MWht					
13	PEE,m	120,00	€/MWhe					
14	PUN	65,00	€/MWh					
15	ONERI	85,00	€/MWh					
16	P Mercato	150,00	€/MWh	CALC				
18	H FABB	739	h	CALC				
19	H MANUT	0	h	da inserire manualmente: fermate di manutenzione PROGRAMMATE				
20	H COG EE	739	h	CALC				
21						AG EE	79%	CALC
22	H EFF EE	585	h	CALC				
24	H INV	744	h	CALC				
25						AG ET	57%	CALC
26	H EFF INV	424	h	CALC				

	O	P	Q	R	S	T
2	PENALE	POTENZA	0,00	€	CALC	
3	PENALE	DISP EE	24.525,44	€	CALC	
4	PENALE	DISP ET	11.970,00	€	CALC	
5	PENALE	FERMO ET	3.462,75	€	CALC	
7	PENALE	TOT	39.958,19	€	CALC	output

Figure 2.10: *Monthly Penalty Report.*

In order to have a more global idea of penalties value and to follow more precisely the contract, which provides for a yearly and not monthly calculation of penalties, an annual summary has been created in a separate worksheet, represented in the figure 2.11 below. Despite this, the monthly sheets give an extremely efficient and useful picture of the CHP scenario.

	CP EE [MW]	AG EE [%]	Calculated Penalty [€]	ART 9.6 [€]	CALC Pen/9.6 [%]	CALC Applyable Penalty [€]
Oct-18						
Nov-18						
Dec-18						
Jan-19						
Feb-19						
Mar-19						
Apr-19						
May-19						
Jun-19						
Jul-19						
Aug-19						
Sep-19						
TOT						

Figure 2.11: *Annual Penalties' Summary.*

In the figure two different penalties are entered because the contract stipulates that the full disservice is not paid to the costumer, but at most a certain percentage of what Nuovo Pignone pays in the bill to the ESCO and art 9.6 represent a specific contractual article, related to the electrical energy supply. However, even just the partial reimbursement in the form of penalty of the inefficiency attenuates the delta of expense between the advantageous contractual price and that of national grid absorption.

The influence of this price difference has been the subject of an in-depth analysis of the electricity market, applied to the supply characteristics and needs of Nuovo Pignone's plant.

3. Electrical energy

3.1. The electricity market and its trend

In Italy, the price of electricity is closely related to the PUN (Prezzo Unico Nazionale), i.e. the reference price of electricity quoted on the Italian electricity exchange, IPEX (Italian Power Exchange). The value of the PUN is published and defined by the GME (*Gestore dei Mercati Energetici*) as the average of the zonal prices of the Day Ahead Market weighted with the total purchases, excluding pumping systems and foreign areas. Its values and trend, concerning the last ten years, are shown respectively in the table and the figure below. [6]

	PUN €/MWh	%V
2010	64,12	
2011	72,23	13%
2012	75,48	4%
2013	62,99	-17%
2014	52,08	-17%
2015	52,31	0%
2016	42,78	-18%
2017	53,95	26%
2018	61,31	14%
2019	53,04	-13%

Table 3.1: *PUN index, GME – [6] www.mercatoelettrico.org.*

The 2019 has been characterized by a decrease of 15% after two years of increase of the index, returning approximately to the values reached in the two-year period 2014-2015, but as we will see this trend of deflection does not reflect the €/MWh spent for the power supply. From figure 3.1, instead, it is noted how much the PUN index's value fluctuates month over month and therefore how much it can be insufficient to dwell only on its annual average, that however gives an idea of the market's general trend at a higher level.

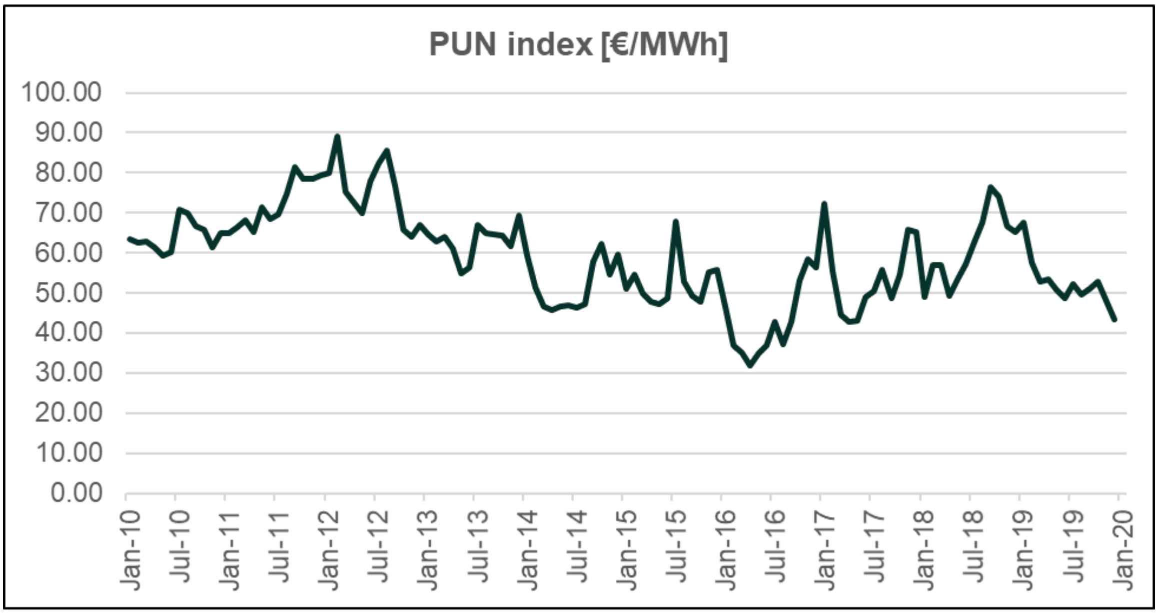

Figure 3.1: *PUN index trend. [6]*

Pursuing energy management goals we realize how much the electricity market has a key role in determining consumption costs for all companies and this applies even more in the case of Nuovo Pignone, for which the focus is on a great manufacturing industry characterized by very volatile power trends during the year, related to highly variable volumes, mainly due to testing activities and periods of stronger productivity and that is why we often talk about power instead of energy, in fact it happens that the power peaks are occasional and have a duration of few hours or even minutes.

In the following part are shown three figures, 3.2, 3.3 and 3.4, in order to show how the two unitary prices of electricity supply are correlated between each other and the PUN index.

In the first one we can see that the purchase energy from the national grid and the national market index are partially correlated, but the behavior of the two curves does not follows the same trend and this is also strictly related to the monthly CHP’s availability, as we will see in the paragraph about the purchasing of energy from the national grid.

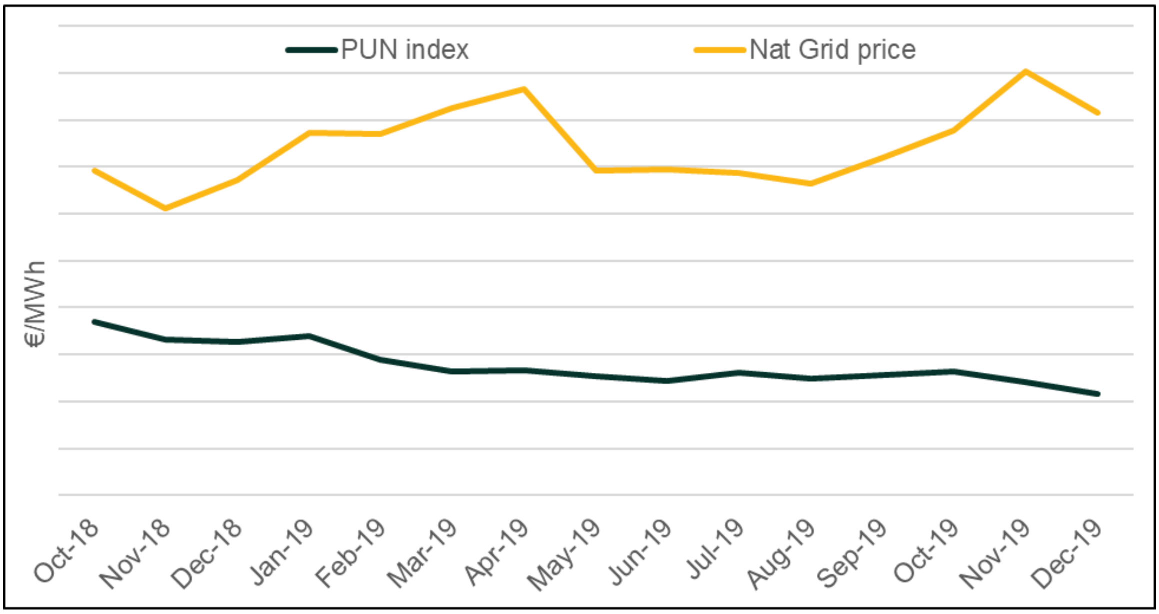

Figure 3.2: *PUN vs National Grid price.*

The second one, figure 3.3, compares the PUN index with the ESCO's contractual price, where the correlation between the two curves is almost always directly proportional as we can imagine after the understanding of the CHP's contractual terms.

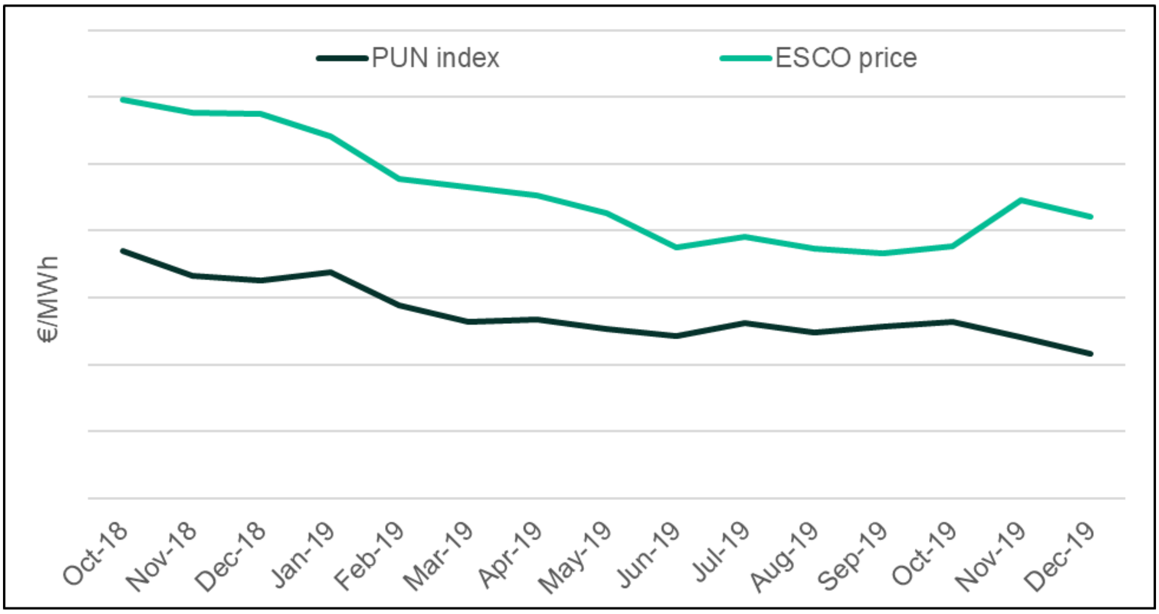

Figure 3.3: *PUN vs ESCO's supply price from CHP.*

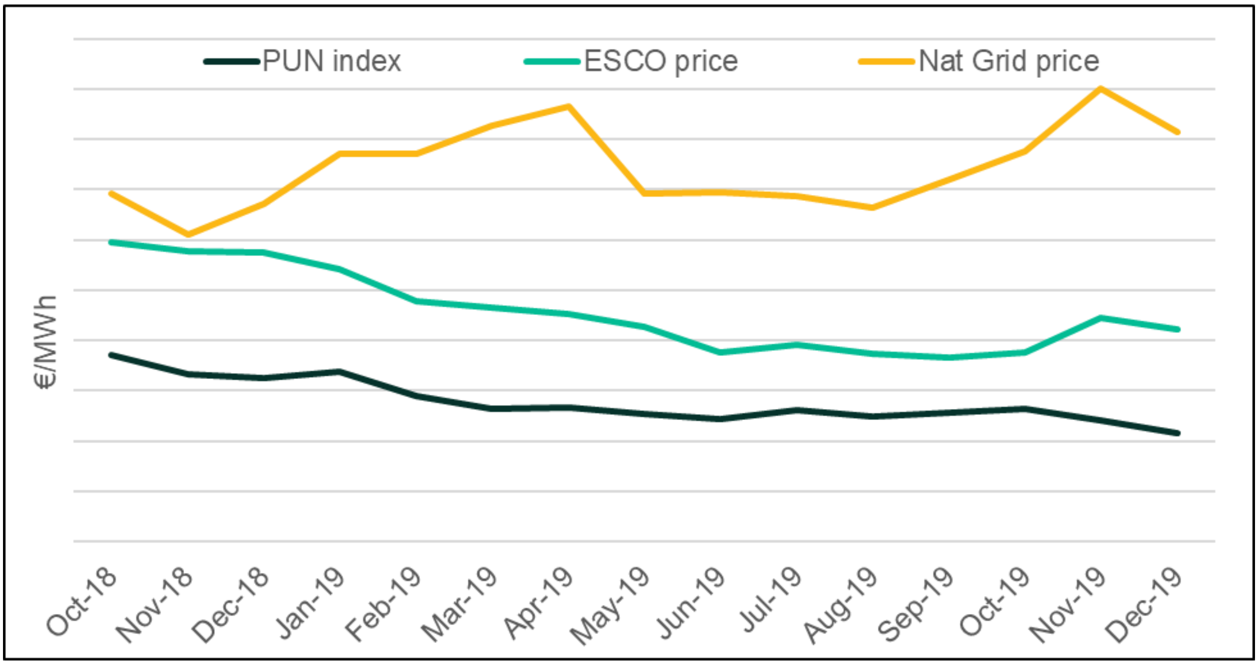

Figure 3.4: *PUN vs ESCO's supply price from CHP vs National Grid price.*

With reference to the graph above, can be seen that the price of energy absorbed by the national grid differs from the PUN index trend and this is mainly based on two reasons: one of a contractual nature, the other related to the company's business and its monthly demand in terms of both energy and power. These aspects will be covered in the dedicated paragraphs below.

3.2. Contractual aspects of energy supply from the national grid

The absorption of electricity from the national grid is regulated by a contract, which is signed annually, between the consumer and the chosen supplier. Its choice is based on an offer evaluated more suitable in terms of general flexibilities and financial competitiveness than those received from other energy sellers, in negotiation phase. The total unitary price - €/MWh - of the purchase electrical energy is historically determined by a series of subcategories thus composed:

- commodity consumption price, which is divided in peak and off-peak, depending on the time at which the energy is absorbed, that represents more than 40% of the total price;
- general system charges, with an average impact of 2% less than the previous one;

- dispatching services and transport price, around 10%;
- transport price, with the remaining 10%.

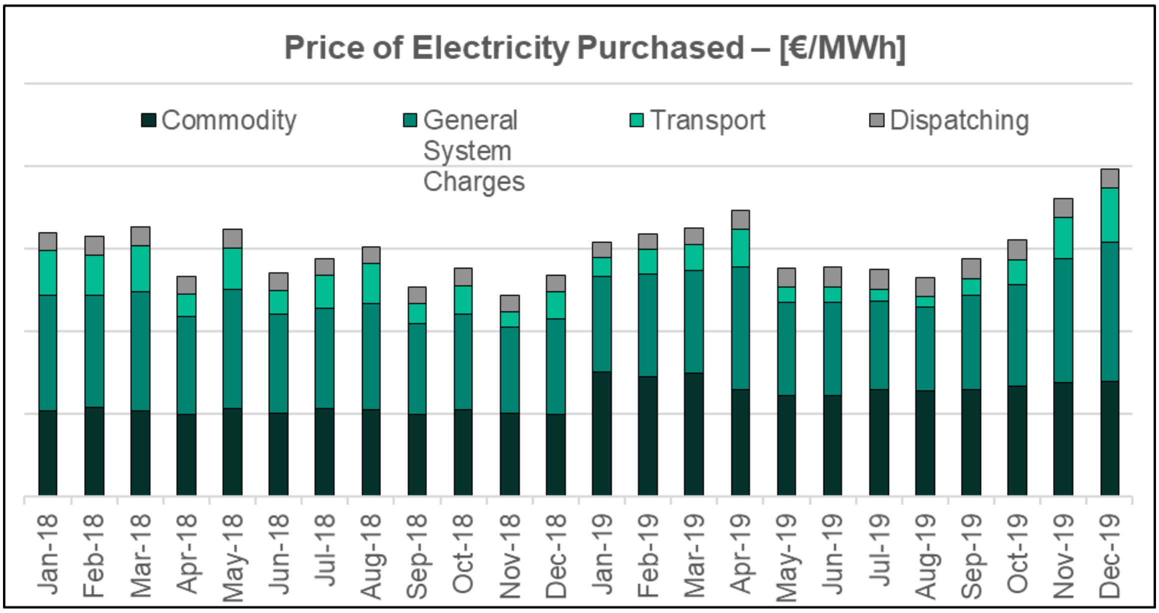

Figure 3.5: *Final electricity price contributions.*

As might be expected, the global trend is impacted mainly by the first two mentioned prices: commodity price and general system charges.

Regarding the first bullet, which represents a commodity product, the contracts allow to follow two different paths: to maintain the fixed purchase price during the year or to leave it uncovered and fix it gradually over the months generally at the rate of 25, 50, 75 or 100%, subject to prior communication in accordance to what has been stated in the contract. The decision on the method of fixing the price is a costumer's responsibility, according to the market price and to the forecasting on the consumption volumes required in the following months of the year, considering that the uncovered price may be profitable in certain market scenarios and, at the same time, risky when the signing of the contract was concluded during a period of particular depression of the power market. In order to be flexible enough without exposing to excessive risks, it's preferable to avoid the two extreme positions: totally open and 100% fixed, but there are not general or right rules on this topic.

Other significant topics related to the consumption price, also named commodity price, are the reliance on:

- the monthly power peaks, which are very fluctuating in time, being mainly related to the testing activities. These peaks, as the name suggests, are "payed" in terms of power and not of energy, because they are typically of short duration, while the energy is the result of a more continuous and typically lower power;
- the CHP workload, which strongly affects the needs of electrical energy absorption from the national grid. The less energy is produced by the CHP, the higher the absorption from the grid and consequently the less its related price, while the expenditure is obviously higher, but as we have seen the optimal scenario is the one in which the CHP run at full load, which determines an expenditure decreasing.

These two aspects are visible from the figure below, although the contractual fixing remains the dominant variable in the determination of this price.

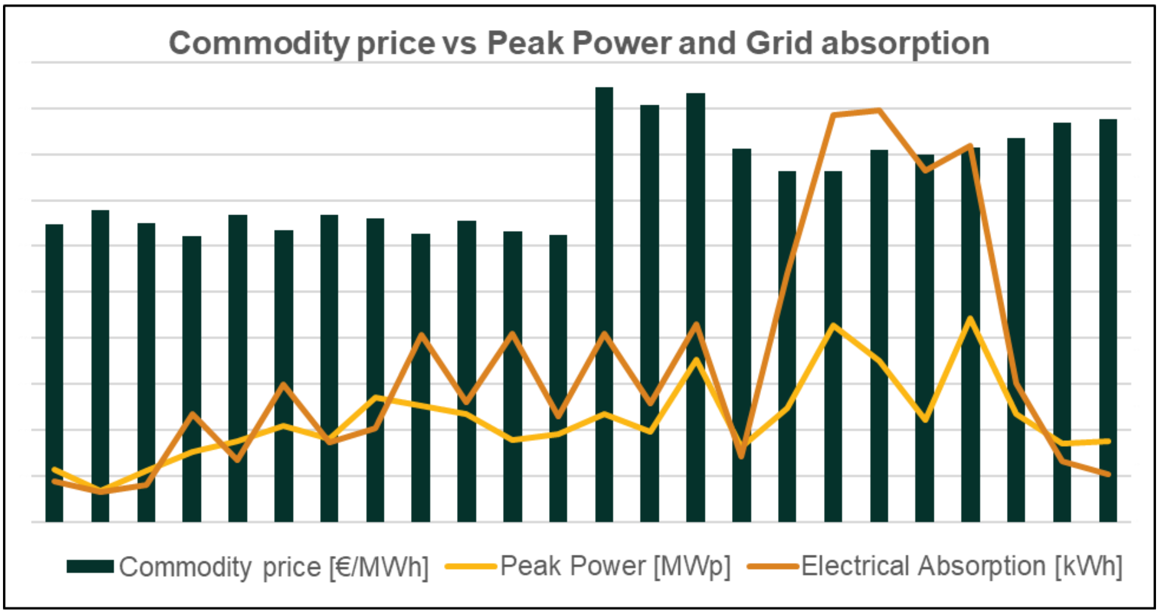

Figure 3.6: *Commodity price vs Peak Power and grid absorption.*

The dispatchment price follow supplier's issues and national laws, so the costumer has no power and control on its negotiation and forecasting, while the general system charges and the transport price vary during the year, almost following an inverse proportional trend with respect to the energy absorption profile.

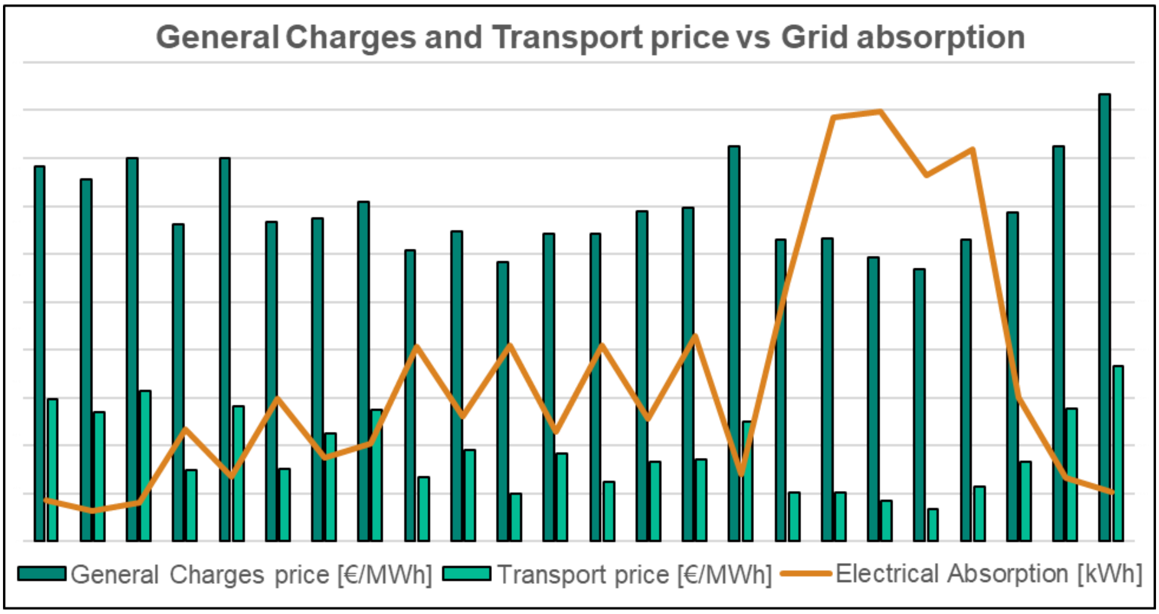

Figure 3.7: General charges and transport price vs grid absorption.

This trend can be explained, another time, considering that periods of considerable absorption volumes are characterized by lower unitary prices, despite the total expenditure will result higher, since:

$$Expenditure\ [€] = unitary\ price\ [€/MWh] \cdot absorption\ volume\ [MWh] \quad (eq. 3.1)$$

After examining in detail the market and contractual scenarios related to the electrical energy, in the next chapter we will discuss the same topics, but connected to natural gas world, which, as we have seen, is the second most impactful consumption of the Nuovo Pignone's site.

4. Natural gas

4.1. The natural gas market and its trend [7]

In Europe, the benchmark index for the natural gas market is the Dutch's TTF (Title Transfer Facility), i.e. a trading platform where the gas, flowing in the European's network, can virtually be sold and bought. This price has a great impact on the other energy sources prices as natural gas is considered to be the fuel that will drive the energy transition towards a "green" future, and it is still widely used in large-scale power generation plants. TTF's value and related trend in the last year, expressed in €/MWh, is shown in the following table.

	TTF €/MWh	%V
Jan-19	21,44	-10%
Feb-19	18,03	-16%
Mar-19	15,71	-13%
Apr-19	15,18	-3%
May-19	13,44	-11%
Jun-19	10,49	-22%
Jul-19	10,95	4%
Aug-19	10,20	-7%
Sep-19	9,93	-3%
Oct-19	10,10	2%
Nov-19	14,42	43%
Dec-19	13,11	-9%

Table 4.1: *TTF trend 2019. [7]*

These monthly prices are calculated as the monthly average of the Day-Ahead prices [7], and then converted in €/Sm^3, multiplying by the natural gas's Lower Heating Value, expressed in MWh/Sm^3.

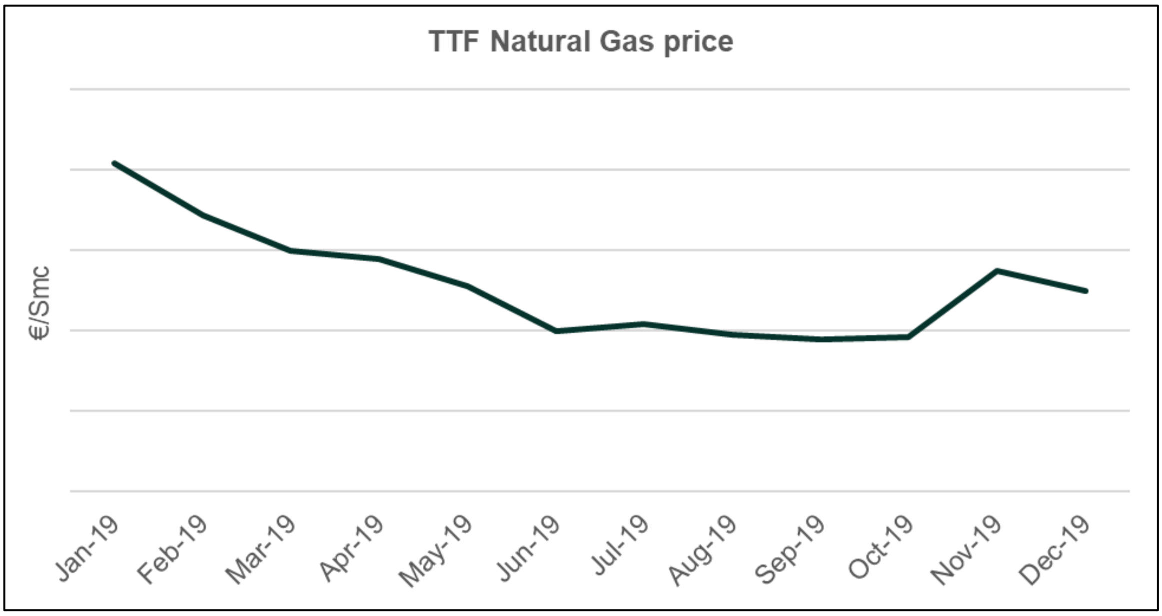

Figure 4.1: *TTF monthly trend, 2019. [7]*

In the figure above is represented the monthly trend of the TTF price during the last year, but if we want to see its real day by day trend, characterized by a high volatility, a more detailed figure is then reported.

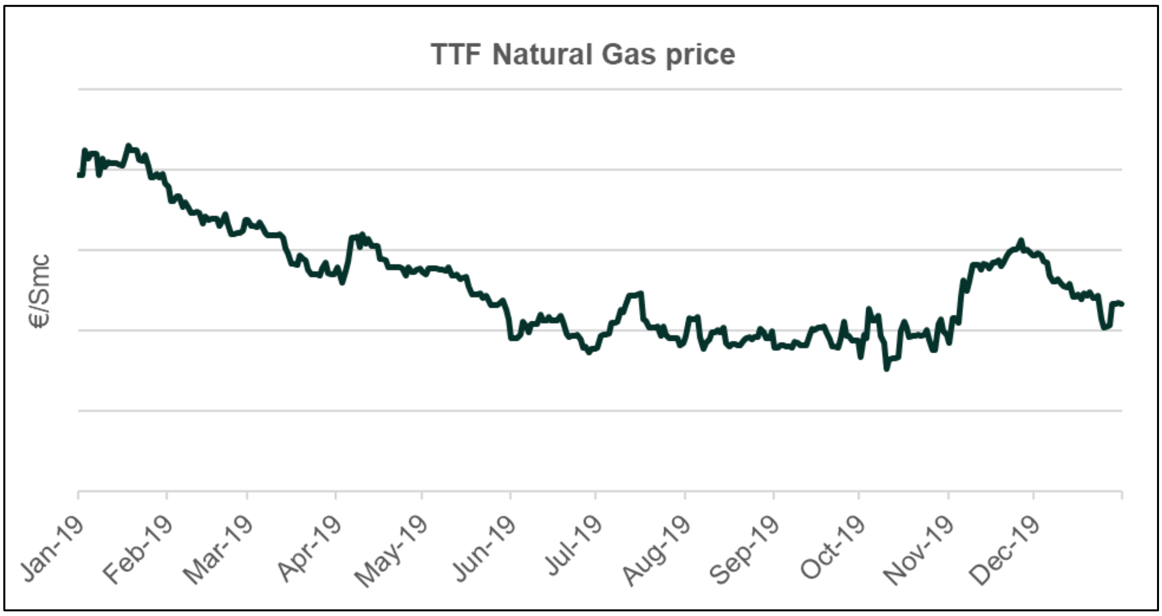

Figure 4.2: *TTF daily trend, 2019. [7]*

As we expected from the table and from the previous graph, the period of the last year characterized by the higher variance is November, with its + 43% compared month-by-month, while the others have generally a decreasing trend.

The TTF price has a great impact on the bill price of the natural gas supply and its trend is directly proportional to the commodity price, which represent the higher contribution, an average of 85% on the final price of the natural gas, excluding the fixed term which will be dealt separately. This proportionality is clearly visible in the figure below, figure 4.3.

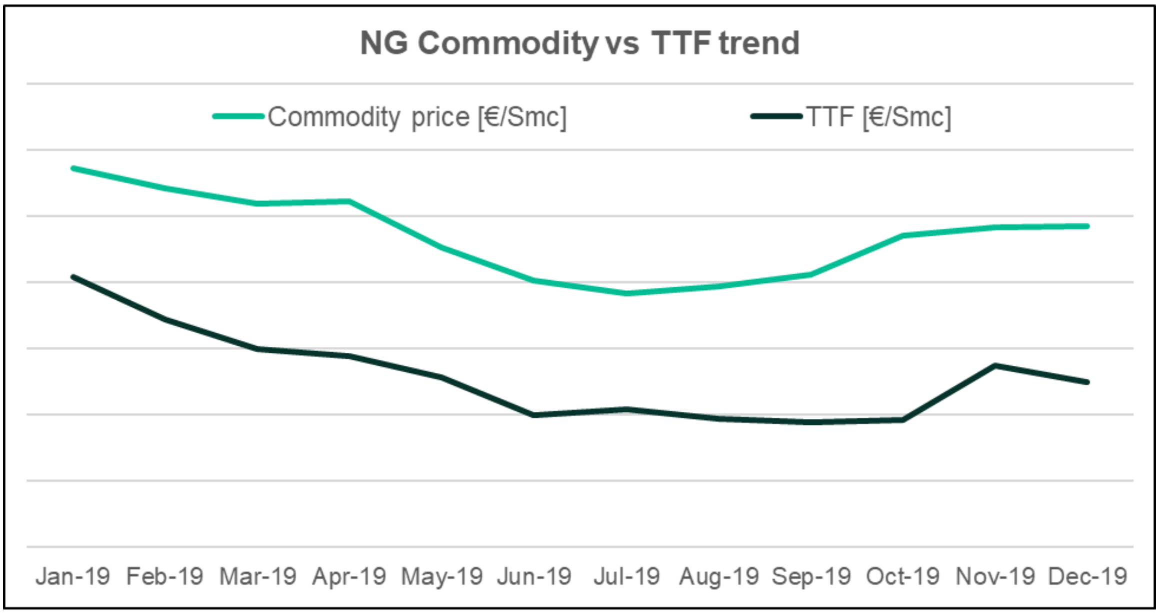

Figure 4.3: *Commodity price vs TTF trend, 2019.*

Also for natural gas, as in the case of electricity, the commodity/consumption price is regulated by contracts which allow to fix the purchase price during the year or to leave it uncovered and fix it gradually over the months generally at the rate of 25, 50, 75 or 100%, subject to prior communication, always in accordance to what has been stated in the contract. The decision on the method of fixing the price is another time a costumer's responsibility and there are not general or right rules on this topic, but the continuous analysis of market data followed by fixing action in high deflation periods can help to better forecast future scenarios and to determine cost avoidance.

Other terms which contributes on the final purchase price of natural gas, excluding the contribution of the fixed term, are:

- General system charges price, 10%;
- Taxes, 5%;
- Transport price, 1%.

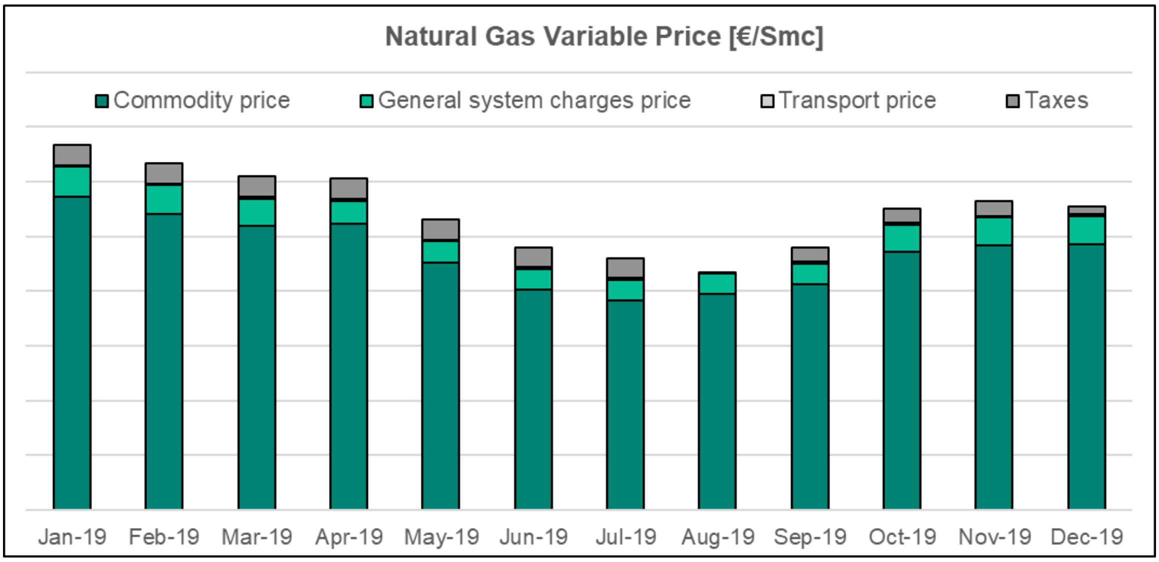

Figure 4.4: *Composition of NG variable price, 2019.*

In conclusion, we can affirm that, due to consumption/commodity contribution of 85% on the final price, also the latter is strongly affected by the TTF trend, when the yearly fixing is not complete, while other prices follow national and network laws as in the electricity case.

However, in order to have a global view on the total price, it is necessary to address the distribution of consumption and its daily peak. This aspect introduces an additional cost related to the supply of natural gas, which is an important portion of the total expenditure and, if accurately investigated and managed, can guarantee significant savings.

4.2. Contractual natural gas fixed term

It is worth making a dedicated speech regarding the natural gas daily capacity, which constitutes what is contractually called "fixed term". This term is directly associated with the maximum natural gas daily capacity: Sm^3/day. It is notified to the supplier at least one month before the beginning of the contractual year and involves it in the bill, directly proportional to its magnitude: the higher it is, the greater the expenses.

The fixed term represents the threshold which must not be exceeded during any day of the year, except within a certain degree of tolerance, if you don't want to sustain the payment of very high penalties able to offset to zero any saving, related to the fixed term reduction, or even to increase expenditure, thereby causing greater financial losses. It is also important to stress that, once it has been agreed, the fixed term cannot be reduced during the contractual year and therefore, in order to find the optimal value able to generate economical savings and the fulfillment of natural gas needs, the topic must be examined in detail.

An in-depth analysis was carried out on the basis of historical trends, but especially in forecast of future needs, whose daily peak depends basically on the test activity, in fact, it is difficult to expect a significant annual variation in daily natural gas demand driven by heating needs, while testing can lead to larger variations.

The turbomachinery testing is managed by a proper business area within the company. Through communication and joint work with this area it is possible to have information about the planning of the tests during the year and the size of the tested turbomachines. At this point you can start to estimate the involved natural gas volumes, not so much focusing on the monthly consumption as on its possible daily peak, which is strictly related, as stated above, to the size of the machine and the timing in terms of simultaneity.

If you look at the figure below, you can see the natural gas daily consumption trend of the last two years with respect to the contractual statement and understand by which approach you determine the final value of the fixed term.

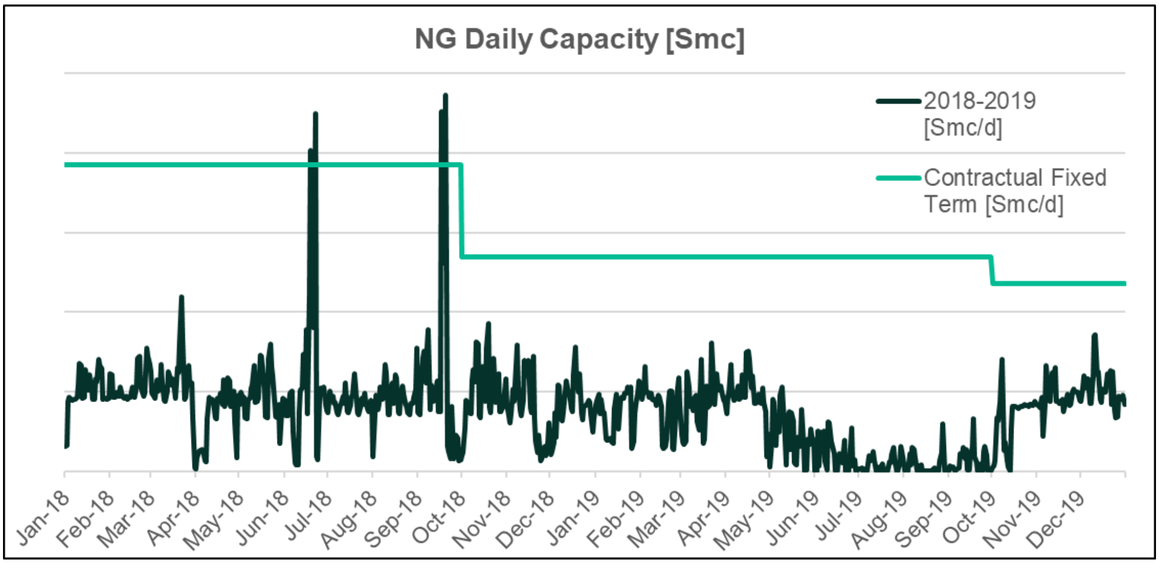

Figure 4.5: *NG daily capacity, 2018-2019.*

The contractual year including the last months of 2018 was characterized by the testing of high-power turbomachines and, as we can see from the curve, the natural gas daily volume has exceeded the contractual threshold twice, in separate months, but during the others the volume was always been far below the limit. This means that the forecast has been generally good, although June and October have seen an unexpected daily volume which has leaded to two penalties and was too overestimated for other months. If the value of the fixed term had been lower, guaranteeing savings during low-capacity months, the expenditure would certainly have been higher due to huge penalties. After this period the natural gas capacity has been lowered by 30%, resulting overestimated but able to avoid penalties during the whole year. Finally, the last amendment was made at the beginning of the new contractual year, with a further 12% reduction that in the first three months proved to be cost-effective compared to the previous year and at the same time the threshold has never been exceeded by the daily volumes. In conclusion the fixed term contractual reduction of 2019 vs 2018 generates a related cost reduction of 48% and the forecast for the next 2020 see an additional cost reduction around 25%.

It appears clear from the above considerations that the fixed term, once formalized, is independent from the consumption volume, which instead constitutes the variable part. The average incidence of the fixed term on the total expenditure, in the last year, has been around 35% with monthly peaks of more than 50% when the consumption is low, as is shown in the figure below, figure 4.6.

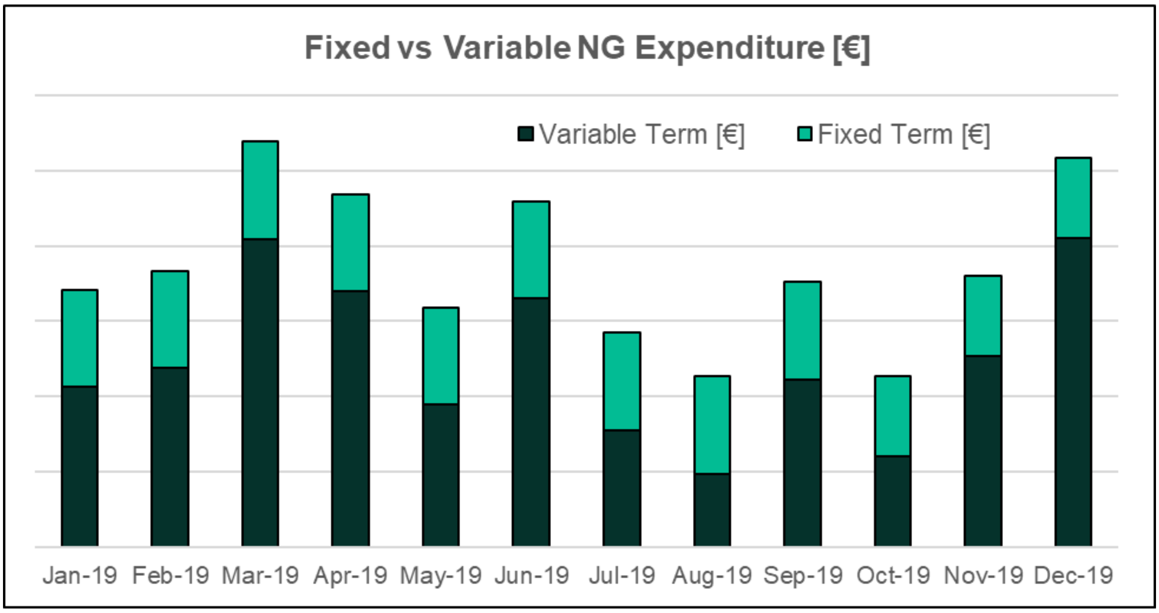

Figure 4.6: *NG Fixed vs Variable term, 2019.*

In this figure only 2019 is considered because, as we have seen in the energy commodity subdivision paragraph, the CHP sale has strongly influenced the Nuovo Pignone natural gas consumption and therefore it would be inappropriate to compare two such different scenarios.

This paragraph is followed by a very relevant topic for the industrial world, strictly related to the natural gas combustion, which is the greenhouse gas emission and related European regulation.

5. The EU Emission Trading System

5.1. Operating policy [8]

The EU ETS is one of the cornerstones of the European Union's climate change policy and an essential mechanism for a cost-effective reduction of greenhouse gas emissions. It remains the largest carbon dioxide (CO_2) trading market in the world.

This system works by putting a limit on overall emissions from covered installations which is reduced each year. Within this limit, companies can buy and sell emission allowances as needed. Its approach gives the flexibility that companies need to cut their emissions in the most efficient way. *"The EU ETS covers approximately 11.000 power stations and manufacturing plants in the 28 EU Member States plus Iceland, Liechtenstein and Norway, as well as aviation activities. In total, around 45% of total EU emissions are regulated by this system."*

The European Union launched the EU Emission Trading System in 2005 by putting a price on carbon emissions and thereby giving a financial value to each saved CO_2 ton, in this way the ETS promotes investment in clean and low-carbon technologies worldwide.

The EU ETS working principle is defined *"Cap-and-Trade"*: the overall volume of greenhouse gases that can be emitted for a multi-year phase by the power plants, factories and other companies covered by the system is subject to a cap set at EU level. Within this cap, companies receive or buy emission allowances which they can trade, if they wish to do so.

5.2. Phases

The ETS is divided in four main phases, which differ one to the other and are:

- Phase 1: 2005-2007;
- Phase 2: 2008-2012;
- Phase 3: 2013-2020;
- Phase 4: 2021-2030.

The necessity for instruments to achieve the targets set by the Kyoto Protocol, in terms of CO_2 emissions, was the main driver for the adoption of the EU ETS. Finally, the Directive started in 2003 and became operational two years later, in 2005.

The first phase was a pilot project for the second phase, by establishing a price for carbon with a emission allowances trade across the European Union and by creating the infrastructure needed conditions to verify emissions from all the included businesses, which were the ones of power generation and of the industrial sector, characterized by high energy-intensive activities. In this first phase, almost all allowances were given to businesses for free and therefore first phase's allowances could not be banked for phase 2. Non-compliance with the EU ETS Directive had a cost of around 40 €/ton. [9]

Phase 2, started in 2008, has for the first time set specific emissions reduction targets to achieve for the different countries of the European Union, according to the Kyoto Protocol. The main differences between the phase 2 and the phase 1 were: lower cap on allowances, Iceland, Liechtenstein and Norway joined the EU ETS and the penalty for non-compliance became 100 €/ton, 150% increase compared to phase 1. Another new key element was the inclusion of the aviation sector in the Emission Trading Scheme in 2012, despite flights to and from non-European countries was not considered for 2012. [9]

During the current phase 3, "*auctioning becomes the default method for allocating emission allowances to companies participating in the EU emissions trading system and initially was expected that 57% of the total amount of allowances will be auctioned"*. However, remain sectors for which the auctioning is still not the default method and for which this period is considered transitional. In 2013, manufacturing industry has received around 80% of its CO_2 allowances need for free, but over this period the free allowances provided by the EU ETS have gradually decreased to 30% in 2020. The linear reduction factor was set in line with the EU-wide climate action targets for 2020: the overall 20% emissions reduction target relative to 2005. [10]

The fourth phase, which will go 2021 to 2030 is the last phase planned by the European Union for the next decade. This phase is set in order to achieve the EU's overall greenhouse gas emissions reduction target for 2030: 43% of CO_2 emissions reduction compared to 2005 levels. One important aspect regards the number of free emission allowances, which will yearly decrease by 2,2% from 2021 onwards, compared to the 1,74% currently.

In addition, the MSR (Market Stability Reserve), i.e. the mechanism established by the European Union to reduce the surplus of emission allowances in the carbon market and to improve the ETS's resilience to future shocks, will become more effective by 2023, when the amount of allowances put in the reserve will overlap the allowances in circulation. *"As a long-term measure to improve the good functioning of the EU ETS, from 2023 onwards the number of allowances held in the reserve will be limited to the auction volume of the previous year and the holdings above that amount will lose their validity"*. [11]

5.3. Thresholds [12]

Looking more in detail about Nuovo Pignone specific case, in the current phase 3 (2013-2020) and in accordance with paragraph 3 of annex I of 2009/29/EC Directive, all types of units and such as boilers, burners, turbines, heaters, furnaces, incinerators, dryers, engines, fuel cells, chemical looping combustion units, torches and afterburners are included in the EU ETS's scope. These stationary units are included when the plant reach the threshold for the activity, i.e. installed thermal power of 20 MW_t and production capacity depending on the activity carried out. In the case that two or more activities carried out in the plant for which the minimum threshold is identified differently from each other, the inclusion must be verified in three ways: if both thresholds are exceeded, than the threshold not expressed as total nominal thermal power takes priority over the other and the installation is included in the EU ETS as part of the activity corresponding to the threshold, if only one of the capacity threshold is exceeded the installation is included in the Directive as part of the relevant activity, if none of the thresholds is exceeded then the installation is excluded from the EU ETS.

For the purpose of checking if the capacity threshold of 20 MW_t is reached, units with a nominal thermal power below 3 MW_t and units using biomass only shall not be considered. However, if this check shows that the installation falls within the scope, it shall still be required to monitor and report CO_2 emissions from units with a nominal thermal power below 3 MW_t and units using biomass only.

5.4. EU ETS in Nuovo Pignone's case

Nuovo Pignone's Florence plant falls within the scope of the EU ETS with a nominal thermal power installed that far exceed the 20 MW_t threshold, to which a series of units greater than 3 MW_t contribute strongly. In particular, the flows regulated by the EU ETS Directive are those produced by the combustion of fossil fuels such as natural gas, diesel, kerosene, etc. The total amount of fuel flows generating emissions regulated by the Directive, where more than 99% consists of natural gas, are used to feed the CHP system, engines, generators and boilers. These units are used for civil and technical purposes and for the steam production.

In order to comply with the EU ETS Directive, a precise and detailed CO_2 emissions monitoring procedure is fundamental, but its importance is not only related to legislative constraints, in fact the monitoring of CO_2 emissions is becoming with time a more and more important action for business analysis towards low-emission targets. Specific emission calculation factors and LHV (Lower Heating Value) of the different fuels are used in the monitoring plan, which follow the national UNFCCC (United Nations Framework Convention on Climate Change) inventory. In each period, these values are the annual average and are listed in the tables below as example.

Fuel	Conversion Factor	Unit of measure
Natural Gas	55,934	tCO_2/TJ
Diesel	73,578	tCO_2/TJ
Kerosene	3,149	tCO_2/t

Table 2.1: *Fuels' conversion factors for EU ETS.*

Fuel	LHV	Unit of measure
Natural Gas	0,000037	TJ/Nm^3
Diesel	0,000043	TJ/kg
Kerosene	1,047	tep/t

Table 5.2: *Fuels' LHV for EU ETS.*

At this point it's necessary to standardize the measured data, some in Nm^3 and others in Sm^3, considering the natural gas, to ensure that they are all consistent in terms of unit of measure. In order to do that a factor equal to 0,9479 and able to convert Sm^3 in Nm^3 and vice-versa is introduced, whose value derives from the simple ratio in temperature terms, between the normal conditions (atmospheric pressure and 0 °C) and the standard conditions (atmospheric pressure and 15 °C), expressed in Kelvin: 273,15 / 288,15 = 0,9479. Then, month by month, the fuel consumption statistics for the various units covered by the EU ETS are monitored and reported, which are subsequently converted to achieve the goal of the analysis, i.e. the result in terms of equivalent CO_2 tons, using the following formula:

$$Fuel\ emission\ [ton_{CO2}] = Consumption \cdot LHV \cdot Conversion\ Factor \qquad (eq. 5.1)$$

As mentioned above, for our company Nuovo Pignone, the predominant fuel in the emission of greenhouse gases is the natural gas used to feed the CHP installation, approximately 80%, while the remaining 20% is still driven by natural gas, but in this case for steam production and civil and technical uses.

The last step consists of drawing up an annual CO_2 emission allowances balance, as shown in the equation below, to determine the expenditure related to this commodity and how much it affects the company's energy budgets and, finally, to ensure compliance with the requirements of the EU ETS Directive, (eq. 5.2):

$$\pm CO_2\ Credit_y = CO_2\ Credit_{y-1} + Free\ Allowances_y + Purchase_y - Needed\ Allowances_y$$

The result, year by year, is nothing different from a cumulative CO_2 emission allowances flow, which identifies the trend from the beginning of the first phase onwards and allows for forecasting analysis of needs for the following years.

Since what has emerged from the paragraph dedicated to the different phases of the EU ETS Directive, a downward trend is expected in the curve related to free allowances and, in fact, the graph below shows just that.

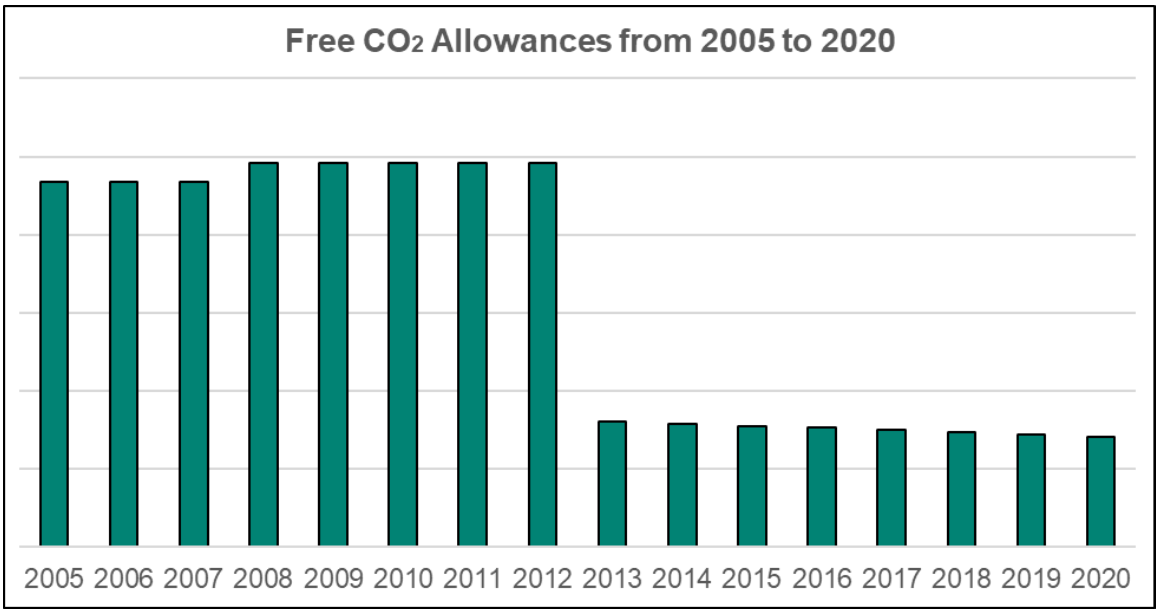

Figure 5.1: *EU ETS's free allowances trend.*

During the first phase (2005-2007), the trend is flat and increases around 5% at the beginning of the second one (2008-2012), along which remains steady again. However, the significant change takes place at the beginning of the following period, in 2013, with a reduction compared to the previous year of around 70%. Within this phase 3 until 2020 the trend will no longer be flat, as in previous cases, but a reduction in free allowances of ~ 2% each year is recorded, according to the EU ETS Directive.

A different issue concerns the annual requirement for CO_2 emission allowances, which is determined by the natural gas and other fuels consumption instead of the free allowances. In fact, the plant requirement varies year by year independently from the corrective actions provided by the EU ETS, but it is mainly affected by the operation of the CHP and other activities involving the consumption of natural gas according to the workloads.

Finally, the purchase of CO_2 is necessary to avoid a negative balance, which would lead to a debt to the European Union and therefore non-compliance with the Directive and it determines a commodity cost affected by market fluctuations, which are discussed in detail in the paragraph below.

5.5. CO2 market

To introduce the argument of this paragraph it's presumed that the expenditure for the purchase of carbon dioxide emission allowances, in the last two years, has contributed for about 10% to the overall expenditure of the plant's energy commodities, so this argument and relative cost has become no longer negligible. This cost is calculated in the following way:

$$CO_2\ Purchase\ [€] = CO_2\ Allowances\ Needs\ [ton] \cdot CO_2\ [€/ton] \quad (eq. 5.3)$$

Recently, in the first period of 2019, the price of the CO_2 is increased significantly, reaching the values of the 2008, when its value was 26,86 €/ton, even becoming 27,92 in July. This surge could give rise to a so called "rally", like that of the last year and it could condition another time the entire energy market. In the following figure we can see the CO_2 price trend in the last twelve years. [13]

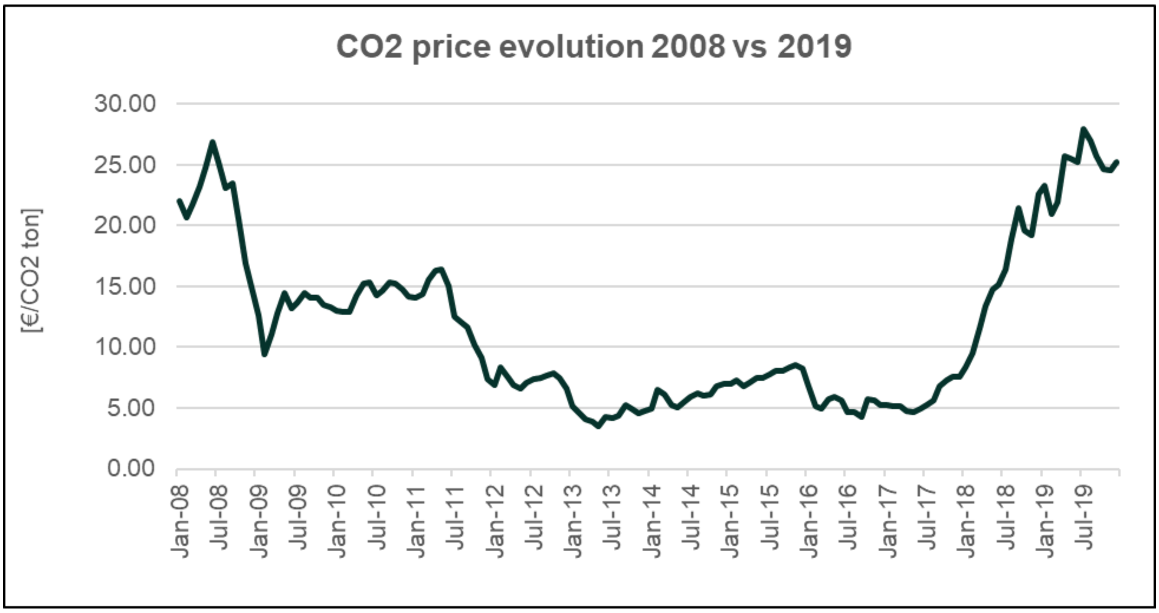

Figure 5.2: *Evolution of CO_2 price since 2008. [15]*

If you want to have an overview on the data, which are less figurative than the graphical evolution but helps to understand and analyze the carbon dioxide market, the average CO_2 price trend over the years and its variation is reported in the table below.

Year	€/ton CO_2	% Variance
2008	21,95	
2009	13,05	-41%
2010	14,32	+10%
2011	12,88	-10%
2012	7,32	-43%
2013	4,46	-39%
2014	5,96	+34%
2015	7,67	+29%
2016	5,36	-30%
2017	5,84	+9%
2018	15,89	+172%
2019	24,80	+56%

Table 5.3: *Evolution of CO_2 price since 2008.* [15]

Over the years, the market has always been very fluctuating, with strong upward effect in some cases and downward in others and peaks of around 40%, but in the two-year period 2018-2019 the CO_2 price has increased like ever before and quadrupled its value.

More in detail, the increasing of 17% of the CO_2 price registered between April and March 2019 seems to be related to the Brexit situation: speculation has intensified purchases, as the hypothesis of a long delay of the London's exit from the European Union seemed the most likely scenario. At the exit moment, UK would bring a large amount of emission allowances onto the market, with downward effects. [13]

The trends of commodities, like electrical power and natural gas on the market are affected by the CO_2, because the market is populated by speculators and there are reasons to think that this "rally" can be further enhanced.

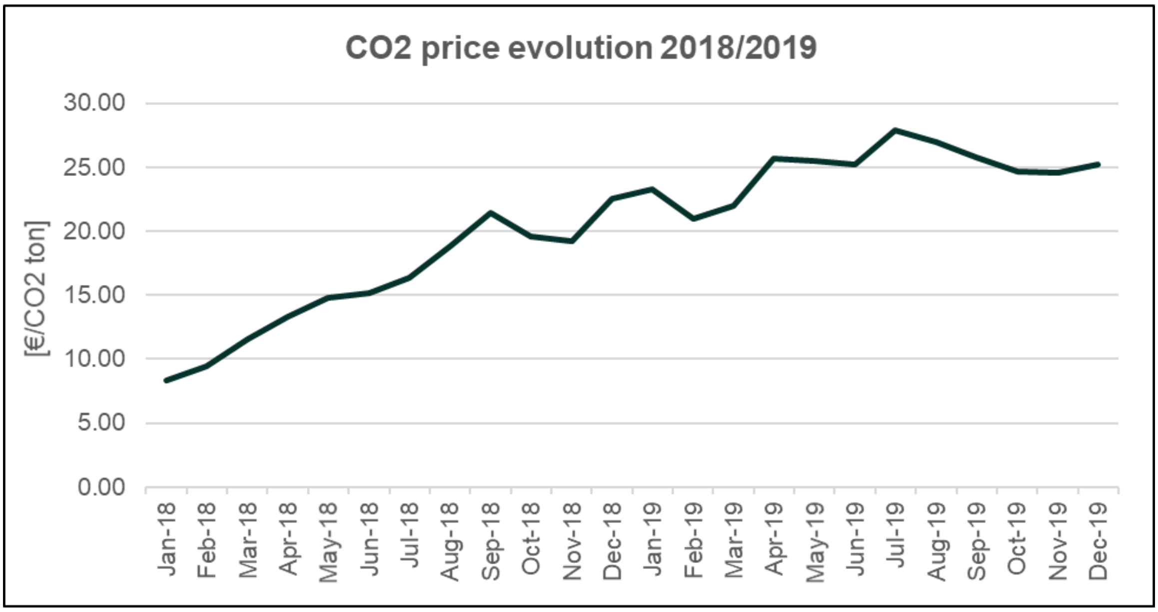

Figure 5.3: *Evolution of CO2 price 2018-2019. [15]*

The increase in prices over the last two years seen in figure 5.3, is judged necessary especially when carbonaceous fuels, which are highly pollutant, become more convenient for the electrical generation with respect to the natural gas.

Another consideration regards the corrected actions adopted by the European Union: at the moment there is no longer a surplus of emission allowances, but a deficit that analysts estimate may become even higher, until it reaches an average price doubled during 2020, but in the first few weeks of the new year data shows that we are still far from this estimation.

Let's look now at the 2019, in which the greatest and most continuous rises of the CO_2 price occurred and especially its first nine months, figure 5.4.

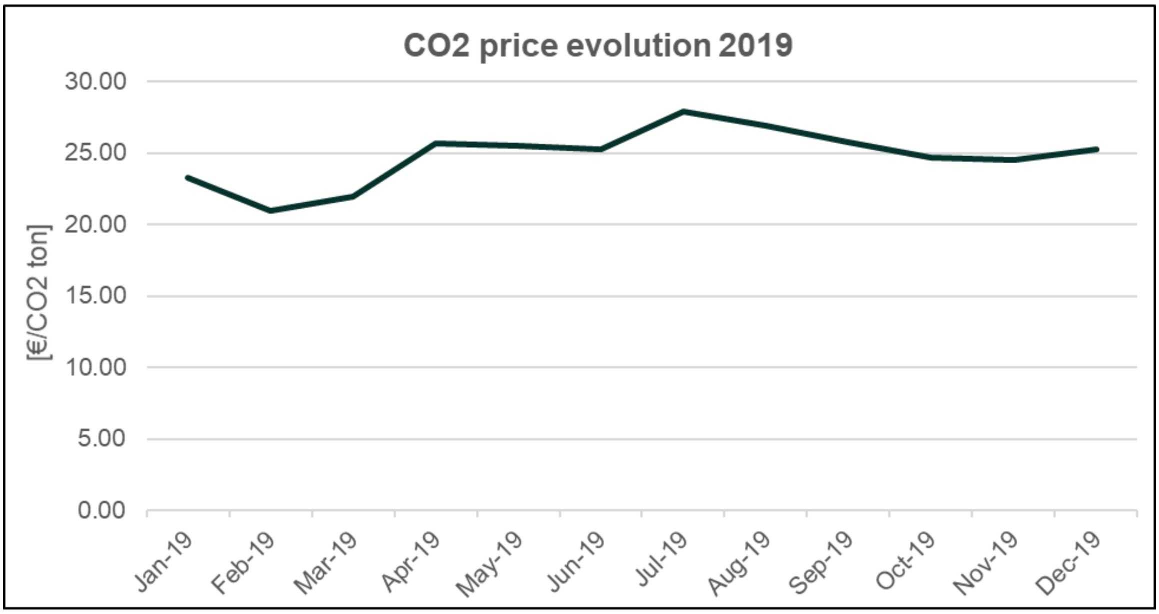

Figure 5.4: *Evolution of CO2 price - 2019. [15]*

From January to September the CO_2 price is increased by 157% and on the whole year by 171%. The only months in which the trend is slightly downward are October and November - 9% and -2% respectively. The most significant aspect is related to the jump in CO_2 allowances price, which has exceeded 20 €/ton after 10 years.

This awakening could be seen as good news, because if pollution is cheap, there is no inducement to achieve a greater energy efficiency or to move away from the use of fossil fuels towards cleaner energy sources. This is exactly what the ETS should be for, but the mechanism, mainly because of the economic crisis, suffered: with too many allowances in circulation compared to the needs, prices became too marginal.

From a surplus of more than 2 billion of CO_2 tons, it is expected that by 2023 a cumulative deficit of 1,4 million could be achieved. The *Market Stability Reserve*, which will withdraw 24% of surplus or unused emission allowances each year between 2019 and 2023, will play a key role in this process. Political orientations are among the uncertainties on CO_2 price trend: the phase-out of coal by an increasing number of countries, could make useless the need of a high price on the markets and vice versa, if the price remains unchanged, there is the possibility that pressures would rise to obtain corrective measures. [14]

Another key variable is the price of energy resources, the trend of which could change completely the scenarios. Natural gas, which pollutes much less than coal, will be fundamental as a fuel to guide the energy transition towards the goal of a complete de-carbonization.

6. Water usage

6.1. World's water scarcity [16]

The attention on water consumption is increasing its importance during the years and the sixth United Nations Sustainable Development Goals is exactly focused on this topic:

Figure 6.1: *#6 Sustainable Development Goal.* [16]

"Ensure access to water and sanitation for all" is a statement that imposes to every water consuming activity to manage accurately water uses and to minimize lack of this precious resource through an efficient use. In fact, is estimated that half of the global population is in a water scarcity condition, impacting on sanitation and hygiene, at least one month per year mainly because its increasing demand due to population growth. This scarcity of access to clean water affects more than 40% of the global population, especially in the poorest countries, where in some cases it can also lead to death. Projections suggest a scenario where this number may increase in the future years, reaching conditions of chronic water scarcity for at least one in four people by 2050, if no corrective actions are immediately implemented.

Obviously, the development of this condition has a cost, both social and economic. Water access improvement requires investments in efficient freshwater management, adequate infrastructures, wastewater treatment plants, recycling and desalination units, especially in developing countries of Africa and Asia. These investments are necessary to ensure access to adequate sanitation conditions for people all around the world and to protect the nature ecosystem, which has a huge impact on all the activities, on health, food, economy, etc. [10]

6.2. Industrial and drinking water consumption

In great industrial realities, such as Nuovo Pignone, the water consumption of the campus has a high impact in terms of sustainability and of its related commodity consumption expenditure, as we have seen at the very beginning, which accounts by 2-3% on the total controlled costs.

The water consumption of Nuovo Pignone various campus is mainly divided in two contributions:

- Drinking water;
- Industrial water.

The first one is the water for sanitation use, which over the years has always constituted about 30-35% of the total water consumption. Industrial water, however, is supplied from wells and is used mainly in cooling tower systems for testing activities and then for irrigation, firefighting, treatments of machinery and parts of them. As a result, the industrial consumption accounts for 65-70% of the total.

From the baseline date of 2012 to present, total water consumption in Nuovo Pignone Italian factories has decreased by almost 50%, with a general downward trend, except for 2016 and 2018, as is shown in the figure below.

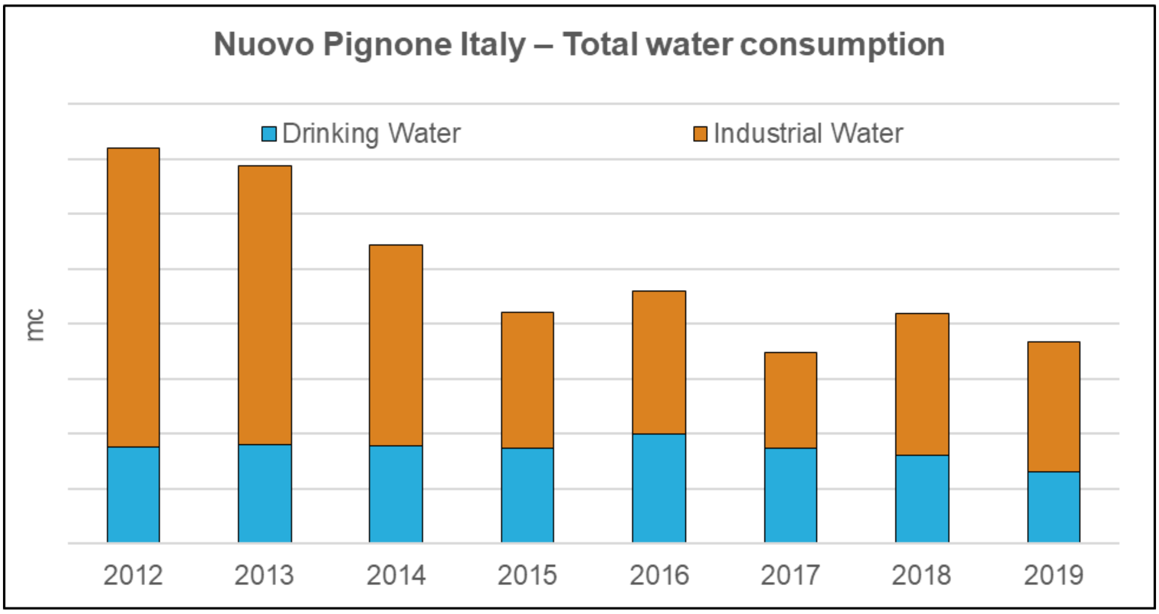

Figure 6.2: *Total water consumption from 2012 to present.*

Then, analyzing separately the two different contributions, industrial and drinking water, it was observed that both consumptions have decreased, but in different ways: the drinking water by over 20% and the industrial one by 60%, with respect to 2012.

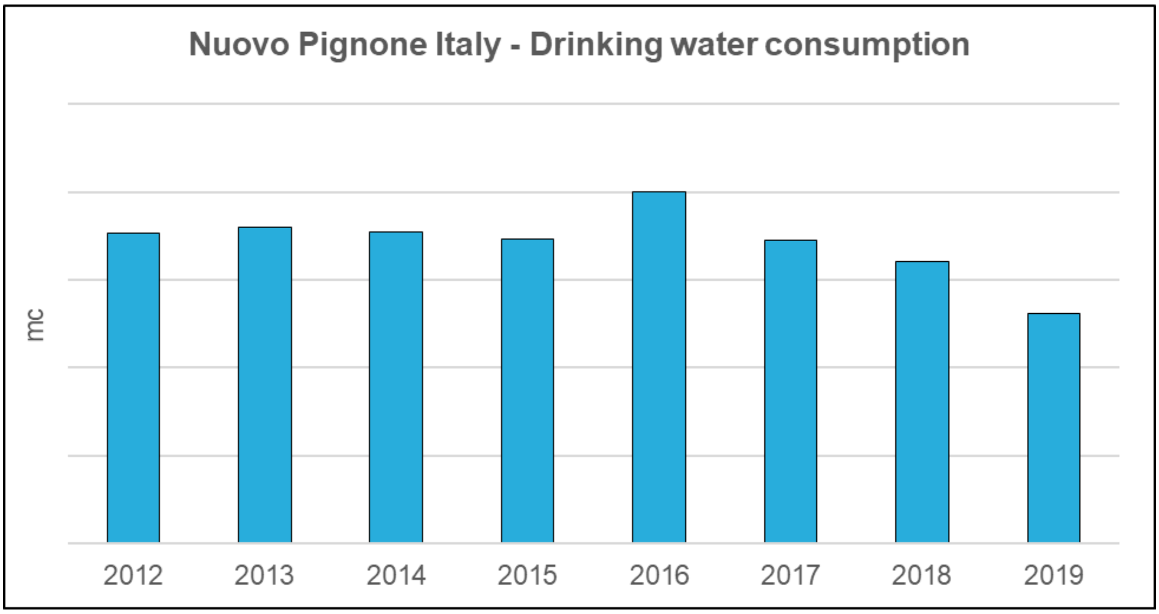

Figure 6.3: *Drinking water consumption from 2012 to present.*

Over the years, drinking water has always had a slightly decreasing trend, but can be defined as flat, except for 2016 when the consumption increased by about 15% and for 2019, with its year-on-year decrease of 20% clearly visible on the graph.

This consumption has a trend which, among other things, is closed correlated to seasonality and holidays. In fact, the months in which, on average, the highest consumption of the years is registered are from April to July, drops in August mainly due to holidays, and returns higher in September. The same goes for the different days of the week: from Monday to Friday, drinking water consumption is much higher than on Saturdays and Sundays.

These factors are the natural consequence of consumption trends based on the number of people at work and their attitudes, while as far as industrial water is involved, the situation changes.

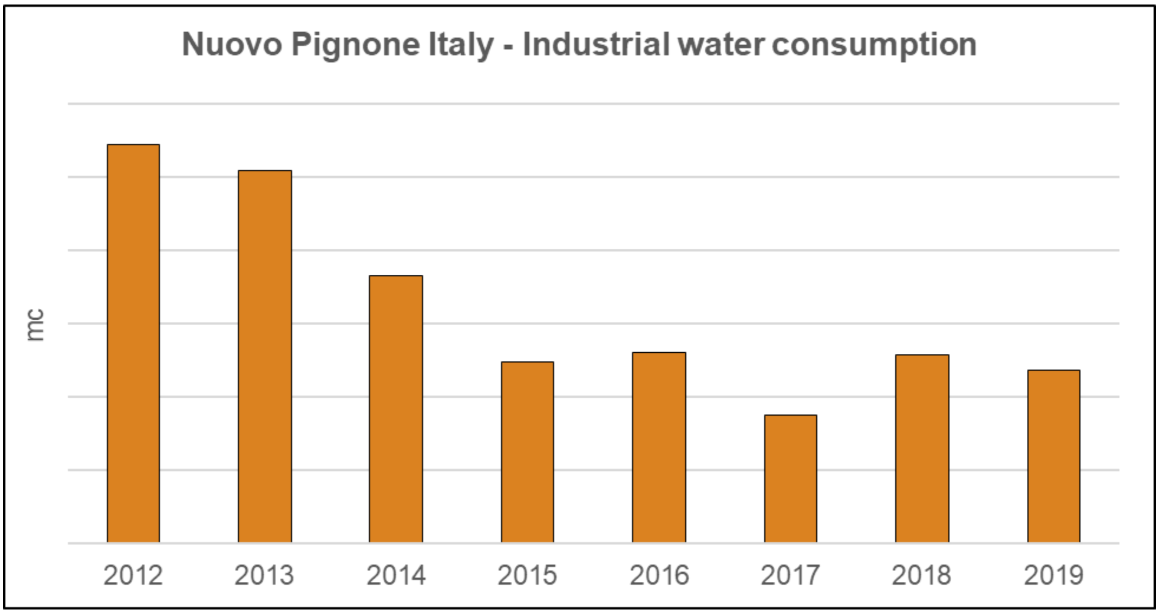

Figure 6.3: *Industrial water consumption from 2012 to present.*

Considering now industrial water, the figure above shows that its trend has been much more downward than in the case of drinking water, but even in this case there was a year marked by a significant increase, i.e. 2018, and then decreasing again the following year.

The minimization of industrial water consumption is due more to the more efficient production activities and technological developments, while the seasonality in this case has no influence. In any case, we have seen that the reduction from 2012 to present has been very relevant and the challenge for the future is to be able to maintain at least these levels of water consumption and improve them further.

6.3. Improvements on water network

Additional improvements to the campus water network are under analysis. The priority is to avoid water losses, which are almost always the main cause of an increase in consumption. In order to find and analyze these leaks more efficiently, measurements and monitoring become essential elements. In fact, measuring points within campuses are increasing and their outputs can be remotely controlled by smart digital systems in order to have an optimal control of the data. For example, if the water measurement point was unique, you would only see the whole incoming water without realizing where the highest water consumption actually occurs and without the possibility of identifying any leaks, but if these points are enhanced, the control and detection will obviously be improved, simplifying the process of leak detection, necessary for the intervention that will lead to the reduction of consumption.

Another key aspect in reducing water consumption, which is more about human rather than technological aspects, is sensitivity on this topic. For example, turning of taps when water is not strictly necessary becomes very important, especially when multiplied by each individual. On this topic, the approach we want to pursue is continuous communication and sensitization on the good standards of behavior to be observed. Let us simply consider a person who wastes 1 liter of drinking water a day in his activities, if this number is multiplied by hundreds or thousands of people, the waste water increases considerably and consequently the fact that everyone behaves properly and carefully on the water problem would lead to a good result both in environmental and economic terms.

In conclusion, for internal company analysis of water consumption, the same consumption has been normalized with respect to the number of company's people working in the plants year by year, obtaining a factor in mc / number of people, i.e. per-capita consumption. This factor is obviously "contaminated" by the fact that everyday there is a continuous number of people visiting the plants, including customers, suppliers and other operators, but is still a significative indicator to assess the evolution of water consumption trends over the years.

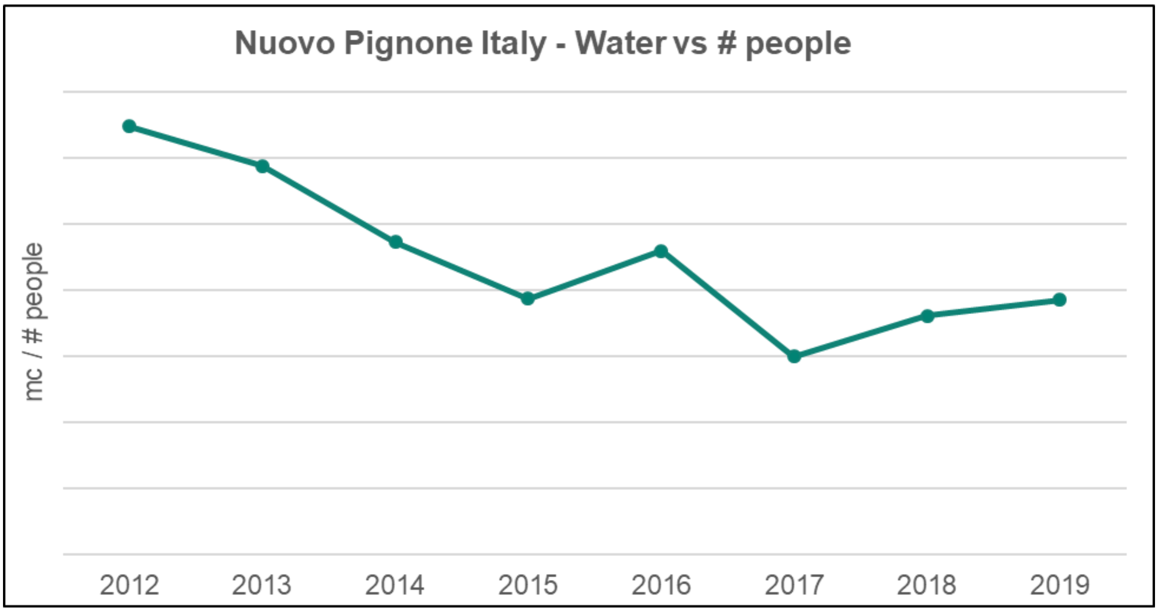

Figure 6.4: *Water consumption vs # people from 2012 to present.*

In the figure above, the factor considers both drinking and industrial water. The trend has recorded a reduction of around 45% from the 2012 baseline to date, a value similar to the absolute one seen previously. However, considering that this factor is more significant if we consider the per-capita consumption only for the drinking water, the industrial one has been normalized with respect to the workshop working hours and the result is shown below.

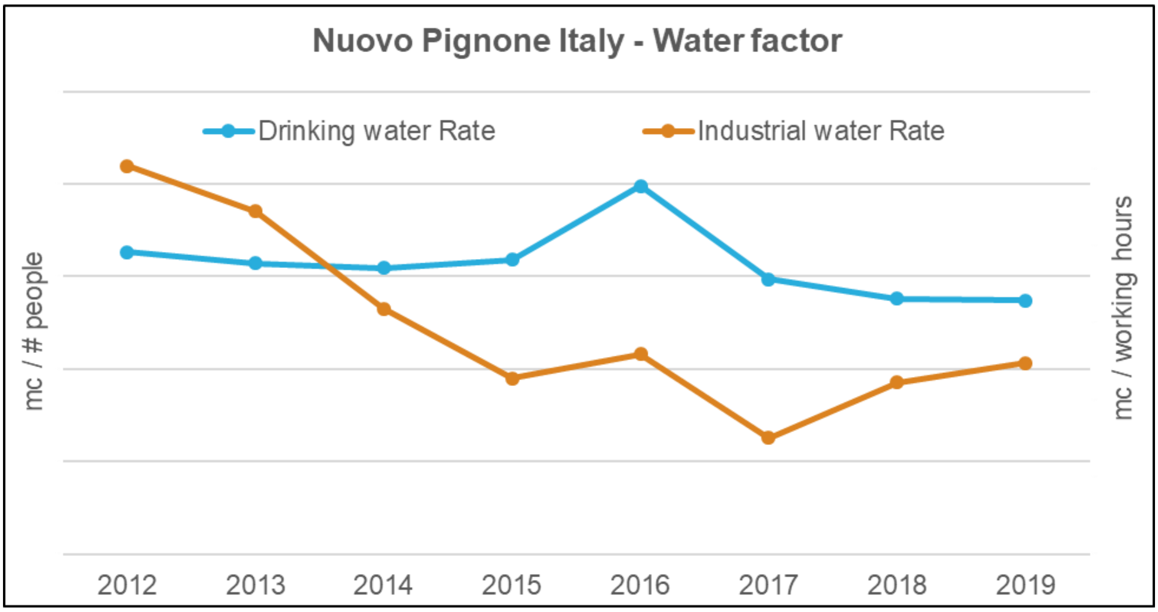

Figure 6.5: *Drinking and industrial water factors from 2012 to present.*

The cubic meters of drinking water vs the number of employees has experienced a decreasing trend around 15-20% from 2012 baseline, near the absolute value analysis. On the other side, the industrial water consumption related to the workshop working hours has decreased by 50% from the baseline to date, while the absolute value seen before has been reduced by around 60%.

The general output of these analysis has stressed that trends has experienced a significant reduction, from every point of view, due to an high attention on this topic, but the path to achieve more challenging results is still long and therefore new implementations and improvements are considered priorities for the future.

7. Actual Energy and Environmental World’s scenario

7.1. United Nations Sustainable Development Goals [17] [18] [19]

As we have seen in the water paragraphs, the United Nations has set seventeen Sustainable Development Goals to achieve global results by 2030, in terms of sustainability, able to improve the people’s quality of life. In particular, three of them are strictly related to the energy industry world and they are the number 7, 9 and 13, despite all seventeen are interconnected one with each other.

Figure 7.1: *#7 Sustainable Development Goal.* [17]

“Ensure access to affordable, reliable, sustainable and modern energy” is one of the United Nation’s priorities by 2030, because energy is essential for all human activities and its more efficient and cleaner use is fundamental to face the future challenges in terms of economic growth, access to electricity in all the countries, currently denied to almost 13% of the world’s population, and climate change, for which the energy accounts of 60% of the total greenhouse gas emissions. Nowadays, the target is far from being achieved and new technologies and investments in industry, transport and every sector are necessary to improve the current scenario. [17]

The second abovementioned statement regards the ninth goal: *“Build resilient infrastructure, promote sustainable industrialization and foster innovation”*.

Figure 7.2: #9 Sustainable Development Goal. [18]

Manufacturing industry is a fundamental sector for the economic growth and for the increasing of new job opportunities, drivers which have a very great impact on the society, but that's not all. In fact, industry processes are responsible of significant greenhouse gas emissions, therefore investments in innovations and new technologies, efficiency and processes improvement in the manufacturing sector and in all infrastructures are crucial to achieve 2030 targets. [18]

The third considered goal is the thirteenth: *"Take urgent action to combat climate change and its impacts",* and this is the one on which we will focus our attention most.

Figure 7.3: #13 Sustainable Development Goal. [19]

Climate change is currently impacting the entire world and all its inhabitant. Its impact is conditioning countries, people life and economies. If we don't act immediately the world's temperature is estimated to reach the increase of 3 °C of the average global temperature during this century, with dramatical effects on our lives. To face this huge challenge, countries has signed in Paris at the COP21 the Paris Agreement, where they have accepted to invest and fight against the climate change in order to limit the global temperature rise below 2 °C.

Thanks to IPCC (Intergovernmental Panel on Climate Change) we discover that the average global temperature increased by 0,85 °C in the last 130-140 years. As a result, many troubling phenomena have occurred and are occurring due to a warmer climate, in fact: agriculture has experienced high yield reductions at global scale, oceans and seas have warmed because the amount of snow and ice have diminished causing a rise in water level of around 19 cm from 1900 and is estimated that this level will rise to 24-30 cm by 2065 and 40-63 cm by 2100 and CO_2 emissions grew by almost 50% since 1990 and ever faster. [19]

To fight or at least mitigate the global warming, action by all is required. In particular, is necessary the inclusion of climate change measures into national strategies, planning and policies, regarding the implementation of investments in new technologies and efficiency, as well as investments in education on climate change, as global priority.

7.2. World's energy consumption [20]

As we have seen, energy is fundamental for each individual activity and at the same time its use and consumption determine a huge impact, for example, on economy, on climate, on agriculture and on global growth in general.

According to the data provided by World Energy Outlook of IEA (International Energy Agency), at global level, energy consumption worldwide is increasing on average by around 1,5% each year, with a peak over 2% in 2018. This upward trend in energy consumption is mainly caused by the needs of the economic development, especially in some countries, and related to the electrical energy demand, but also to heating. The immediate result of this scenario is the CO_2 emissions growth, which we will discuss later.

The figure 7.4 below, describes the global situation in terms of energy consumption absolute value in Mtoe, during the last thirteen years. The toe (ton of oil equivalent) *"is a conventional standardized unit defined on the basis of a ton of oil with a net caloric value of 41868 kJ/kg"*. [22] In this case is very useful because this unit of measurement allows us to compare the different energy consumption, which otherwise would not be possible to compare.

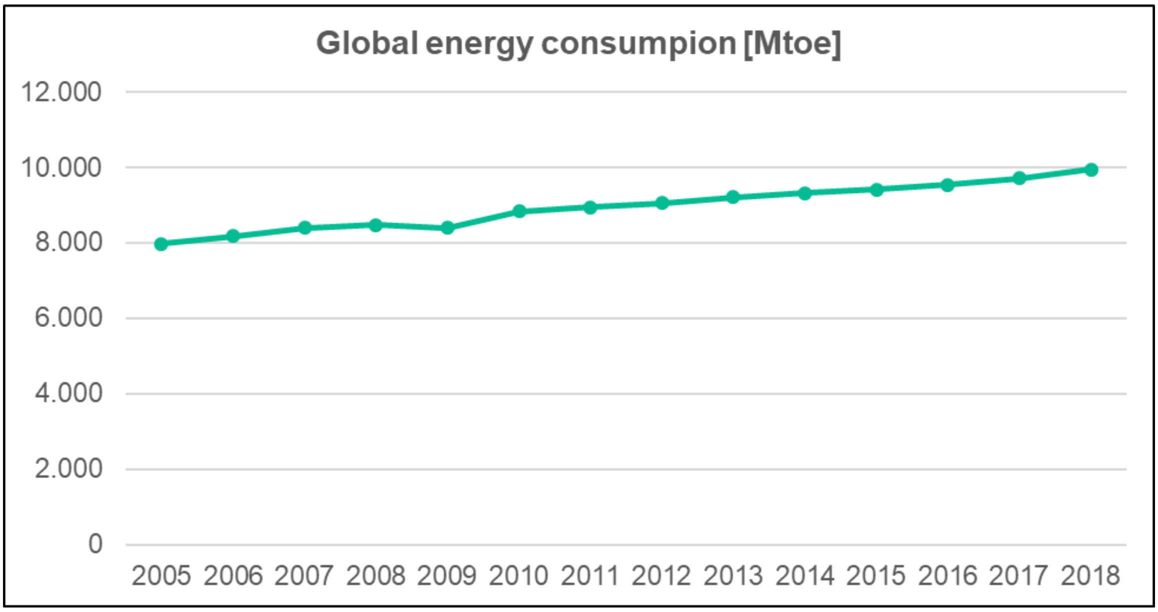

Figure 7.4: Global energy consumption. [20]

In order to better understand the nature of this energy consumption growth at global level, we can analyze this trend considering two main drivers:

- the sectors;
- the energy sources.

Considering the first one, an explicative figure is shown below, in which the global Mtoe consumed in the last years are divided by sector.

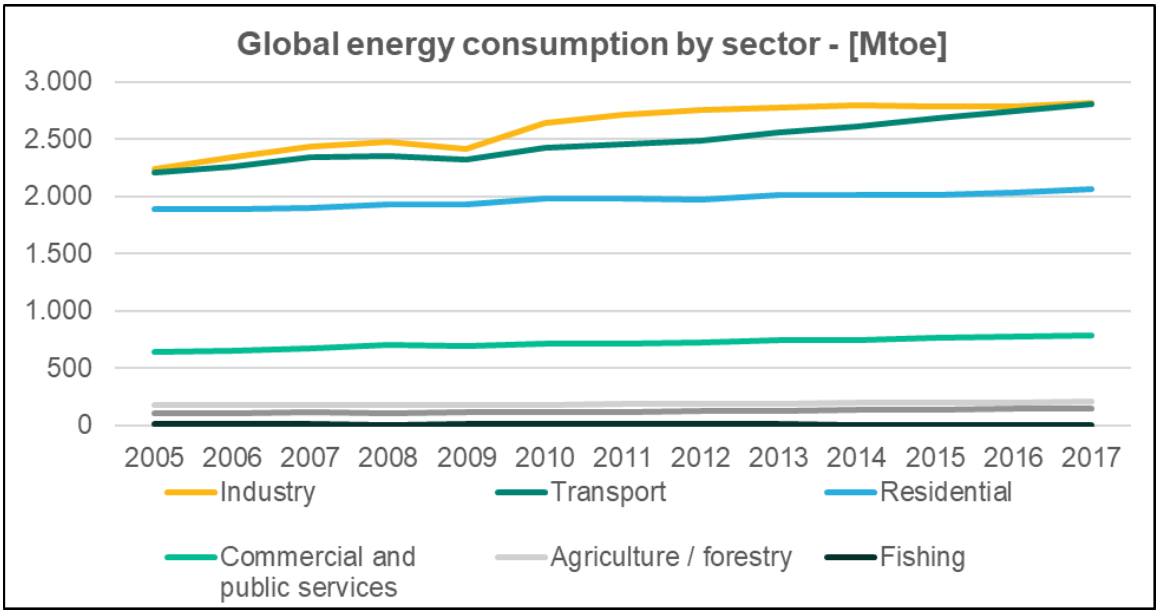

Figure 7.5: Global energy consumption by sector. [20]

The trend is mainly driven by three sectors: industry, transport and residential which account for the 80% on average. Industry and transport sectors are increasing strongly their impact during years, with a contribution respectively of 30% and 27-28%, while the residential is almost flat and between 20 and 22%. Commercial and public services constitute around 8-9% and the remaining part is related to agriculture, fishing and other non-specified uses. In general, all the sectors are increasing their energy consumption, but due to their strong impact the industry and the transport are more visible in the figure.

Figure 7.6 above, shows the energy sources which origin the most relevant consumptions.

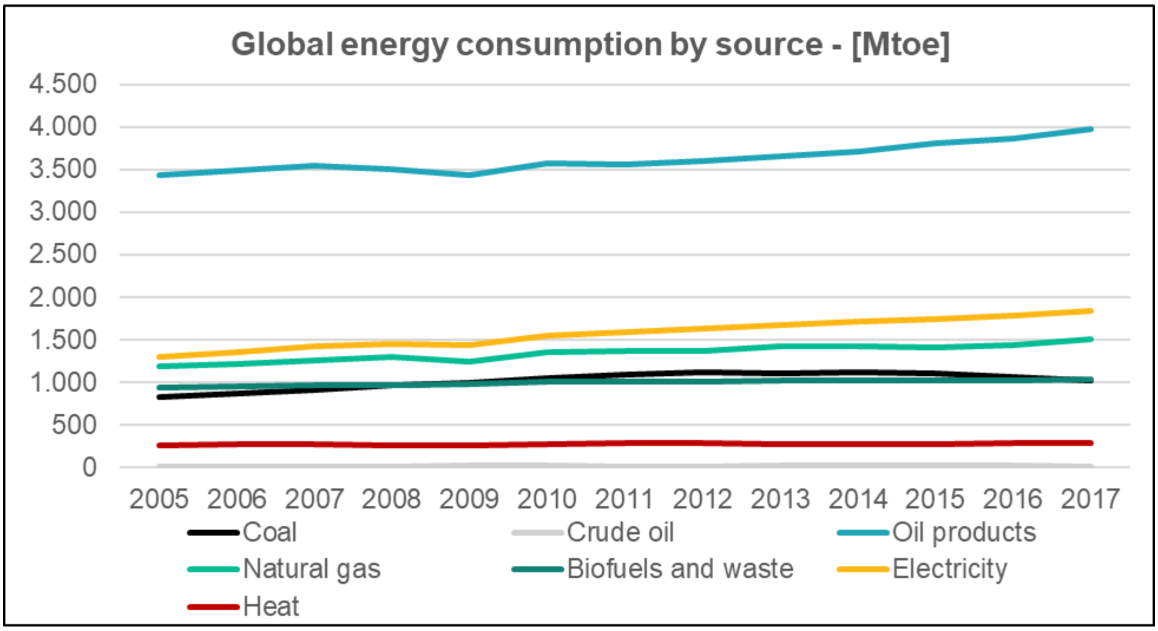

Figure 7.6: *Global energy consumption by energy source.* [20]

Oil products are predominant and account for the 40% to the consumptions, with an increasing trend around 15% from 2005 to date. The second higher contribution regards electricity, which is grown of 40% in the last thirteen years. Then there is natural gas with 15%, coal, biofuels and waste with 11%, heat with 3% and crude oil and renewables which are almost negligible with respect to the others, despite the last one has recorded +280% from 2005. In this analysis is also clear that all the energy sources responsible of consumptions are increasing their values, but renewables and electricity among the others.

7.3. World's greenhouse gas emissions [21]

One of the most crucial natural consequences of the energy consumption is the greenhouse gas emission, which is increased by 20% from 2005 to 2017, even though in the last three considered years the increase has almost stopped, while energy demand was growing by 22%.

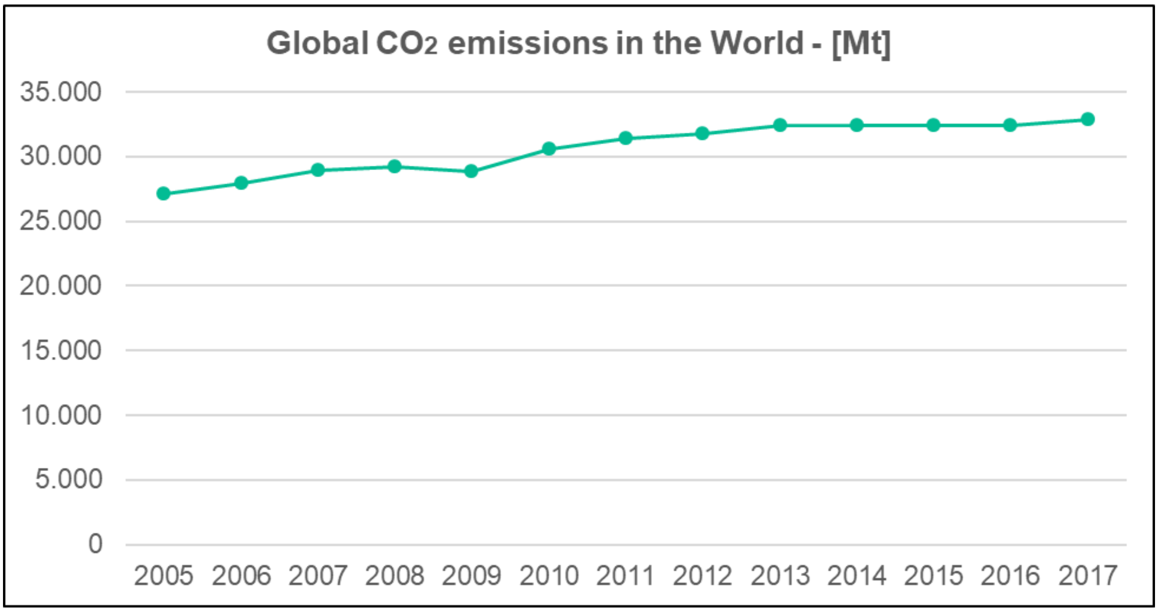

Figure 7.7: *Global CO_2 emissions.* [21]

Naturally, emissions are not the same if we consider, for example, different energy sources because each one has its characteristic conversion factor to obtain the resulting CO_2 tons. In fact, we must separate the greenhouse gas emissions, as in the paragraph on global energy consumption, by different drivers to obtain a clearer overview on the past and current scenario. In this case, to ensure consistency, it was decided to analyze trends with respect to the two previous drivers with the addition of a third one, which may be even more explicative of this important topic compared to world economic growth. Therefore, will be considered:

- the sectors;
- the energy sources;
- GDP / GDP (PPP). [23]

Gross Domestic Product (GDP) is a financial indicator of the market value of all the goods and services produced in a specific period, within the borders of each country. These goods and services are produced through market sales, but also includes some other services, such as education and defence. Being the GDP a unique indicator for each single country, it is measured in its related currency. Therefore, if we want to compare the GDP of different countries, become necessary to normalize this indicator introducing the Purchasing Power Parity (PPP) exchange rate to convert each currency in U.S. dollars. [23]

Starting from this third driver, we will evaluate the trend of greenhouse gas emissions in terms of kg CO_2 / $ and the result is shown in the figure below.

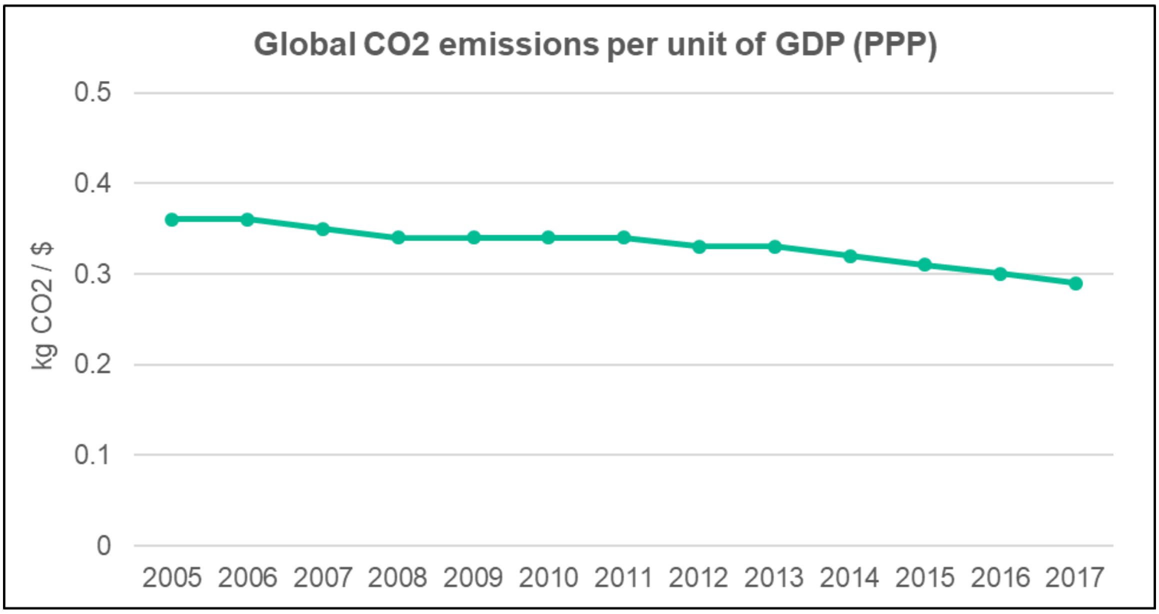

Figure 7.7: *Global CO_2 emissions vs GDP (PPP).* [21]

As we expected the trend does not correspond to the one of CO_2 emissions in absolute value. In fact, in this case the curve never tends upward, but on the contrary in most cases it is downwards. Despite all the government, global institutions, public and private companies have set their targets to achieve, for example, by 2020, 2030 and 2050 in terms of reduction in absolute value, this economic indicator gives an idea of where we are going to.

Instead, considering the most polluting sectors, we realize that the most impacting are:

- the production of heat and electricity, which accounts for the 41%;
- transport with 23-24%;
- industry with its 19-20%.

These top three is followed by residential and other energy industries, which accounts by 6 and 5% respectively, while the lower emissive sectors are commercial and public services with 3% and agriculture, which accounts by almost 1%.

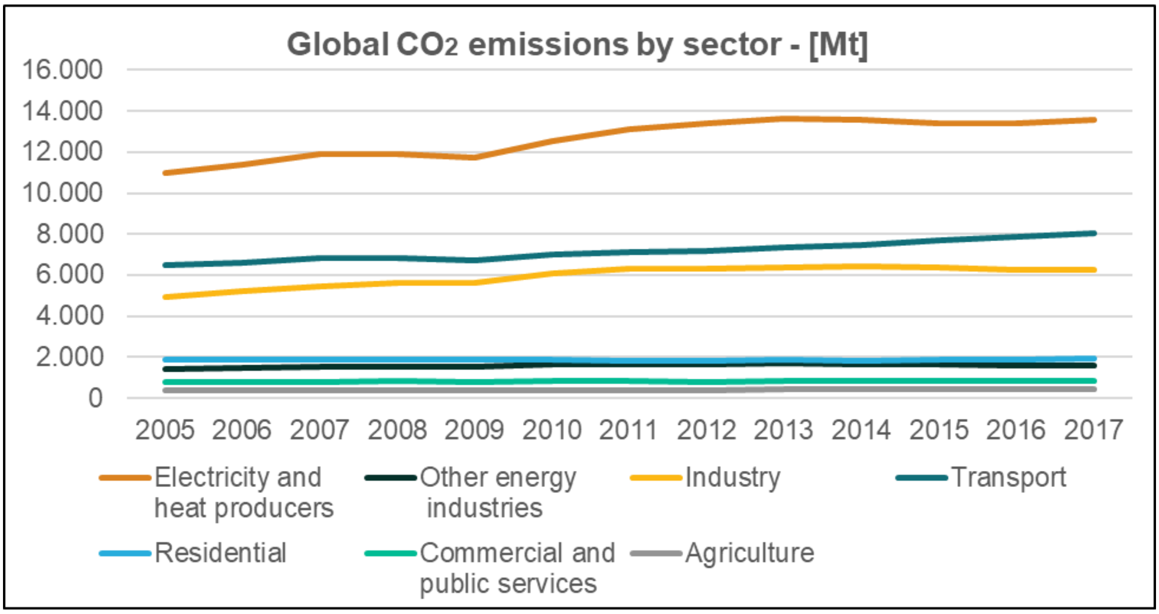

Figure 7.8: *Global CO_2 emissions by sector.* [21]

Finally, with reference to what has been told at the beginning, the impact of each energy source is a fundamental aspect that must be considered. The coal is definitively the greatest source that determines the global carbon footprint, in fact, its contribution reaches the 45% of the total due to a high conversion factor. In addition, its trend is increased by 27% from 2005 to date. At the second place there is the oil, which also is growing, with 35% of contribution. Natural gas has an impact of 20% on the total and a 30% increase. Lastly, although the impact is lower than the other, the remaining 1% occupied by the other energy sources has grown over 100% and these considerations are visible in the figure below.

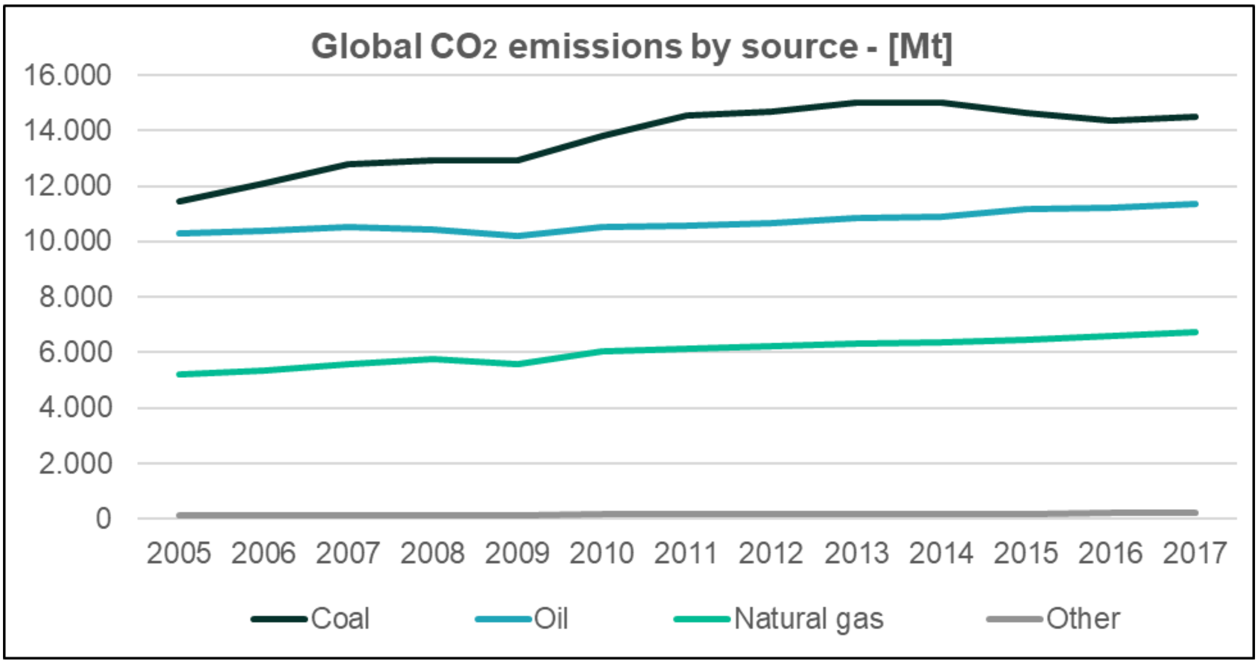

Figure 7.9: *Global CO_2 emissions by energy source.* [21]

These two paragraphs related to global energy consumption and CO_2 emissions, thanks to the data provided by the World Energy Outlook of International Energy Agency, have been very functional to better understand and analyze what the responsibilities of the different business sectors are and how manufacturing industry is fundamental to achieve the targets, which are necessary to fight the climate change.

8. Baker Hughes's Decarbonization

"In addition to reducing our own carbon footprint, a priority of Baker Hughes's strategy is to help reduce our costumers' carbon footprints. We believe that leadership in the energy transition to low-carbon solutions is both the right thing to do for the planet and good business.". [24]

8.1. Baker Hughes's focus on Climate and Energy [24]

"Our commitment to protect the environment has never been more important. Scientists are in broad consensus on the increasing risks from climate change and its potentially catastrophic consequences for the earth's ecosystems and species if left unchecked. As a company, we pledge to be part of the solution, as demonstrated by our commitment to achieve a 50% reduction in CO_2 equivalent emissions by 2030 and net zero CO_2 equivalent emissions by 2050. This commitment aligns us with the Paris Climate Accord and demonstrates we will do our part to limit global warming to 1.5 degree Celsius".

Baker Hughes is focused on energy efficiency and reducing the carbon footprint of its operation activities, which regards both direct emissions from the use of natural gas and company's vehicles fleet, and indirect emissions for electricity purchase. All efficiency projects implemented until now are the starting point of the company's overall plan to reduce further its energy use, greenhouse gas emissions and operating costs.

Clear pathways have been enforced to reduce company's Scope 1 and 2 emissions. Scope 1 direct emissions include natural gas and fleet vehicle fuel use. Scope 2 emissions include indirect emissions from purchased electricity. The reduction pathway includes several categories and their implementation:

- Renovation of buildings with more efficient and sustainable equipment;
- Operational improvements helped by energy efficiency "treasure hunts" and audits;
- Installation of smart meters;
- Additive and intelligent manufacturing;
- Potential conversion of existing vehicles fleet to lower emissions models;
- Increment of renewable energy in utility contracts and further onsite power generation;
- Use of recycled and sustainable materials in manufacturing processes;

- Redesign of tool and equipment.

Looking in detail at improvements in the Baker Hughes's emissions trend from 2016 to 2018, the reduction concerns both the scopes: Scope 1 has a downward trend of 13% the first year and 8% in the second one, while Scope 2 decreases by the 8% and 15% respectively. As a result, the overall reduction 2018 vs 2016 has been in the order of 22%, while the combined Scope 1 and 2 emissions has reduced by 34% since 2012, which is considered the baseline year.

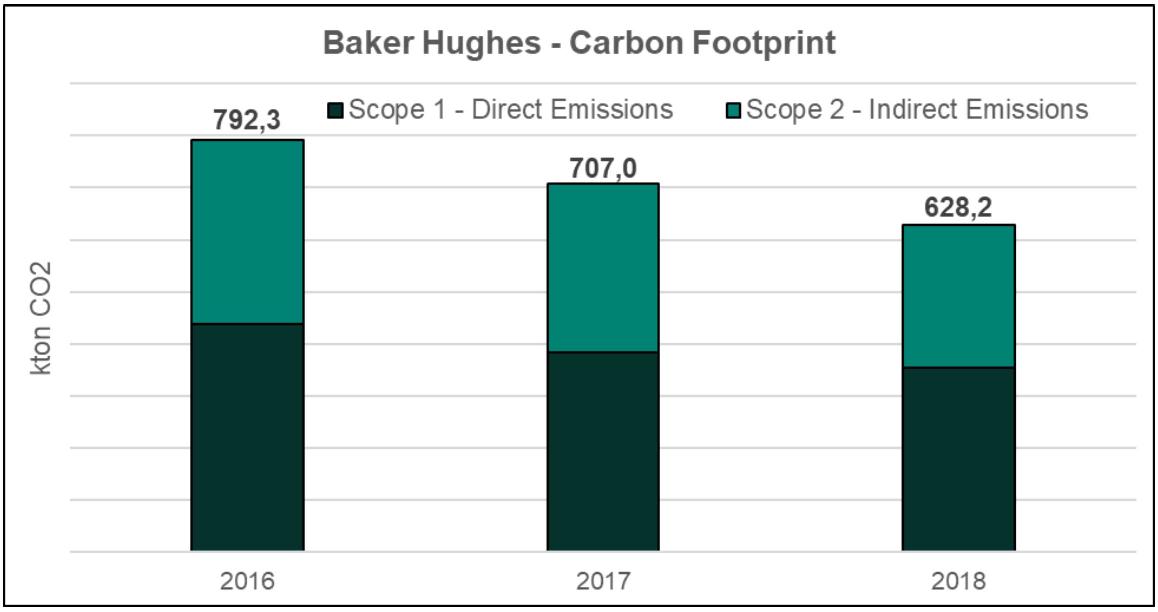

Figure 8.1: *Baker Hughes's Carbon Footprint 2016 vs 2018.*

8.2. Nuovo Pignone's Carbon footprint

Baker Hughes' carbon footprint global data have been reported above, but now we are focusing on reporting the Nuovo Pignone's Italian manufacturing plants carbon footprint from the 2012 baseline to 2019, in order to measure the progress in terms of CO_2 emissions reduction. If we consider both Scope 1 and 2 absolute values, the variables that determine those are: natural gas consumption in Sm^3, purchase of electricity in kWh and the refrigerant / cooling gas consumption in kg. These terms are then multiplied by special conversion factors, officialized and used by the company, which enable to obtain the resulting amount of CO_2 tons deriving from the direct or indirect use of energy sources, as shown in the table below.

	Consumption	CF	Emission
Natural Gas	[Smc]	[ton/Smc]	[ton]
Power	[kWh]	[ton/kWh]	[ton]
Refrigerant Gas	[kg]	[ton/kg]	[ton]

Table 8.1: *Conversion Factors for the Carbon Footprint evaluation.*

The trend of Nuovo Pignone's carbon footprint, starting from 2012 baseline, is generally decreasing: from 2012 to 2019 the total CO_2 emission has decreased by more than 60%.

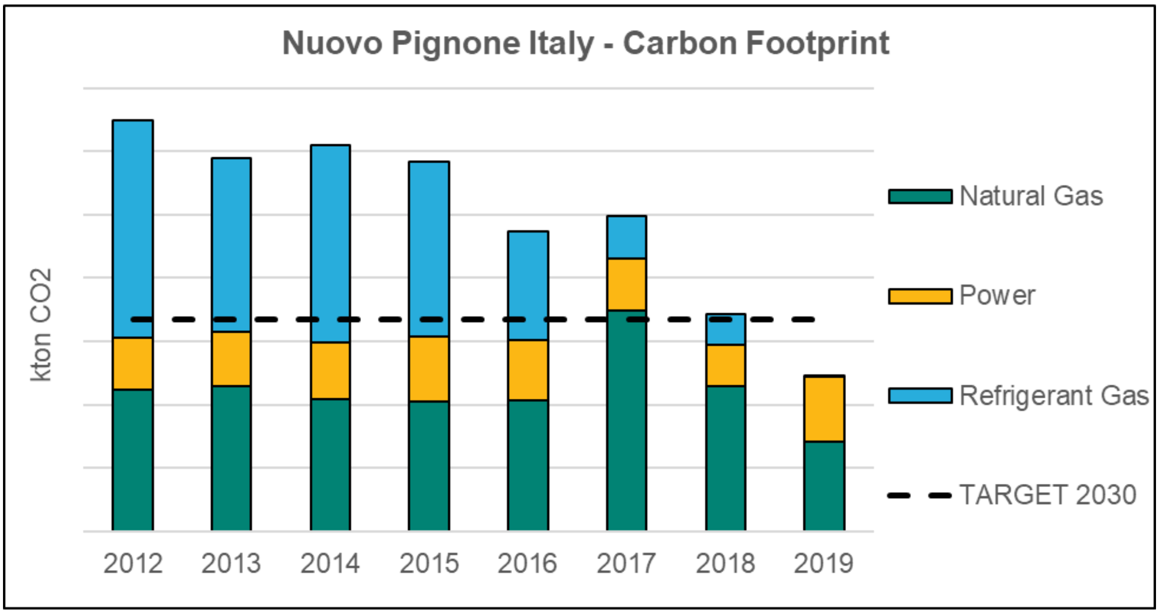

Figure 8.2: *Nuovo Pignone decarbonization pathway 2012 vs 2019.*

Looking at the figure above, we can notice that the refrigerant gas used for testing activities has a high impact, generally more than 35% with peaks greater than 50% in the first years and around 15% in 2017 and 2018, on the total emissions of Nuovo Pignone's production plants. Consequently, the 60% of reduction abovementioned is strongly guided by optimizations related to this gas. The efficiency of the refrigerant recovery system has been improved with good results, but in order to achieve more challenging goals for the future, the current refrigerant will be also substituted with a new refrigerant gas less pollutant. For this purpose, 2019 has been the transition year and the results of this replacement are clearly visible also if we consider a photograph of the CO_2 equivalent emissions distribution in 2019 and baseline scenarios and not at the yearly trend, figure 8.3, figure 8.4.

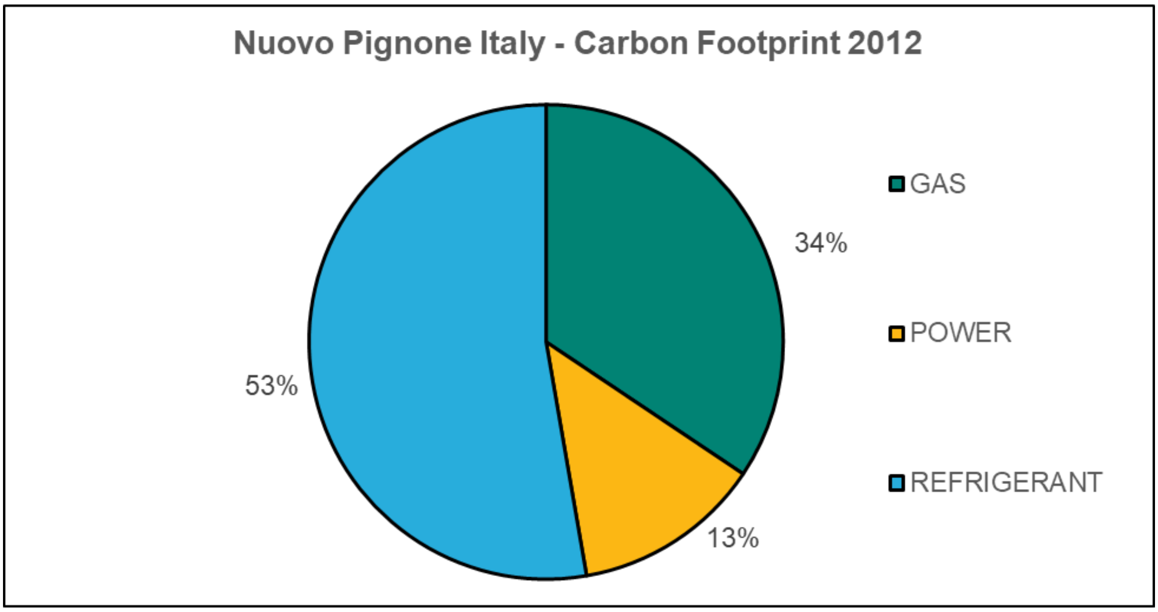

Figure 8.3: *Nuovo Pignone emissions distribution in 2012.*

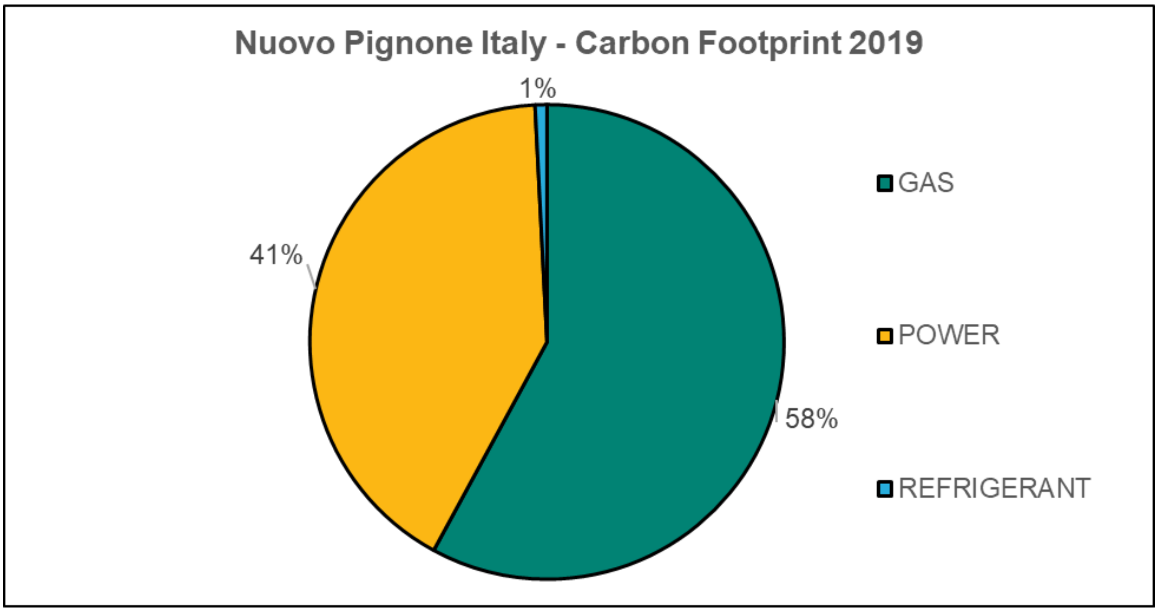

Figure 8.4: *Nuovo Pignone emissions distribution in 2019.*

Just because of its great impact, if we separate the refrigerant contribution from the total in order to see also electricity and natural gas trends, the reduction passes from -60% to -20%, with a -36% regarding natural gas contribution, while the electricity part increases by ~ 20%, as the figure shows.

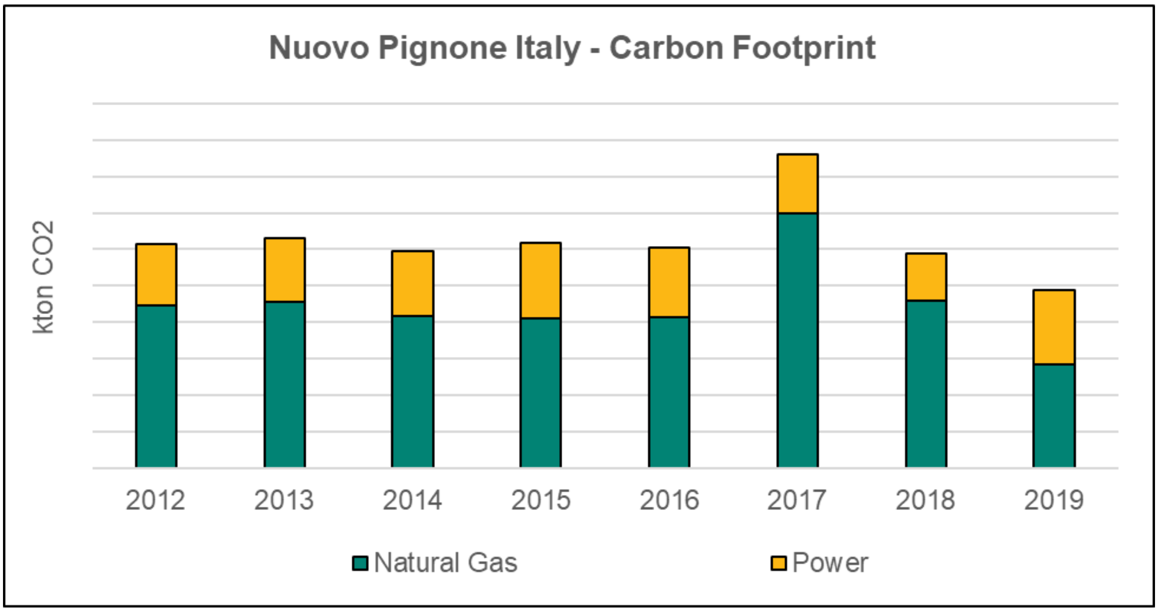

Figure 8.5: Nuovo Pignone decarbonization pathway 2012 vs 2019, without refrigerant contribution.

To recap, company's CO_2 emissions can be divided by both consumptions, as we have just seen, and final uses:

- Purchased electricity for both production and testing activities;
- Natural gas for both production and testing activities;
- Refrigerant gas for testing purposes only.

Therefore, even analyzing the emission trends in terms of final use, as before with and without the refrigerant, we can see how they change by case. Considering the total emissions, testing activities, which are characterized by wide fluctuations, account on average by 60% on the total CO_2 emissions, in the years under review. Consequently, the remaining 40% is provided by production and ordinary activities, whose emissions have decreased by 10% compared to 2012.

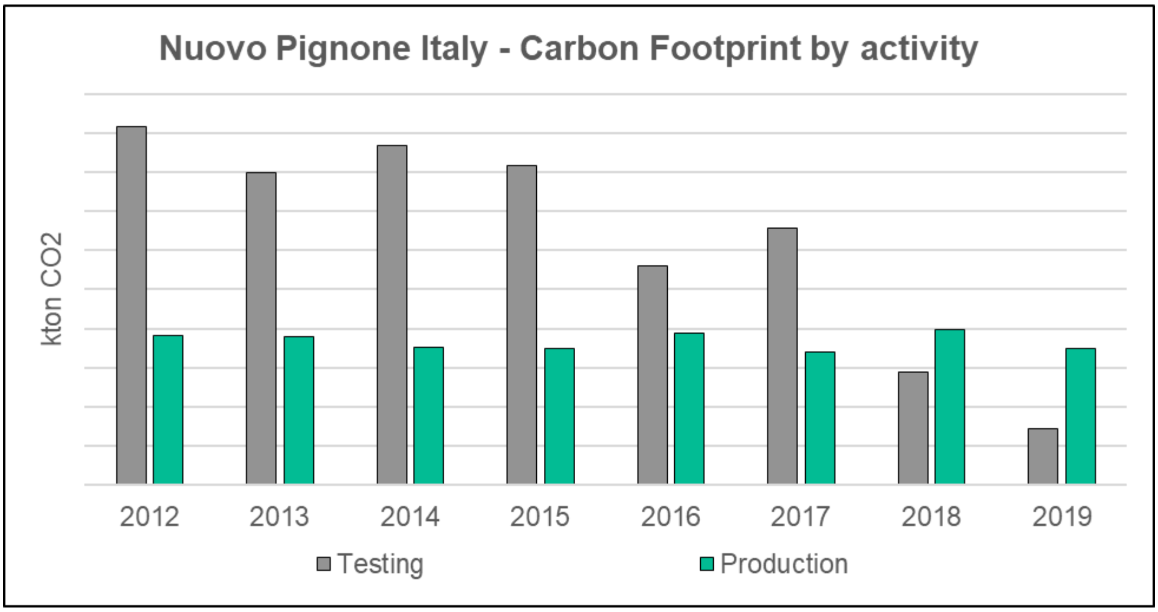

Figure 8.6: Nuovo Pignone decarbonization pathway 2012 vs 2019 by activity.

Looking at this figure, the contribution of the testing has been predominant from 2012 to 2017, while in the last two years it has become lower than ordinary and production activities, firstly due to the optimization of the refrigerant recovery system and then to its replacement. As already stressed, this gas has been able to completely change the CO_2 distribution between testing and production activities, compared to the last year, and to confirm this another figure is shown below.

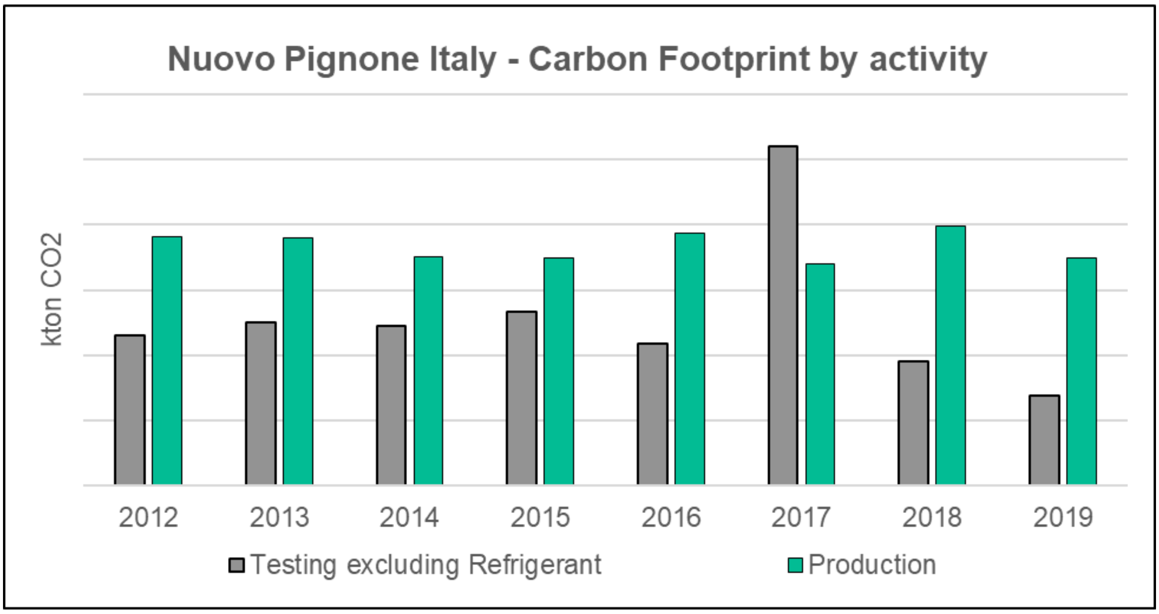

Figure 8.7: Nuovo Pignone decarbonization pathway 2012 vs 2019 by activity, without refrigerant.

Without considering the cooling gas contribution, the emissions related to the testing, except for 2017 , which has been characterized by extraordinary tests, were always below the production and ordinary activity level with an average percentage of 40% compared to the 60% of the previous analysis and vice-versa the emissions related to production have grown up to 60% with respect to the previous 40%.

In any case, actually, the target for 2030 has been reached, but in the next years Nuovo Pignone CO_2 emissions must decrease further through new and continuous improvement projects, efficiency and low-carbon investments and the good management of energy balances and new technologies in order to remain below the 2030 target and to advance as much as possible the goal of becoming net-zero carbon in 2050.

8.3. Decarbonization Performance Indicators

To better understand the trend of these emissions in the last years, we have performed an in-depth analysis, which does not consider the CO_2 emissions absolute value, but clarifies and highlights the more emissive activities and sources. An additional study about their evolution with respect to the company business has been carried out, through the introduction of two KPIs (Key Performance Indicator):

- CO_2 emissions with respect to the working hours, which are representative of the productivity status of the company;
- CO_2 emissions with respect to the revenue, which is representative of the company's business development and consequently of its productivity.

The first KPI is nothing but the ratio of the total emissions vs annual working hours, kton CO_2 / working hours, i.e. the total number of working hours in the offices and in the workshops for all Nuovo Pignone's Italian plants. These hours have experienced a generally upward trend since 2012, hence, knowing the decrease in emissions from the previous analysis, it is reasonable to expect a downward trend in this index, as confirmed by the figure below.

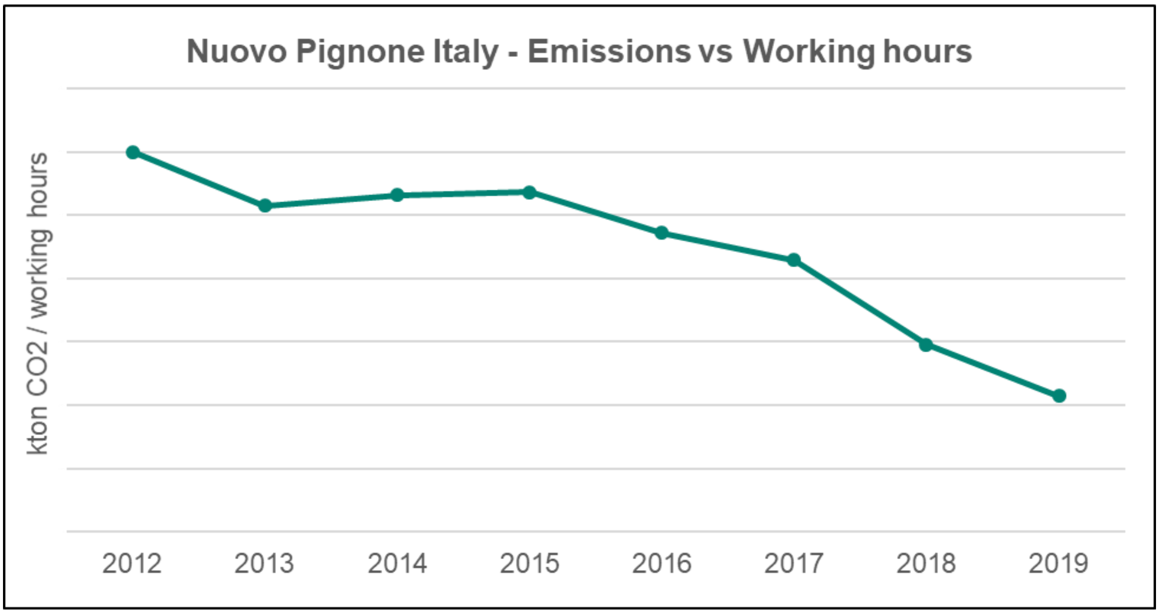

Figure 8.8: *Nuovo Pignone working hours KPI 2012 vs 2019.*

In fact, the indicator kton CO_2 / working hours, except for a year-over-year increase of 2% in 2014 and 2015, has progressively dropped over the last few years, registering a -65% drop in 2019 compared to 2012 baseline.

The second KPI, CO_2 kton / M€, has been evaluated until 2018, as the data for 2019 are not yet available. In this case the ratio is related to the total emissions vs the annual revenue. The latter, contrarily to what was said above for working hours, had a generally decreasing trend from 2012 to 2018, but despite this the KPI has produced positive results, especially in the last year, with a downward trend that recorded a -25%, while 2017 vs 2016 had been negative and rising by 15%.

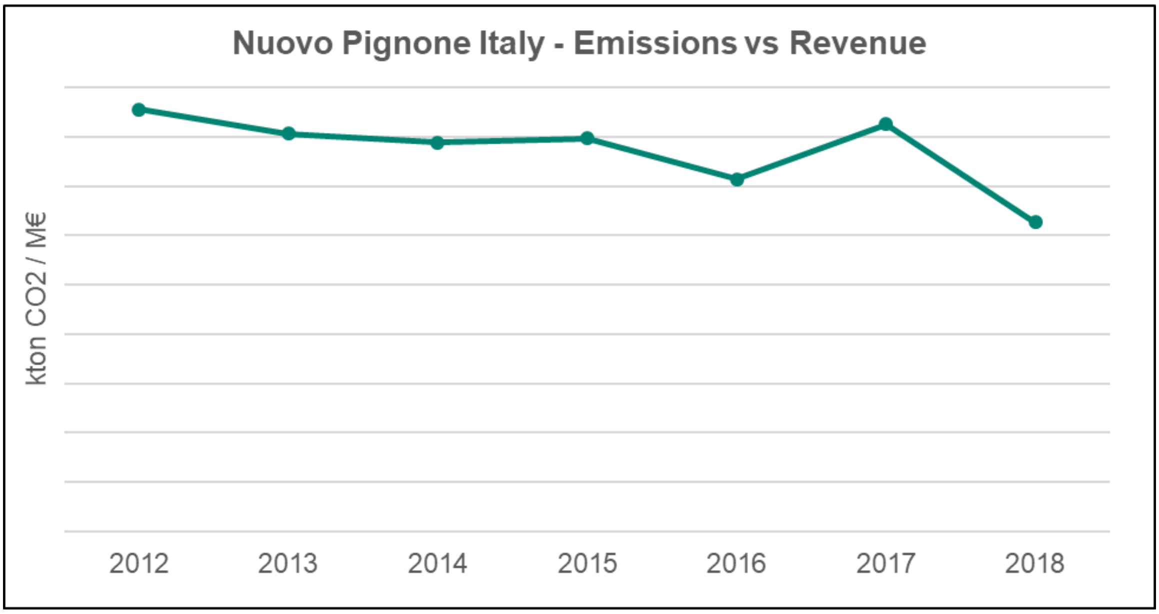

Figure 8.9: *Nuovo Pignone revenue KPI 2012 vs 2018.*

All these different analysis highlights the positive trend in greenhouse gas emissions of Nuovo Pignone's plants and the direction to follow to achieve more ambitious targets, such as becoming net zero by 2050, for which the pathway is still long and will require strong investments and a focus on energy efficiency in all its aspects.

Progress has been made over the last year and energy efficiency projects have been reviewed in order to improve further Nuovo Pignone's carbon footprint and to reduce energy commodities costs.

8.4. Target 2030

It was already shown that the target for 2030 of reduce by 50% the greenhouse gas emissions with respect to the 2012 baseline, in absolute terms, is currently being met. However, this condition must first of all be maintained and constantly improved. In this regard, a decade's roadmap has been estimated, considering:

- Efficiency projects that will have an immediate impact and other possibilities for the future;
- Hypothesis of 30% future increase of consumption due to workload and testing activity.

Projects will be analyzed in detail in the following chapters, while the increase of volumes is nothing but a forecast that could be cautious from the point of view of CO_2 emissions for both Scope 1 and 2, or optimistic for the company's revenue. In any case, the simulation of this "journey" is reported in the figure below.

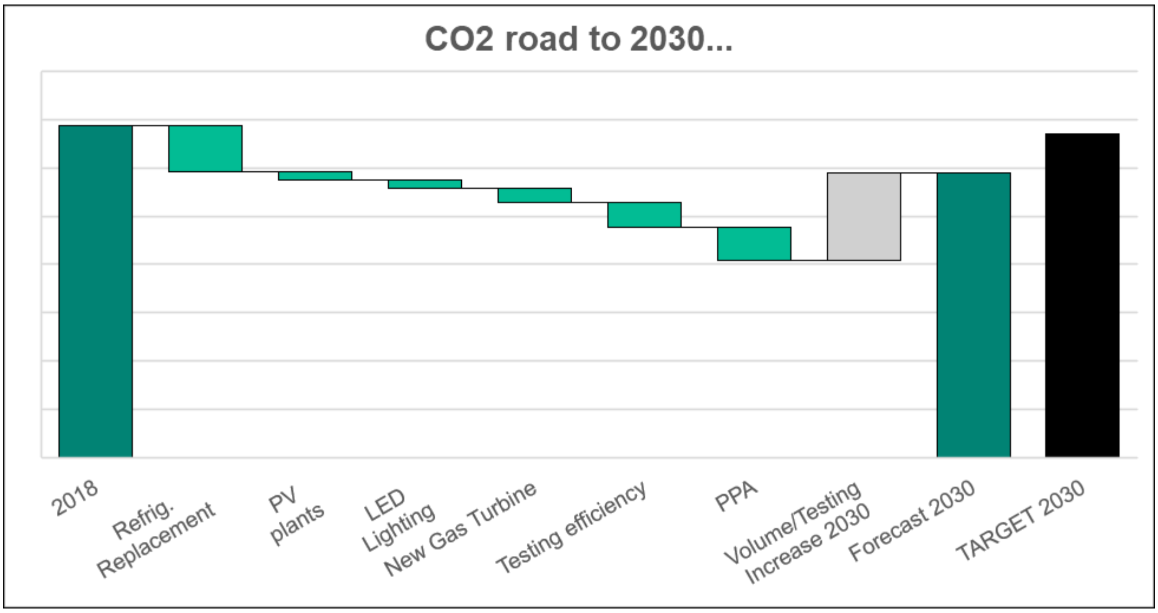

Figure 8.10: *CO_2 roadmap from 2018 to 2030.*

Figure 8.10 shows what were the expectations for 2030 the last year, considering:

- Refrigerant replacement;
- Installation of photovoltaic plants;
- Lighting replacement with LED;
- New gas turbine for the cogeneration plant;
- Improvement of the testing activity, due to more efficient Baker Hughes's turbomachines and energy storage;
- Power Purchase Agreements;
- 30% of consumption increase.

This analysis shows a positive trend, meeting the target due to a high downward contribution coming from the refrigerant replacement and the other projects, some of which have had an immediate impact.

In 2019, however, the scenario seems to be further improved, figure 8.11.

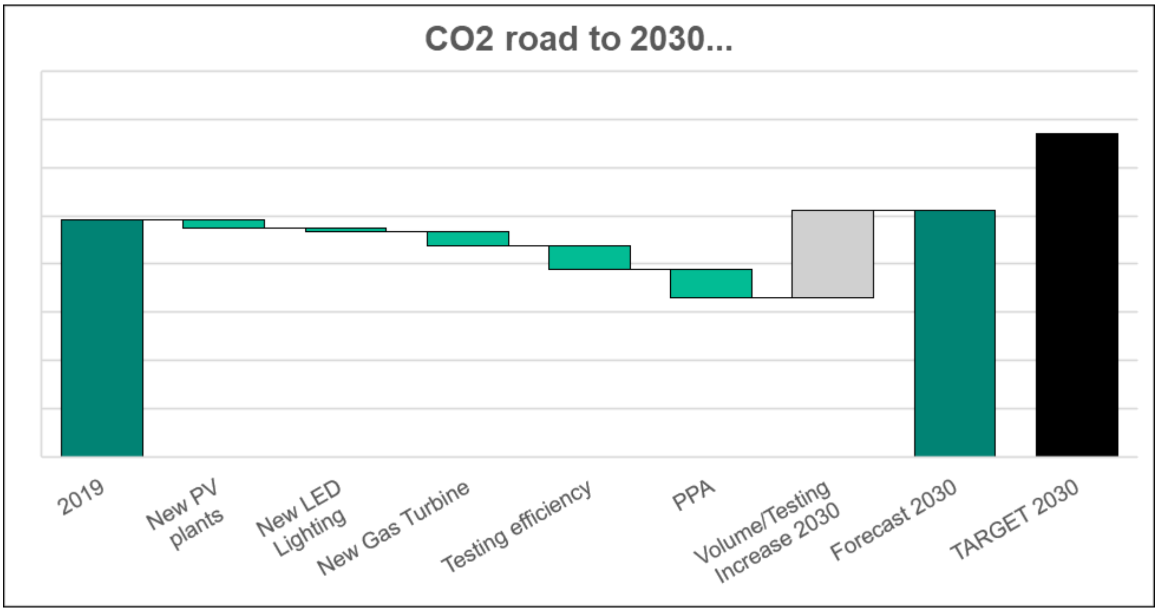

Figure 8.11: *CO_2 roadmap from 2019 to 2030.*

The impact of running projects and other initiatives show a more optimistic scenario that hopefully could become better and better through investments in energy efficiency and focus on the CO_2 reduction, as an industrial's world priority to fight climate change.

9. Onsite photovoltaic power production

Photovoltaic is one of the most common and efficient technologies among those related to renewable energy sources, despite its discontinuity and its strong dependence on the geographical area and related weather conditions in which the solar panels are installed.

For these reasons, in all Nuovo Pignone's Italian sites has been decided to install a series of photovoltaic plants, with an overall size that will permit to reach a self-consumption above 90% and in some cases of 100%. This energy efficiency project will contribute to the decarbonization process, reducing by 10% the current emissions related to Scope 2, and to the reduction of operating costs.

As we had seen in the chapter about energy consumption and related expenditure, the company's power profile is highly fluctuating due to production and testing activities, therefore the weekly peaks will be obviously uncovered by the solar profile, in fact, the way to "follow" the power peaks will be one of the most important future challenges. At the same time, not only the higher power peaks overcome the photovoltaic profile, as the figure 9.1 shows, but also another great portion of the absorption power curve, mainly due to two reasons:

- 100% self-consumption is an efficiency priority;
- Space availability on the sites rooftops is a not negligible issue.

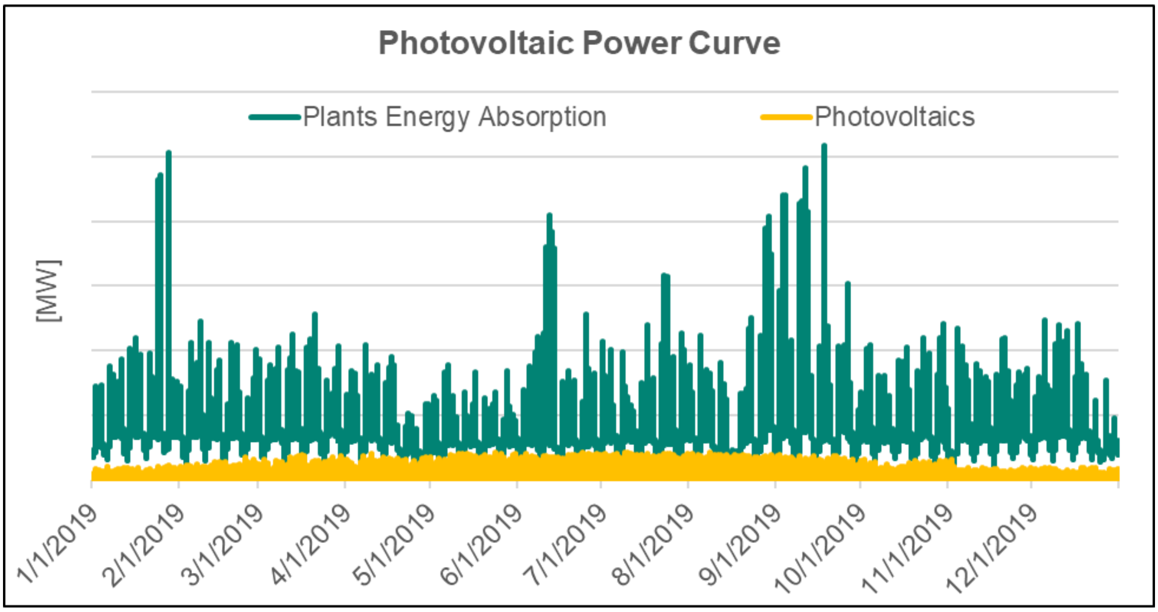

Figure 9.1: *Photovoltaics vs plants energy absorption.*

From a decarbonization point of view, these installations represent an excellent solution to reduce CO_2 emissions, but this is not the only reason. In fact, those on photovoltaics are investments on energy efficiency that allow to achieve interesting PBT (Pay-Back Times), thanks to good electricity savings and acceptable initial costs, in particular when the power installed size is in the order of MW_p (Mega Watts of Peak).

9.1. Investment opportunities on photovoltaic

There are three main possibilities to invest in photovoltaics for a company:

- Direct capital expenditure;
- ESCO (Energy Service Company) - formula contracts;
- PPA (Power Purchase Agreement).

In the first case, the initial capital expenditure and the operation and maintenance costs are entirely attributable to the company, which will benefit both from the entire savings on the kWh_{el} and from the surplus sold to the grid, when the internal consumption is lower than 100%.

In the second one, a second company, the ESCO, finances the total investment and is also responsible of operation and maintenance costs in order to make the costumer free from any possible risk, but in this case the benefit for the company is reduced because the saving on the kWh_{el} is no longer the effective market electricity price as in the previous case, but it depends instead on the price negotiated in the contract, which is fixed for a certain number of years.

The last possibility concerns the PPAs, i.e. a new long-term option whereby the company decides to purchase electricity, at a fixed price over the years, directly from a renewable energy producer, which means that the environmental benefit will be equal to those of the cases mentioned above, while the economical one, to date, is significantly lower because the supply price is higher than the market price. Despite the current situation, surveys in energy field predict that also PPA will become very competitive long-term investments, not suffering from energy market fluctuations due to their fixed price throughout the contract period.

As explained above, the reduction of greenhouse gas emissions is the same for all different types of investment because the energy source of supply is always the same and is renewable, however from a financial point of view the situation is not exactly the same, so will follow a more detailed comparison between the "CAPEX" and the ESCO-formula cases, while the analysis on PPA will be carried on later.

Firstly, it is important to stress that the decision to install a photovoltaic system for industrial plants is more effective if the self-consumption reaches values very close to 100%, because the remuneration price for the electricity sell to the grid is lower than the purchase one, therefore the investment would become less profitable. This consideration is valid in both cases, satisfying both costumer and supplier.

In the direct investment are considered:

- Capital expenditure at time zero, which accounts all initial costs, such as panels, inverter, cables, cabins, infrastructures, safety, labor, etc.;
- Operation and maintenance, which are annual costs, usually considered between 2 and 5% of the initial expenditure.

The evaluations regarding the ESCO contract are not affected by the two bullets just explained, being an "all inclusive" contract without initial capital expenditure. The main saving indicator in both cases is the one related to the electricity price. Let's now consider our system size guarantees a 100% self-consumption, our revenue is calculated as:

$$Incomes\ [€/y] = saving_{el} = price_{el} \cdot selfconsumption \quad (eq. 9.1)$$

$$Costs\ [€/y] = cost_{operation} + cost_{maintenance} + cost_{labor} \quad (eq. 9.2)$$

On the opposite side, if we must sell energy and therefore our capital expenditure becomes higher due to a higher photovoltaic installation size, costs increase almost proportional to the size, while incomes become, (eq. 9.3):

$$Incomes\ [€/y] = saving_{el} + sold_{el} = price_{el} \cdot selfconsumption + sales\ price_{el} \cdot surplus$$

Considering the 100% self-consumption, as the representant of the best solution, for the ESCO contract incomes and costs become:

$$Incomes\ [€/y] = (price_{el} - offer\ price) \cdot selfconsumption \quad (eq. 9.4)$$

$$Costs\ [€/y] = 0 \quad (eq. 9.5)$$

In equation 9.4, price is the market price considered also in the previous equation, while offer price is the one stipulated in the contract, which is obviously more competitive.

Then, a cashflow analysis to evaluate how good is our energy efficiency project in terms of return of the investment is necessary only for the "CAPEX" case, while for the ESCO-formula the initial and operational costs are equal to zero and so the balance between positive and negative cashflows always assumes a value higher than zero. In any case, will be represented below for comparison purpose and to stress that the higher will be the NPV (Net Present Value) at the end of the installation lifetime, the better will be the company's economic conditions, which guide the choice.

9.2. Cashflow analysis of a photovoltaic investment

For a proper cashflow analysis, first it is necessary to define the main financial indicators of interest, which will be the result of the business investment plan:

- NPV (Net Present Value): it compares the value of a dollar today to the value of that same dollar in the future, taking inflation and returns into account. If the NPV of a project is positive, it is considered acceptable, otherwise if the NPV is negative, the project will probably be rejected because cashflows will also be negative;
- IRR (Internal Rate of Return): it's the discount rate that makes the net present value of all cashflows of a project equal to zero, so the IRR is the rate of growth an investment is expected to generate;
- PBT (Pay-Back Time): it's the length of time required to recover the cost of an investment, so the better project is the one with the shorter payback period.

The "simple" cashflow is the result of a balance between the inflows and outflows. The first concern savings, credits and the potential electrical energy sale when the self-consumption is lower than 100%. Outflows, instead, consist of taxes and various operational expenditures and purchases occurring during the lifetime of the photovoltaic plants.

$$Cashflow\ [€/y] = Incomes - Costs - Taxes \quad (eq. 9.6)$$

Where taxes until the depreciation time are calculated as follows:

$$Taxes\ [€/y] = Tax\ rate \cdot (Incomes - Costs - Depreciation\ rate) \quad (eq. 9.7)$$

At this point is introduced the depreciation rate, which is the ratio between the initial capital expenditure and the depreciation time, which depends on the type of asset we are considering and can be different from the lifetime of the plant:

$$Depreciation\ rate\ [€/y] = \frac{CAPEX}{Depreciation\ time} \qquad (eq. 9.8)$$

and is also introduced the Tax rate, which is a percentage depending on the country and on the type of investment.

Finally, in order to obtain the present cashflow it is necessary to introduce the Discount rate, which is a percentage parameter based on particular market conditions and on financial company's choices:

$$Present\ Cashflow\ [€/y] = Cashflow \cdot Discount\ rate \qquad (eq. 9.9)$$

Making a cumulative of these present cashflows year by year the comparison of the two possible choices has been implemented and the results are reported, figure 9.2.

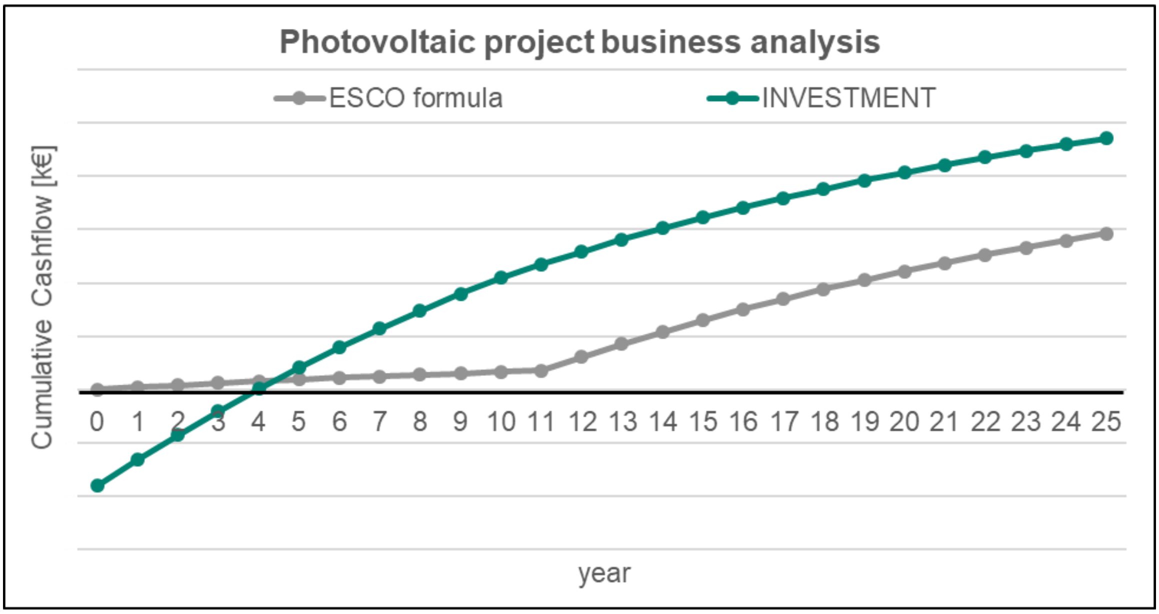

Figure 9.2: *Photovoltaic cashflow analysis.*

The representative figure of this financial analysis has confirmed the assumptions made before. In fact, if the company has the budget availability to invest on this energy efficiency project, the "CAPEX" is the best choice, despite is riskier, from a long-term point of view and for several reasons:

- From the payback time, which is around 4 years, the “CAPEX” curve overlaps more and more the one of the ESCO-formula, therefore incomes are higher;
- The NPV at the assumed end of the plant lifetime, i.e. 25 years, is 60% higher;
- CO_2 emissions reduction is equal for both cases.

The installation of photovoltaics on Nuovo Pignone’s plants rooftops, will enable the company to reduce, in Italy, its whole carbon footprint by 2% during the next year and by 5% considering only the electrical contribution (Scope 2). This investment is considered a starting point, further improvements and investments in renewable energy sources will proceed and are continuously under investigation.

9.3. Power Purchase Agreements

A forward-looking alternative to direct investments in renewable energy plants, but still aiming to meet the goal of the decarbonization in the industrial sector are the PPA, mentioned above as the third alternative. Power Purchase Agreements are contracts that support the construction of new renewable plants around the world and are currently more popular in America than in Europe, mainly for reasons related to energy market prices. [25]

These long-term contracts have a duration of more than 10 years and provide the purchase of energy at a fixed price from a supplier, which is the constructor and owner of the renewable installation. This option can be seen in part as an opportunity against possible fluctuations in market prices and, in part as a strong contractual constraint due to the multi-year duration of the agreement. The opportunity consists in the fact that, compared to traditional purchasing contracts, PPAs will help industries and, more in general companies, get the best price on the market by providing access to a much wider range of suppliers. [26]

At the moment, the company is exploring the applicability of these contracts, which will not be the total solution, because of the usual power peaks related to the testing. Nevertheless, their possible inclusion in the energy supply would help to achieve the decarbonization targets related to its industrial activity in the coming years, together with many other improvement projects. As we are talking about Nuovo Pignone’s Italian production sites, most likely the signing of this agreement will support the investment on a new renewable power plant in Italy. This new renewable power plant on the country territory would further increase the onsite photovoltaic installations curve, thus allowing a significative reduction of the CO_2 emissions related to the electrical absorption from the grid (Scope 2). PPAs would also allow other companies to do the same, and in this case the size of the renewable plant could increase significantly, generating a sustainable as well as image benefit for the whole country.

10. LED Lighting installations

The Baker Hughes's Corporate Responsibility Report of 2018 said: *"To demonstrate ongoing progress and commitment to meeting our long-range targets, we will establish much shorter-term, interim milestones to ensure we are on track. We set goals as ambitious as 10% emissions reduction each year. For 2018, we achieved an 11% reduction in emissions associated with our Baker Hughes direct carbon footprint. This was achieved through a combination of strategies, including 33 LED lighting building retrofits, the installation of solar panels on rooftops and on covered parking, as well as numerous other facility-specific energy efficiency projects worldwide".* [24]

10.1. Investment on lighting technology

In parallel with the investments in renewable energy generation that we have just addressed, LED (Light Emitting Diode) technology results a fundamental part of the Baker Hughes's committing. These ceiling lights allow to reach high saving in terms of energy consumption and there are essentially two main reasons why the focus on these investments is crucial for the company's strategy:

- CO_2 reduction concerning Scope 2;
- Energy costs reduction.

Compared to traditional lighting lamps, LEDs provide the same luminous flux per unit of surface (Lux) in the respective ambient, but with a lower installed power. As we have seen, the result of the lights replacement from the "as was" configuration to the "as is" one consists in an electrical energy saving with important economic and sustainable implications and is calculated as follows:

$$Saving_{el}[kWh/y] = \left(P_{old\ lights} \cdot \#old\ lights \cdot h_{as\ was} - P_{LED} \cdot \#LED \cdot h_{as\ is}\right) \quad (eq.\,10.1)$$

A different number of lights and hours must be considered in order to take in account any difference from the two configurations. Then, multiplying the energy saving by the unit price of electricity will result the yearly cost reduction, which is the income of the cashflow analysis, while the electricity conversion factor is applied to achieve the CO_2 equivalent reduction. For the financial analysis of this project has only been investigated the direct investment solution, which we have previously called “CAPEX”, thanks to its high profitability.

In 2017, the fluorescent tubes of the Nuovo Pignone’s workshops have been substituted with a large number of LED ceiling lights equipped with automatic regulation systems, in order to improve the operations in areas of the various sites where production is operative around 24 hours a day, which are those where the highest consumption is recorded, but also in sites characterized by hours of operation lower than 24. This energy efficiency project has allowed to reduce the overall electrical energy consumption by more than 5% and the total carbon footprint by 2-3%. The figure below reports the business analysis of this project, obtained by the same financial parameters and market conditions of the photovoltaic case, and underlines the good quality of this investment.

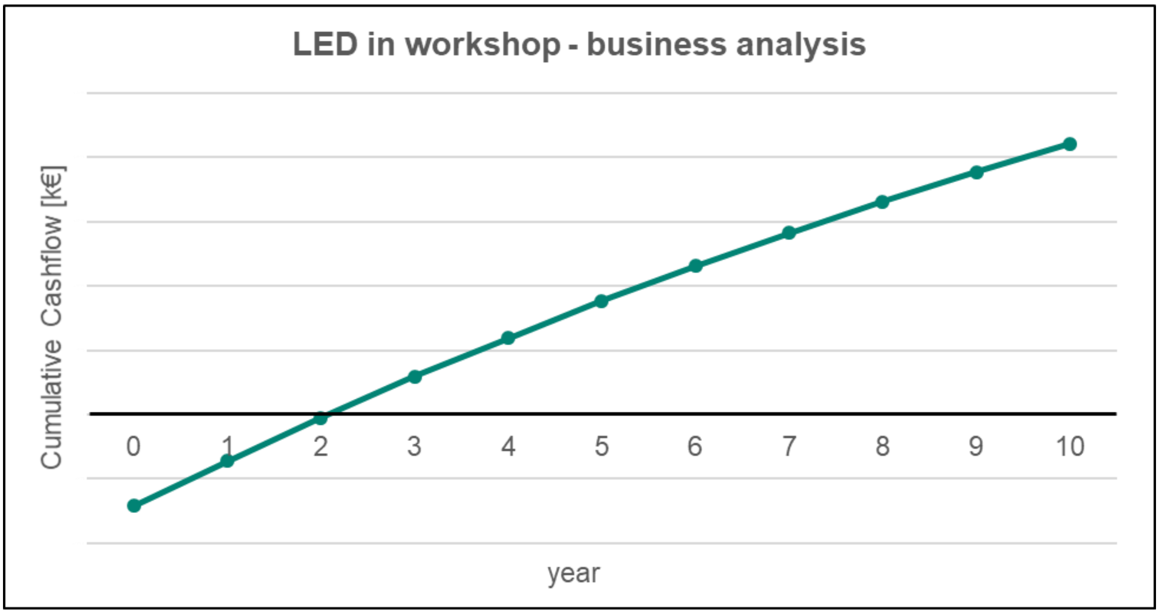

Figure 10.1: LED in workshop cashflow analysis.

Considering the figure 10.1, a payback time very close to 2 years can be seen, thanks to a great contribution from the hours of operations in the “as is” configuration. The reasons why these hours are very impactful are mainly two:

- Operational hours of the new configuration are lower than the previous one, under the same lighting condition, due to the automatic regulation system;
- Workshop is a 24h operative area in most sites.

The second point is useful to compare this business analysis with respect to the investment on the replacement of the lighting in the offices. In fact, the greatest difference between the two projects is the number of operation hours, although is not the only one: the difference between the light's power is lower, but the number of LED is higher and in the order of the tens of thousands.

In the company's offices the hours during which lighting is required are rarely more than 12 and the number of days per week is at most 6 out of 7. We have seen previously, as in the case of the workshop, that the total number of hours developed in a year is significantly higher, thus generating higher savings and assuming the same power and number of lights differences. Thus, for the project on offices lighting, is expected a higher payback time than the previous one mainly for the reasons listed above. However, other differences may arise from a different price per ceiling light due to the power involved and a possible different supplier.

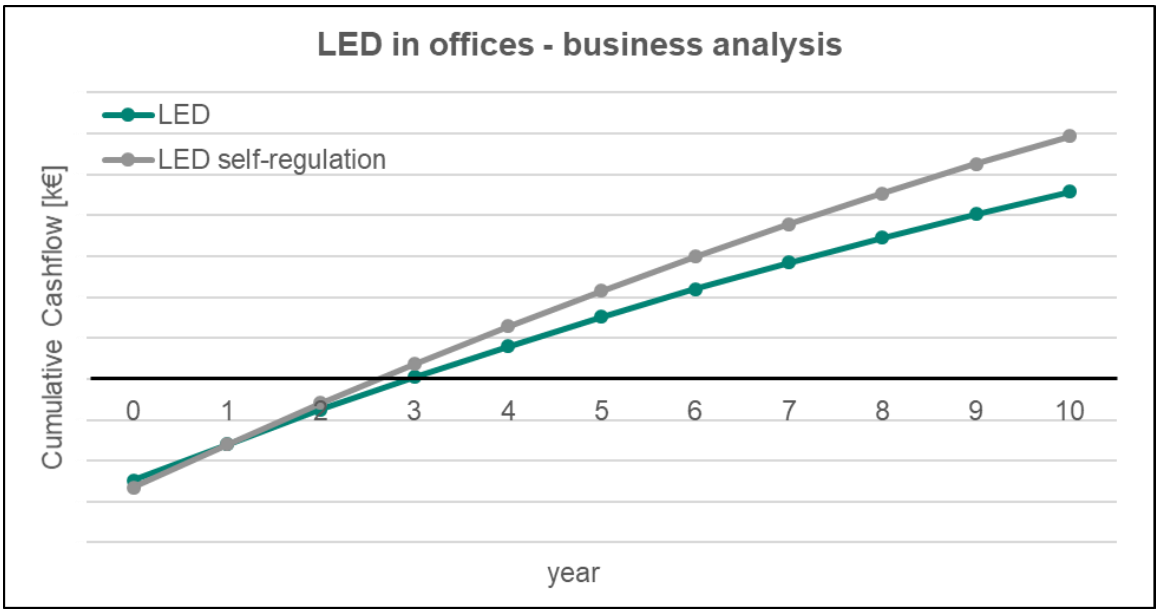

Figure 10.2: LED in offices cashflow analysis.

In this case the payback period is higher than 2 years as in the workshop case, but 3 years is still a good result. The analysis considers to possible choices: simple on-off lights and the ones with the self-regulation system. The second one is characterized by a comparable capital expenditure and has a more interesting Net Present Value than the simple ceiling lights due to greater savings, apart from a little lower PBT.

This saving is a benefit also for the decarbonization pathway, in fact this project is in an advanced stage of development and will allow in the next months a further reduction of the Nuovo Pignone's carbon footprint by 1-2% with respect to the last year.

10.2. Energy Efficiency Incentives [27]

Is important to stress that in these energy efficiency projects the costs reduction not only concerns the savings related to the lower electricity purchase from the grid, but also the incentives arising from energy efficiency title, which in Italian are called "Titoli di Efficienza Energetica (TEE)" or "Certificati Bianchi", while the impact on the carbon footprint is not affected by them.

In Italy, these incentives became effective in 2005 as the main instrument for promoting energy efficiency in industries, in other energy-consuming sectors as transport and services and also involve behavioral measures. They are negotiable titles that certify the achievement of energy savings through projects to increase the energy efficiency. A single certificate is equivalent to the saving of one ton of oil equivalent (toe), resulting from the conversion of electrical kWh, in our specific case, into toe through a coefficient (kWh / toe). The GSE, in Italian "Gestore dei Servizi Energetici", awards a certificate for each toe saving achieved through the implementation of an energy efficiency project. Then, according to the GME, "Gestore dei Mercati Energetici", the certificates are delivered on dedicated accounts.

The projects that can included in this mechanism are the ones that have not yet been implemented and are able to generate additional energy savings or to reach a consumption reduction lower than a reference threshold. There are basically two ways to submit the project:

- "A consuntivo": providing an accurate measurement of the specific parameters both in the "as was" and in the "as is" configuration;
- "Standardizzati": providing the possibility of measuring the specific parameters of a suitable representative sample of the operating parameters of the project.

It is not possible to submit requests for certification of savings and therefore receive the energy efficiency incentives in absence of a project approved by the GSE.

For the Nuovo Pignone lighting replacement project in the workshops, a smart monitoring system has been developed. Every month, in fact, a reporting file is automatically produced and thanks to this smart report the toe saved are visible. With a history of more than two years of data, it has been possible to notice that on average, each year, if certificates were obtained, their impact would increase the total economic savings of the project by about 30%.

The output of the monthly report is the amount of kWh saved, already converted to tons of oil equivalent through its specific coefficient (CF). Remembering that each energy efficiency certificate corresponds to a toe, it will be very simple to see the number of certificates achievable each month, and consequently each year.

$$Certificate/y = toe_{saved}/y = kWh_{saved}/y \cdot CF \quad (eq. 10.2)$$

At this point, the additional cost-saving produced by these certificates is calculated as follows:

$$Incentive\ [€/y] = Certificate/y \cdot price_{TEE} \cdot (1 - fees) \quad (eq. 10.3)$$

In the equation above, the price is the market price of the certificates which are released by the GME, [28].

	TEE €/toe
2017	267,02
2018	303,60
2019	260,00

Table 10.1: *TEE market values. [28]*

Fees are a percentage that is due to a company, usually an Energy Service Company, which supports the procedures necessary to obtain these incentives.

If the monthly incentives of one year are summed up, incomes for the cashflow analysis will become higher than the previous one:

$$Incomes\ [€/y] = Saving_{el} + Incentives \quad (eq. 10.4)$$

As a consequence, the payback time will result lower and the NPV higher than the solution without incentives, as is shown in the figure below.

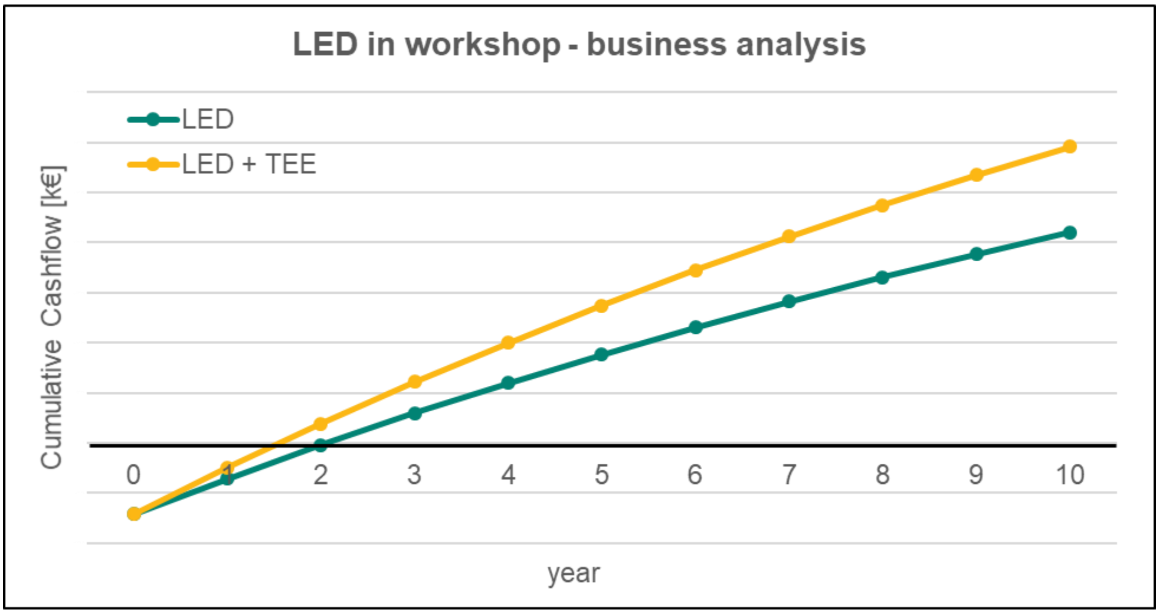

Figure 10.3: TEE contribution on LED in offices cashflow analysis.

The same considerations are being developed for the offices and for a possible future implementation of LED lights technology in the outdoor areas of the sites.

Conclusions

The purpose of this thesis work has been to explore the world of energy management and current decarbonization processes and to describe which methods and projects can be implemented to achieve the desired goals, in all their aspects. The context in which it was carried out is a great manufacturing industry, operating in the energy sector: Nuovo Pignone, part of Baker Hughes company.

Data on global scale have shown a strong impact of the industrial sector on both energy consumption and related greenhouse gas emissions, around 30% and 20% respectively. In fact, these numbers highlight how much a continuous and efficient control and management of energy consumptions are important and how much this approach has a positive effect on the environment and on reducing costs, in a global developing scenario where energy demand is expected to grow.

It has been seen how a setup of the processes focused on efficiency, not only in technological terms but also behavioral, can be fundamental. An efficient planning of strategies and budgets leads to great management benefits, as well as an efficient implementation of the improvement actions allows the achievement of the set targets. This interconnection would not be possible without continuous monitoring of any kind of performance, as an essential phase of the whole process. In addition, it has been noted that the constant updating and knowledge of the energy market and its commodities, such as natural gas, electricity and CO_2, all of which are characterized by high volatility in short term and by a strong connection among them, can lead to cost benefits and saving.

In the Florence site of Nuovo Pignone, the presence of the Combined Heat and Power plant is a key aspect. Its operation affects the whole management of production processes and consumptions. Only the CHP contributes on average to more than 70% of the natural gas consumption of the entire site and consequently to more than 50% of the carbon footprint, can lead to a cost variation in the order of millions and is the main player in the compliance with the European ETS Directive on CO_2 emissions. In this case, in fact, the efficiency mentioned above concerns any improvement to support the proper performance of the system. It would be extremely difficult to consider reducing the carbon footprint, for example, through a stop or a reduction in the production volumes of a plant, because this would not be in accordance with a growth trend both at company and global level, and this is why the path of efficiency is the best one to follow.

To conclude, the most challenging aspect regards the optimal configuration to achieve a reduction of the carbon footprint and at the same time to reduce operating costs. The main way forward is to invest in energy efficiency combined with a good communication to minimize waste. But which investments are the best? Theoretically, the best investment is the one characterized by the shortest payback time, thus the greatest revenue with respect to the capital expenditure, and by a higher impact on the reduction of CO_2 emissions. For instance, consider that in the project for the replacement of the ceiling lights for each kiloton of CO_2 equivalent reduced the related required investment is in the order of 1-2 million euros, while for the renewable installations the order of magnitude is the same but the value of the invested capital doubles. The considered ratio between euros and kilotons of CO_2 is indicative, as it is affected by different variables that may be of contractual, design or structural nature.

It is clear that moving towards the future and to achieve the goal of becoming carbon net-zero in 2050, the grater the investments in clean energy solutions, the more consistent will be the reduction of greenhouse gas emissions. There is already a certain propensity to look less at the payback period in decisions on projects in order to develop even those which are economically less profitable, but with a significant impact on the carbon footprint and a resulting not negligible image benefit. Another suggestion could be a future and global carbon tax that would revolutionize the approach to energy projects. Anyway, the evolution of market dynamics will be crucial, as a technology that is currently unsustainable from an economic point of view, but extremely impacting on the carbon footprint, may have a competitive price in the future and can be faced. Just think of hydrogen, coal gasification, carbon capture and all the most promising technologies that would help the energy transition. The most important factor will be to manage every opportunity in advance in order to exploit future developments in the best possible way and to remember that the benefit will not only be economic or image-based, but above all it will be a step forward in the challenge of global warming.

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