Local and global impact considerations on the turbo gas combined cycle

P. Baggio[1], A. Cemin[1], D. Cocarta[1,2], A. Gasparella[3] & M. Ragazzi[1]
[1]*University of Trento, Italy*
[2]*Technical University of Bucharest, Romania*
[3]*University of Padua, Italy*

Abstract

Studies on the impact on public health from macro and micro pollutants released from significant punctual sources have shown a remarkable development during the last years. These depend on the possibility of associating information on each pollutant to multiple pathways of exposition of the population present in the area of interest. In the field of energy generation the implementation of turbo-gas plants has not always have found a favourable welcome from the local population, nevertheless they have shown improvements compared to conventional systems. The present work wants to analyse in details some aspects related to the most recent debates on this topic, in particular pointing out the role of the introduction of a selective catalytic reduction for the removal of NOx from the off-gas of the turbo gas plants. Aspects related to ammonia release, the secondary particulate formation and the heavy metal release (in particular Vanadium) are dealt with, both in terms of global balance and in terms of local balance. At a local scale, the present work is faced with the role of the various methods of pollutant release (off-gas velocity, temperature, stack height).
Keywords: environmental impact, gas turbine, incineration, selective catalytic reduction.

1 Introduction

Production in the electric energy sector is based more and more on the realization of the new turbo gas combined cycle or the conversion of existing plants to this technology. Thanks to the contained costs of management, elevated flexibility and continuity of exercise, the turbo gas combined cycle guarantees high-performance production and lower polluting emissions in comparison to coal plants and combustible oil plants.

Concerning this last aspect some scientific works have recently underlined that, also using a less polluting fuel, these kinds of plants can constitute a source of impact for the environment though this does call for some cognitive closer examinations.

The purpose of the present work is to analyze some aspects of these plants from the point of view of the impact on the environment and on the health of the population in order to assess technological interventions of mitigation.

2 The turbo gas combined cycle plants

For the thermal power plants adopting the turbo gas combined cycle (CCGT) natural gas is used as fuel.

Currently this technology constitutes a valid solution for the conversion of old plants burning coal or combustible oil.

In the case of the turbo gas combined cycle plants the natural gas is mixed with compressed air in the combustion chamber and the off-gas produced from the combustion at high pressure and temperature are expanded in a gas turbine (turbo gas) that, rotating, operates an alternator for the generation of electric energy.

The products of the combustion at elevated temperature exiting the gas turbine are subsequently sent to a steam generator. The off-gases cooled by the process of thermal exchange go to the stack while the water that crosses the reheating system of the steam generator is vaporized. The steam is used for operating a steam turbine which is connected to an alternator. The steam at low pressure exits the turbine and is condensed in a special reheating system (condenser). The cycle is closed with a pump which sends the condensed water to the steam generator.

Currently this kind of plant is receiving remarkable interest, both in Europe and in non-European countries, for the high production efficiency that can be more than 55% and the low management costs. Moreover, partial heat released from the condenser can be used for applications of district heating (co-generation). In conclusion, this approach results in one of the less pollutant systems among those that use fossil fuels for the generation of electric energy.

3 NO_x emissions from a CCGT power plant

On a global basis, the relevance of the emissions of a power plant with respect to other emission sources of a specific region can be considered. Some data are reported for the CCGT power plant of Sermide (Mantova), in the North of Italy.

The plant is composed of two CCGT lines, respectively for 760 MW and 380 MW of electric power. The plant is allowed to work up to 8760 hours per year. Considering a technical availability of around 7500 hours the energy production is 8550 GWh_e per year while the natural gas consumption ranges from 5.1–5.2 million Sm^3. The incidence of the plant in terms of NO_x emission at the authorised limit concentration (50 mg/Nm^3) is around 2317 t per year. This amount is compared in Figure 1 with the NO_x emissions from other sources in the Lombardia Region, while in Figure 2 in the Mantova Province. The available data were reported for the year 2001 in the INEMAIR database [7]. The 2003 electricity final consumptions were 62570 GWh_e and 3620 GWh_e for the considered Region and Province respectively [5].

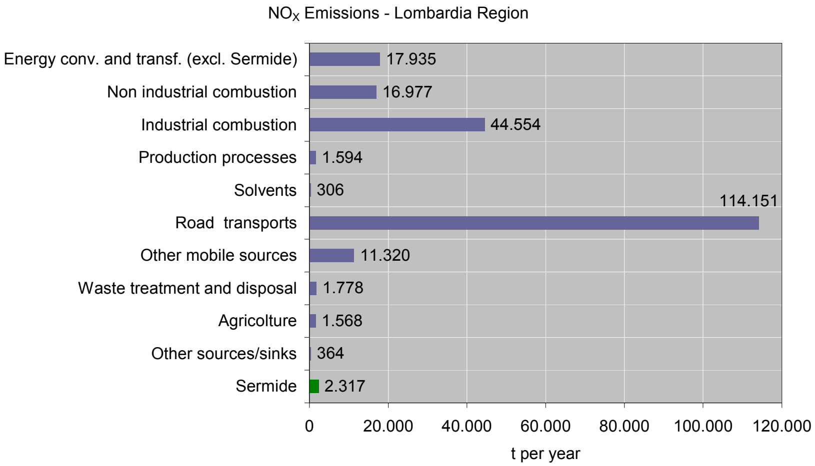

Figure 1: Annual NO_x emission in the Lombardia Region.

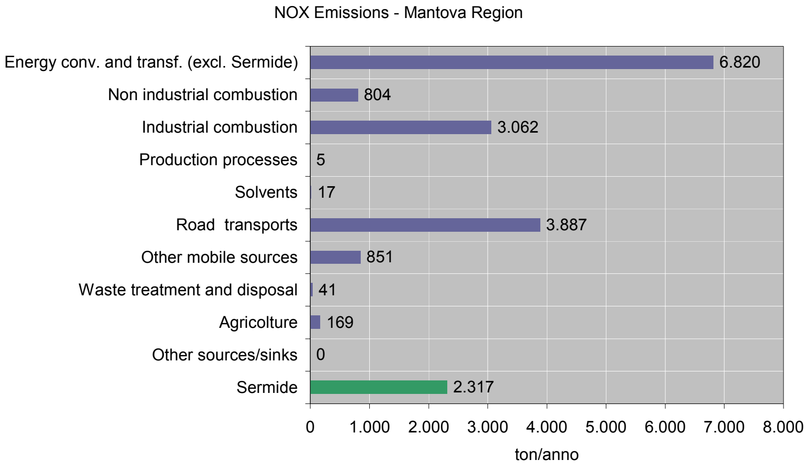

Figure 2: Annual NO_x emission in the Mantova Province.

As can be seen, the considered plant emissions are very much lower than the regional ones from the road transport sector or from the industrial combustion. The NO_x emissions from the energy conversion sector (excluded Sermide plant), which included in 2001 power plants for an electric power of 6805 MW besides to district heating plants, refineries, etc., were 17935 t.

The energy conversion sector assumes a significant relevance on a provincial scale.

As a general consideration, the NO_x emission from a medium to large size CCGT contributes up to a few percent of units to the total emissions on a regional basis while the relevance on a provincial basis is comparable to the emissions of a single sector of industry or road transport.

4 The CCGT plants atmospheric emissions and health effects

The main pollutants from the turbo gas plants belong to the macro pollutants category. Those that are more interesting from the point of view of the health risk and for the emission quantities into the atmosphere are the carbon monoxide and the nitrogen oxides. Ammonia emission appears if the plant is equipped with a system of selective catalytic reduction (SCR) for the nitrogen oxide removal. The existence of the micro pollutants in the atmospheric emissions can be both of organic nature (for instance, polycyclic aromatic hydrocarbons) and of inorganic nature (heavy metals). The quoted micro pollutants, besides having a high level of toxicity, generally have a long lifetime (in the order of years) and once introduced into the environment their dangerousness does not diminish with time. So, it is therefore important to verify that the emissions allow one to respect the most stringent targets of environmental quality.

Recently, because of the more and more frequent exceeding of the reference levels foreseen by the standards of air quality for the particulate matter in urban areas, attention to the problem of the secondary particulate has grown. This is not constituted of fine particles emitted directly from the plant but of particulate matter formed in the atmosphere following photo chemical reactions beginning from precursors, typically nitrogen oxides, sulphur oxides and ammonia. One of the remarks of the opponents of the SCR systems is the presence of ammonia releases and the consequent formation of secondary particulate. As we will see, the problem must be faced with the development of a cost-benefits balance. A second remark concerns the presence of Vanadium emissions that would be released by the catalyst of the SCR systems. This aspect should also be treated with a more correct approach, that keeps in mind the released quantities and the multiple pathways impact, with the aim of assessing which is the concentration limit to be authorized (if it is necessary to state it).

Presented below is a comparative example among an incineration plant for municipal solid waste (MSWI) and a CCGT plant both of great dimensions. The data used for the comparative balances are certified by the environment protection agency. The two plants are supposed to release the pollutants through stacks of the same height and temperatures. As a first approximation, in this paper the hypothesis that the dilution of the pollutants in the atmosphere has the same characteristics is made. The incineration plant for MSW has a net generation of 320 GWh_{el}/y while the CCGT can supply 8550 GWh_{el}/y. It can be noted the different role of the two plants in terms of generators of energy.

In Table 1 the amounts of emitted macro pollutants are presented comparatively. As can be noticed, the quantity of NO_x emitted by the thermo power plant is one order of magnitude higher than the amount emitted by the waste incineration plant. So, the importance of locating the plants in climatologically favorable areas and of assessing the environmental pressure in order to avoid exceeding the daily limit of NO_x in ambient air is clear (in fact NO_x is already a potential problem for incineration plants located in polluted areas and with a low dilution level).

Table 1 also reports a comparison between the two plants in terms of emitted heavy metals. Concerning the used data for the CCGT plant sector, it must be specified that in other plants higher values for Vanadium (also one order of magnitude) and lower values for Nickel (also one order of magnitude) were measured. As can be observed, for some cases the differences between the two plants are of some orders of magnitude.

In consideration of the heavy metals cancer potency emitted by the MSW incinerator the risk is driven by Cd. The other heavy metals contribute to the risk, but their dangerousness is of one or more orders of magnitude lower.

Table 1: Comparison between pollutants.

		MSWI	CCGT	
macro pollutants	NO_x	206.8	1966.5	t/y
	CO	48	128.3	t/y
	TOC	1.4	3.7	t/y
heavy metals	V	0.8	183.8	kg/y
	Cd	0.3	4.3	kg/y
	Tl	0.3	4.3	kg/y
	Cr	0.8	17.1	kg/y
	Ni	2.8	2659.1	kg/y

In fact, the pollutants of interest can be expressed as equivalent Cd through the ratio between their cancers potencies. For example, with reference to the risk by inhalation, Nickel is 16 times less dangerous than Cadmium and even if the emitted amount is around 9 times higher, the order of magnitude of the risk does not change.

In the present comparison the CCGT plant is assumed to have a similar release modality, from which the following considerations are reached. The most recent studies of health risk applied to MSW incineration underline that for operational values, the maximum individual risk from Cd results about 10^{-8}. From that it is deduced that for the CCGT plants the carcinogenic risk is driven by Nickel and it can be attended of about 10^{-6}. In fact, it one order of magnitude is lost because of the higher amounts (4.3 against 0.3 kg/y of Cd); a factor 16 is gained for the dangerousness of Nickel in comparison to Cadmium, but a factor around 900 is lost because of the different amounts. In consideration of the adopted approximation it is clear that there is a need for closer examination in order to verify the respect of the limit of 10^{-6} given by the World Health Organization.

Concerning BaP (Benzo(a)pyren), such a pollutant will soon be considered a tracer of the presence of other carcinogenic PAH. In fact, according to a recent Directive (2004/107/CE), an ambient air value of 1 ng/Nm^3 will be fixed. In the case of this paper, the concentration in the flue gas resulting from the CCGT is equal to 1μg/Nm^3. In order to comply with the quoted Directive, the atmospheric dilution of the stack flue gas must guarantee a dilution higher than 1000 times. A modeling verification is necessary.

The CCGT quality as an energy generator is underlined if the pollutants emission factors are expressed in comparison with the generated kWh (Table 2). However, Vanadium and Nickel result in counter tendency.

The turbo gas plant contribution to the secondary particulate ($PM_{2.5}$) formation is an aspect that requires additional studies. In recent months the first data of qualitative characterization of the PM_{10} have been issued. Such data will be useful to clarify which is the thermo power plant role to this concern. Concerning the primary particulate, there is a lack of unitary vision. Studies showing significant PM releases [1, 2] have been followed from studies [6] demonstrating an equivalence among input and output concentrations.

Table 2: Comparison between the emission factors.

		mg/kWh MSWI	mg/kWh CCGT
macro pollutants	NO_X	646.25	230
	CO	150	15
	TOC	4.375	0.435
heavy metals	V	2.625	21.5
	Cd	0.875	0.5
	Tl	0.875	0.5
	Cr	2.625	2
	Ni	8.75	311

5 The SCR issue

The selective catalytic reduction is the best available technology for the reduction of NO_x. It involves the ammonia injection in the combustion products before a catalytic bed.

The process catalysts can be constituted by titanium oxide (carrier material), vanadium oxides and tungsten (active elements). The SCR systems have a wide diffusion in environmentally aware regions like California, but they are still not very diffused in Europe. One of the reasons for opposition of this system is the presence of an ammonia slip that can be responsible of the formation of secondary particulate.

The optimal operating temperature depends on the type of catalyst. The range of operation is 180–260 °C for Platinum and 300–455°C for Vanadium. This range of temperature must be respected for two main reasons: 1) if the temperature goes down under the first range considered, it also lowers the efficiency of the reaction and in this way it also increases the ammonia release from the stack; 2) if the temperature increases too much the catalyst looses its proprieties.

The convenience of the SCR is demonstrable from the following considerations: starting from a quantity of 50 mg/Nm^3 of NO_x, the addition of NH_3 can decrease the concentration to 5 mg/Nm^3 of NO_x with a release of 5 mg/Nm^3 of NH_3. The conversion coefficients in secondary particulate vary, but the available information on it allows one to state that, even taking into account the contribution of NH_3 to the secondary particulate, the advantages of SCR are clear. Considering the ratio of dangerousness of the considered pollutants equal to 6.8 (value obtained as the ratio between the exposure levels for Ammonia and NO_x according to EPA: 3200 $\mu g/m^3$ and respectively 470 $\mu g/m^3$ - Inhalation Reference Exposure Level), it is evident that the substitution of NH_3 with NO_x gives a lower environmental toxicity.

In order to assess the convenience, the costs of the flue gas cleaning system of the nitrogen oxides must be compared with the external costs of the pollutants (or to the environmental, social and economic costs). This type of approach is used with the target of individualizing the environmental sustainability of the use of a SCR system. The environmental costs (EC) can be considered from the European Commission ExternE method [3] (expressed in Euro/t of NO_x emitted into the atmosphere), comparing them with the costs (CT) for the nitrogen oxides removal system: the resulting EC/CT ratio is around 1.1. Therefore the installation of a SCR system appears justified.

Another reason for concern is the possible release of Vanadium as an element of the catalyst: as it has been seen that in reality Vanadium is already present in trace amounts in natural gas.

6 Conclusions

The CCGT plants fed by natural gas undoubtedly result in a “clean” way of energy production. This does not cancel the importance of analysing some aspects with reference to their global and local impact. In particular, it is necessary to verify the carcinogenic risk from heavy metals emissions, (already present in natural gas), the contribution to the environmental background with reference to the new Directive 2004/107/CE (for Cd, Ni, BaP) and the role in the secondary particulate balance. Finally the opposition to the installation of SCR for the removal of the nitrogen oxides is not acceptable, as the obtainable benefits overcome the disadvantages.

References

[1] N. Armaroli, C. Po: Emissioni da centrali termoelettriche a gas naturale. La letteratura corrente e l’esperienza statunitense. La chimica e l’Industria – Chimica e….Ambiente, May 2003.

[2] N. Armaroli, C. Po: Centrali termoelettriche a gas naturale Produzione di articolato primario e secondario. La chimica e l'Industria – Chimica e….Ambiente, November 2003.
[3] European Commission, in "Research and Development ExternE Externalities of Energy - Vol X: National Implementation"1999.
[4] Eurosea http://www.eurosea.net/turbogas/ciclo.htm.
[5] GRTN, National balance of electric energy 2003 http://www.grtn.it.
[6] Macchi E.: Impatto ambientale dei cicli combinati alimentati a gas naturale, con particolare riferimento alle emissioni di polveri sottili (environmental impact of CCGT, with particular reference to PM emissions). Technical University of Milan. November 2004 – Italy.
[7] Regione Lombardia: Piano di Risanamento della Qualità dell'Aria - INEMAR (INventario EMissioni ARia), data 2001 updated to 2003 – Italy.