Methodological approach for the assessment of technological structure impact and risk

G. Genon & E. Brizio
Politecnico di Torino, Italy

Abstract

The environmental sustainability of technological plants, which is a fundamental requirement for territorial planning, needs the development of different widening moments. First, of all it is necessary to consider the plant as a potential source of pollutant emissions and to verify that the best technologies have been used to limit these fluxes, taking into account economic restraints. Second, the effect of the release on air quality modification should be established, with reference to air quality in particular, in order to be able to make suitable comparisons with recognized standards. Finally, it is necessary to evaluate the pollutant dose that has an impact on the exposed subjects, and the risk that arises from this impact, taking into account both toxicological and epidemiological considerations. The description of this path, with reference to some real cases of substantial impact and public concern, can be considered a methodological outline for the required compatibility assessment.
Keywords: emissions, environmental impact, dose, standards, modelling, interphase transfer.

1 Introduction

The construction of different types of technological structures (production plants, energy plants, incineration plants, wastewater treatment stations, highways, etc.) is useful to satisfy some natural requirements of society, but at the same time almost always encounters strong opposition, in relation to the environmental sustainability of the indicated structures.

Therefore, in order to help political decision, from a technical point of view, it is necessary to identify the conditions that relate to the required compatibility; the aim of this work is the presentation of some methodological indications in

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order to verify compatibility. Some illustrative examples referring to European experiences are also reported.

The logical path for an acceptance verification starts from the evaluation of the anthropic activity, and first of all its emission capacity; the verification of the limitation of this emission to minimum levels, according to technological possibilities, for a defined production potentiality, is the first assessment step, that it should be considered necessary, but not sufficient.

It should also be considered that the thus defined emission level allows the real weight of a new plant to be verified in comparison with an existing emissive scenario, taking into account possible compensation effects; this numerical definition cannot be used immediately for a sustainability verification, but it is, however, useful to establish the relative magnitude of different impacts that are introduced in the same territory.

A second step requires the evaluation of the changes in the environment quality level, and this is performed by defining the pollutant concentration, in different media, that arise from the new flux; a comparison of these levels with quality standards is a new practice, that is definitely more useful than the previous one, which was used to state the compatibility. Nevertheless, in order to obtain this result, it is necessary to have suitable and verified modelling tools available, that are able to correlate the generated emission fluxes to the ambient concentrations, taking into account the physical and chemical phenomena that define the pollutant transfer.

The reconstruction of the path of the pollutant from different environmental compartments to the final target, the humans, and the consequent definition of applied dose, are the essential information for sustainability verification; in fact, if it is possible to establish that the thus obtained impact can be contained within toxicological or health and sanitary bounds, this can be enough in order to surely assess the so-required compatibility.

More details are presented in the following chapters about the three previously mentioned fundamental steps; some specific numerical examples are also presented; these examples are obviously only valid for the particular local situation, but they can however also be useful to better understand the significance of the approach.

2 Emissive fluxes and best technological limitation

A first necessary condition to establish acceptability of a specific technological structure is the application of the best available technologies that are useful to limit impact; process modification, raw materials and reagent choice and application of end-of-pipe pollutant removal solutions must be considered as part of this condition, in order to limit the emission levels to the best updated environmental performance.

Good references to existing guidelines for the identification of the BAT of different sectors can easily be found within some European [1] and USA [2] documents; it is however necessary to take into account that these indications must be applied in the framework of the considered area, paying great attention to the specific economic applicability.

The performances of municipal solid waste incinerators and their atmospheric emissions can be considered as an example of this approach: the different levels that have been obtained in different periods are reported in Table 1; the emission standards fixed from different regulation agencies are also reported, in consideration of specific local sensitivities or fixed times to achieve appropriate technological levels.

Table 1: Improvements of emission standards over the last few decades.

	1970	1980	1990	Danish standards	EU standards	Actual plant guarant.
Dust (mg/Nm^3)	500	100	5	10	10	5
CO (mg/Nm^3)	1000	300	5	50	50	25
HCl (mg/Nm^3)	1100	100	5	10	10	5
NO_x (mg/Nm^3)	500	500	80	200	200	150
Dioxin (ng/Nm^3)	100	50	<0.1	-	0.1	0.1
Hg (mg/Nm^3)	0.8	0.8	0.05	0.05	0.05	0.05

The best result that can be obtained with a technological approach is clearly not an absolute value; it in fact depends, at least for the most part of the emission parameters, on the cost that the plant owner is able to pay to reduce emissions. For instance, Table 2 [3] reports the corresponding performances and costs for the removal of nitrogen oxides from cement kiln emissions. As for cost sustainability, in comparison to potential environmental advantages, the IPPC Bureau has drawn up a specific document [4].

Table 2: Costs and performances of different techniques to control NO_x emission from cement kilns.

Technique	Kiln systems applicability	Reduction efficiency	Reported emissions		Reported costs	
			mg/m^3	kg/tonne	investment	operating
Flame cooling	All	0-50 %	400-	0.8-	0.0 -0.2	0.0-0.5
Low-NO_x burner	All	0-30 %			0.15-0.8	0
Staged combustion	Precalciner	10-50 %	<500-1000	<1.0-2.0	0.1-2	0
	Preheater				1-4	0
Mid-kiln firing	Long	20-40 %	No info.	-	0.8-1.7	No info.
Mineralised clinker	All	10-15 %	No info.	-	No info.	No info.
SNCR	Preheater and Precalciner	10-85 %	200-800	0.4-1.6	0.5-1.5	0.3-0.5
SCR – data from pilot plants only	Possibly all	85-95 %	100-200	0.2-0.4	ca. 2.5 [4] 3.5-4.5 [5]	0.2-0.4 [4] No info. [5]

However, it is very important to underline that in order to evaluate the environment improvement that arises from the adoption of BAT, it is necessary to examine the dispersion and the final fate of pollutants; these aspects are the subject of the following chapter; it must be considered that the previously mentioned BAT criterion is only responsible for the feasibility evaluations within the industrial structure, with a perspective that does not take into consideration the final environmental results to any extent.

Moreover, it is interesting to take into account that the adoption of the best available techniques often refers to maximum concentration values for emitted fluxes, corresponding to end-of-pipe technological possibilities; the same concentration levels, applied to different activity sectors, can lead to very different emission fluxes. For example, one can consider the PCDD emission from three technological plants that are the main sources of this pollutant, namely RDF incineration plants, cement kilns and electric steel ovens. Table 3 shows that the emitted mass flow rates are completely different (the basis of this Table are the emission concentration levels today considered as BAT, volumetric specific waste gas fluxes, and the typical average potentialities of these plants).

Table 3: PCDD/F emissions from different technological plants.

	B.A.T. concentration (ng/Nm^3)	specific volumes (Nm^3/kg)	Potentiality (t/d)	emitted flux (mg/d)
RDF incinerator	0.1	5	250	0.125
Cement kiln	0.1	2	3000	0.6
Steel electric oven	0.5	11	2000	11

On the basis of this consideration, it is possible to consider the adoption of BAT values as a minimum requirement in order to accept a technological installation, but this aspect does not seem to be sufficient to define an acceptability condition; very often in fact it would not be able to define the real impact.

3 Environmental impact, map of created concentrations

The following step in the compatibility assessment is, as it has been indicated, the definition of the concentration map in different media (air, surface and underground waters, soil) due to a specific emission; these concentrations should be compared with the standards fixed for this compartment by the regulating agencies (these standards are generally considered as statistical values, mean values on different time lengths, or, in some cases, limit values).

As the evaluation of the correlation between emission and quality is in general based on a predictive approach which is conducted when the acceptability of a plant must be defined, it can only be based on suitable physical-mathematical models; these models have been created to interpret physical movement mechanisms or chemical transformation phenomena, and also even physical-chemical phenomena of interphase transfer; all these phenomena interact in order to define the final fate of a pollutant in different media.

A very large amount of literature is available concerning for air compartment [5], surface waters [6], underground water and soil [7] models; these models have different complexity levels and different capacities to correspond to

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different phenomena, and also to different territorial situations; some difficulties arise when choosing the most suitable model, its validation with reference to the particular system we are interested in and above all the definition of kinetic parameters that are considered as variables in any model.

It is very important to take into account that the numerical correlation between a pollutant emitted flow rate and the air concentration where the receptors are placed (this correlation can be represented by an α factor, that is, a dimensionless ratio between a volumetric concentration and a mass flux) is greatly influenced by the capability of the environment to “accept” the pollutant, or on the contrary the environmental sensitivity. As far as the atmospheric field is concerned, first of all the emission height and afterwards the wind dilution, low stability conditions, open volumes for horizontal dispersion, and the frequency of rain wash-out are all conditions that can lead to a lower sensitivity of the system; in these cases lower mean concentration values and also lower maximum values can be obtained for the same pressure factor.

Similar considerations can be made concerning emissions in surface or deep aquifers; in these cases, another phenomenon should be added to the previous dilution and dispersion mechanisms; this phenomenon, of different weight and consequently more or less able to modify receptor environmental sensitivity, derives from the removal rates non only due to chemical or physical factors but also biological.

As a general example, we can consider one fundamental aspect that should be taken into account in the acceptability assessment, i.e. dispersion in the atmosphere from isolated sources, and the consequent air concentration at a ground level deriving from the source: the value of the described factors for some typical situations in the Piedmont region, NW Italy, is reported in Table 4; the values were calculated for isolated sources in different territorial areas and with different emission heights.

Table 4: Transfer factors for different technological and environmental situations.

	Pollutant	Emission flow rate (g/s)	Emission height (m)	Maximum concentration (μg/Nm^3)	Topography	α (μg/Nm^3/g/s)
Cogeneration power plant	NO_x	0.047	10	10	flat terrain	25.4
Cement kiln	NO_x	2	67	5	valley	2.5
MSW incinerator	NO_2	4.5	80	0.3	urban area	0.067
Electric oven	dust	0.67	35	3.2	valley	4.8
Combined Heat and Power (CHP)	NO_x	0.11	10	5	hills	45

The table can obviously only be considered an illustrative example, but in the last column one can observe that the effect of the emission factor on the environmental concentrations is closely dependent on the emission height, as the dispersion is more powerful in larger areas and moreover a higher dilution effect can be observed because of a higher wind speed (dependent on the height). The topographic aspects also represent an important influence, as they can increase the stagnation phenomenon, and the geographical position can also be important, as it influences the frequency of stagnation and wind calm phenomena. In consideration of all these aspects, the different values can be justified, and the different impact represented by factor α can be understood and accepted.

Apart from the maximum concentration, which is a fundamental parameter for risk considerations, it is important to take into account the distribution of the concentrations, which can change at any time due to meteorological conditions; it is therefore possible to define the maximum values of concentration that can be reached, and the potential variation during the daytime hours.

As an example, Figure 1 [8] reports the map of the yearly mean concentrations that can be calculated for an incinerator that has to be constructed for the city of Turin; the concentrations can be compared to actual concentrations and law limits, in order to be able to decide whether a deterioration will be observed, its values and to verify whether law limits will be exceeded; this approach seems to be an important instrument for the territorial evaluation for the possible location of new plants.

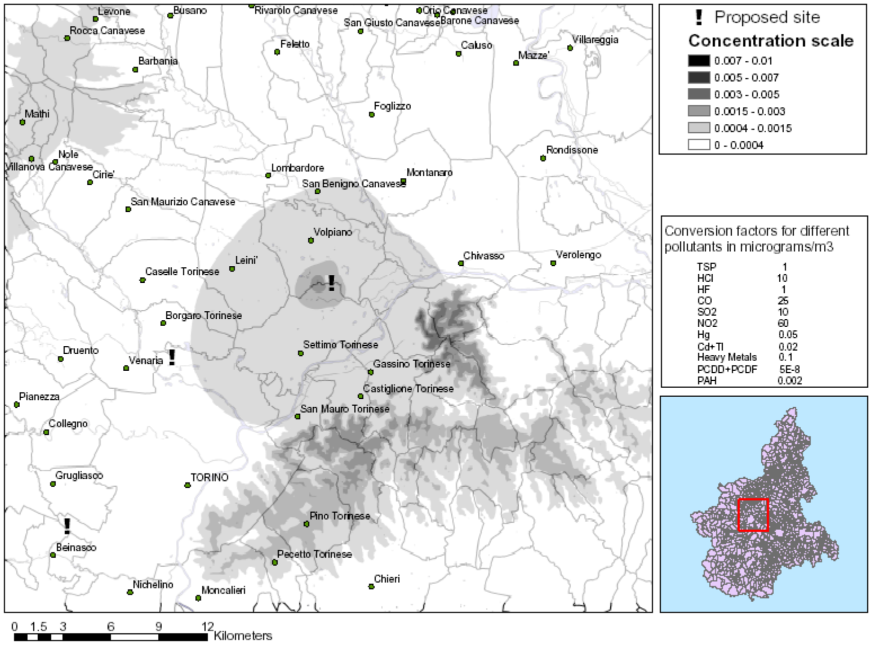

Figure 1: Isoconcentration map for the incinerator located near Turin.

If the same calculation process is applied to river water, it is possible to forecast the effect of a point or diffused load emitted into a river, and it is therefore possible to identify the influence of a flow rate regime and seasonal effects due to temperature and solar irradiation on the concentration and water quality downstream from a pollution source. A conservative mass balance, taking into account flow rates and concentrations in the river body and in the wastewater, leads to a prevision of final fate of persistent pollutants; if this balance is instead coupled to biological and physical-chemical elimination kinetics it can be used for estimations of the degradable pollutants. Plots like the ones reported in Figure 2 (taken from [9]) have been drawn applying this approach.

It can therefore be concluded that the environmental models together with the right definition of sources, can support the definition of quality values of different environmental media, to be compared to established standards, with the hypothesis that the compliance to the standard corresponds to the required acceptability condition.

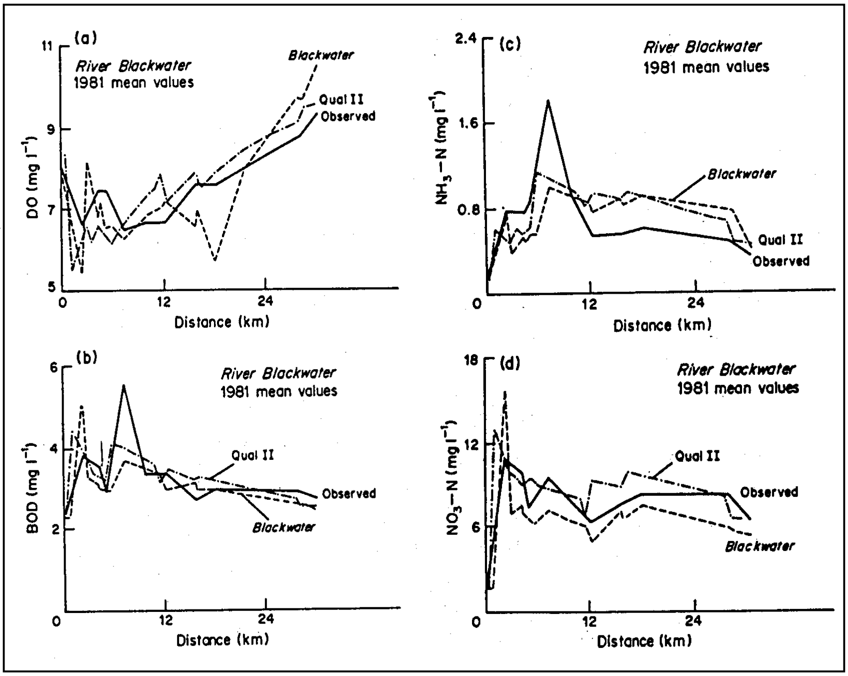

Figure 2: Modelled and measured concentrations in a river.

4 Multimedia transfer and introduced dose

The final and essential step corresponds to the definition of dangerous pollutant transfer through different media (soil, vegetation, water, food) towards the final target, that is, humans, where a precise dose through the different assumption paths can be defined.

An illustrative example of this whole transfer mechanism is reported in Figure 3.

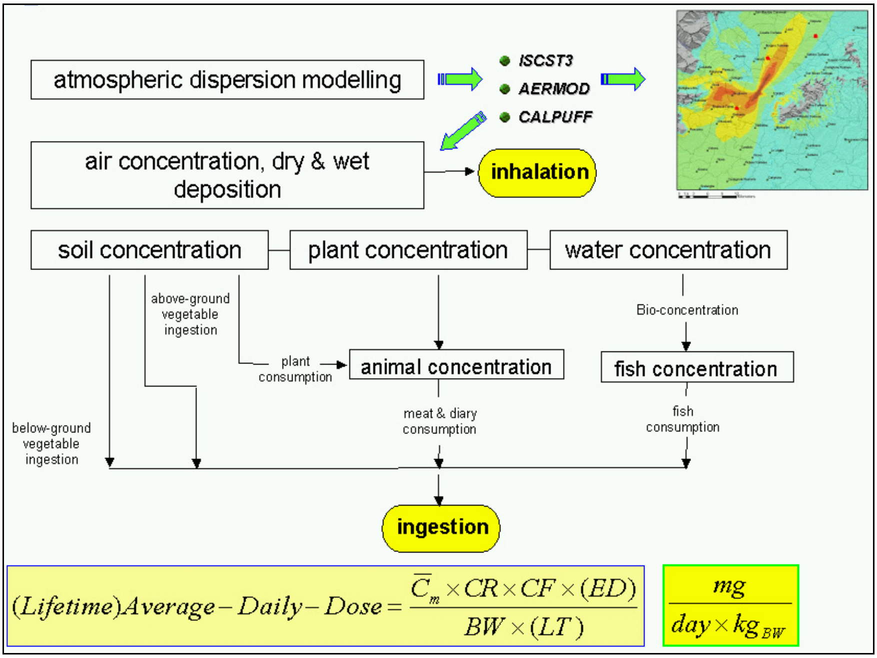

Figure 3: Conceptual scheme for a multimedia transfer mechanism from concentration to dose.

The scheme of these multi-medial transfers has been evaluated by means of equilibrium ratios between the contacting phases, or, alternatively, through interface transfer kinetic models, and it has been widely studied, at least with a model approach [10]; obviously, also in this case, as in the case of reconstruction of environmental dynamics, great difficulties arise concerning the definition of the specific kinetic parameters for the particular case.

It is also necessary to consider the probabilistic aspects involved in this approach, as both the transfer parameters and single doses for the final targets can be subject to very high casual variations.

As an example of the last part of the definition path, Table 5 reports two estimations of the maximum PCDD doses (daily intakes) for people living near a cement kiln [11] or a municipal solid waste incinerator [12].

In both cases the reported values are literature values, which were calculated using the methodology of a series of transfer equilibrium stages, for which a direct experimental determination is very difficult.

Table 5: Relationship between ground level air concentration and given dose.

	Air concentration (ng/Nm^3)	Dose (ng/d kg)
Cement kiln	$1\ 10^{-8}$	$5\ 10^{-7}$
MSW incinerator	$5\ 10^{-4}$	$1\ 10^{-2}$

The reported results seem to be in reasonable agreement, al least as far as the order of magnitude is concerned, and this fact is an indication of the correct definition of a similar, and substantially general, transfer model mechanism.
The dose that was calculated should be transformed into a consideration of sanitary environmental risks, taking into account different aspects, with reference to cancer or other risks. This latter information can only be derived from specific research studies [13], concerning medical, epidemiological or hygienic aspects. From these studies, it is possible to find threshold safety doses (the so-called reference dose for non carcinogenic risk), or numerical estimations of the correlation between dose and cancer probability (the cancer slope factor).

On this basis, the comparison between the calculated dose and the acceptable risk seems to be a useful criterion, that is sufficient to establish compatibility; this conclusion can be quite acceptable at least in order to avoid strongly critical situations corresponding to the exceeding of the limit (acceptable risk), while the final evaluation is more difficult when the limit is complied with, but it is only possible to identify a contribution to be added to others in order to establish the total damage.

5 Conclusions

In order to give a solid, and at the same time realistic and practically feasible aid to the compatibility assessment of a technological structure, the main aspects can be summarised as follows:
- the application of BAT can be considered an essential minimum condition, also taking into account economic aspects; these conditions cannot be translated into a significant assessment of the real impact on the environment, but they represent an attempt to adopt all the accessible technological tools in order to limit the introduced load;
- a compatibility verification could be identified by means of a comparison between concentrations in different individuated media and quality standards for the media defined on the basis of their use; the model approach used to arrive at the environmental concentrations starting from emissions can be considered rather reliable, taking into account the need to adopt specific validation steps for each application case;
- a final compatibility criterion should be the definition of the risk for the population; it can be evaluated taking into account the multimedia transfer chain of natural media, ecosystems and foods; this criterion can be considered in itself as being reliable, but it presents some limits, on the one hand the great difficulty of establishing the multimedia transfer parameters, on the other, the right

consideration of sub-critical doses, that added to the previously existing doses can lead to potentially critical situations.

All the above-mentioned considerations should be considered together in a compatibility assessment, in the case where a location must be decided on, or when it is necessary to establish whether a proposed technology is acceptable or not; it is necessary to combine minimum conditions, which are easier to verify and realise, with optimal ones (corresponding to sufficient conditions), which are more difficult to establish but which have a higher and more general meaning.

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