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Abstract
The goal of this study is to develop an emission based indicator for the health impact of the air pollution caused by traffic. This indicator must make it possible to compare different situations, for example different Urban Travel Plans, or technical innovations. Our work is based on a literature survey of methods for evaluating health impacts and, more particularly, those which relate to the atmospheric pollution caused by transport. We then define a health impact indicator based on the traffic emissions, named IISCEP for Chronic health impact indicator of pollutant emission. Here health is understood in a restricted meaning, excluding well-being. Only primary pollutants can be considered, as the inputs are emission data and an indicator must be simple. The indicator is calculated as the sum of each pollutant emission multiplied by a dispersion and exposition factor and a substance specific toxicity factor taking account of the severity.
Last, two examples are shown using the IISCEP: comparison between petrol and diesel vehicles, and Nantes urban district in 2008 vs 2002.
Even if it could still be improved, IISCEP is a straightforward indicator which can be used to gauge the chronic effects of inhaling primary pollutants. It can only be used in comparisons, between different scenarios or different technologies. The quality of the emissions data and the choice of the pollutants that are considered are the two essential factors that determine its validity and reliability.

Key words: Health impact, indicator, air pollution, traffic-related emissions

1. Introduction

Road transport emits a large number of substances potentially toxic for humans. It is especially the case in urban areas, where the main part of the emissions is due to traffic and the population densities are among the highest. Even if the average individual health risks are low, a large number of people are exposed, and the health impact of these emissions can be important.

It is therefore essential to assess air quality and its impacts, especially on health. Such assessment can be absolute or relative, comparing or ranking different situations. For evaluating policies, tools for assessing health impact are necessary. Among other tools, impact indicators allow us to synthesize different elements in a simplified way, quicker than more comprehensive but complex models.

The term ‘indicators’ can be understood and used in a number of ways, as witnessed by the literature review by Gudmundsson et al. (2010a). The indicators may be categorised as follows:

−A marker or *sentinel*, indicating the presence or absence of something

−A measurement tool, indicating variations along important dimensions of the indicated phenomenon

−A decision support tool allowing to take a precise action

- A combination of the above

An indicator can be defined as a variable based on measurements, representing as accurately as possible and necessary a phenomenon of interest. The closeness of the link between a phenomenon and the indicator used to describe it varies. The indicator is therefore used to provide an appropriate simplified representation of something, and can fulfil a variety of functions.

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The goal of this study is to develop an emission-based indicator for the health impact of the air pollution caused by traffic (see the full report by Lépicier et al., 2011). This indicator must make it possible to compare different situations, for example different Urban Travel Plans, or technical innovations (vehicle engines, fuels etc.). According to the indicator categories listed above, we aim at defining both a measurement tool and a decision support tool. It is a composite or aggregated indicator (sometimes called compound indicator), i.e. the mathematical combination of individual indicators that represents the chronic health impact of traffic-related pollutant emissions, whose description is the objective of the indicator users (see Saisana and Tarantola, 2002). Our work is based on a literature survey of methods for evaluating health impacts and, more particularly, those which relate to the atmospheric pollution caused by transport. The paper then goes on to make documented choices to ensure that the indicator we have created meets a number of quality criteria, such as reliability and relevance.

The literature affords a variety of methods for health impact assessment, of varying complexity and accuracy. We have studied four of the main ones, which have provided the basis for our work on the indicator. They are presented briefly below with reference to three aspects: input data, the approach followed and the units used:

- The Health Risk Assessment (HRA) is the method with reference status in the area of environmental health (InVS/AFSSET, 2007; National Research Council, 2009). Substances that have been identified as hazardous are studied independently of each other using toxicity reference values (TRV) which have been developed by recognized bodies (Word Health Organisation WHO, the US Environmental Protection Agency etc.). Exposure can be assessed with measurements or modelling, in particular on the basis of emissions. The result is expressed as a hazard ratio or a risk.
- The Health Impact Assessment (HIA) of urban atmospheric pollution (APHEIS, 2004; WHO, 2011) provides a way of determining the number of attributable cases or the number of years of healthy life that was lost attributable to air pollution (disability-adjusted life years DALYS, developed by the WHO: Murray, 1994; Granados et al., 2005; Mathers et al., 2006)). It is based on an exposure-risk relationship and links the ambient concentration of the substance with the appearance of a specific effect in the population. Such relationships are obtained by means of epidemiological studies. A selected substance is used as a marker for pollution.
- The Life Cycle Impact Assessment (LCIA) which is conducted in the framework of the life cycle assessment (LCA) is based on the pollutant emissions throughout the life cycle of a product or a service. Each link in the chain of causality corresponds to a factor: obtaining the exposure fraction, the effect of each substance and its severity (Krewitt et al., 2002; Hauschild et al., 2008). The exposure fraction is the proportion of the emissions which will effectively reach humans via the various environmental compartments (air, water, foodstuffs etc.) and the exposure channels (inhalation, ingestion and skin contact) (Rosenbaum et al., 2008). LCIA uses intra- and intercompartmental exposure and dispersion models, but takes neither the location of the emissions nor the exposed population into account, which is problematic in the case of local impacts such as those on health. In addition, the consideration of toxicity needs further improvement, as some methods sum substances without taking account of the severity of their effects (Huijbregts et al., 2000) and other methods propose extremely complex toxicity factors (Huijbregts et al., 2005, Goedkoop et al., 2009) and in some cases lack transparency.
- The Population Pollution Index (PPI) is used in France prior to the construction of roads (CERTU, 2005). It provides a measurement of the exposure of individuals to road traffic emissions. This spatialized approach takes account of the population and considers just one pollutant, which is taken to be a marker for pollution. It is a relative indicator.

Emissions are responsible for impacts on the environment and human health as a result of chains of cause and effect, which are also known as chains of causality (Joumard, 2011). A chain of causality is defined as the causal framework that describes the interactions between society and the environment. The causal chain we are concerned with is the *Direct effects of air pollution on human health in its restricted sense* (Gudmundsson et al., 2010a), i.e. the effects of primary pollutants on health rather than well-being, described in next section. A health indicator for an activity attempts to provide a simple evaluation of the link between the activity and its impact on health, i.e. of the chain of causality. Health indicators allow us to compare how health impacts vary over time or between different scenarios and appraise the outcomes of choices (plans, programmes etc.) that may affect the causal chain of the impact in question. As the total effect of a mixture of pollutants will be different from the sum of their individual effects (Dominici et al., 2010), there is a need for multi-pollutant methods (Kortenkamp et al., 2009).

We do not feel that any of the four methods we have described provides a satisfactory indicator of the causal chain to be represented, particularly in terms of simplicity. We shall therefore propose a new health impact indicator which is based on all the above methods, described below.

2. Materials and methods

We are developing an "Indicator for the Chronic Health Impact of Pollutant Emissions", so-called IISCEP indicator, whose acronym stands for "Indicateur d'impact sanitaire chronique des émissions de polluants".

The causal chain we have considered breaks down as follows: Transportation emits pollutants which affects air quality and increases primary pollutant concentrations. Exposure of the population increases and health effects may appear. Each of these stages is represented by a component of the IISCEP indicator.

The form of the IISCEP draws on LCA approaches (Huijbregts et al., 2000; Guinée , 2001; Krewitt et al., 2002; Huijbregts et al., 2005; Goger, 2006; Rosenbaum et al., 2008; Goedkoop et al., 2009; van Zelm et al., 2009) as emissions are multiplied by weighting factors. It is important for this indicator to be usable in very different situations, for example when comparing different technologies or evaluating regional transport policies. This means that the IISCEP must be adaptable, allowing, for example, factors to be added, removed or modified, as we shall see below.

The general formula for the IISCEP is (1):

$$IISCEP = Emissions \times FExp \times FTox \qquad (1)$$

Where *FExp* is an exposure factor,

FTox is a toxicity factor.

2.1. Emissions

The most problematic stage in the computation of the indicator is the evaluation of pollutant emissions. How this is performed depends on the purpose of the study. Vehicle emissions are generally calculated on the basis of unit emission factors, a representation of the vehicles on the road and traffic data. These three items of data make it possible to estimate how much of a pollutant is emitted on the basis of the composition of the vehicle fleet on the road, i.e. the proportions of the different types of vehicle, engine and fuel. This provides a degree of freedom with regard to the simulation of different scenarios as the composition of traffic can be modified for forecasting result.

In order to take account of the exposed population, the emissions of each pollutant p are calculated for zones that are homogeneous in terms of population and dispersion characteristics ($Emissions_{p,zone}$). The indicator can therefore be computed for individual zones and then aggregated to give a single figure.

Ideally, all pollutants should be considered, but in practice we do not have an emission factor and a toxicity factor for every substance. The pollutants which can be considered is one of the IISCEP indicator's most sensitive parameters as the emission of a very toxic pollutant may change the direction in which the IISCEP changes between two situations. We take into account the pollutants chosen by Cassadou et al. (2004) according to the levels of their emissions and toxicity factors.

As toxicity factors are known per pollutant, when emissions are only known globally for a set of pollutants (NMVOC for instance), hypotheses are needed about the mass distribution of pollutants in the pollutant set.

2.2. Exposure factor

The exposure factor represents the dispersion conditions and the exposed population. In some situations it is not used, in particular when the indicator is used to compare generally applicable technologies, in situations where all other things are equal. But, in a spatialized context, dispersion and the population have to be considered, particularly in the case of an urban zone.

The dispersion and the population correspond to the following factors in the IISCEP:

$$FExp = Population_{zone} / \left(Surface\ \ area_{zone} \times h_{zone}\right) \qquad (2)$$

where $Population_{zone}$ is the number of inhabitants of the zone,

$Surface\ area_{zone}$ is the zone surface,

h_{zone} is the mixing height in the zone.

2.2.1. Dispersion

Exposure is closely linked to dispersion, as dispersion determines ambient pollution levels. It depends primarily on the density and type of the built environment.

The PPI (see Section 1) is constructed using data on emissions that have been dispersed in a very simplified manner, by applying a wind matrix to the emissions (which are referred to as wind-influenced emissions). We have adopted a close approach, expressing emissions in terms of emissions per unit surface area and considering them to be homogeneously dispersed within the zone. Dispersion also takes place vertically, up to what is known as the mixing height. The mixing height provides a means of taking account of obstacles that interfere with dispersion, such as buildings. We therefore represent the concentration in the zone in terms of the emissions divided by the surface and the mixing height (*h*).

We have made the hypothesis that the impact is proportional to emissions without considering physico-chemical transformations. This means we can represent dispersion solely as the outcome of homogeneous dilution, as long as the indicator is applied only to "nearby" sources. There are two contrasting situations, city centres and the suburbs. According to the work of Mestayer (2010) and the observations reported by Grimmond and Oke (1999), a distinction between the two may be made by altering the value of the density of the built environment (*d*). We have assumed that the boundary between the city centre and the suburbs occurs at a density 0.35 m^2 of buildings/m^2.

In city centres (d>0.35), little exchange takes place between the canopy layer and the upper atmosphere. The mixed layer therefore consists of the canopy layer. The thickness of the mixing layer *h* is therefore given by the displacement height:

$$h = H \times \left(0.6 + 0.4 \times d\right) \qquad (3)$$

where *H* is the mean height of the buildings in the zone.

In the case of the suburbs (d<0.35), the mixing height is the atmospheric boundary layer, which is generally limited by a thermal inversion which acts as a lid. It is difficult to determine the thickness of the atmospheric boundary layer as it depends on a number of factors such as the thermal conditions and the wind. At the scale of a medium-sized city, the distance between sources and impacts is insufficient for homogeneous dilution to occur throughout the thickness of the atmospheric boundary layer. We can therefore replace the thickness of the atmospheric boundary layer by the thickness of the (virtual) internal boundary layer which would have developed over this distance *L*, assumed to be equal to the square root of the surface area of the zone:

$$L = \left(Surface\ \ area_{zone}\right)^{0.5} \qquad (4)$$

To avoid excessively complex parameterization, we shall use that proposed by Pendergrass and Arya (1984):

$$h = 0.38 \times Z_0 \times \left(L / Z_0\right)^{0.8} \qquad (5)$$

where Z_o is the roughness length of the zone, which can be expressed in suburbs on the basis of the mean height *H* of the buildings in the zone in question and the density of buildings *d* by:

$$Z_0 = 0.45 \times H \times d \qquad (6)$$

Then, using (4), (5) and (6),

$$h = 0.38 \times (0.45 \times H \times d)^{0.2} \times \left(Surface\ \ area_{zone}\right)^{0.4} \quad (7)$$

In rural areas, Z_o is the local roughness length, depending mainly on the vegetation.

2.2.2. Population

In order to take account of the persons who are exposed, it is necessary to know either the population or the population density of each zone. These can be found from available population data. Emissions are computed for each zone and then weighted by a factor that represents its population.

Geographic Information Systems (GIS) make it straightforward to characterize the spatial distribution of emissions. In the case of the PPI, the distribution of the population within the studied zone is provided by a population database. This may be constructed from census data, the use of aerial photographs, land use databases such as the European Corinne Land Cover geographic database, or by arbitrarily creating zones with the same populations and assigning a density to each (CERTU, 2005).

The indicator can be computed for each of these zones and comparing the results could provide a way of identifying the most problematical zones.

This type of approach has limitations due to the large number of simplifications involved. Its representation of the exposed populations is approximate as there is no way of taking account either of local travel time budgets (too complex to measure or use) or sensitive groups such as the elderly, people who are ill or young children, due, for example to the presence of old people's homes, child care centres or hospitals.

2.3. Toxicity factor

Toxicity is included in the IISCEP on the basis of two dimensions: the pollutant's potential for toxicity (toxic value TV_p) and the severity of its effects. The potential for toxicity refers to the threshold or the risk of an effect occurring. The severity is used as a criterion for applying a weighting to different substances: a substance which is just an irritant will not have the same impact as a carcinogen and will therefore be assigned a lower weighting in the indicator. We separate carcinogenic effects from non-carcinogenic effects. Toxicity is expressed as follows:

$$FTox_p = Severity_{Carc,\ p} / TV_{Carc,\ p} + Severity_{Non\ \ carc,\ p} / TV_{Non\ \ carc,\ p} \quad (8)$$

2.3.1. Potential for toxicity

As they are easy to obtain and widely used in the field we have decided to use toxicity reference values (TRV). These can be obtained from a number of databases belonging to recognized bodies. We used the inventory of pollutants for which emission factors and VTRs are available made by Cassadou et al. (2004). These VTRs are coming from a Canadian database (TERA) inventorying VTRs established by international bodies well known in the field of health risk assessment (ATSDR, Health Canada, IARC, ITER, RIVM, US-EPA and WHO/IPCS)[2].

, for example the IRIS database (USEPA), the WHO database or that belonging to the International Agency for Research on Cancer.

[2] TERA: Toxicology Excellence for Risk Assessment & Concurrent Technologies Corporation; ATSDR: Agency for Toxic Substances and Disease Registry; IARC: International Agency for Cancer Research (WHO); ITER: international Toxicity Estimates for Risk; RIVM: Rijksinstituut voor Volksgezondheid en Milieu (Netherlands); US-EPA United States- Environmental Protection Agency; WHO: World Health Organization; IPCS: International Programme on Chemical Safety

A single value is adopted for each substance and each type of effect (carcinogenic or non-carcinogenic). Each TRV is determined for an effect, generally a critical effect (the first to appear). This does not necessarily reflect the severity of the effects experienced by populations that are exposed to higher doses.

Atmospheric pollution from traffic usually results in low dose chronic exposure. The TRV represents the threshold or the risk of an effect occurring. The concentration at which different substances become toxic varies greatly, and may be extremely low (measured in ng/m^3 or µg/m^3 etc.) or very high (g/m^3).

The non-threshold effects are expressed as a risk of developing the disease, generally cancer. In order to make this approach consistent with that applied for other substances, a concentration value which corresponds to a risk of 10^{-6} is used, which is the level generally used for a negligible risk. This should in no case be interpreted as a toxicity threshold.

The value of our indicator must increase with health impacts. For example, the value of the indicator must increase with the number of persons exposed or with the amount of pollutant emitted. However, a high TRV indicates a lower level of toxicity. We therefore use the reciprocal of the TRV to represent the toxicity of the substances: those which cause effects at the lowest levels have the highest factors and, conversely, the lowest factors will apply to substances which are toxic at a higher dose.

The indicator is only concerned with chronic health effects. This is because the way it is constructed means that it seems to be impossible to include acute effects in a satisfactory manner. First, the way we have computed emissions for a whole zone is not appropriate for that way acute effects occur. On the other hand, as acute effects appear at higher exposure levels, they will have a lower toxicity factor and their effect will automatically be eliminated in favour of carcinogenic effects, because of the architecture of the health indicator (i.e. its use of the TRV). Furthermore, acute effects with high thresholds only apply to persons near the roads or under particularly poor dispersion conditions.

It is possible to apply different values on the basis of the toxicity of each substance, as has been done in particular in the case of LCA (McKone *et al.*, 2006). Table 1 shows the principal advantages and limitations of the four types of parameter that can be used to take account of the potential for toxicity of each substance, i.e. the experimental values (or points of departure POD), the effective dose (ED50), acute toxicity data and the toxicity reference values (TRV).

Table 1: Advantages and limitations of the different toxicity values

Value	Advantages	Limitations
Experimental value (POD)	- No factors of uncertainty	- Obtained from a limited number of individuals - Often consist of animal data - May depend on the experimental protocol - Depend on exposure conditions
Effective dose (ED50)	- Suitable for low doses	- Availability is currently limited - Recognition/acceptability?
Acute toxicity data	- Widely available	- Not for chronic risks (which are the most important in the case of atmospheric pollution) - The relative proportions of acute and chronic effects vary from one substance to another
Toxicity reference value (TRV)	- Readily available - Recognized and widely used to evaluate health risks - Critical effect (severity)	- Uncertainty factors - Generally obtained from experimental values, may therefore possibly depend on the protocol - Accuracy in the case of low doses not always certain

The working groups that were set up to work on LCA recommended using the effective doses (Owens, 2002; McKone et al., 2006), as these are of interest in situations of low concentrations.

Due to lack of data, the TRVs for fine particle emissions from diesel vehicles were applied to gasoline fine particle emissions. As no TRV is available for chronic risk of carbon monoxide, it is not possible to take into account this pollutant. Only air quality objectives are available for CO, but they are rather administrative and are not effect thresholds.

2.3.2. Severity

The severity factor must be representative of the effects of the substance, and the selection of a relevant effect is of prime importance. It is therefore necessary to select a reference effect or a type of reference effect for exposure to each substance and decide on a severity value for each effect.

When they are known, the effects that are observed on humans in the course of epidemiological or experimental studies are used. However, the effects of some substances on humans have never been studied, or the studies that have been performed failed to identify any specific effects. In this situation, we consider the target of the toxic effect observed in the animal (nervous system, kidneys etc.).

Another possibility would be to use the critical effect that corresponds to the TRV selected for each substance. The critical effects generally consist of the least severe effects observed in animals. These are already used to classify pollutants into different severity categories (Owens, 2002). This approach has certain limitations, for example, it is possible for a substance to act via several biological mechanisms. Furthermore, the use of animal data could introduce a bias due to the assumption that the effect in animals and humans is identical. In addition, the effect of the substance depends on the exposure and possibly the amount of pollutant emitted: the severity of the critical effect in no way determines the severity of the effects caused by higher exposure.

So, choosing weightings on the basis of the critical effects would mean giving a high weighting to substances that are not very toxic when one considers all their toxic effects and a low weighting to substances whose critical effect is benign but which can be fatal in higher concentrations. Finally, it may not be possible to exploit the critical effects of the TRVs because of excessive specificity (for example the amount of a compound in the blood) or because of insufficient specificity, as in the case of total proteins in urine, or the lack of a precise description, for example for developmental problems.

In the case of each substance, the choice of the effect that is considered, i.e. the critical effect or a more severe effect, is extremely important. This choice can be made on the basis of the levels of emissions.

Assigning a value to severity is the subject of much discussion, and to date no consensus has been reached, mainly because of the inherently subjective nature of a classification of diseases. Two questions arise with regard to this stage: how can we determine severity factor values, and is it better to deal with each effect individually or group them into categories that are as homogeneous as possible (reversibility, pain, etc.)? There are three possible ways of obtaining values: conducting a survey of an appropriate and legitimate sample of the population, using available values, or assigning a subjective score determined on the basis of a variety of criteria.

The method we selected involves aggregation on the basis of categories of effect. A straightforward separation between carcinogenic effects and non-carcinogenic effects was rejected in favour of a more sophisticated separation that took account of all the effects, which is a compromise in order to classify the toxicity. The substances are first grouped together on the basis of their principal target organ or system (nervous system, kidneys, lungs, reproductive system, etc.). We thus make the hypothesis that the different pollutants act additively, i.e. that there is no interaction between them. Using the findings of the research conducted in the framework of the UNEP/SETAC initiative (Burke et al., 1996), three categories were selected, with reference to two criteria: reversibility of the effect and impact on longevity.

The distribution of the different toxicities between the classes is shown in Table 2. Neurotoxicity may be placed in either category 1 or 2. The advantage of this classification is that it has already been used on a number of occasions, in particular in Life Cycle Analysis studies.

Table 2: Classification of effects into the 3 severity categories (Burke et al., 1996)

	Category 1	Category 2	Category 3
	Irreversible / reduced life expectancy	Probably reversible / perhaps fatal	Reversible and non fatal
Effects	Cancer Teratogenic effects Reprotoxic effects (Neurotoxicity) Fatal or severe and irreversible acute effects	Immunotoxicity (Neurotoxicity) Kidney damage Liver damage Heart disease Lung disease	Irritation (eyes, skin etc.) Sensitization (allergies) Reversible acute effects

For determining weightings of the effect categories, as it was not possible to carry out a survey among the general population, we have used values and orders of magnitude that were available in the literature. The most appropriate values we found in the course of our literature survey are the weightings used to calculate Disability-Adjusted Life Years (DALY) (Mathers et al., 2006, Table 3A.6). These values have the advantage that they were obtained using normalized methods and have been criticized and improved (Üstün et al., 1999; 2001; Mathers et al., 2006; Van Baal et al., 2006). They are currently based on expert opinion and their soundness will be enhanced in the future by the use of data collected in the course of major WHO surveys of the general population (Mathers et al., 2003; 2006). However, these values are not applicable to the effects of non-carcinogenic pollutants as it is not possible to establish a link between the effect of all the substances and a disease in the list given by the WHO in the Global Burden of Disease study, as each disability weighting is defined for a human disease (WHO, 2008). In some cases the symptoms are too benign compared with those considered by the WHO, for example a permanent loss of sight or wasting due to a protein deficiency. There is also a major difference because in the case of many effects the symptoms may disappear if exposure, even chronic, ceases. In addition, the use of DALYs in our situation is quite outside their conditions of use.

Weightings of 100, 10 and 1 have been finally assigned to categories 1, 2 and 3 respectively according to subjective assessment by Burke et al. (1996) without clear justification. Such weighting has been adopted by Pennington et al. (2002) and Bachmann (2006).

2.4. Results: detailed proposal for the IISCEP

Taking into account the choices made above, we get the formulae of the IISCEP indicator, by combining formulae (1), (2) and (8):

$IISCEP =$

$$\sum_{p=1}^{n}\left[\left(\frac{Severity_{Carc}}{TV_{Carc,\ p}}+\frac{Severity_{Non\ \ carc}}{TV_{Non\ \ carc,\ p}}\right)\times\sum_{zone=1}^{k}\left(\frac{Emission_{p,\ zone}}{Surface\,area_{zone}\times h_{zone}}\times Population_{zone}\right)\right]\times c$$

Where

- n is the number of pollutants p,
- $Severity_p$ is the severity factor for pollutant p for its carcinogenic and/or non-carcinogenic effects,
- TV_p is the toxicity value for the pollutant p in mg/m^3 for its carcinogenic and/or non-carcinogenic effects,
- k is the number of geographical zones, defined on the basis of their population (in number of inhabitants) or their surface area (in km^2),
- $Emission_{p,zone}$ is the emission of pollutant p in the zone,
- $Surface\ area_{zone}$ is the surface of the zone,
- h_{zone} is the mixing height in the zone. If H_{zone} is the average building height in the zone and d_{zone} its building density,

- if $d_{zone} < 0.35$, from (7), $h_{zone} = 0.32 \times \left(H_{zone} \times d_{zone}\right)^{0.2} \times \left(Surface\ \ area_{zone}\right)^{0.4}$
- if $d_{zone} > 0.35$, by using (3), $h_{zone} = H \times \left(0.6 + 0.4 \times d_{zone}\right)$

- c is a fitting constant.

3. Applications

The IISCEP indicator has two main types of application:

- The global comparison of vehicles, technologies, driving conditions etc. where it synthesizes emission factors of different pollutants. The local conditions (dispersion conditions, spatial population distribution etc.) are supposed not to change. Such comparisons are very frequent, but usually made by considering the different pollutants independently: the indicator allows us to aggregate all the pollutants.
- The local comparison of populations, areas etc., where it synthesizes emission inventories of different pollutants, population and dispersion conditions.

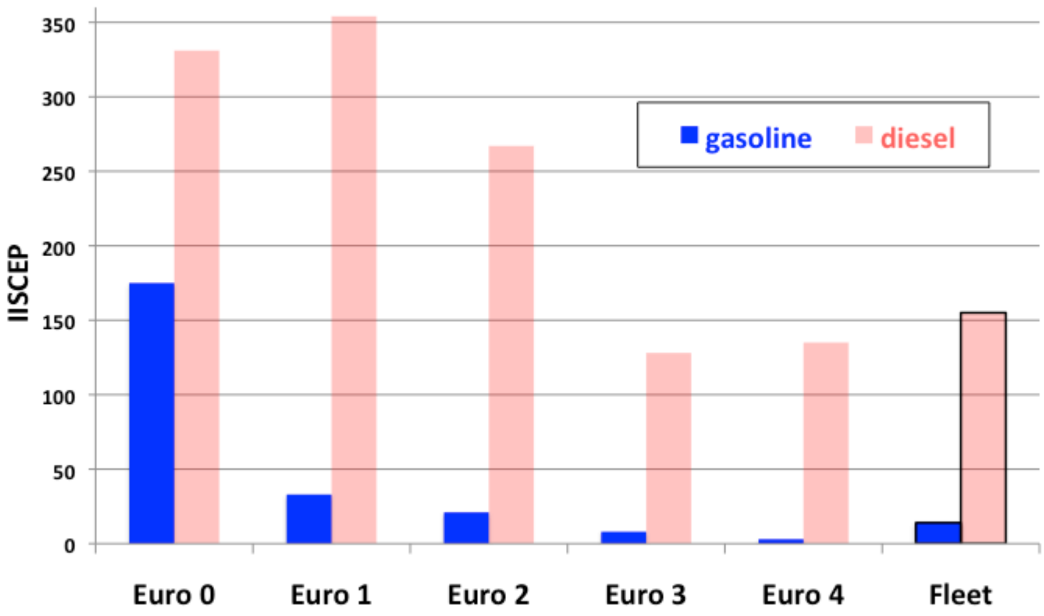
The first type of application is without any time or geographical scale.

For the second application type, the basic geographical scale of application is defined by homogeneous areas in terms of emissions, population density and dispersion condition; then the indicators per area can be added up without limit. The time scale of application depends on the evolution over time of emissions, population and dispersion conditions (especially buildings); The year seems an appropriate scale, but the indicator could be used also to compare the health impact along the day: In this case the time scale will be the hour.

The IISCEP indicator was therefore applied in two cases, one per type of application: to compare fuels in terms of health impact, and to evaluate the evolution of the Nantes urban district.

The indicator needs data on the study area (surface, population etc.) and, for each pollutant considered, on the toxicity factor and emission. Any pollutant with missing emission or toxicity factor is not considered.

Figure 1: The health indicator IISCEP according to fuel and emission standard of the French passenger car fleet in 2009.



3.1. Comparison of petrol and diesel passenger cars

Vehicle emissions are obtained from the emission factors provided by the HBEFA model (HBEFA, non dated) and a traffic scenario. In the case of this theoretical example, the monitored scenario consists of an urban situation with relatively fast traffic (a mean speed of 30 km/h). Five toxic pollutants were available (nitrogen oxides, sulphur oxides, cadmium, ammonia, particulate matter), as well as non-methanic volatile organic compounds NMVOC, for which the speciation given by Flandrin et al. (2002) is used. Computation of the indicator was very simplified as the same dispersion and exposure factors were the same in both situations; So we gave them a value of 1. A constant of 10^{-6} was also applied to simplify interpretation of the result. We have computed the indicator for each fuel and emission standard combination, then for exclusively diesel and exclusively petrol fleets making the hypothesis that the vehicles are distributed between the Euro emission standards in the same way as in the entire vehicle fleet on the French roads: See the results in Figure 1.

The emissions from the petrol vehicle fleet appear to be less toxic than those from the diesel fleet. The results from the indicator reflect the increasing stringency of the emission standards. The value of the indicator is principally due to emissions of two substances, fine particles and emissions NMVOCs: For diesel vehicles, fine particles count for 95-99 % of the indicator. For gasoline vehicles this percentage is increasing from 9 to 67 % according to the emission standard Euro 0 to Euro 4; For NMVOCs, the percentage is decreasing from 91 to 13 %. Similar outputs were found in the next application.

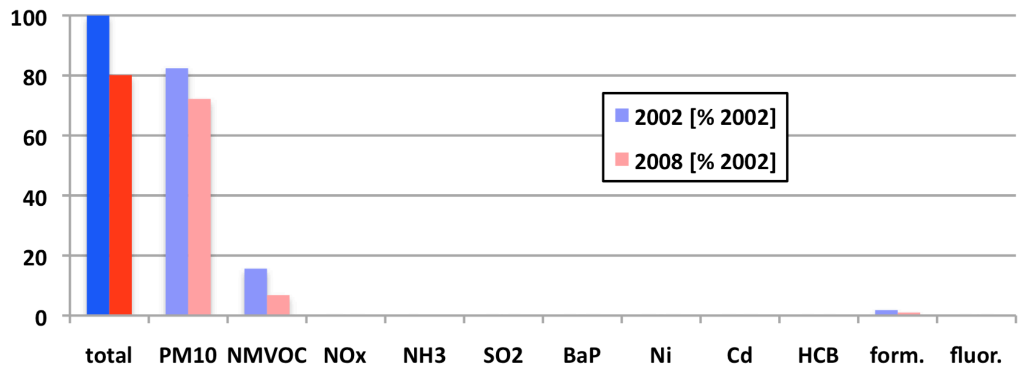
3.2. Evolution of the Nantes urban district 2002-2008

The emissions of 10 pollutants with health impacts (NOx, PM10, NH_3, SO_2, benzo[a]pyrene BaP, nickel Ni, cadmium Cd, hexachlorobenzene HCB, formaldehyde and fluoranthene) and NMVOCs were computed for the Nantes urban district in 2002 and 2008 by Rebours (2009). This area of 580 000 inhabitants and 535 km^2 was divided into 290 zones on the basis of population. Each of them was also characterized in terms of its building density and mean building height.

For the zone as a whole, the values of the IISCEP decreased approximately by 20% between 2002 and 2008: see Figures 2 and 3. This difference would tend to indicate that the health impact of road traffic emissions in Nantes improved during the period. Particulates play an overriding role in both situations, accounting for respectively nearly 82 and 90% of the value of the indicator. For 91 % of the zones, representing 98 % of the indicator in 2002, the value of the indicator fell. The increases in 9 % of the zones can to a large extent put down to population growth in these zones. In most cases these zones are not densely populated with below average IISCEP values in both years. Again, PM10 and NMVOC play the major role in health impact (see Figure 3).

Figure 2: Relative evolution 2002-2008 of health indicator IISCEP per zone in Nantes urban district (decrease in green, increase in yellow, absolute change in red increasing according to the circle surface)

Figure 3: Evolution 2002-2008 of global health indicator IISCEP for Nantes urban district per pollutant considered



4. Discussion

A number of hypothesis and simplifications were made in order to compute the Indicator for the Chronic Health Impact of Pollutant Emissions IISCEP:

- The toxicity values for carcinogenic substances were computed for a risk of 10^{-6};
- The effects were distributed between 3 severity categories on the basis of two criteria, their reversibility and their impact on life expectancy;
- The choice of the TRV was based on the criteria that are recommended for health risks (US-EPA, WHO, IARC, etc.);
- The TRVs for fine particle emissions from diesel vehicles were applied to gasoline fine particle emissions;
- The choice of pollutants taken into account was made according to Cassadou et al. (2004) who inventory all the pollutants with emission factors and VTRs for chronic effects;
- Hypotheses have to be made about the mass distributions of non-methane volatile organic compounds (NMVOC) within the emissions in order to obtain a toxicity factor, when NMVOC emissions are known globally, as toxicity factors are known for each compound; It is consistent with WHO report, which highlights the lack of knowledge on emissions and concentrations in the environment, for instance for PAHs. WHO made the proposal of an air quality objective for benzopyrene, knowing its carcinogenic power and the corresponding VTR.

4.1. Advantages

The indicator IISCEP allows us to aggregate a large amount of differing data in order to obtain a single interpretable result. It also has the following noteworthy qualities:

- Its transparent construction means our proposed default parameters that we propose can be modified if more recent data become available;
- It is computed rapidly with a spreadsheet. Measurement is therefore straightforward and inexpensive;
- Its starting point is emissions, it is specific to its source, i.e. transport. This is the origin of its sensitivity, allowing it to identify important changes that affect the source;
- All the input data are detailed and public and their values can be modified.

Although the indicator has been developed for transport applications, it could be applied in other fields with minor changes.

4.2. Limitations

The IISCEP's principal limitations are either "by default" in designing the indicator (first 7), or due mainly to data availability (2 last). They are as follows:

- The present version of the indicator covers only the traffic emissions: as in many planning practice an indicator is needed to cover the health impact of all emission sources, the indicator is not applicable in global planning when non traffic emissions are important; Anyway, is was developed for assessing the impact of traffic only and other methods are available for global evaluation of health impact;
- The emissions that enter the area analysed from outside (via transmissions effects, depending on the meteorological conditions) do affect the human health of the population concerned, as well, but are not taken into account by the indicator; nevertheless the imported pollution is usually low for primary pollutants;
- It only considers primary pollutants, but the health impact of some secondary pollutants is not negligible;
- It only considers chronic effects;
- It considers only one route of exposure, inhalation. This is a major limitation for estimating emission-related risk, particularly for toxic substances such as dioxins whose main route of exposure is ingestion;
- It cannot be used to compare two periods with different meteorological conditions as it does not currently consider this factor (this is particularly important for periods when there are temperature inversions);
- As it is only a relative indicator it does not have any meaning in itself and can only be used for making comparisons;
- The number of pollutants considered has a major impact on the indicator and most of its components, particularly by modifying the overriding influence of ultrafine particles;
- Both the weak link between emissions and health impacts and the level of uncertainty associated with the IISCEP are unquantifiable;

4.3. Self-evaluation of the indicator

A sensitivity analysis showed that the parameters that have the most impact on the result of the comparison between two situations (Nantes urban district 2002, and 2008) are the pollutant selection and the population (Lépicier et al., 2011, chap. 6.3.1). The taking into account of the surface of the zone or of the mixing height has a low impact on the evolution. The severity factor has also a low impact.

In order to evaluate the quality of the indicator we have used the 10 criteria identified in the framework of COST Action 356 (Gudmundsson et al., 2010b), we have considered with reference to health. The assessment of each criterion was made subjectively by the authors and therefore gives an indicative evaluation. The results are presented in Table 3.

Table : Evaluation of the indicator on the basis of 10 criteria

	Criterion	**Evaluation**
Representation	Validity	+
	Reliability	+
	Sensitivity with regard to transport	+
Operationality	Measurability	+
	Availability of data	+/-
	Ethical concerns	+
Decision-making aid	Transparency	+
	Interpretability	+/-
	Target relevance (links with a goal)	+/-
	Actionality (means of action)	+

The validity of an indicator means that it effectively measures the issue or factor it is supposed to, and validity was a central consideration during the development of the IISCEP. The indicator is constructed on the basis of current knowledge and is theoretically valid; it avoids empirical weightings, as toxicity and severity weightings are based on scientific considerations. It should be validated empirically by comparisons with results from other methods or models, or by measurements, but we had no opportunity to do that.

The reliability of an indicator corresponds to its reproducibility. The IISCEP is reliable when the different tests calculate the emissions in the same way. This applies both the model that is used and its underlying hypotheses (driving cycles, unit pollutant emissions, composition of the vehicle fleet, traffic, etc.) and the pollutants considered. The IISCEP is therefore a reliable indicator for a given application in that it will have the same value if it is computed several times under the same conditions.

Measurability was one of the main considerations we monitored during development of the indicator. The input data need to be readily accessible, by which we mean in terms of cost and time. One of IISCEP's main limitations is the calculation of emissions. It requires the knowledge of methods and data, in particular on the characteristics of transport (emissions factors, composition of the vehicle fleet etc.) and the zone (transport system, traffic etc.) and therefore the participation of an emission expert. Some data, such as the population and the building height, must be known for the zone in question, but in many European countries they are not readily available at higher spatial resolution. It is not essential to have a Geographic information system (GIS) as the data may be exploited on a zonal basis in the spreadsheet. However, unit emission data are not available for all toxic pollutants, neither in some cases is the toxicity reference value. It would, for example, be interesting to know the emissions for each type of VOC and PAH. All the indicator's data and parameters are available, but some data may require access to software, for example in order to calculate emissions and for a GIS, or have to be purchased (BDTopo etc.).

With regard to ethical considerations, the IISCEP does not in itself raise any moral issues. One question is, however, raised, concerning the weightings applied to different diseases as this involves assigning a subjective value to each of them. The values given to each disease by the population are variable and depend in particular on the group that is affected, i.e. everybody, children and the elderly etc. Sorting diseases into categories on the basis of precise criteria provides a certain consensus. Our use of three categories and weightings of 1, 10 and 100 as default parameters is debatable, but we do not feel that it raises an ethical problem, especially because they are easy to modify.

Modifying parameters in this way is very easy because of the indicator's transparency. Input data should however only be modified as more accurate data become available.

An interpretable indicator is unambiguous and can be understood intuitively. The interpretability of the IISCEP is limited, because although it is proportional to the impact it does not give an absolute value. It can only be used in the framework of comparisons. One can understand intuitively that the highest value corresponds to the situation which is least good in health terms. Likewise, a reduction in the indicator's value indicates a reduction in the health impact. The value that is to be considered is, in fact, the ratio between the values of the indicator for different scenarios. However, these values are not always meaningful in view of the fact that input data may be affected by a very high degree of uncertainty. We lack a basis for determining what constitutes a reliable difference between the IISCEP values for several scenarios. We could suggest applying a minimum difference of 5%, but this threshold is based on a judgment and has not been validated scientifically.

A relevant indicator should measure performance in relation to stated goals, targets or levels. The IISCEP cannot measure the total health impact of transport. It is relevant for comparing different situations according to the chronic health impacts of inhaling the emitted pollutants. This estimation is limited in its coverage of health impact because it ignores toxic secondary pollutants such as secondary particles, toxicity by ingestion (which in some cases is more relevant than inhalation, for example for dioxins and certain metals) and acute effects that may be very severe, such as asthma attacks or heart attacks. These limitations, with the exception of inhalation, are apparent from its name, which means that it satisfies the condition of relevance for relative objectives. It would nevertheless be useful to compare the IISCEP to other chronic health impact indicators such as the *Health Impact Assessment*, but we did not do so . However, the IISCEP is not appropriate for achieving an absolute, numerical, result.

Last, the IISCEP can assist decision-making, because it is used to compare several situations. In this way, it makes it possible to establish if one of them is genuinely different from the others in terms of potential chronic health impact and choose it or reject it on this basis.

The indicator fully meets 6 of these 10 criteria, more or less meets at least 3 or more, and further verification is required for 1 criterion to enable this to be accepted without reservations in practice.

5. Conclusion

Atmospheric pollution forms a complex mixture whose impacts on the environment and health are difficult to measure. Transport contributes to this state of affairs and only a few pollutants are currently monitored without reference to their impact on health. Taking emissions as our starting point, it is theoretically possible to consider all toxic pollutants.

Based on research that has been conducted in the framework of Life Cycle Analyses (LCA) we have constructed an indicator that takes account of these pollutants and their individual toxicities. It is a straightforward indicator which can be used to gauge the chronic effects of inhaling primary pollutants. It can only be used in comparisons, between different scenarios or different technologies. The quality of the emissions data and the pollutants that are considered, due to their available emission factors and TRVs, are the two essential factors that determine its validity and reliability. A comparison with the results from other methods would be necessary to evaluate its reliability and sensitivity to changes.

This indicator can be improved, in particular by using the most accurate parameters that are available or adding a component that takes account of local meteorological conditions. It would also be possible to consider taking sensitive groups into account. Additional knowledge would also enable us to reduce the high degree of uncertainty that applies to the indicator. Examples are the toxicity reference values for other substances (for example nitro-PAHs), unit emission factors for additional toxic pollutants whose uncertainty is quantified, and documented severity values in order to apply weightings to diseases.

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Highlights

Developing an indicator for the chronic health impact of traffic-related pollutant emissions

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- The goal of the study is to develop an emission based indicator for the health impact of the air pollution caused by traffic.
- It is based on a literature survey of methods for evaluating health impacts related to the atmospheric

pollution.

- We define a composite indicator based on the traffic emissions and on local data as dispersion conditions and population.
- The indicator is a combination of pollutant emission, dispersion, exposition factor, and substance specific toxicity factor.
- Applications are global (e.g. comparison of vehicle technologies) or local (e.g. comparison of populations or areas).