
Environmental sustainability assessments: toward a new framework

---

Robert Joumard

Laboratory Transport and Environment
French Institute of Science and Technology for Transport, Development and Networks (IFSTTAR)
Bron, France
Fax +33 472 37 68 37
E-mail: joumard@inrets.fr

Abstract: Definitions of the environmental dimension of sustainable development are usually general and the variety of impacts rarely considered. A correct representation of the full range of effects is necessary for an accurate and transparent environmental sustainability assessment. Environmental impacts and their characteristics are described through the concept of causal chains between a source and a final target. Its parameters are the source target, time and distance scales, and the final target. The scientific disciplines involved in defining indicators are considered. This analysis is based on research on environmental impacts resulting from transport. It allows us to define 49 independent causal chains that address all effects. They are organized into a hierarchy of 27 aggregated chains and 8 groups, as the usual binary classification (quality of life/natural heritage, present/future generations, reversibility, local/global) lacks meaning.

Keywords: Environment, definition, impact, assessment, typology, source, process, target, sustainability

Reference to this paper should be made as follows: Joumard, R. (2011) 'Environmental sustainability assessments: towards a new framework', *Int. J. Sustainable Society*, Vol. 3, No. 2, p. 133-150.

Biographical notes: Robert Joumard is a Senior Scientist in the Laboratory Transport and Environment at the French National Institute for Transport and Safety Research (INRETS). He chaired the COST action 356 "EST - *Towards the definition of a measurable environmentally sustainable transport*", 2005-2010.

---

1 Introduction

The economic and grey literature (applied research, international organisations, local applications) on sustainable development presents most of the environmental impact assessments conducted about policies, plans, programmes, projects or technologies. How are environmental issues considered and how is sustainable development's environmental pillar defined in such literature?

Economic papers limit discussion of environmental questions to greenhouse gases or a few other well-known effects. They unconsciously reduce the scope to effects for which simple-to-use assessment tools are available, without justifying such simplification. Often, health, safety or land-use issues are considered alongside the environment, inferring that they are not part of the environment itself (for example Wolfram, 2004; SSNC, 2006; Droulers, Le Tourneau, and Marchand, 2008). Some authors, nevertheless, consider that it is of utmost importance to take into account health, safety and land-use effects, regardless whether these are included within the environmental or social pillar. Although it is important, of course, to consider all environmental impacts, classifying each impact has political meaning, because it implicitly defines economic, social, and environmental issues. Citizens, and often policy makers, are unable to consider social and environmental issues in detail while keeping a macro perspective at the same time. A precise definition of each pillar is needed to arrive at transparent evaluations and clear political choices.

When only some impacts or concerns are considered, without any justification whatsoever (for example Droulers, Le Tourneau, and Marchand, 2008), discussing the relevance of these impacts is impossible. For instance, Lardé and Zuindeau (2008) do not justify their choice of 12 criteria for designing the environmental profiles of 21 countries. The output, a country typology, depends on the criteria used. In addition, the 12 criteria are considered equally important, whereas the statistical tools used discard well-correlated parameters. Thus, the CO and CO2 emissions criteria, which are clearly not well correlated, play the same role in defining environmental profiles although today CO is considered a secondary pollutant and CO2 the primary source parameter. This undoubtedly builds a typology, but we question its meaningfulness.

Besides the use of environmental sustainability indicators, an alternative approach increasingly used in industry is life cycle assessment (LCA). LCA aims to evaluate the environmental impact of the entire life cycle of a product, process or service (ISO 14040, 2006). One of the advantages of LCA is that it is a well-established, standardised method that also includes an impact assessment phase life cycle impact assessment (LCIA) where potential effects are quantified and totalled. Several tools are based on LCA, such as building for environmental and economic sustainability (Lippiatt and Boyles, 2001), the ecological scarcity or Eco-factors 2006 methods (Frischknecht et al., 2009) or the ReCipE method (Goedkoop et al., 2009). LCA has been used, for instance, to estimate environmental impacts from fuels made from biomass (von Blottnitz and Curran, 2007; Zah et al., 2007), from water systems (Lundin and Morrison, 2002) or from buildings (Assefa et al., 2007; Scheuer, Keoleian and Reppe, 2003). In these methods and studies, the environmental effects considered vary widely. Without explanation, comparisons between methods and between studies are difficult.

Although most of the papers discuss the environment, they almost never deal with it as a whole. It remains an idea that is not defined clearly and precisely. Without such a definition, the idea can be interpreted at will, adapted so widely that it sometimes remains only a vague expression, and, at worse, used only to justify one's project or policy.

On the contrary, Block et al. (2007) or Van Assche, Block, and Reynaert (2008), stressed the need to define first a matrix view for a sustainable and viable city to provide a normative framework for choosing the relevant indicators. Then, they went on to define almost 200 indicators of a sustainable city for Flemish urban areas. They later remarked that each indicator must be connected clearly with an item of the matrix view.

Environmental issues are sometimes varied and questionably structured. Thus, the environmental objectives of sustainable development, as presented for instance by Swedish municipalities (Gudmundsson, 2007, p. 37), merge primary objectives (for example, environmental quality) with objectives for solutions (for example, less use of non-renewable resources, more use of public transport). The differences are imperceptible and objectives are not ranked.

A second definition of the environmental issue is more global and top-down. For instance, OECD (2001) distinguishes between development criteria - whose environmental aspects deal with environmentally conditioned welfare and the role of air, noise and water quality in the health of present generations - and sustainability criteria, whose environmental aspects address conditions of long-term development thanks to access to critical natural resources, ecosystems and climate stability. Economists often consider this last criteria as natural capital, in other words as a resource used by humans for producing economic goods. This resource is an ecosystem, that is the association between a physico-chemical and an abiotic (the biotope) on the one hand and the conditions that allow the latter to live (the biocenosis), including fossil resources, on the other. When this resource is destroyed, it can be renewed to a certain extent. The environmental issue is about resource reserves, resource flow and the capacity of the biosphere to support the effects of human activities (carrying capacity). The causal frameworks for describing the interactions between society and the environment adopted by the OECD - pressure-state-response or PSR - and by the European Environment Agency - driving forces-pressures-states-impacts-responses or DPSIR - (EEA, 2009) seem well applicable to this meaning with a pressure representing a flow.

In parallel, the environment is often understood as the quality of our physical environment or the quality of life. It is difficult to consider only flows and pressure when looking at a calm area with pure air and water, or a beautiful landscape (Job, 2005; Gudmundsson, 2007).

Both these global meanings of the environment correspond roughly to the concept of internal and external territorial sustainability defined by Wackernagel and Rees (1996). Internal sustainability consists in protecting one's direct environment and living area, whereas external sustainability consists in protecting the world as a whole.

These synthetic, global and top-down definitions of the environment's sustainability pillar are not based on explicit analyses of environmental impacts, objectives or issues. Such definitions are too vague to be useful for describing actual environmental issues or impacts on the environment or for designing environmental impact indicators. An exhaustive list of environmental impacts or objectives is necessary to present a full picture, especially if the clear aim is to identify the most important issues mentioned by Black (2000) or Borken (2003), and those that are important in decision making (Ahvenharju et al., 2004; Nicolas, Pochet, and Poimboeuf, 2003; Zietsmann and Rilett, 2002). How can key issues be identified with a top-down approach, without a comprehensive assessment of all relevant ones?

Below, we try to describe precisely environmental issues in the transport sector. We begin with a review of the literature and then present the concept of a causal chain. Finally, we analyse the relevance of global descriptions of the environmental issue. This research is detailed in a specific report (Joumard et al., 2010).

2 Precise description of environmental issues in the transport sector

2.1 In the literature

Environmental or ecological impacts are often listed in transport literature (for example USEPA, 1996; OECD, 1996; Swedish EPA, 1996; EC, 2001; OECD, 2002; EEA, 2002; Borken, 2003; Ahvenharju et al., 2004; Goger, 2006 or Goger and Joumard, 2007; Calderon, Pronello and Goger, 2009; Joumard and Nicolas, 2010), in public surveys conducted at a national (Boy, 2007) or international level (EC, 2008), or in building literature (Assefa et al., 2007; Bunz, Henze and Tiller, 2006; Lippiatt and Boyles, 2001; Scheuer, Keoleian and Reppe, 2003). See some examples Table 1. Their definition is rarely clear or precise; the lists are often heterogeneous - merging sources, intermediate states of the environment, such as local air or water quality, and final impacts on the environment, such as visual effects. For instance, USEPA (1996) or Ahvenharju et al. (2004) list mainly the pressures or the principal consequences of the transport system on the environment, rather than environmental impacts (although the consequences are labelled as impacts). While some effects are often mentioned – such as climate change, photochemical pollution or noise - others, including soil erosion, vibration, light pollution, hydrologic and hydraulic risks, odours, soiling or visibility, are rarely discussed. Dimming, risk of fire or electromagnetic pollution are not mentioned in the 13 references studied. Some impacts listed are broad, combining several effects on the environment, such as air pollution or soil protection and landscape. Some lists, like this one from the European directive (EC, 2001), repertory the final targets, but with redundancies such as biodiversity/fauna and flora or population/human health. Environmental impacts also depend on the society in which they occur. Esoh Elame (2004), for instance, shows how the values and beliefs of a given African people's cultural heritage determine to a large extent the items of nature they want to protect. In Sub-Saharan Africa, the natural capital cannot be dissociated from the cultural capital. To speak about nature means to speak about culture, and *vice versa*. Roqueplo (1988) and Brüggermeier (2002) have noted similar relationships for forests and acid rains in Germany. More generally, Lammel and Resche-Rigon (2007) show how the idea of the environment itself differs between holistic societies, such as Totonaque, Inuit or Badui ones, and individualistic/analytic societies such as Western ones.

In Western countries at least, the environmental issue is a personal construct, based on an individual perception of its components mediated by our senses and completed by intellectual elements from technical or scientific news we receive through education and the media (Brüggemeier, 2002; van Staëvel, 2006). This personal construction is thus now structured by a long-term view.

One of the most structured descriptions of the environmental issue consists in using objectives to discuss the environment, as Keeney (1992) proposed. Rousval (2005) and Rousval and Maurin (2008) applied this method to the environment, and arrived at a hierarchy of 24 goals by interviewing local decision makers and environmental specialists. This list is nevertheless heterogeneous, merging final targets (fauna, flora), processes (greenhouse effect) and intermediate impacts (soil pollution). Its main advantage, like the approach Van Assche, Block and Reynaert (2008) or Block et al. (2007) took, is the use of a systemic perspective and a clear logic.

Table 1 Environmental impacts listed by 13 references and their correspondence with the proposed causal chains

USEPA (1996)	All impacts from transport			pollutant emissions	
OECD (1996)		use of non renewable resources		greenhouse effect	stratospheric ozone depletion
Swedish EPA (1996)				greenhouse gases	depletion of ozone layer
EC (2001)				climatic factors	
OECD (2002)	All impacts from transport	use of natural resources		climate change	
EEA (2002)			energy consumption	climate change	
Borken (2003)		consumption of (energy) resources		climate change	stratospheric ozone depletion
Ahvenharju et al. (2004)		consumption of solid raw materials	energy consumption	greenhouse gases	
Goger (2006), Goger and Joumard (2007)	Impacts due to pollutant (grey: out of the scope)			greenhouse effect	ozone depletion
Boy (2007)				climate change	
EC (2008)		depletion of natural resources			
Calderon, Pronello and Goger (2009)	From transport (grey: global; white: local/regional)	use of material resources	non-renewable energy consumption.	climate change	ozone depletion
Joumard and Nicolas (2010)	From transport (grey: irreversible; white: reversible)	non-renewable resource use, including energy		greenhouse effect	
Correspond. chain in Table 3		39		42	21, 22

	health effects due to local and reg. pollution	urban air pollution, effects of metals, effects of POP	air, human health	air quality	human health	human health	emissions of air pollutants	direct restricted health effects	air pollution	air pollution	air pollution	local air quality	11
	damages to agriculture					ecosystem health		Direct ecotoxicity					12
	photochemical pollution	photochemical oxidants			photochemical smog	photosmog		photochemical pollution				regional air quality (smog)	13, 14, 15, 16
		eutrophication of water	water	water quality				eutrophi-cation	water pollution	water pollution	water pollution	water quality / uses and regime	19
highway and airport runoff							runoff pollution						23, 24, 25
toxic release					illegal & accidental discharge of oil by ships at sea		wastewater, discharges of oil, waste-water and waste at sea						26, 27, 28
													29
sewage dumping			soil			protection of soil and landscape					soil pollution		23, 24, 25
release of deicing compounds													
		nitrogen saturation of soil											
											soil erosion		37

		habitat disruption and land take by infrastructure		roadkill, wildlife collisions			noise		direct waste from vehicles	waste
		landtake	perturbation of regional ecosystems				ambient noise			
		exploitation of land and water					noise		non-cyclic material flows, waste & envir. hazardous residues	
			severance				noise			
		landtake	fragmentation of ecosystems and habitat		safety		noise		waste	
			protection of nature and landscape				noise			
		hardening of surfaces	fragmentation of land	collisions with wildlife		light emissions	noise		waste	
sensitive pollution										
							noise		family waste, (nuclear risk?)	
							noise pollution		growing waste	
	hydrologic/hydraulic risks	land uptake	barrier effects / land fragmentation		traffic accidents		noise nuisance/vibration		waste production	
		Landuse			traffic safety		light and noise nuisances			
8, 9, 10	30	31, 33	35, 36	7	6	45	1, 2, 3, 4	5	41	40

-	habitat dis-ruption wakes / anchors	introduction of non-native species	hazardous material incident							
-				acidification		perturbation of regional ecosystems			damage to equipment	negative aesthetic effects
-		introduction and spread of alien organisms			acidification of water and soil		pressures on areas of special conservation interests			
-						fauna and flora, biodiversity		cultural heritage including architectural & archaeological heritage	material assets	landscape
-				acidification		loss of biodiversity	historical / archaeological / nature conservation			visual impacts
-										
-				acidification						protection of nature and landscape
-	damage of underwater habitats	introduction of non-native species	polluting transport accidents				losses of nature areas, prox. of tr. infras. to designated nature areas			
-				acidification		(direct ecotoxicity)		degradation of historic man-made heritage	degradation of common man-made heritage	
-			nuclear risks			fauna and flora degradation				landscape degradation
-			natural and man made disasters			loss in biodiversity				
-								landscape / visual effects / aesthetics / cultural heritage		
-			technological and natural hazards			biodiversity and protected areas			man-made heritage	visual qualities of landscape / townscape
20, 43, 44, 47, 48	26	46	49	18	17	32	31	34	18, 30, 34	38

2.2 The concept of causal chains

We seek to adopt a systemic approach to environmental issues that will consider all an environmental policy's impacts and objectives. We propose to extend the pressure-state-impact structure from EEA to the concept of causal chains between a cause and a final target, with the possibility of a succession of cause-impact pairs. A causal chain can be defined as an ordered sequence of events or issues, in which one event or issue in the chain causes the next. A good example is the greenhouse effect: greenhouse gas emissions are a first cause, which, by physical phenomenon, increase the earth's temperature, changing global and local climates, affecting agriculture and sea levels, leading to consequences for the whole biocenosis, including humans.

Impacts such as odours, soiling, visibility, habitat fragmentation, visual quality of landscape and loss of cultural heritage cannot be explained by a mechanistic view of flow and carriage capacity. To cover all impacts, the concept of causal chains has to be much wider than a reserve or flow problem inspired by physics. Any type of process can be considered: cultural, psychological, psychophysical, biological and, of course, physical.

A causal chain can be described through:

- The element(s) of a field of human activity (the transport system or any other sector), which is at the start of the process, taking into account the life cycle approach, i.e.: considering all the subactivities involved. For the transport sector, three main subsystems are involved (infrastructure, energy use, and vehicles), and for each of these, there are five types of activity (production, existence, use, maintenance, destruction).
- The final targets: Three targets (nature, humans, man-made heritage) and a pseudo-target, the earth (that encompasses the three targets, plus the atmosphere and oceans), are usually considered (e.g. Goger, 2006). In addition, the Eco-indicator approach (Brand et al., 1998; Goedkoop and Spriensma, 2001) includes three types of end point damage: resources, ecosystem quality and human health. The first two are subdivisions of the target 'nature'. The World Health Organisation (WHO, 1946) defines human health as "*a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.*" Therefore it is useful to distinguish health in its restricted meaning (absence of disease or infirmity) from so-called human well-being, because the processes are often different. Finally, we arrive at the target 'structure' presented in Table 2, with six targets: resources, ecosystems, human health in its restricted meaning, human well-being, man-made heritage, and the earth.
- The intermediary elements, that is the causal chain between human activity and the final target, to be described in detail. This can be summarized, for instance, through the scientific disciplines involved, the space and time scales, and the linearity and reversibility of the process. Scientific disciplines point to the process involved and who is able to discuss how representative an environmental impact indicator is. Space and time scales are important parameters in environmental studies (Schulze, 2000; Huijbregts, Guinée and Reijnders, 2001; João, 2002). Process linearity shows how proportional the impact is to the source and how the latter is a major parameter for lessening the effect. Reversibility deals with sustainability, but one has to make a distinction between individuals and species. For example, the impact of traffic accidents is irreversible for humans who die in them, but not for society as a whole.

The causal chains allow for an all-encompassing assessment of relevant impacts known today (completeness). They should overlap as little as possible (independence). For instance, the chains "health effects of photochemical pollution" and "health effects of air pollution" are incompatible because they overlap.

2.3 Description of the causal chains

In line with the structure above, we have proposed a list of 49 environmental impact causal chains (especially due to the transport system) (see Table 3), a detailed description of which is given in Joumard and Gudmundsson (2010, annex 6, pp.325-366). The list of chains could be detailed further by dividing a chain into two or more chains, if it is felt processes or targets are not treated homogeneously. In addition some chains may be missing.

A first attempt to build a typology or structure of the 49 causal chains means merging them into 27 aggregated chains (by not considering the final target), and then into 8 groups (see Table 3). This typology suits usual structures and allows a simpler presentation of the whole.

To be practical, the number of categories should not be plethoric. Also, given the availability of data, some impacts can be merged and minor chains deleted. This must be done explicitly to allow others and future users to also perform such simplifications. The chain's structure must be as detailed as possible, because it is easier to merge and delete than to add processes.

Table 2 Typology of environmental impact targets

<table>
<tr><th colspan="2">Targets</th><th>Pseudo-target</th></tr>
<tr><td rowspan="2">Nature</td><td>Resources</td><td rowspan="5">Earth: covers all the targets: the three previous targets (ecosystems, humans and man made heritage) and physical environments such as the atmosphere and the oceans</td></tr>
<tr><td>Ecosystems: nature understood as ecosystems, i.e. the association between a physicochemical and abiotic (the biotope) environment and a living community characteristic of the latter (the biocenosis)</td></tr>
<tr><td rowspan="2">Humans: humankind which we extract from nature and focus on its health as defined by the WHO</td><td>Human health: in a restricted meaning</td></tr>
<tr><td>Human well-being</td></tr>
<tr><td colspan="2">Man-made heritage: with a distinction made between common and historic buildings</td></tr>
</table>

Table 3 Hierarchy of the 49 causal chains

Noise and vibrations
- . Noise:
    - . Disappearance of quiet areas (chain 1)
    - . Annoyance and sleep disturbance to people due to noise (chain 2)
    - . Effects on human health (restricted meaning) of noise (chain 3)
    - . Noise and wildlife (chain 4)
- . Vibrations (chain 5)

Accidents
- . Effect of traffic accidents on human health (chain 6)
- . Animal collision: Animal fatalities (chain 7)

Air pollution
- . Sensitive air pollution
    - . Odors (chain 8)
    - . Soiling (chain 9)
    - . Visibility (chain 10)
- . Direct (restricted) toxicity of air pollutants
    - . Direct restricted effects on human health of air pollutants (chain 11)
    - . Direct ecotoxicity on fauna and flora of air pollutants (chain 12)

. Photochemical pollution
- . Health effects of photochemical pollution (chain 13)
- . Loss of crop productivity due to photochemical pollution (chain 14)
- . Ecotoxicity on fauna and flora of photochemical pollution (chain 15)
- . Loss of cultural heritage due to photochemical pollution (chain 16)
- . (Secondary effects: greenhouse gas, acidification)

. Acidification
- . Decrease of ecosystem health, loss of biodiversity due to acidification (chain 17)
- . Deterioration of historic buildings and other cultural assets due to acidific. (chain 18)

. Eutrophication (chain 19)

. Dimming (chain 20)

. Ozone depletion
- . Health effects of ozone depletion (chain 21)
- . Ecotoxicity on fauna and flora of stratospheric ozone depletion (chain 22)

Soil and water pollution

. Pollution of soil, surface waters and groundwater
- . Effects on ecosystem health of pollution of soil, surface and groundwater (chain 23)
- . Health effects of pollution of soil, surface waters and groundwater (chain 24)
- . Recreational areas forbidden due to pollution of soil and surface waters (chain 25)

. Maritime pollution
- . Effects on ecosystem health of maritime pollution (chain 26)
- . Health effects of maritime pollution (chain 27)
- . Recreational areas forbidden due to maritime pollution (chain 28)

. Hydraulic changes and risks
- . Hydraulic changes (chain 29)
- . Hydraulic risk (chain 30)

Impacts on land

. Land take
- . Loss of natural habitats due to land take (chain 31)
- . Degradation of ecosystems due to land take (chain 32)
- . Modification of outdoor recreation areas, due to land take (chain 33)
- . Loss of cultural heritage due to land take (chain 34)

. Habitat fragmentation
- . Loss of ecosystem health, loss of biodiversity, due to habitat fragmentation (chain 35)
- . Reduction of living areas of people, due to fragmentation (chain 36)

. Soil erosion (chain 37)

. Visual qualities of landscape/townscape (chain 38)

Non-renewable resource use and waste handling

. Non-renewable resource use (chain 39)

. Non-recyclable waste (chain 40)

. Direct waste from vehicles (chain 41)

Greenhouse effect (chain 42)

Other impacts

. Electromagnetic pollution

. Health effects of electromagnetic pollution (chain 43)

. Effects on ecosystem health of electromagnetic pollution (chain 44)

. Light pollution (chain 45)

. Introduction of invasive alien species (chain 46)

. Introduction of illnesses (chain 47)

. Fire risk (chain 48)

. Technological hazards (chain 49)

3 Pertinence of top-down approaches

How do these 49 causal chains fit in with the global descriptions of the environmental pillar of sustainable development seen above? These are related mainly to four types:

- Related to life environment/natural resource, with two main subcategories: A1) for well-being, quality of life, and A2) for the resources needed for life, natural heritage, the conditions of a long term development
- Related to time scale with two main subcategories: B1) for present generations – or short term, and B2) for future generations – or long term
- Related to reversibility, with two main subcategories: C1) reversible, and C2) irreversible
- Related to their local (D1) or global (D2) character

When classifying the chains according to A1/A2, B1/B2, C1/C2 or D1/D2, some cannot be differentiated according to such binary classification because they belong to both classes. For instance, most of the impacts on the ecosystems belong to A1 and A2, B1 and B2, and the effects on cultural heritage concern present and future generations. If we consider the irreversible character for society, that is the definitive modification of our life conditions on earth, the reversible/irreversible dichotomy is often the only obvious one. Several causal chains, and important ones indeed, are neither totally reversible nor totally irreversible. Thus the greenhouse effect is indeed reversible, but only after a few centuries. At an upper level, most of the 27 aggregated chains are combining detailed chains belonging to both categories.

As shown on Figure 1 for axes B and D, the four axes are continuous rather than discrete. The top-down approaches of the environment through simple and discrete classifications seem not to correspond to the reality of the impacts on the environment when the causal chains are considered. They cannot be used to characterise some causal chains. Reality is more complex than the all-embracing approaches.

Figure 1 Ascending order of magnitude of the 49 causal chains' distance and time scales

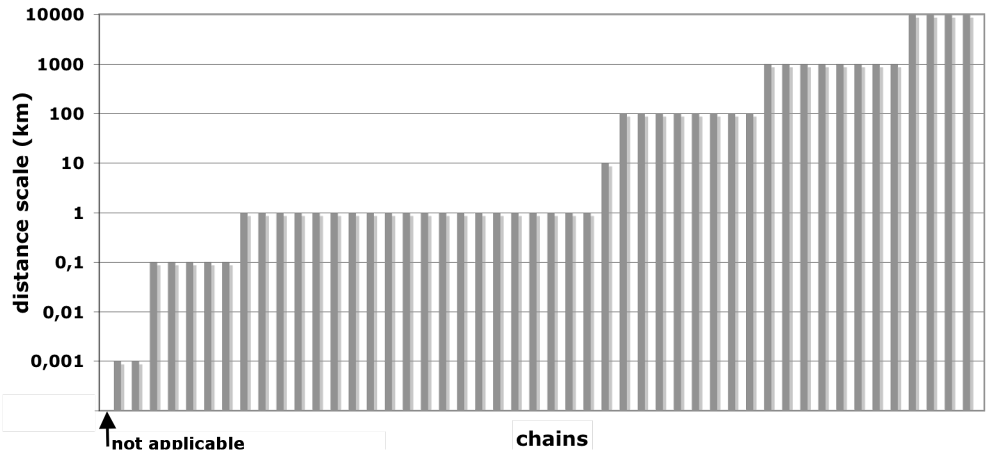
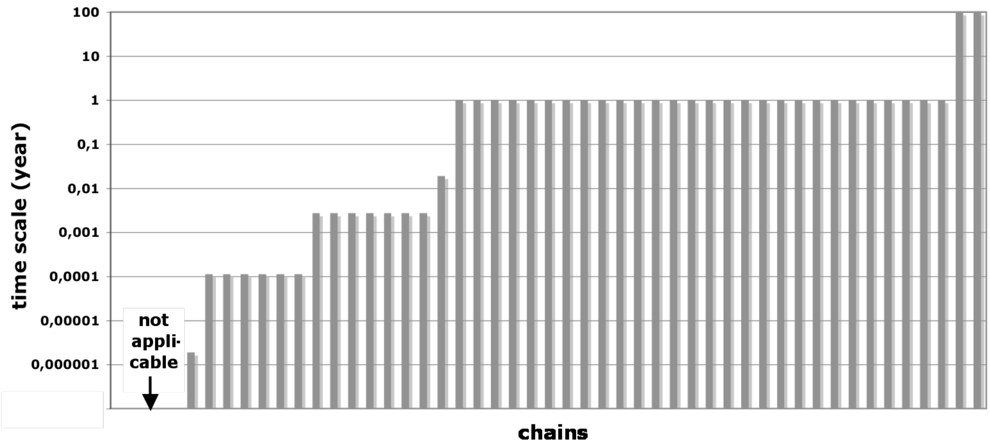


Figure 1 Ascending order of magnitude of the 49 causal chains' distance and time scales (continued)



4 Conclusion

To describe the environmental impacts of an activity such as transport through a complete list of independent causal chains allows us to give a precise definition of the term 'environment'. However, in most cases, the list of chains we propose here is much too detailed to be used in a decisional context. The chains have to be aggregated, or some have to be retained and others dropped. That a comprehensive list exists allows for aggregation or choice with full knowledge of the facts.

The causal chain approach does not deal with interactions among chains, although in practice interaction could occur. For instance, we know that psychophysical effects are not independent from one another (such as impacts because of odours, noise or landscape quality). More generally, the processes leading to the different effects on a same final target (humans, or ecosystems) react to each other. Nevertheless, considering 'independent' chains is a first step before describing in depth the possible synergies.

The framework for the causal chains should be a universally valid analytical one. Nevertheless, the chains have been proposed to cover impacts on the environment only in the transport sector. Although most of them are not specific to transport, the same analysis should be carried out in other domains such as agriculture, energy production, industry, and so on. This would allow us to arrive at a universal framework different methods and tools could use to assess the environmental dimension of sustainability in different sectors.

The framework's main limitation is cultural. Adapted to Western societies, it may not be as suitable to Eastern, African or other societies where the concept of environment can be fundamentally different or inexistent in this form.

The precise description of environmental processes forms a powerful tool to assess environmental impact indicators. *A priori*, the closer to the final target the indicator is, the more precisely the final impact will be estimated. It is mainly a tool to define what precisely an indicator represents. Does it represent the final impact, or an intermediate one? How accurately is the process translated into the indicator role? Which relevant impacts do existing indicators ignore? Is there a possibility of double counting? When the aim is not only to reorganise information that exists, but also to build the tools necessary to represent environmental impacts, the all-inclusive description of the impacts is the first step of the process.

References

Ahvenharju, S., Könnölä, T., van Grol, R., Walker, W., Klautzer, L., Röhling, W., Burg, R., de Tommasi, R., Arendt, M., Steiner, P., Bickel, P. and De Ceuster, G. (2004) Operationalising Sustainable Transport and Mobility: The System Diagram and Indicators, The Netherlands: SUMMA Deliverable 3, Rand Europe report.

Assefa, G., Glaumann, M., Malmqvist, T., Kindembe, B., Hult, M., Myhr, U. and Eriksson, P. (2007) 'Environmental assessment of building properties—Where natural and social sciences meet: The case of EcoEffect', *Building and Environment*, Vol. 42, Issue 3, pp.1458-1464. Available at: http://dx.doi.org/10.1016/j.buildenv.2005.12.011 [accessed 25/10/2010]

Black, W. R. (2000) 'Toward a measure of transport sustainability'. Paper Presented at 79th Annual Transportation Research Board Meeting. January 9-13, 2000.Washington, D.C.

Block, T., Van Assche, J., Vandewiele, D., De Rynck, F. and Reynaert, H. (2007) *Steden op koers? Stadsmonitor voor Leefbare en Duurzame Vlaamse Steden*. Editie 2006, Brugge, Belgium: Vanden Broele.

Borken, J. (2003) 'Indicators for sustainable mobility – a policy oriented approach'. *Paper Presented at the 1st International Symposium Environment & Transport. June 19-20, 2003. Avignon, France.* (Published in Proceedings, n°93 (pp.87-94), Arcueil, France: Inrets).

Boy, P. (2007) Les représentations sociales de l'effet de serre (8e vague d'enquête) [Social representations of greenhouse gases – 8th survey]. Paris : RCB Conseil report.

Brand, G., Braunschweig, A., Scheidegger, A. and Schwank, O. (1998) *Weighting in Ecobalances with the ecoscarcity method – Ecofactors 1997*, Bern, Switzerland: BUWAL (SAFEL) Environment Series, No. 297.

Brüggermeier, F.J. (2002) 'Le dépérissement de la forêt (Waldsterben) : construction et déconstruction d'un problème d'environnement' [Forest decline (Waldsterben): construction and deconstruction of an environmental issue], *In:* Bernhardt, C. and Massard-Guilbaud, G. (eds.), *Le démon moderne*, (pp.75-91), Clermont-Ferrand, France: Presses universitaires Blaise Pascal.

Bunz, K.R., Henze, G.P. and Tiller, D.K. (2006) 'Survey of Sustainable Building Design Practices in North America, Europe, and Asia' *J. Arch. Engrg.*, Vol. 12, Issue 1, pp.33-62. Available at: http://dx.doi.org/10.1061/(ASCE)1076-0431(2006)12:1(33) [accessed 25/10/2010]

Calderon, E., Pronello, C. and Goger, T. (2009) *Integrated assessment of environmental impact of traffic and transport infrastructure,* Madrid, Spain: Univ Politécnica, COST 350 Final Report.

Droulers, M., Le Tourneau, F.M. and Marchand, G. (2008) 'DURAMAZ, un système d'indicateurs de développement durable en Amazonie brésilienne' [DURAMAZ, an indicator system of sustainable development in Brasil Amazonia]. *Paper Presented at the Internat. conf. La problématique du développement durable vingt ans après : nouvelles lectures théoriques, innovations méthodologiques, et domaines d'extension.*, November 20-22, 2008. Lille, France.

EC (2001) Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32001L0042:EN:HTML [accessed 3/5/2010]

EC (2008) *Attitudes of European citizens towards the environment*. EC report, Brussels, 92 p. Available at: http://ec.europa.eu/public_opinion/archives/eb_special_300_280_en.htm [accessed 3/5/2010]

EEA (2002) Paving the way for EU enlargement - Indicators of transport and environment integration - TERM 2002, Copenhagen, Denmark: European Environment Agency, Environmental Issue Report, N° 32.

EEA, (2009) Glossary. European Environment Agency. Available at: http://glossary.eea.europa.eu/EEAGlossary/D/DPSIR [accessed 26/7/2010]

Esoh Elame, J. (2004) 'Interculturaliser le développement durable' [The intercultural dimension of sustainable development]**.** *Paper Presented at the Conference Développement durable – leçons et perspectives. , June 1-4, 2004*. Ouagadougou, Burkina Faso. Available at: www.francophonie-durable.org/documents/colloque-ouaga-a1-esoh.pdf [accessed 3/5/2010]

Frischknecht, R., Steiner, R. and Jungbluth, N. (2009) *The Ecological Scarcity Method – Eco-Factors 2006. A method for impact assessment in LCA*. Bern, Switzerland: Environmental studies no. 0906, Federal Office for the Environment.

Goedkoop, M. and Spriensma, R. (2001) *The Eco-indicator 99: A damage oriented method for life cycle impact assessment, Methodology report*, Amersfoort, The Netherlands: PRé Consultants, Report, No. 1999/36A, 3rd ed. Available at: www.pre.nl/download/EI99_methodology_v3.pdf [accessed 3/5/2010]

Goedkoop, M., Heijungs, R., Huijbregts, M., De Schryver, A., Struijs, J. and van Zelm, R. (2009) ReCiPe 2008 - A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. Report I: Characterisation, The Hague, The Netherlands: VROM. Available at: www.lcia-recipe.net/@api/deki/files/11/=ReCiPe_main_report_final_27-02-2009_web.pdf [accessed 25/10/2010]

Goger, T. (2006) Un indicateur d'impact environnemental global des polluants atmosphériques émis par les transports [An aggregated indicator of air pollution impacts involving transport]. PhD thesis. Insa, Lyon, France. (Subsequently published as Inrets report, n°LTE 0633, Bron, France) Available at: http://cost356.inrets.fr/pub/conferences/these_Goger_2006.pdf [accessed 26/7/2010]

Goger, T. and Joumard, R. (2007) 'A method of building an aggregated indicator of air-pollution impacts'. *Paper Presented at the 3rd International Conf. Sustainable development 2007, April, 25-27, 2007*. Algarve, Portugal.

Gudmundsson, H. (2007) *Sustainable Mobility and incremental change – Some building blocks for IMPACT*, Copenhagen, Denmark: Danish Transport Research Institute report.

Huijbregts, M. A. J., Guinée, J. B. and Reijnders, L. (2001) 'Priority assessment of toxic substances in life cycle assessment. III: Export of potential impact over time and space', *Chemosphere*, Vol. 44, Issue 1, pp.59-65.

ISO 14040 (2006) *Environmental Management – Life Cycle Impact Assessment – Principles and Framework*, Geneva, Switzerland: International Organization for Standardisation.

João, E. (2002) 'How scale affects environmental impact assessment', *Environmental Impact Assessment Review*, Vol. 22, Issue 4, pp.289-310.

Job, L. (2005) 'Agriculture, environnement et développement durable : une analyse des effets des politiques contractuelles en France' [Agriculture, environment and sustainable development: Analysis of the impacts of contract policies in France], *In:* Maréchal, J.P. and Quenault, B. (eds.), *Le développement durable, une perspective pour le XXIe siècle*, (pp.149-164), Rennes, France: PUR.

Joumard, R. and Gudmundsson, H., eds. (2010) *Indicators for environmental sustainability in transport: An interdisciplinary approach to methods*. Bron, France: INRETS report, Recherches R282. Available at: http://cost356.inrets.fr and http://hal.archives-ouvertes.fr/hal-00492823/fr/ [accessed 26/7/2010]

Joumard, R. and Nicolas, J.P. (2010) 'Transport project evaluation methodology within the framework of sustainable development', *Ecological Indicators*, Vol. 10, No. 2, pp.136-142. Available at: http://dx.doi.org/10.1016/j.ecolind.2009.04.002 [accessed 3/5/2010]

Joumard, R., Gudmundsson, H., Kehagia, F., Mancebo Quintana, S., Boulter, P., Folkeson, L., McCrae, I., Boughedaoui, M. and Calderon, E. (2010) 'Transport, environment and sustainability', *In:* Joumard, R. and Gudmundsson, H. (eds.), *Indicators for environmental sustainability in transport, An interdisciplinary approach to methods*, (pp. 45-78), Bron, France: INRETS report, Recherches R282. Available at: http://cost356.inrets.fr and http://hal.archives-ouvertes.fr/hal-00492823/fr/ [accessed 26/7/2010]

Keeney, R. L. (1992) *Value-focused thinking: a path to creative decision-making*, Cambridge, MA: Harvard University Press.

Lammel, A. and Resche-Rigon, L. (2007) 'La pollution atmosphérique comme objet cognitif : diversité des perceptions' [Atmospheric pollution as cognitive object: diversity of perceptions], *In:* Charles, L., Ebner, P., Roussel, I. and Weill, A. (eds.) *Evaluation et perception de l'exposition à la pollution atmosphérique*, (pp.71-84), Paris: La Documentation française, collection Primequal-Predit.

Lardé, P. and Zuindeau, B. (2008) 'Théorie de la régulation et développement durable : analyse de la diversité nationale des profils environnementaux et des politiques environnementales' [Regulation theory and sustainable development: Analysis of the diversity of national environmental profiles and environmental policies]. *Paper Presented at the Internat. conf. La problématique du développement durable vingt ans après : nouvelles lectures théoriques, innovations méthodologiques, et domaines d'extension*. November 20-22, 2008. Lille, France.

Lippiatt, B.C. and Boyles, A.S. (2001) 'Using BEES to select cost-effective green products', *Intern. J. Life Cycle Assessment*, Vol. 6, N 2, pp.76-80. Available at: http://dx.doi.org/10.1007/BF02977841

Lundin, M. and Morrison, G.M. (2002) 'A life cycle assessment based procedure for development of environmental sustainability indicators for urban water systems', *Urban Water*, Vol. 4, Issue 2, pp.145-152. Available at: http://dx.doi.org/10.1016/S1462-0758(02)00015-8 [accessed 25/10/2010]

Nicolas, J.-P., Pochet, P. and Poimboeuf, H. (2003) 'Towards sustainable mobility indicators: application to the Lyons conurbation', *Transport Policy*, Vol. 10, pp.197–208.

OECD (1996) Environmental criteria for sustainable transport: Report on phase 1 of the project on Environmentally Sustainable Transport (EST), Paris, France: OECD.

OECD (2001) Sustainable Development: Critical Issues. Paris, France: OECD.

OECD (2002) *Impact of Transport Infrastructure Investment on Regional Development*. Available at: www.oecdbookshop.org/oecd/display.asp?CID=oecd&LANG=fr&SF1=DI&ST1=5LMQCR2KC022 [accessed 3/5/2010]

Roqueplo, P. (1988) Pluies acides : menaces pour l'Europe [Acid rain: Threats for Europe], Paris, France: Economica.

Rousval, B. (2005) Aide multicritère à l'évaluation de l'impact des transports sur l'environnement [Multicriteria assistance in evaluating the impacts of transport on environment]. PhD thesis. Univ. Paris IX Dauphine-Lamsade, Paris, France.

Rousval, B. and Maurin, M. (2008) 'Évaluation de l'impact des transports sur l'environnement : quels modèles utiliser ?', [What models should be used to assess the environmental impact of transport?]. *Recherche Transport Sécurité*, No. 100, pp.169-184.

Scheuer, C., Keoleian, G.A. and Reppe, P. (2003) 'Life cycle energy and environmental performance of a new university building: modelling challenges and design implications', *Energy and Buildings*, Vol. 35, Issue 10, pp. 1049-1064. Available at: http://dx.doi.org/10.1016/S0378-7788(03)00066-5 [accessed 25/10/2010]

Schulze, R. (2000) 'Transcending scales of space and time in impact studies of climate and climate change on agrohydrological responses', *Agriculture, Ecosystems & Environment*, Vol. 82, Issues 1-3, pp.185-212.

SSNC (2006) Website of Swedish Society for Nature Conservation. Available at: www.snf.se/snf/english/english-sust-transport.htm [cited Nov. 1st, 2006 by Gudmundsson, 2007]

Swedish EPA (1996) *Towards an environmentally sustainable transport system*. Stockholm, Sweden: Swedish Environmental Protection Agency, report n°4682.

USEPA (1996) Indicators of environmental impacts of transportation - Highway, Rail, aviation and maritime transport. Washington, D.C.: USEPA report, 230-R-96-009.

Van Assche, J., Block, T. and Reynaert, H. (2008) 'Une méthode participative pour mesurer la durabilité urbaine. Le cas du Moniteur des Villes Flamandes' [Participative method for measuring urban sustainability. The case of the Monitor of Flemish cities]. *Paper Presented at the Internat. conf. La problématique du développement durable vingt ans après : nouvelles lectures théoriques, innovations méthodologiques, et domaines d'extension*. November 20-22, 2008. Lille, France.

Van Staëvel, E. (2006) *La pollution sauvage [Illegal pollution]*, Paris, France : PUF, Coll. Partage du savoir.

von Blottnitz, H. and Curran, M.A. (2007) 'A review of assessments conducted on bio-ethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life cycle perspective', *J. Cleaner Production*, Vol. 15, Issue 7, p. 607-619. Available at: http://dx.doi.org/10.1016/j.jclepro.2006.03.002 [accessed 25/10/2010]

Wackernagel, M. and Rees, W. (1996) *Our ecological footprint: Reducing human impact on the Earth*, Gabriola Islands, B.C., Canada: New Society Pub.

WHO (1946) *Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference*, New York, 19-22 June, 1946; signed on 22 July 1946 by the representatives of 61 States (Official Records of the World Health Organization, no. 2, p. 100) and entered into force on 7 April 1948.

Wolfram, M., (ed.) (2004) Expert Working Group on Sustainable Urban Transport Plans. Final Report, (Deliverable D4), Cologne, Germany: Rupprecht Consult.

Zah, R., Böni, H., Gauch, M., Hischier, R., Lehmann, M. and Wäger, P. (2007) *Life Cycle Assessment of Energy Products: Environmental Assessment of Biofuels*, Bern, Switzerland: Swiss Federal Office of Energy, Federal Office for the Environment and Federal Office for Agriculture.

Zietsmann, J. and. Rilett, L. (2002) Sustainable Transportation: Conceptualization and Performance Measures, Austin, Texas: Texas Transportation Institute, Univ. of Texas, Report No. SWUTC/02/167403-1.