Eco-design for infrastructures in all transport modes

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ABSTRACT:
During last decades, a lot of research has been aimed at mechanical characteristics improvements of materials and roads pavements, taking into account traffic requirements and service time for the initial construction. Besides, environmental impacts linked to roads are still seen today throughout regulation and focused on the use phase. Regulation imposes environmental impact studies (EIE) mainly in relation with nature and people protection. Then, studies are performed before roads construction, mainly devoted on roads location and on local effects of roads exploitation.
On the other hand, since the 90's, Life Cycle Analysis (LCA) has been considered by road civil engineers and public institutions workers as a possible way to improve road design at the international level. Life Cycle Analysis is a standardized environmental assessment method, which has been developed for products manufacturing improvement by USA chemical industries (SETAC). LCA proved to be well adapted for large numbers of manufactured products. It requires the use of a functional unit (FU) that accurately defines the product properties and functionalities to consider for a given service time. Moreover, it gives a relative assessment using a reference case, which has to be defined for each study.
Hence, in France, a public reflection on national environmental stakes, has been conducted by the government since 2007. Concerning public works, it has led to the progressive incorporation of environmental criteria into public calls for tenders. In this context, the strategy of LCPC/now Ifsttar was to develop a tool –called ECORCE-, for LCA assessment and optimisation, in accordance to both road and LCA codes of practice. A set of steps and hypotheses for tool functionalities and implemented models is available, it is actually refined, including work on LCI data related to earthworks. The idea in this paper is to show pertinent indicators enabling the calculation of a series of eco-design parameters to better master the different effects on the environment; whereas the principles to minimise environmental loads are described as well. Both method and tool shall allow the professions concerned to deduce the best compromise between the different technical as well as environmental factors taken into account.

In this paper the results mainly discuss earthworks, which are one of the main parts of construction works and overall common to all transport modes and apply to both urban and non urban areas, roads and railways using ECORCE. Typical results exhibited by two case studies are presented and the key parameters for eco design are discussed in order to determine possible improvements of considering environmental impacts during the design phase.

1 INTRODUCTION

In France, a workgroup on national environmental stakes -“the Grenelle environment”- has set ambitious goals for transport systems in many areas as biodiversity, natural resources and climate change. The French National Transport infrastructure scheme (SNIT 2011) was set up according to this, and, in particular, it was planned to build 4000 kilometres of high speed railway. In order to optimize these new investments, RFF, the manager of the French railway network, and IFSTTAR launched a common study concerning a complete life cycle analysis (LCA) of railways, including the energy consumption during the operating phase.

The expected results of this optimization are: the reduction of environmental global impacts of infrastructures considering geometry and construction; the sparing of natural resources (including energy, water); the reduction of emissions (GHG,) the reuse of deconstruction materials in comparison to other possibilities; the development of a method prior to standardization. Besides, earthwork companies face nowadays the challenge of reducing their environmental impacts. On the one hand, engineers need to stress themselves with environmental issues such as pollutant emissions and ground structure interactions. On the other hand, these can be used as a marketing argument to facilitate transactions.

Concerning public works, it has led to the progressive incorporation of environmental criteria into public calls for tenders. In this context, the strategy of LCPC and now Ifsttar was to develop a tool for LCA assessment and optimisation, called ECORCE, with respect to both the road and the LCA codes of practice. A set of steps and hypotheses for tool functionalities and implemented models is available, it is actually refined, including work on LCI data related to earthworks. Its principles are detailed and applications discussed. Today the need for benchmarking is real as quite no literature deals with parametric studies on earthworks environmental impacts. The idea is to show pertinent indicators enabling the calculation of a series of parameters to better master the different effects on the environment; whereas the principles to minimise environmental loads are described as well. Bothe method and tool shall allow the professions concerned to deduce the best compromise between the different technical and environmental factors considered.

The research here focuses on earthworks which are one of the main parts of construction works and overall common to all transport modes and apply to both roads and railways. The research described covers following items: 0) showing the work performed on two case studies the RN7 national road construction and the LGV Rhin-Rhone 1)Perform an assessment of earthwork practices for different infrastructures construction. 2) Reduce natural resources consumption (including energy, water) and minimise emissions (including GHG and other impacts) and environmental global impacts 3) consider geometry effects and construction/maintenance scenarios of pavements 4) Optimise the construction and reuse of local materials with soil treatment in comparison to other possibilities (i.e. consumption of new aggregates).

The way to think using environmental tools and comparisons of data is pointed out in the conclusions, in order to favour the developed practice towards various countries and think to the development of a method prior to standardization, which needs to adapt the data base and the local practice for country specific assessment.

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2 MATERIALS FOR INFRASTRUCTURES AND LCA METHODS

There is quite no literature focused precisely on LCA assessment of earthworks in the framework of infrastructure construction, while the literature on pavement LCA has been more extensively investigated within the 10 last years. The generic system that can be used for road LCA can be considered as shown on figure 1. Depending on site configuration and chosen technical solution for construction or maintenance, only some processes among these are considered. Each process selected is associated with a LCI (Life Cycle Inventory) process that allows for unitary released fluxes calculations for material processing. Based on these LCIs and also on a model for impacts calculation, the calculation of impact indicators, according to a model dedicated to site impacts assessment as explained in a previous work by Sayagh *et al.* (2010), is as follows:

$$Ind^{j} = \Sigma_i \ \alpha_i^{j} \times C_i^{j} \times m_i \qquad (1)$$

with: Ind^{j}, indicator associated with impact category j; m_i, mass of inventory flow i (kg); C_i^j, contribution coefficient of inventory flow i to impact category j; and α_i^j: classification coefficient. Each indicator is expressed in specific units per kg or t. Hence, the method aims at avoiding double counting. The chosen impact categories (and indicators for quarry site assessment) derived from classical LCA comprise:

- Energy consumption: the specific energy consumption of each process
- Global Warming Potential (GWP), from IPCC (2001),
- Acidification Potential (AP), from Goedkoop(2001),
- Photochemical Ozone creation potential (POCP), from Goedkoop (2001),
- Eutrophication Index (EI), from Goedkoop (2001),
- Human toxicity potential and Ecotoxic Potentials (TP and EP), from Huijbregts *et al.* (2000).

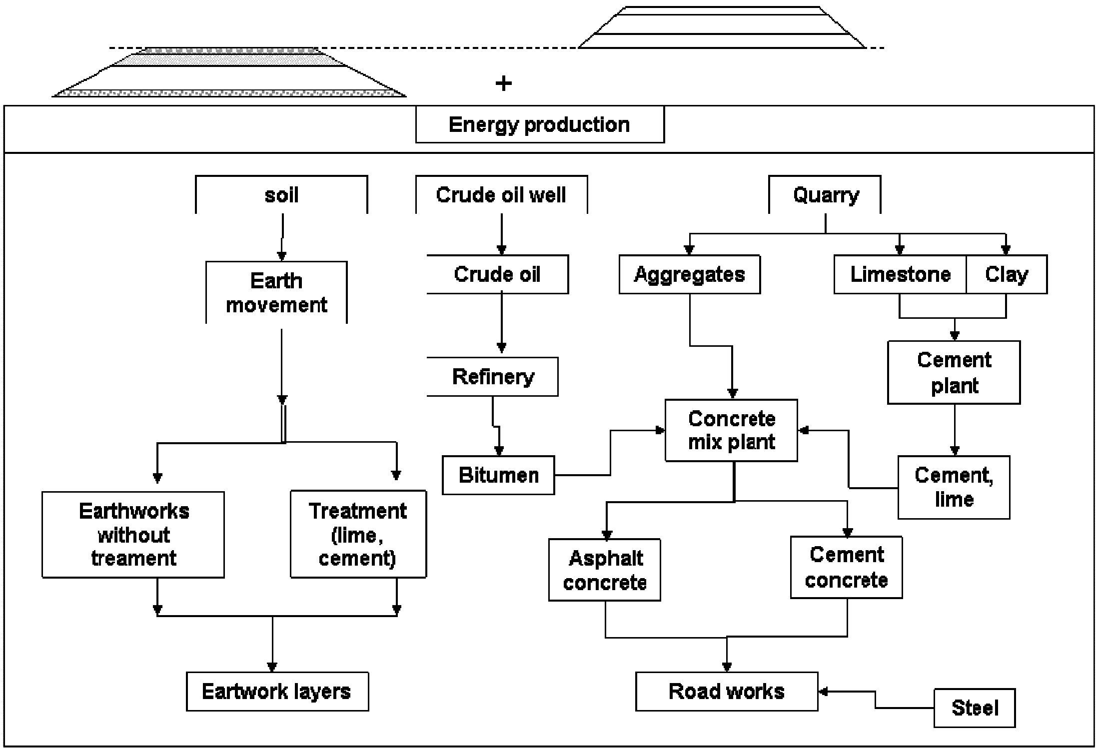

Figure 1: Generic system for earthworks and road pavement works LCA.

3 ROAD CASE STUDY (RN7) AND ENVIRONMENTAL ASSESSMENT

3.1 *The site-a 8.9 km road : Parameters for longitudinal profile ecodesign/construction works*

The National Road 7 (RN7) earthwork yard was the first stage of the construction of a 2x2 ways highway of 8.9 km long. The studied site was part of the RN7 and consisted of a 1.9 km long strip of land (Fig. 2) positioned at the beginning of the earthwork yard (from 0.76 to 2.66 kilometric mileposts “MPs”). A characteristic of the studied site was the importance of cuts relative to fills. Furthermore, cuts were primarily located at 1.00 and 1.90 MPs whereas fills were close to 2.66 MPs. This contributed to increase the amounts of unusable cuts and average distance crossed by moved earth for fills. The earthworks exceeded 3 years (from June 2006 to December 2009). During this period, more than one million cubic meters were engineered, 10 pools were excavated to reduce the loading of runoff waters with particles and associated pollutants, and more than 15,000 tons of materials were processed for road coating. Finally, the entire earthwork employed up to 70 earth-engineering machines. The data collected then can be used for all earthworks LCA.

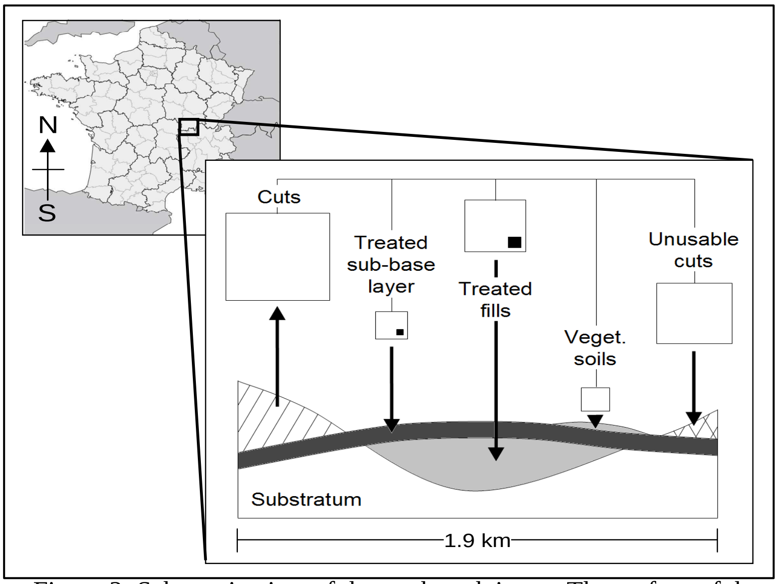

Figure 2: Schematic view of the earthwork items. The surface of the open (resp. filled) squares were set proportional to the volume of moved earth (resp. of used quicklime). The lengths of arrows were set proportional to the corresponding average distance crossed by moved earth. (source: Capony et al, 2011)

3.2 *Collected local data on the site during earthworks*

To assess the environmental impacts of the studied earthwork, in-situ and literature information were collected about most of the significant construction materials and unit operations. These included the type and quantity of earthmoving machines, their particular daily work, their localization and fuel consumption, the production and manufacturing of added materials as well as the amount, origin and destination of engineered earth volumes. Some indicative values are presented in the Table 1, Distinction was made between the different earthwork items.

The engineered earth volumes and quicklime amounts were determined according to the site diary managing all the daily construction activities on the studied site: e.g. the quantities of works and nature of activities executed, the employed equipment, the materials and supplies received. The average distance (L) crossed by the moved earth of a given type of earthwork item was calculated using the time-location plan of the studied site. These were formulated as follows:

(2)

$$\bar{L}_{item} = \frac{\sum_{i=1}^{n}(L_i \cdot m_i)}{\sum_{i=1}^{n} m_i}$$

where “L” is the G.P.S. measured distance between the origin and destination of the moved earth (in m) and “m” is the amount of transported material (in kg). The subscript “i” stands for the different earth transportations relative to the considered earthwork item (e.g. from cuts to treated fills). Finally, the consumption of fuel represents the total consumption of all the employed equipment / machines (i.e. bulldozers, compactors, dumpers, excavators, graders).

Earthwork item	Engineered earth volume (m^3)	Average distances crossed by moved earth (m)	Fuel consumption (m^3)
Treated sub-base layer	22,000 (880)	900	20.4
Unusable cuts	110,000	770	90.9
Treated fills	80,000 (3200)	2100	59.2
Vegetalisable soils	17,000	50	9.1
Overall	229,000	1060	179.6

Table 1: Engineered earth volume, average distance crossed by moved earth and fuel consumption data. Values in brackets account for used quicklime amounts (in tons).

3.3 *Environmental impacts and engineering processes for earthworks*

Six environmental indicators defined in Ventura *et al.* (2010) were calculated: the consumed energy (i.e. E.E.; MJ), global warming potential (i.e. G.W.P.; kg eq. CO2), acidification potential (i.e. A.P.; kg eq. SO2), eutrophication index (i.e. E.I.; kg eq. PO4), photochemical ozone potential (i.e. P.O.C.P.; kg eq. C2H4) and toxicity potential (i.e. T.P.; kg eq. 1.4 D.C.B.). Ecotoxicity potential is not determined because some pollutants are lacking in the Stripple’s LCI. Throughout the text, we refer to the selected set of indicators as I6. .An important parameter that affected I6 calculations was the presence / absence of quicklime treatment. Hence, the contributions of quicklime treatment were separately assessed as shown on Fig. 3 for RN7 using ECORCE.

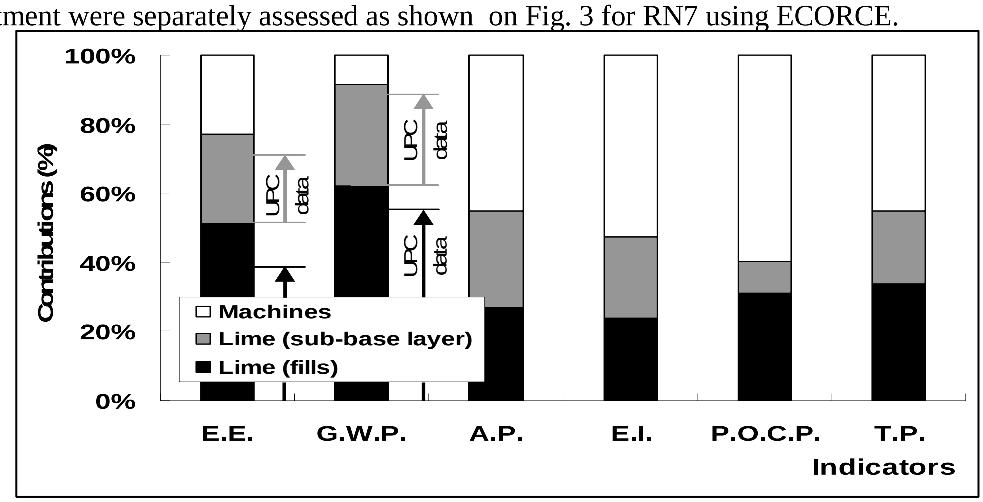

Figure 3: Relative contributions of earth-engineering machines and quicklime treatments to the selected environmental indicators. The horizontal bars account for the calculation results based on UPC (2010).

This experiment and its associated calculations point out that for an earthwork realization, the machines impacts are of the same order of magnitude of those of lime (production+ use), while a big amount of local soil is used due to lime. Lime LCI exhibit strong differences between available data sets that lead to implications in terms of I6 LCA results. Hence, in 2001, Stipple has first proposed an LCI for quicklime production in Sweden. Later, the Union of Lime Producers (U.P.C., 2010) performed a similar LCI fitted to the quicklime production in France (Table 2). Between the two countries the difference is the considered technology processes for lime production. Due to the lack of generic (i.e. non-site-specific) data, the number of considered pollutants markedly varies between LCIs: 2 *(Stripple's data)* vs. 5 (*U.P.C. data*) compounds for G.W.P. and 3 vs. 22 compounds for T.P. Whatever the data discrepancy is, the soil consumption saving is interesting and efforts have to be done for machine impact reduction during earth moving.

Indicator	**Compounds emitted into the atmosphere**	**Stripple / U.P.C.**
Global warming (G.W.P.)	CH_4, CO_2, CF_4, *Halons*, N_2O	2,100 / 1,100 kg eq. CO_2 ton^{-1}
Human chronic toxicity (T.P.)	*As*, Ba, Be, *Cd*, Co, *Cr*, *Cu*, *Hg*, Mo, *Ni*, *Pb*, Sb, Se, Sn, Tl, V, Zn, *NOx*, *SOx*, *HCl*, H_2S, NH_3, CS_2, $H_2C{=}O$, *Ph-H*, *Ph-OH*, *Ph-Me*, *Ph-Et*, *Me-Ph-Me*, *PAH*, $H_2C{=}CHCl$, *DCE*, PM_{10}	1.5 / 309 kg eq. 1.4 D.C.B. ton^{-1}

Table 2: Comparison of quicklime production step LCA performed with various processes and LCIs. The compounds in italics and underlined letters were reported in the LCIs by U.P.C and Stripple, respectively (Source : Lepicier et al, 2012).

3.4 *Comparison with the operation phase impacts*

The environmental impacts of the entire RN7 earthwork yard were finally estimated (Table 3). The calculations used the projected data for the engineered earth (overall volume of 1,300,000 m3), the characteristics of soils (as determined from preliminary drills) as well as the type / quantity and tasks of earthwork machines. In a first step, the consistence of environmental indicators was checked. This consisted in comparing the figures obtained when separately applying the ECORCE software to the 8.9 km long RN7 earthwork yard and to the smaller studied site. Accordingly, the I6 environmental indicators exhibited comparable results: i.e. 0.9<I6 (entire yard /m3) : I6(studied site /m3)<1.4. This supported that both the projected data and these of the studied site were consistent and therefore representative of the entire RN7 earthwork yard (Table 3).

Indicator N°	1) IE.E. (MJ)	2) IG.W.P. (kg eq. CO2)	3) IA.P. (kg eq. SO2)	4) IE.I. (kg eq. PO4)	5) IP.O.C.P. (kg eq. C2H4)	6) IT.P. (kg eq. 1.4 DCB)
Entire RN7	$1.7\ 10^8$	$2.9\ 10^7$	$2.5\ 10^4$	$2.0\ 10^3$	$3.8\ 10^3$	$3.8\ 10^4$
Annual road traffic	$1.4\ 10^8$	$1.1\ 10^7$	$3.1\ 10^4$	$2.9\ 10^3$	$7.7\ 10^3$	$5.4\ 10^4$

Table 3: Values of I6 environmental indicators calculated using ECORCE 1.1 software for the studied site (1.9 km long), the entire RN7 yard (8.9 km long) and the projected annual road traffic.

The entire earthwork yard accounted for 2.9 10^7 kg eq. CO_2. Hence, we compared this value to the projected CO_2 emissions of 9,000 vehicles d^{-1} of 0.13 L km^{-1} of averaged diesel fuel consumption; the total amount of CO_2 emitted by vehicles would reach 1.1 10^7 kg eq. CO_2 by year. Despite the uncertainties of these calculations, the results clearly indicated that a few years of road traffic reach the same amount of G.W.P produced by earthworks for its initial construction, as for other environmental indicators it is reached over a smaller period of time (i.e. <1 year) .

4 RAILWAY CASE STUDY (LGV RHIN RHONE) AND ECO-DESIGN

4.1 *The line –a 140 km length railway –Parameters for longitudinal profile ecodesign-use phase*

Existing environmental studies on railways are relatively recent (Lee et al, 2008; Vandanjon *et al*, 2012) , some aim to compare different modes of transport and are based on the use phase. Hence they are one step beyond construction and maintenance options although the whole life cycle has not really been examined considering earthworks and pavement construction/maintenance. Chester and Horvath (2010) argue that for high-speed rail system, energy consumption is mainly attributed to the operation phase, despite the fact that impacts of construction, maintenance and generation of electricity are also important. The main issue would be to reduce energy consumption, whereas different solutions are investigated to reach this goal. One can say both longitudinal profile and vertical structure can be influent on the LCA. The original feature of a recent study which is a partnership between an owner RFF and Ifsttar aims at improving the design of rail infrastructures while taking into account earthwork, structure and operation phase (Coiret *et al*., 2012) . Hence the train consumption is investigated along with a 140 km length in order to precisely describe the links between consumption and slope (Figure 4). The global longitudinal profile is obviously an eco-design parameter if some modeling is available for assessing consumption along an itinerary work performed at Ifsttar in progress (Coiret *et al*., 2012) .

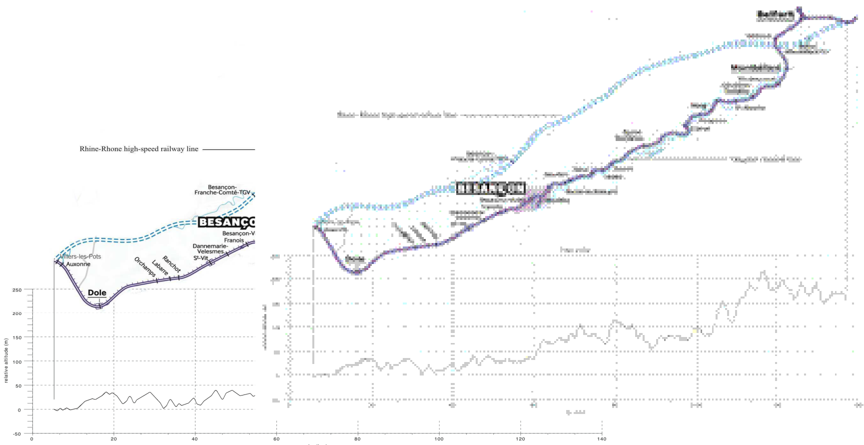

Figure 4 :Map and track profile of the test section (source: Coiret et al, 2012)

4.2 *Parameters for structure ecodesign*

Some authors have evaluated environmental impact of alternative structural materials or alternative solutions of construction to reduce energy consumption, natural resources use and emission of pollutants (Lee ret al, 2008; http://ofrir2.ifsttar.fr) . One of the constructive solutions especially analyzed (Huijbregts, 2000) is the ballastless slab track vs. ballasted track. Such ballastless technology does not necessarily increase the total energy consumption of the infrastructure (Vandanjon et al, 2012) given its 60 years life use of and its low maintenance. Nevertheless the NetworkRail study seems to indicate the opposite, ballastless slab track emitting significantly more emissions than ballasted track. Figure 5 shows different scenarios of railway structure design investigated by now and requiring a lot of data for indicators calculations.

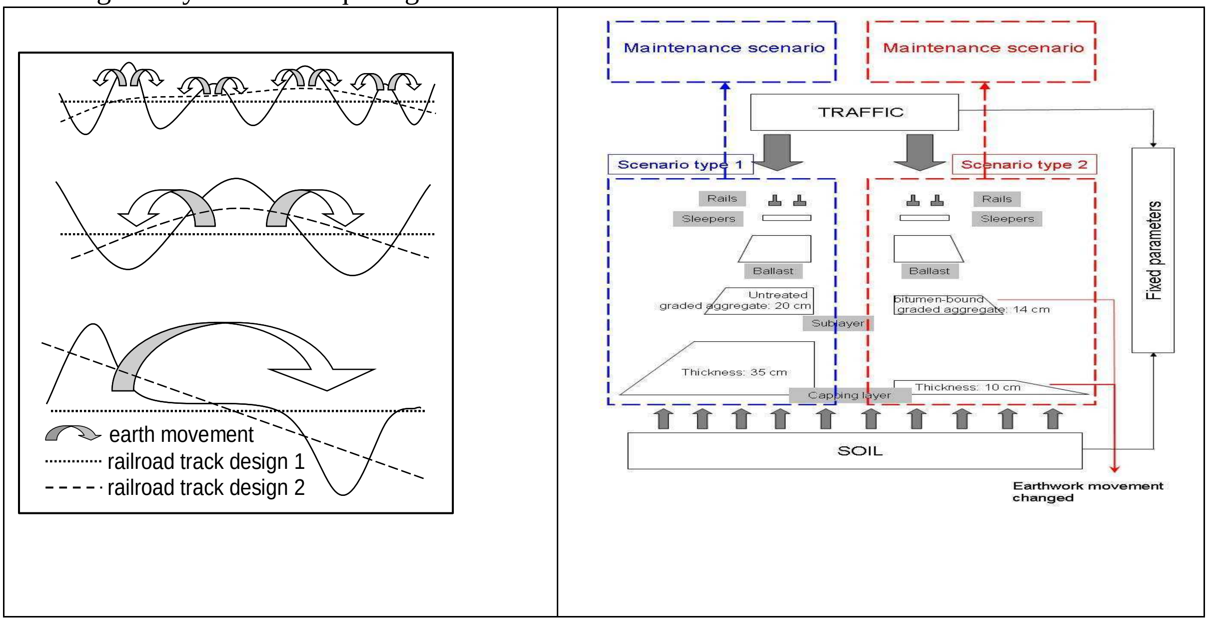

Figure 5: Parameters of Ecodesign -scenarios selection for the structure (source: Vandanjon et al, 2012)

5 CONCLUSIONS ON ECO-DESIGN FOR TRANSPORT INFRASTRUCTURES

Road and rail geometries analysis derived from the two bids examined (RN7 and LGV Rhin Rhone) indicate that the desired slopes of longitudinal profiles as well as their vertical profiles strongly influence the general design. First about earthworks strategy, the earthmoving assessment is typically linked to the local soil characteristics and the treatment performed (binder addition to the soil, namely quicklime in this paper) all studies performed on a road site show that earthmoving can be also optimised choosing the machines and their operating conditions. A for railway infrastructure, which are more flat than roads, one can imagine that earthworks optimisation in terms of machines work durations, running conditions, distances of transport for soils cuts within the local road area, all being key parameters of eco-design as regards the construction phase.

Looking at the vertical structure for both types of infrastructures, one can say that the soil treatment is one key parameters for energy consumption and GWP impacts on one hand but this allows to save a huge amount of local soil and may be to reduce the machines working time that impacts a lot also. Refinements in calculations should be interesting to perform as future work. When examining the pavement structure (road and rail), the analysis would be to assess binder use (several % of binders) for initial construction compared to the maintenance required if no binder is used and the induced transport phases.

6 AKNOWLEDGEMENT

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