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Determination of Environmental Impacts of Bituminous Highway's by Life Cycle Assessment

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ABSTRACT

Nowadays transportation is one of the most Indispensable parts of every society, which has significant effects on economics, society, and the environment. In this study; asphalt surfaced roads environmental loads using Lifecycle Assessment Analysis have been studied. This study aims to; assess environmental impacts of road construction, maintenance and its application with defining loads causes, results of the most important procedure throughout its lifecycle and suggestion resolves for critic processes in order to develop a perspective for decision-makers, managers and anyone who related to asphalt-surfaced roadways. In this paper Life Cycle Assessment (LCA) has been done in three categories (human health, ecosystem quality, and resources) using SimaPro 7.1 software. What makes this paper distinct from previous studies in road life cycle assessment is; a comprehensive analysis has been done in three main categories, which have subcategories that all the subcategories and categories analyzed with characterization, and weighting option, it is necessary to specified the most critique processes in road LCA, so that the next step to reduce the negative effects could be possible, there are no specific studies in road LCA so we did this study more specific in terms of environmental impacts details rather than just analysis 3 main categories. In the results, the resources category determined as the highest environment loads in asphalt surfaced roadways life cycle. Due to high fossil fuel affects which is one of the resources subcategories the resources category is the first impact category. Ecosystem quality and human health are respectively in the second and third places on the environmental impact.

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1. Introduction

Nowadays, especially with the beginning of feeling the destructive effects of climate change; The importance of environmental problems and the urgency of solutions have become an accepted reality all over the world. Climate change, biodiversity decreases, natural environments are polluted, natural resources are consumed rapidly. Atmospheric concentrations of greenhouse gases such as carbon dioxide (CO2), methane (CH4) and nitrogen (N2O) have increased significantly since the beginning of the industrial revolution. This is largely due to fossil fuel use, changes in land use and human activities such as agriculture. According to the IPPC 5th Assessment Report (2014), people have a clear impact on climate change. The report, in which the scientific foundations of global climate change and the factors that cause climate change are evaluated, reveal that the observed climate change is human reason, and according to the report, the increase in global temperatures in the period of 1951 - 2010 is definite (95% - 100% probability). It results from human activities. When analyzed sectorally; The contribution to global warming is 49% from energy use, 24% from industrialization, 14% from deforestation, 13% from agriculture [1].

The global warming potential of carbon dioxide gas, which has a share of 80% in total greenhouse gas, is low compared to other greenhouse gases.

CO2 emissions from the anthropogenic origin; Energy production ranks first with 36%. Secondly, transportation is a significant source of CO2 emission. When we say transportation systems; systems such as airlines, railways and highways are included. The ecological system affects ecological balance and human health at different rates. The consumption and division of natural lands during the construction of transportation subsystems, the activities that occur during operation, the formation of air and noise pollution and the contribution of climate change due to the resulting CO2 negatively affect the ecological balance. People like all living things are also affected (10) when the effects of these types of transportation compared, the roadways give the most carbon dioxide gas to nature [2].

For this purpose, the life cycle analysis method was used to determine the environmental performance of the system in all processes including construction, operation, maintenance, and repair stages of highways. At this stage of this study, the life cycle assessment was carried out in three steps: In the first step, the limits of the road transport system were determined with the aim and scope definition, the aims of the study and the main components required to reach the intended outputs. Road length, type, and construction are included in the determination of system boundaries. The aim of the study is to determine the environmental impacts of highways, especially bituminous roads, because of the different effects of construction and maintenance of existing bitumen roads, road construction, maintenance and operation stages. The functional unit is defined for the environmental effects of the 1km 'highway. Then, for all stages, data on material and energy flows are compiled; The system boundaries are considered as a closed box and all raw materials and energy components entering into this box and the side emissions are evaluated on the basis of functional units. Finally; life cycle analysis (LCA) for three main impact categories (human health, ecosystem quality and consumption of natural resources) was made. According to the evaluation made between existing LCA software; To be in compliance with ISO 14040, the most used LCA software in the world, for the quality of the database and methods it contains, and for ease of use, in this study, SimaPro 7.1. software is decided to use. In addition, the ECO-INDICATOR-99 method, which is one of the most commonly used methods of impact assessment, has been used.

1.1. Roadways impacts on earth

Atmospheric concentrations of greenhouse gases such as carbon dioxide (CO2), methane (CH4) and nitrogen (N2O) have increased significantly since the beginning of the industrial revolution. This has been largely due to human activities such as fossil fuel use, land-use changes, and agriculture. It has been scientifically reported that climate change results from human activities with 100% anthropogenic effects. Recent climate changes have had widespread effects on human and natural systems [3].

As discussed in Fig. 1 anthropogenic origin CO2 sources; Energy production ranks first with 36%, and Secondly, transportation.

According to the IPPC report, in 2014, 18% of the CO2 produced in the world belongs to the transport sector, and 74% of the CO2 emissions from the transportation sector originate from road transportation. Reducing the amount of CO2 generated by the energy and transportation sector is a significant part is extremely important for the future of the world. Fig 2. shows the fuel consumption and CO2 emissions of each transportation subsystem for freight transport. The possibility to be selected in the figure provides an important advantage in terms of pollution. While the share of railways in air pollution is 5%, the share of highways is 85% [4].

According to EAPA statistics, more than 90% of the European road network and 92% in the United States are composed of asphalt and bituminous roads [5]. On the other hand, the materials used in asphalt roads are composed of aggregate and petroleum products and therefore play an important role in terms of resources that will end in the future.

Many studies on the asphalt highway have been done before.

In the study of Facanha and Horvath [6], USA, the LCA method was used for the determination of pollutant emissions such as CO2, NOx, PM10, CO, SO2 caused by road, rail and air freight. In the study, the burning of fuel for each type of transportation, infrastructure operations, the operation, and maintenance phase of roads and the fuel used in these stages have taken into account the production. This study has been done in most respects, but in our study, we have not only examined the above-mentioned emissions but also examined all of the emissions in the LCA under 3 main categories and also discussed the impacts of each category.

Federici et al. [7], in their study, Italy land transport (highway, high-speed train rail, and conventional train rail) Infrastructure inspected. In all analyses; a common database of materials and energy inputs used in the maintenance, production or construction phases of vehicles, railways, and highways. In this study, the importance and energy saving of energy in transportation systems were discussed while the effects of energy and highway life cycle on the environment were discussed. These effects are on human health, ecosystem quality, and resources, and the effect amounts of the operations aimed at reducing these effects are given in the study.

Çağatay et al. [8], aims to evaluate environmental impacts on highways. As highway construction, the ecological effects of a highway under traffic as well as the impact of maintenance have been systematically analyzed over 30 years using the LCA methodology and according to ISO 14040. In this study, the production of materials, energy supply, production of necessary materials, transportation service, study services and the disposal of each material are examined. Air-based, water-based and soil emissions were calculated using the Dutch CML method, and global warming potential (GWP), ozone thinning potential (ODP), photochemical ozone generation (POCP), acidification potential (AP) and eutrophication potential (AP) were investigated in the effect groups. The data were evaluated using the LCA program, Simapro, and the reduction of possible environmental impacts was calculated by considering different scenarios. The difference between the study and our study is the method and effect categories used, and the effect categories in our study were calculated as quantity.

In the study of Ali [9], an Open LCA framework was carried out on a certain asphalt highway until the end of the construction, maintenance and road service to evaluate the energy and environmental impacts. A method to calculate the energy savings of raw materials production in bitumen has been developed and a method for evaluating the mass-energy flow of additives is described. In this study, we have been concentrating on energy flow and saving again, and the road has not been studied as a holistic system of the life cycle, whereas in our study the road was holistic and examined as a one-piece system.

Samaneh et al [10], describes the role of construction in the earth's environment and environmental pollution, in a project aimed to increase the level of knowledge of managers according to the environmental impacts of the project. In this study, environmental impacts were obtained only by distributing a questionnaire to a group of experts, which is why they asked which group of environmental problems occurred in the construction sector. However, it was done as a very simple research and there is no analysis. Our study has been conducted on several bases that are not based on personal glances.

Fauziah et al [11], The LCA, which was reviewed in its studies, provides up-to-date information on the environmental impacts of road construction and maintenance. In this study, the knowledge of the relationship between highway plating and the environment as a research area of highway coating LCA's is still lacking and there are still no regular surveys in the LCA's.

Fabio et al. studies were carried out by taking an interstate asphalt road in the UK and the road coating was aimed at the extension effect of system boundaries in the evaluation of life turnover. However, this study generally mentioned CO2, CO, NOx, and HC. This study examines the environmental impact of traffic and the general issue is on traffic and there are no categories of impact. However, only a part of the highway has been examined in the studies mentioned, in our study there is no traffic examination.

John et al. In this white paper road pavement, it has examined GHG emissions, their interpretation, analysis, and reduction with road transport and transportation sector. This white paper is a research synthesis of a number of previous and current projects and has emphasized both the methods and the findings that have been established and the methods discussed and currently discussed. The aim is to inform federal, state and local policymakers; road coating industry for professionals; For private road plating industries and for transport and other researchers, the road plating industry has aimed to explain the importance of LCA and reduce adverse environmental impacts. This study is again on GHG gases and the main theme of the study is on these gases. Paths are not a holistic life cycle assessment. The proposed methods, however, are very important in the decision-making process and in our study, they are composed of principles similar to some suggestions. Unlike the previous studies, the categorization of the main domains within the scope of this thesis is examined in detail in terms of subtitles.

From the previous studies it could be understood the comprehensive study is not been done so far on the overall impacts of roads in terms of released emissions, energy consumption, construction phase, and detail of the subcategories which lead to significant depletion of the material and energy usage, in this paper an overall LCA method has been used which includes 9 different subcategories with the amount of the environmental effects in terms of Pt unit.

2. Methodology

Nowadays, there is much commercial software that is used by the LCA method. This software varies according to the database they contain, the methods of impact assessment and their conformity to ISO 14040. Priority, purpose, functional unit and system boundaries are determined. The "Km" as the functional unit was chosen as the length of the roads.

2.1. Eco-indicator-99

The impacts evaluated in the eco-indicator 99 are composed of three main categories: human health, ecosystem quality, and resources, and these main categories are divided into subcategories.

Human health: In the method, the unit of this impact category is given as DALY (Disability Adjusted Life Years). DALY is a unit used by the World Health Organization (WHO) and the World Bank to describe the health effects that cause disease and death. The health effects that cause death, such as cancer or respiratory effects, are defined using the indicator of life lost years (ROI, years of life lost). Respiratory health effects are considered acute and chronic. Many statistics have been used by the WHO to calculate the number of years of life lost due to a fatal disease. These statistics show the age and the rate at which death from cancer or a respiratory health effect occurs. In these statistics, the dose and exposure value can be combined to determine how many years of life have been lost due to the increase in the concentration of a particular pollutant. DALY takes into account not only the lethal effects but also the effects that reduce the quality of life (cough, asthma, hospitalization, etc.) by giving pain and pain for a certain period of time, which is not immediately the cause of death. These effects are described as years of disability (YLD). Disease, pain and pain due to the weighting factor of the disease vary from 0 to 1. In a disease with a 0.5 weight factor, the painful one year is considered to be half the severity of early death year.

2.2. System boundaries

In determining the scope of the LCA, determining the system boundaries of the study is very important. System boundaries define the processes and processes that are selected in the study (production, transport, waste management, etc.) and the LCA study. In LCA studies, system boundaries consist of the following stages;

• Production of raw materials and energy

• Production (transport of materials to the factory, production at the factory, packaging, distribution of products)

• Use / reuse / maintenance repair

• Recycling / incineration / storage etc. waste management.

When defining system boundaries, the process/product flow diagrams of the system should be established and system boundaries should be defined more clearly.

Thus, by creating flow diagrams of the processes, the selected systems/processes can be considered as a closed box and the material and energy flow entering the system/process can be determined.

system boundaries are three different groups;

1. The first group; includes the effects during the preparatory phase before road construction. Includes handling and use of materials and equipment. At this stage, the effects during the transportation of the materials, using fuels and the production of these fuels.

2. The second group consists of the construction of the road and the materials used for the construction, maintenance after the construction of the road and disposal of the road after the completion of the life of the road. All transport operations carried out at this stage are covered in the first group.

3. The third group includes emissions from the system and wastes and energy and raw materials supplied to the system. The effects of the energy and raw materials used were calculated in road construction, in the first and second stages, but the production and processing of energy and raw materials were not calculated as a system in road construction.

2.3. Inventor analysis

Vehicle-related calculations, all the vehicles in the system described; During the operation, transportation of materials, production of vehicles, construction of the road, infrastructure and operation of the road were carried out and operations were carried out through fuel transportation.

Infrastructure construction, building materials, construction machinery, the energy used for construction, the resulting emissions and the movements that because traffic was taken into account.

Emissions from the construction of cars, trains, trucks, and transport vehicles are not calculated in this study;

• Raw material production: The most important materials in road construction are bitumen and aggregates. There are different data in the Simapro database, which database selection doesn't make a big difference in the results, and in general, the data based on European countries are collected in the database. The aggregation and aggregation of aggregates are based on data from the Swedish Zurich, ETH University. The aggregate extraction and energy used were obtained by ETH from various data and the land use was estimated by ETH.

• The selection of bitumen and crude oil products is in the Swedish and Western European data, such as oil field research, crude oil production, long-distance transportation, oil refining, regional distribution and the use of local and industrial crude oil products, operations in power plants and spark-ignition engines.

• Energy generation; System model energy carriers describe the production of commercial products with energy uses. Petroleum products (light and heavy fuel oil, diesel, and gasoline), coal and lignite products (lignite briquettes, lignite powder, hard coal briquettes and cola, solid coal and lignite from European mines, one by one), natural gas products High-pressure natural gas for single Western European countries and low-pressure natural gas for Switzerland), calculated.

• Vehicles: According to the Simapro database, the production of materials is calculated on an average distance of 5,000 km and the vehicles are assumed to return to the factory empty after delivery of the material. The roads in the study are assumed for private cars, trucks that can carry 16 tons, 28 tons and 40 tons.

3. Weighting analysis

At the characterization stage of the life cycle, the sub-effects that constitute different categories of effects such as global warming, ecotoxicological effects, and depletion of natural resources can be expressed numerically, but it is not possible to compare these categories with each other. To compare the impact categories with each other, weighted assessments are made. The purpose of weighted evaluation is to sort, weight, and group different life cycle impact categories in order of importance [12].

The weighting analysis of the categories under this study is given in the Table 1. All categories in weighting analysis shown in Pt unit which 1 Pt is a millionth of a normal European human impact on the environment in a year. From the table 1. the most important impact caused by highways is natural resources. Then comes the ecosystem quality and human health respectively. The sub-headings of these three main impact categories are also compared with each other by weighting method. Fig 3. Represents the tree analysis for the fossil fuels which has the highest impacts on environment, in this analysis the subprocesses are illustrated, the crude oil production shows a significant pollution which is used in asphalt mixture as a raw material, the quantitative amount of the relatively high processes is given in the table 2.

The second spot in terms of pollution resource is the land use category which is shown in the Table 3. By it is sub processes. Respectively the respiratory inorganic category is given in the table 4.

4. Conclusion

As a result, according to the analyzes in this study, the highest amount of road life cycle in the three main categories is on natural resources consumption, ecosystem quality and human health. Sources are the most important impact factor in the category of impact fossil fuels, the highest impact in the category of ecosystem quality; In the sub-category of land use and the category of human health, the highest impact amount belongs to the sub-category of inhaled inorganic substances. Unlike previous studies, the categorization of the main domains within the scope of this study was examined in detail in terms of subtitles.

The highest impact in the road life cycle of subcategories is the extraction of crude oil to the subcategory of fossil fuels, natural gas and coal were detected in all processes in the road life cycle, thus the operation of each oil is taken up to 42.6 MJ per 1 kg of crude oil.

There are three main reasons for this effect; the first one is the bitumen used in road construction, that is to say, the production of bitumen is directly related to the extraction of oil, and oil extraction means high energy expenditure in road construction. The second reason is that the machines used in the road construction use diesel and the other means that more fuel is needed. The third reason is the preparation of the bitumen material, as we know, the bitumen is produced in petroleum refineries, and the energy used by this production is again accounted for in the system we describe, meaning that the energy used in petroleum refineries is included in the road life cycle. As a result, we know that it will suggest different options to reduce these effects; The first recommendation is to use the substance with less effect than bitumen. Bitumen is used as a material adhesive on highways and it is an alternative if it can do this operation. The second recommendation is the use of renewable energy for fossil fuels instead of fossil fuels. The third option is the design and operation of petroleum refineries as more environmentally friendly.

The second damaged sub-category obtained in the results of the analysis is land use. Destruction of land in road construction was inevitable in road construction because the existence of the road consists of destruction of the land. Bitumen, aggregate, iron, coal and other materials obtained in the extraction of minerals from the ground in the extraction of soil, stone and other matter leaving the ground in another area of the soil and the quality of the soil and disrupts the ecosystem. And finally, the storage and disposal of all kinds of waste in the life cycle of roads means occupying a place. These damages are not only for the soil, but maybe on all kinds of rivers or on wetlands, road construction, construction of tunnels and pouring of land wastes consisting of excavations into the land cause destruction or occupation of the land. These were all considered as land use categories in life cycle analysis.

The third damage effect is the emission of inhaled inorganic substances according to the analyzes, the substances occurring in the inhaled inorganic effect category are Nitrogen oxides, Tiny Particles and Sulfur oxides. The source of this pollution; The other source of these gases occurs in factories producing energy and electricity. By replacing renewable energy in vehicles using diesel instead of fossil fuels, the use of methods to filter gas emissions of plants or to use gases to reduce gases can reduce these effects. complicates the examination of environmental impacts. Of course, it is not possible to address these alternative processes and related combinations in this study. Therefore, in this thesis; In the analyzes, the process and / or process was examined in the most damaging hammer of each effect. The fuels burned by the equipment and machines used in the construction of the road do not cause solely the inorganic inorganic effect. This process has been determined in the analysis of the climate change effect. Some of the emissions caused by these processes are the most important gases of the climate change category, such as carbon dioxide, methane, diazo tic oxide and carbon monoxide.

Other effect of fuel refinement of machines used in road construction. Acidification / eutrophication effect was determined. This effect is caused by the formation of nitrogen oxides and sulfur oxides. Cement production and transportation also show this effect. To reduce the effect of acidification / eutrophication, the procedures proposed in this thesis are the most important ones for the use of renewable energies instead of fossil fuels. Change of road construction method and materials is a suitable alternative if it causes less damage.

Ecotoxicity effects of zinc and nickel gases. Operations that have an ecotoxicity effect are composed of factories, iron, sinter or energy producing factories. Steel conversion process is the most important reason of this effect category. Besides, the sinter process takes second place. Works that can be done to reduce ecotoxicity should generally be on the factories or completely change the material used. This leads to the reduction of these effects by applying hazardous gas capture and filament system in factories.

In the inhaled organic subcategory, the most road infrastructure is damaged. After this process, crude oil production and the effect of both the organic sub-category and the ozone layer were determined. In this process, emissions from mine are composed of tiny particles, methane types, ethylene, radon and carbon 14.

But when it comes to wastes, it was determined that the stored coal wastes exhibit the effect of carcinogens.

As a final word, it is possible to add a lot of processes in the highway life cycle and each process is a completely different matter than the other process. For example, crude oil production and transportation are completely different. Nevertheless, to reduce environmental impacts in the road life cycle, it is necessary to work on most processes and not only environmental experts or civil engineers, but also microbiologists, petroleum experts, transport engineers, chemical engineers, material engineers etc. need contribution. However, in this short study, the most important and effective works, emissions and quantities were given.

Figures and tables

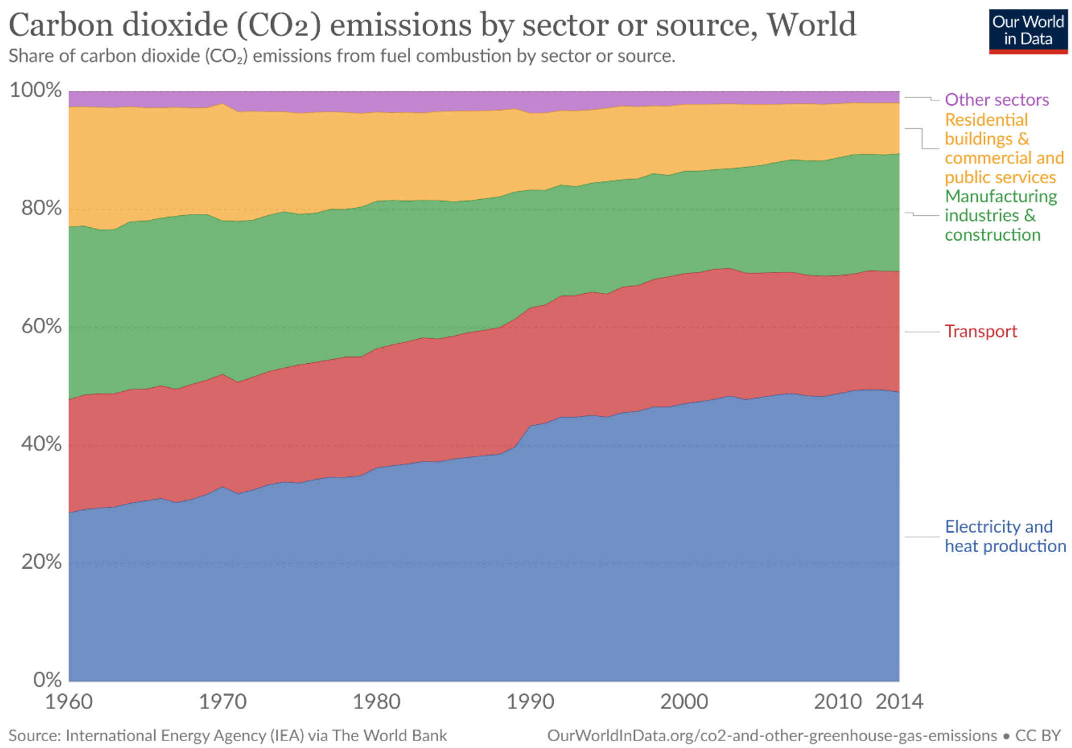
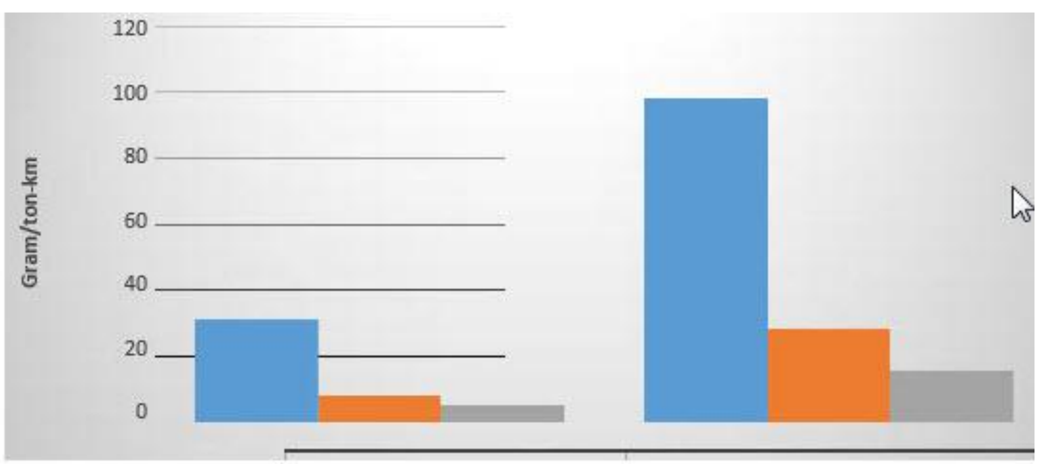


Fig. 1. Global CO2 emission distribution according to sources.



	fuel	CO_2 Emison
roadways	31,33	98,3
railways	8,311	28,33
waterways	4,82	15,45

Fig 2. Average fuel consumption and CO2 emissions of transportation subsystems (Gram / ton-km).

Source: International Energy Association. IEA and IPCC (2014) Summary for Policymakers.

Table 1
Weighting analysis of the categories.

Category	Sub Category	Unit (µ Pt)	Unit (µ Pt)
Human Health	Respiratory inorganic	263.547	357.882
	Carcinogens	18.397	
	Respiratory organic	3.163	
Ecosystem	Climate change	68.921	590.652
	Acidification /eutrophication	29.36	
	Eco toxicity	27.514	
	Radiation	3.309	
	Ozone layer	0.545	
Resources	Fossil fuels	632.159	635.028
	Land uses	533.778	
	Minerals	2.869	

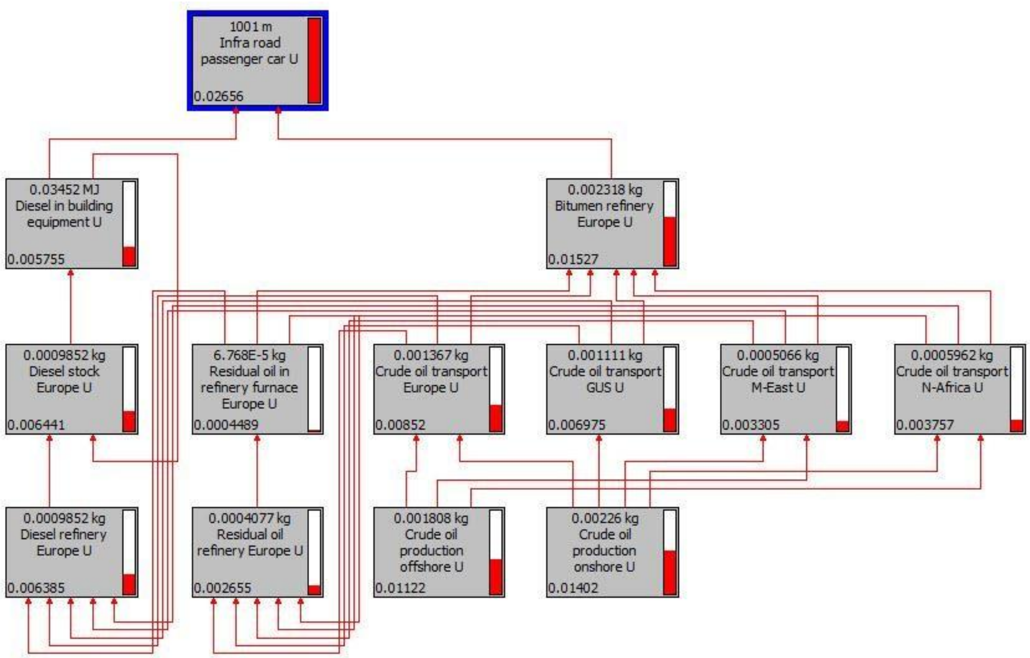


Fig 3. Tree analysis for the fossil fuels stream.

Table 2
Fossil fuel sub processes weighting analysis.

No	**Total processes**	**Unite**	632.2
	Remaining processes	µ Pt	1.906
1	Crude oil production onshore	µ Pt	329.8
2	Crude oil production offshore	µ Pt	263.8
3	Raw natural gas NL U	µ Pt	11.56
4	Coal from underground mine UCPTE U	µ Pt	9.078
5	Raw natural gas GUS U	µ Pt	7.059
6	Raw natural gas D U	µ Pt	2.915
7	Raw natural gas Alg. U	µ Pt	2.673
8	Raw natural gas N U	µ Pt	2.192
9	Coal from open mine U	µ Pt	1.187

Table 3
Land use sub processes weighting analysis.

No	Total processes	Unite	533.8
	Remaining processes	µ Pt	2.422
1	Infrastructure road passenger car U	µ Pt	491.5
2	Gravel ETH U	µ Pt	23.68
3	Uranium natural in concentrate U	µ Pt	11.46
4	Infrastructure road delivery van U	µ Pt	2.66
5	Waste inert to landfill U	µ Pt	1.478
6	Infrastructure transport long distance U	µ Pt	0.6092

Table 4
Respiratory inorganics sub processes weighting analysis.

No	Total processes	Unite	263.5
	Remaining processes	µ Pt	3.908
1	Diesel in building equipment U	µ Pt	134.1
2	Lignite power plant in D U	µ Pt	11.58
3	Cement ETH U	µ Pt	10.61
4	Electricity oil I U	µ Pt	8.245
5	Diesel in diesel generator onshore U	µ Pt	7.845
6	Truck 40t ETH U	µ Pt	7.415
7	Residual oil in refinery furnace Europe U	µ Pt	7.196
8	Freighter oceanic ETH U	µ Pt	6.614
9	Coal power plant in E U	µ Pt	5.388
10	Tanker oceanic ETH U	µ Pt	5.293
11	Petroleum gas flaring U	µ Pt	4.691
12	Lignite power plant in Gr U	µ Pt	4.382
13	Residual oil Europe in boiler 1MW U	µ Pt	3.924
14	Lignite power plant in E U	µ Pt	3.593
15	Excavation skid steer loader U	µ Pt	3.525
16	Diesel in diesel generator offshore U	µ Pt	3.426
17	Coal power plant in D U	µ Pt	3.01
18	Passenger car W-Europe ETH U	µ Pt	2.429
19	Coal power plant in F U	µ Pt	1.924
20	Refinery gas furnace Europe U	µ Pt	1.876

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