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ECOLOGICAL FOOTPRINT COMPARISON OF DIFFERENT MEANS OF TRANSPORTATION BASED ON SUSTAINABLE PROCESS INDEX (SPI) METHODOLOGY

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Abstract. *Mobility plays an important role concerning environmental effects and climate change issues. Public transport needs to be extended and especially energy provision networks behind each transportation system. Several new transportation systems are available like electric, E85, hybrid and biogas cars and buses. Ecological footprints are calculated to compare several new and conventional means of transportation based on person kilometer. Ecological footprint measurement through Sustainable Process Index (SPI) methodology gives the possibility to compare and measure different means of transportation based on the same method. SPI allows the quantification of environmental impacts for goods and services based on the inventory data of a Life Cycle Assessment (LCA). Ecological hotpots can be easily identified because the whole production chain is considered. Environmental impact is mainly influenced by the type of fuel and not the engine itself. Also construction and maintenance of road infrastructure has a high impact. For electricity based technologies there is also a major difference where in Europe it is operated because every country has a different electricity mix. Electric mobility without a "green" electricity production would not improve the sustainability of transportation. Purified biogas is also an interesting alternative to fossil fuels but agriculture plays the key role in that case. Mineral fertilizer and fossil driven machinery in agriculture have to be reduced to improve the ecological benefits for biogas transportation. The difference compared to conventional transportation with petrol or diesel is the amount of new technologies which rely on different biofuels. Decision makers need an overview of all available options. Ecological footprint measurement is one possibility to easy compare all of them based on one single unit.*

1 INTRODUCTION

Mobility and climate change issues are strongly connected. One major pollution emitter of greenhouse gases beside industry and residential buildings is mobility. Different means of transportation are compared based on one indicator. Ecological footprint calculation based upon Sustainable Process Index methodology describes such an indicator which allows comparing different kinds of goods and services. Results from detailed Life Cycle Assessment datasets are used to calculate footprints for many different transportation systems. This offers the possibility to compare them on the same level. Especially public and private transportation means are compared to each other. Because of the importance which country is considered for operation there is a special chapter about the difference in footprints between different countries.

2 SUSTAINABLE PROCESS INDEX (SPI)

Sustainable Process Index (SPI) methodology [1] describes an LCIA (Life Cycle Impact Assessment) method which can be used for interpretation of LCA (Life Cycle Assessment) results. SPI is part of the ecological footprint family and uses square meters of land as ecological indicator. There are seven different categories of partial areas which are uses within SPI:

- Area for area
- Area for renewable resources
- Area for non-renewable resources
- Area for fossil carbon
- Area for emissions to water
- Area for emissions to air
- Area for emissions to soil

The final SPI value is a result of summarizing seven sub categories. A higher SPI stands for a higher environmental impact. All material and energy flows over the whole production chain are taken into account for a specific process. Also emissions into the three compartments air, water and soil are included. This inventory data is converted into the seven categories of footprint areas for each step in a process chain. A final product (e.g. kilometer of transportation) is based on several sub processes (e.g. fuel production). Based on these sub processes a process chain can be built which is the base for SPI calculation. Ecological hotspots can be identified easily which give much information about optimization potentials. Additionally CO_2 life cycle emissions can be calculated out of the sub category “Area for fossil carbon”. These CO_2 life cycle emissions are not only the local emissions, it includes also emissions from the production chain before.

3 COMPARISON OF DIFFERENT MEANS OF TRANSPORTATION

For footprint calculation the software tool SPIonExcel was used [2]. Raw data for materials, energy consumption and emissions are from the ecoinvent database [3]. This raw data was used as basic information for calculating the footprint in SPIonExcel. The inventory includes mainly operation of transport systems which is fuel consumption and emissions because of combustion. Infrastructure data for vehicles (e.g. production of cars), roads and tracks (e.g. tram track) are also part of the footprint. Disposal is not included because in the final result the footprint of the disposal part is negligible.

Figure 1 illustrates footprint values in m² per person kilometer by each transportation system. The definition of person kilometer is about transporting one person a distance of one kilometer and has the unit *pkm*.

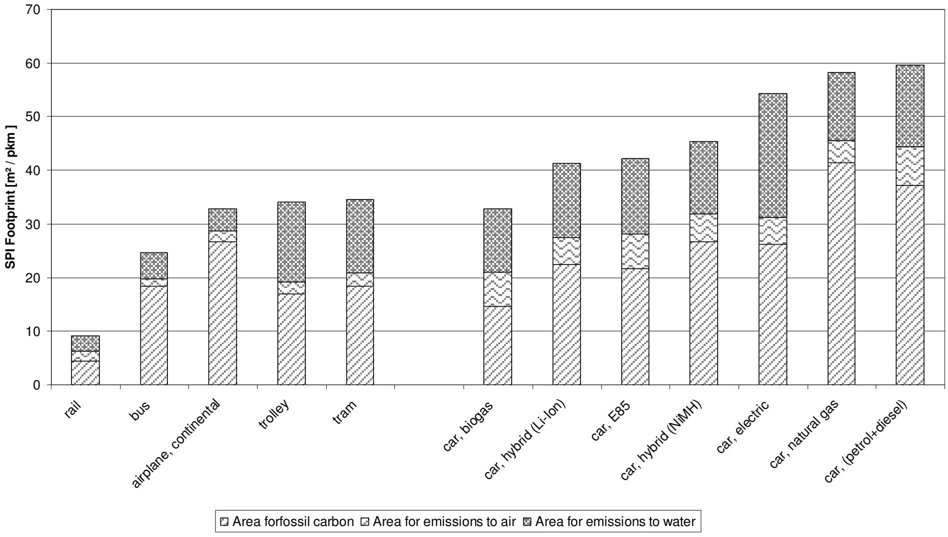

Figure 1: Comparison of different transportation systems based on person kilometers in Austria

Each bar is a result of the summarized value of the seven categories. Only three main categories (Area for fossil carbon, emissions to water and air) are shown because theses are the main impact categories in that case and the others are negligible. The gap in the figure divides public and individual transportation systems. The results are related to Austrian conditions because for electricity driven vehicles (e.g. tram) the Austrian electricity mix was used for calculation. Fossil carbon sub category is in every case the main part of the footprint. Emissions to air are very low for public transport and high for individual transportation because the emissions (mainly nitrogen oxides) per *pkm* for a car are much higher compared to a bus. An emission to water mainly derives from utilization of electricity for maintenance and operation of roads (e.g. street lightning).

An average passenger car driven by fossil petrol or diesel has the highest impact. The share between petrol and diesel is 45 % to 55 % [4] which is typical for Austria. Alternative passenger cars like electric car, E85, hybrid cars, natural gas car are not that better compared to the conventional car. Electric cars are worse than hybrid cars and E85 cars because electricity production has still a high footprint even in Austria where a huge amount of hydro based electricity is generated. E85 cars (85 % ethanol from rye and 15 % petrol) are better than electric cars but this is highly dependent on the agriculture inputs during the production of rye. Biogas car is the only individual transportation system which is better than the worst public transport option. But the biogas car result can be seen as lower limit because no fertilizers are used during production of corn silage (only biogas manure as fertilizer).

Figure 2 gives an overview how the footprint is shared between different sub processes.

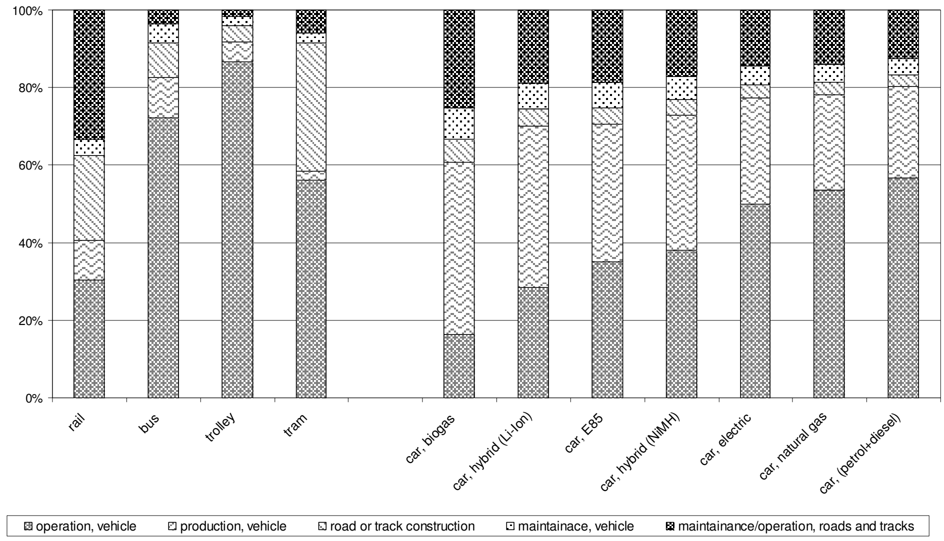

Figure 2: Share between different sectors of consideration

There is a clear difference between public and individual transportation in terms of how the footprint is devided to different sectors of considerations. Operation of vehicle part decreases for individual transportation which shows up that also the road construction has a huge impact. Vehicle Operation for public means of transportation usually the main impact factor. The exception of the rail is in that case very country specific. Due to the fact of a hydro only powered rail grid in Austria the operation takes only a small part of the whole footprint. This raises the part for building and maintaining the tracks. A huge difference between individual and public vehicles is the footprint for the production. For cars the impact for car manufacturing per *pkm* is very high because the average amount of persons per kilometer and car is around 1.6. In contrast a high amount of transported people for public transportation which lowers the vehicle production part. This fact tells that there is a long ecological amortization time for a produced passenger car compared to a public transportation vehicle. Except for tram, bus and trolley road or track construction and maintenance has a big part of the footprint which must not be neglected.

4 CONTEXUALIZATION

As already mentioned before the ecological impact is also dependent where these transportation means are operated. For the production of the vehicles electricity consumption was calculated with EU-27 electricity mix but for maintenance of vehicles, roads/tracks and operation the local electricity mix (Austrian) was used. Due to the fact that every country has a different setup of energy production the footprint per *kWh* of electricity provision differs. To calculate SPI values for different countries production data from the IEA [5] was used. According to Figure 3 the Austrian SPI value of 204 *m²/kWh* is quite low compared to the EU-27 value of 510 *m²/kWh*. Reason for that is the fact that Austria has no nuclear power plants but many hydro power plants. But there are countries in Europe which are even better to get an idea about the possible bandwidth in terms of footprints for electricity generation.

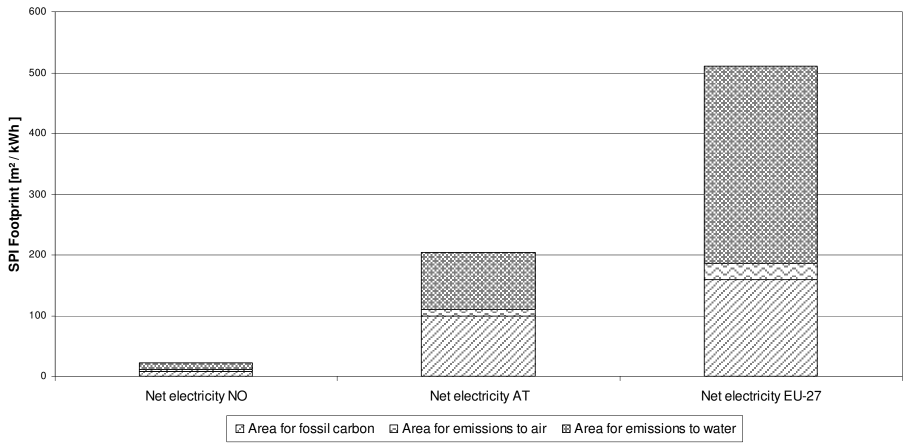

Figure 3: Comparison of different energy mixes per kWh of electricity

For example Norway has an energy production mainly out of hydro power which results in a SPI value of 22 *m²/kWh*. Although it is not possible to use hydro power in every country in that amount, there are some alternatives for a renewable based production which is mainly dependent of the availability of resources. Figure 4 compares several transportation systems with the electricity mixes discussed in Figure 3.

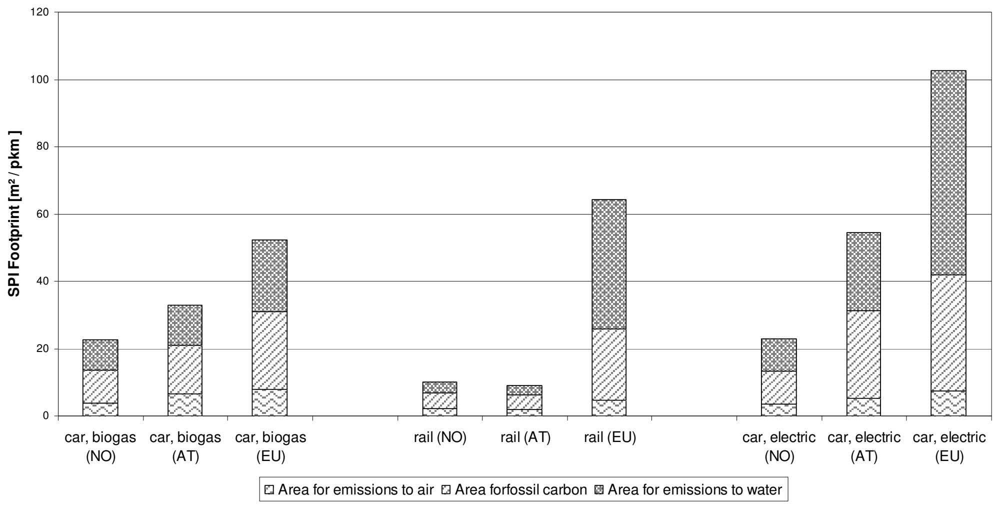

Figure 4: Several means of transportation dependent on the local electricity mix

For biogas driven cars the footprint is not only mainly dependent from the fuel type like in fossil driven cars. It is important to look how the fuel is made. In that case biogas was made from corn and grass silage with no utilization of mineral fertilizers. Instead of mineral fertilizers biogas manure is used for substitution. The difference in footprint occurs during purification from biogas containing around 60 % CH_4 to 96 %, which is equal in quality to natural gas. For rail transportation Norway and Austria are comparable because of the hydro power only electricity consumption in Austria. Therefore this huge difference to trains operated with EU-27 mix which has a high amount of nuclear energy included. The importance of a sustainable electricity production for electric cars is obvious. Especially before countries start to subsidize electric car transportation for consumers.

5 CONCLUSIONS

Results show an advantage for public transport from the ecological point of view. Because of the main part of the footprint for operation of public transportation systems it makes sense to invest in renewable driven buses (e.g. biogas) to lower the environmental impact. In general it should be a goal for every country to follow a renewable based energy strategy to develop a "greener" electricity production. A lower footprint for the grid would also affect many other applications which results in an according decrease of the footprint for these applications. This applies not only for transportation but also industry and residential. The results show also very clear that a massive change to electric cars is contra productive until the electricity provision itself has not changed. Another point is that every country needs different solutions in terms of changing the mobility. It is highly dependent of available resources in which direction a country can go. Since fossil resources are getting more expensive and difficult to get (peak oil), industry and community has to develop itself to a multi resource based energy provision. Our society is used to utilize one source for nearly everything which is not applicable anymore due to the fact that we are reaching the end of the fossil era.

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