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SUSTAINABILITY IMPACT ASSESSMENT IN THE FORESTRY-WOOD-CHAIN -IMPACT OF ROAD TRANSPORT COMPARED TO RAIL TRANSPORT OF WOOD IN BADEN-WÜRTTEMBERG

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Abstract: *Only if forests are managed sustainably they yield great chances in a regional perspective as well as in a global context for the future. The forest-based sector has been at the forefront during the last decades in bringing forward the sustainability concept and developing principles, criteria and indicators for sustainable forest management (SFM) which could help to promote a development that supports all pillars of sustainability.*
Consequently, assessing sustainability in the forest-based sector means measuring environmental, economic and social indicators for production technologies along the Forestry Wood Chain (FWC).
Therefore, a decision support tool called ToSIA (Tool for Sustainability Impact Assessment) was developed in the EU-project EFORWOOD, which was launched in the 6th EU framework programme. ToSIA assesses sustainability of existing FWCs as well as impact on sustainability of internal and/or external drivers such as changes in global economy and policy or technological innovations by aggregation of indicator values along the FWCs which consist of value-adding production processes. By analysing the FWC with the help of sustainability indicators, the integrated tool highlights the advantages and disadvantages of different actions, as well as synergies and trade-offs by modelling.

In the presentation first the theoretic framework of the project will be explained. In order to present concrete SIAs of Forestry Wood Chains from harvesting- and hauling operations including different transport modes a case study of Baden-Württemberg will be presented.

1. Introduction

The EU has set ambitious goals to promote sustainable development and innovation in environmental technologies and expects the forestry-wood sector therefore, like all other sectors, to contribute to the aims set in the Lisbon Strategy and in the Sustainable Development Strategy (Bürzle, 2009; Fundel, 2009). It was the Brundtland report in 1987 (WCED, 1987/1991) which brought forward the idea of sustainability. Since then, sustainable development has emerged as a key element at latest since the Earth Summit in Rio de Janeiro in 1992, where both forests and forestry have been added to the international agenda, because of concerns about the sustainability of forests regarding biodiversity and economic and social contribution to development of local communities.
Several methods have been developed to study environmental impacts of actions (Ness et al., 2006; Lindner et al., 2009), but none of the existing tools addressed yet all three sustainability dimensions in a balanced way. The EU-project "EFORWOOD", funded under the EU "Global change and ecosystems" research activity of the Sixth Framework Programme aimed to provide methodologies and a tool which allows integrating Sustainability Impact Assessment (SIA) of the whole Forestry Wood Chain (FWC) by

using indicators for all three pillars of sustainability. The Tool for Sustainability Impact Assessment (ToSIA) allows various end-users such as companies, national and international policymakers, as well as researchers to analyze the effects of changes, due to deliberate actions (e.g. in policies or business activities) or due to external forces (climate change, global markets).

The objective of this study is to compare alternative transport systems towards their sustainability. The first analyzed FWC (1) reflect the most common systems of forest management, harvest, hauling and transport of timber to the arrival at the processing industry in the German federal state Baden-Württemberg in the reference year 2005. 70% of the timber is transported truck (gross vehicle mass 40t; 25t payload), 29% via rail and 1% via inland waterways. The second FWC (2) is a scenario in which transportation is undertaken with a total gross weight of 60t per truck (40t payload), which is not allowed due to legal restrictions in Germany. To make the results comparable, all undertaken modes, assumptions, backhaulages, volumes and processes are the same than in the reference (1) except the increased total gross weight of the truck. In a third calculation (3), the modal split of the timber transport is changed in a way, that 70% of all timber is transported via rail, 29% via 40t truck and 1% via inland waterways. Additionally to the transport at rail, an increased road transport via truck is assumed which is caused by pre- and post transport phases (Borcherding, 2007).

At the moment efforts are made either to shift more timber from road to rail to or to allow an increased total gross weight of the trucks (e.g. actual discussions in the German “Bundesverband Säge- und Holzindustrie Deutschland”, www.bshd.eu) with the aim to disencumber traffic and contribute to the environment at the same time. The results of the study can give an impression of what the social, economical and environmental impacts of alternative scenario could be, Furthermore, it could help support policy makers in their decision while seeing how big effects of possible actions could be.

2. Method

In the decision support tool ToSIA the impact of each process of a specific FWC is determined by aggregation of indicator values along the chain. The complete FWC consists of a large amount of different processes, starting from forest regeneration, tending and harvesting, followed by transporting of the wood for converting and manufacturing in the forest industry and its down-stream industries, ending with the consumption and recovery of a broad range of products containing wood- or fibre-based materials. Firstly, these processes have to be modeled. In this study, only transport processes in the partial chain approach from forest to industry are presented because the main focus is lying on comparisons of different FWCs from Baden-Württemberg representing different transport modes.

Figure 1 as an example shows partial FWCs from forests to millgate in Baden-Württemberg. As more than 50 processes belong to this part of the FWC, the figure only shows two typical supply chains of beech and of spruce timber: the harvesting and hauling processes represent logging operations common in Baden-Württemberg. In the study, the volume flows of all processes were taken into account. The sum of the volume flows in the system for the partial chain from forest to mill is equal to 9.992.532 tonnes of carbon and thereof, transport processes cover 27.9%. Considering the material of the whole FWC from forest to consumer interaction the volume is equal to 100.901.762 tonnes of carbon. Due to time limitation, in the presentation only results of alternative transport processes of road and rail transport are presented.

When it comes to the transport of the timber from roadside to the mill, three alternatives are analyzed:

1. The actual status quo which is presented by transport processes with the following modal split: 70% with a 40t truck, rail 29% (and inland waterway 1%).
2. A scenario upon the status quo with the following modal split: 70% with a 60t truck, rail 29% (and inland waterway 1%).
3. A possible future scenario with the following modal split: 29% with a 40t truck, rail 70% and (inland waterway 1%).

All processes along the chain are linked by the volume flows and characterized in terms of criteria and indicators of sustainability. In wood production and processing in most cases the physical result of processes split up in main products (target products) and by-products. To quantify the volume flow along the whole chain, the quantities of these different products of a specific process must be adequately reflected, taking into account realistic conversion factors. In this concept all indicators are linked at the level of each process to quantified reference units (for instance hectare, cubic meter of timber, tonnes of carbon). The modelling of chains and assigning of indicators was made for the base year 2005 and as common reference unit m³ under bark was selected. Furthermore, conversion factors to other units as e.g. to tonnes or tonnes of carbon were provided to compare different partial chains. In order to perform the data collection and data calculation respectively, not only the volume flow information but also the indicators have to be identified first.

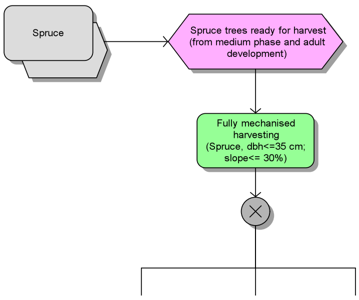


Figure 1: Typical supply chains of beech and spruce timber in Baden-Württemberg

To ensure the acceptance of the stakeholders involved the set of sustainability indicators in the project EFORWOOD was chosen on the base of already established indicator sets. Within the project, a detailed review of existing sustainability indicator concepts and sets of relevance for the FWC, review of potential indicators for selection and their assessment was undertaken. In this paper, only five selected key-indicators are presented as an example (see chapter 3.4). The data collection for each process and for the indicator values was done according to the following approaches: i) specific and empirical, which means data was collected from organizations or "follow–up" routines; ii) generic or derived, which means that data was extracted from National or European statistics; iii) model based data and iv) expert estimated data. A manual supported the researchers in the collection and calculation of economic, environmental and social indicator values for the processes along the chain. Possible impacts of general drivers on forest operations were determined and quantified and the results were integrated into a calculation model to ensure the comparability of the results.
The indicator values of the transport processes are calculated with the aid of a specific calculation programme, called "transport tool" which was developed in the framework of the project. Existing transport methods and alternative methods or new approaches with data about costs, labour input and energy consumption were identified and the assessment of the different logistic concepts and their sustainability impact was analysed. Further information and undertaken assumptions are described in chapter 3.3 as well as in Chesneau and Le Net (2010). Pre- and post transport phases were calculated

according to Opferkuch (2007) who came to the conclusion that 25km of road transport via truck for pre- and post phases are realistic.

3. Material

3.1 Baden-Württemberg case study

In order to provide ToSIA with data about forest and logging operations in Europe, a set of case studies was created and supplied with data. The presented Baden-Württemberg case study is focused on a region and aims to describe the complete network of relevant FWCs in Baden-Württemberg (BW). BW as geographical region within Europe covers a high degree of diversification and specialisation of forest and wood industry. The industrial base is characterised both by highly advanced technology industries of international importance and on the other hand strongly influenced by the locally important rural based agricultural and forestry sector. The wood-based industry present in BW also is characterised by the contrast between private-owned small and medium sized companies producing for the local and regional market on one hand and large consortia operating internationally on the other (Eforwood, 2010). This is important for the transport operations in urban areas. There, the network of highways is mostly wide-meshed so that timber is not transported at highways (approximately 20% according to Smaltschinski).

3.2 Volume flow, assortments and processes

The total area of BW comprises 3.6 mio ha, out of which approximately 1.4 mio ha (38.1% of the total area) are forested, mainly in even-aged mixed stands. In the base year 2005 the main tree species were *Picea abies* with approximately 39% of all tree species and European beech *Fagus sylvatica* with approximately 21%. The analysis of the sustainability impact was based on the forest resource as assessed in the National Forest Inventories in 1987 and 2002 (National forest inventory for Germany, 2010). According to 2005 harvesting statistics, total harvested volume was 9.1 mio m^3 roundwood under bark (softwood 7.1 mio m^3ub, hardwood 2.0 mio m^3ub). The harvested wood is provided as long logs ("long poles" acc. to DIN EN 844-2) and short logs for sawmilling, short logs for board production, mechanical pulping, chemical pulping, and wood for bio-energy production. There is a material import and export into and out of BW for roundwood, semi-finished products and end-products, whereby in the partial chain from forest to mill only roundwood is important. Imports and exports from the other federal states in Germany can not be quantified. To overcome this problem, volumes of material in exports and imports in each category are handled as net-balance. The volume of material is derived from known volumes produced in BW and known volumes processed/ consumed in BW. In the framework of the project it can not be quantified from which city/ country imported roundwood is coming from or where exported roundwood is delivered to. For this reason no longer distances, can be assumed. This has to be taken into account when discussing the results as especially rail transport is usually foreseen for longer distances >250km. Altogether 60-80% of the annual production of the BW-forests is covered. The sum of the volume flow through the system from forest to consumer interaction is equal to 100.901.762 tonnes of carbon. The flow from forest to industry has a volume equal to 9.992.532 tonnes of carbon.

In BW there are over 20 different harvesting and forwarding systems in use (Sauter et al., 2009; Forbrig, 2004). They can generally be classified into the three categories: motor-manual, partly mechanised and fully mechanised, and are applicable either to softwood, to hardwood or to both species groups. The decision on the harvesting system depends in general either on the diameter of the trees or on the terrain. Most of the wood is harvested by thinning operations (~90%), also finals cuts are selective in most cases. Machines are only operating on skid-roads at distances between 20 to 40 meters, depending on the soil conditions. There are three main transport modes (and combinations thereof, named "combined transport") in operation for forestry and wood industry: road transport by truck, rail transport by train and water transport by ship (in BW inland waterway). Cost effectiveness for those modes depends on the volume and largely on the distance (Hedden, 2009; Borcherding, 2007).

3.3 Undertaken assumptions

For the examples given in this paper, the following assortments based on roundwood are transported: spruce and beech long-logs, short logs, pulpwood, fire wood logs, LDT (timber of large dimension), wood chips from forests and plantations, kraft pulp. Due to legal restrictions in Germany a total gross weight of 40t per truck was chosen for the calculation of the "transport with truck" mode with a loading capacity of 25t (20t for long logs and LDT). In chain two values were calculated with an increased total gross weight of 60t per truck (payload 40t).
For transport via road, urban driving as well as highway driving was considered (75%, 25%). The emission standard of the vehicle is an important criterion for the emissions of the vehicle. In European transport, different standards are in use in 2005: EURO 1, EURO 2, EURO 3 as well as EURO 4. For the calculation of carbon monoxide, nitrogen oxides, sulphur dioxide and carbon dioxide, an average emission (year 2008) out of the LIPASTO database was taken for a semi trailer combination. The following distances from the forest to the mill were assumed: long logs and LDT: 65km (expert guess from Thomas Smaltschinski), firewood 40km (no other mode than road transport), pulpwood/ short logs 100km, imported kraft pulp 500km, imported short logs/ exported beech long logs 200km, chips 25km.
The distances increase when including pre- and post transport phases (chain 3). According to Opferkuch (2007) the distances increase plus 8% due to the network of roads as there is a limited number of cargo stations. Furthermore, an additional transport of the timber from the forest to the cargo station which is about 25km is included. Borcherding (2007) mentions that every log has to be transported at least once with a truck, e.g. to get to a cargo station or a harbour. He comes to the conclusion that (in 2003 in all over Germany) the transport via truck is 99.4% although 11% of the timber is transported at rail and 1% via water.
The backhaulage in chains one and two is 42% for long logs and LDT, for all other assortments 48%. Transport of beech and spruce fire wood logs as well as transport of chips was assumed to be transported via truck in short distances in all cases. There´s no backhaulage foreseen for roundwood which is transported to or from the cargo stations. This is also valid for the transport via rail. As the system boundaries of the case study are defined by the borders to other federal states, it was not possible to include a change to longer distances in rail transport (e.g. export or transport of LDT or long logs). Borcherding (2007) comes to the hypothesis that rail transport is mainly meaningful if it happens transnational.
Furthermore, it should be taken into account that mainly the long distances would be used for rail transport while shorter distances would still be undertaken by trucks, so that the overall logistic system would be optimized. The infrastructure and availability of cargo stations was assumed to be available in the demanded level, which is not the case in all areas of BW, as since some years cargo stations disappear in rural areas. The share of electricity use in rail is 74% (diesel use in rail 26%) and was considered as well as time, costs and emissions of shunting. All calculations were done for a medium sized train (1.200t).

3.4 Sustainability Indicators

In the BW case study, more than 160 indicators and subindicators were calculated for the whole FWC. It has to be considered that not all indicators are relevant in all stages of the chain (e.g. biodiversity in production processes). In order to get comprehensive and informative results, a limited number of five indicators were chosen for this analysis: *Production cost* (Average production cost and share of cost of woodbased materials) in € per m^3ub; *Employment* (Number of persons employed in total) in total per m^3ub; *Greenhouse gas emissions from machinery* in kg CO_2 equivalents per m^3ub; *Total distance by mode* (road, rail) in km and tkm and *Non-greenhouse gas emissions into air* in kg/m^3ub.

4. Results

The objective of the study is to provide a comparison of three alternative transport systems (chain 1,2,3).
The scenarios are described in table 1.

Table 1: Analysed transport systems in Baden-Württemberg

Transport mode	chain 1	chain 2	chain 3
Share of road transport, weight	70%	70%	29%
Share of rail transport	29%	29%	70%
Share of water (inland) transport	1%	1%	1%
Gross vehicle mass	40t	60t	40t

Table 2 shows the distances (total km and tonne kilometer (tkm)) of road and rail transport of the alternative chains. Beech and spruce fire wood logs as well as chips were assumed to be transported only via truck. The transport distance via inland waterway is in all scenarios the same (12.455.189 km) and therefore not considered in the further analysis and discussion.

The distance (total km) shows the highest value in chain one (33.680.128 km) and decreases to 19.639.575 km in chain two due to the use of another type of vehicle (gross vehicle mass 60t).

Chain three shows the highest value in the sum of tkm (1.065.927.214 tkm). There is an increase of distance in rail from 84.865 km in chain one and two to 474.027 km in chain three as 70% of the volume is transported via rail. Only 30% of the volume is assumed to be transported via road in chain three, so consequently the distance (total km) at road shows the lowest value: 6.191.051km (143.866.452 tkm). There, another 17.456.795 km (391.150.674 tkm) have to be added which are caused by the pre- and post transport. Together, the overall distance (total km) at road is 23.647.846 km (535.017.127tkm).

Table 2: Aggregated indicator results of the indicators "distances by mode" in total km and tkm

Transport mode	chain 1	chain 2	chain 3
Distance total km road	33.595.263	19.554.709	23.647.846
Distance total km rail	84.865	84.865	474.027
Sum total km	**33.680.128**	**19.639.575**	**24.121.873**
Ton km road	782.188.379	782.188.379	535.017.127
Ton km rail	95.049.069	95.049.069	530.910.087
Sum tkm	**877.237.448**	**877.237.448**	**1.065.927.214**

Table 3 shows the values for the emissions per tkm or km which were used to calculate the total emissions of the alternative transport processes.
The data are taken out of the LIPASTO -emission calculation system.

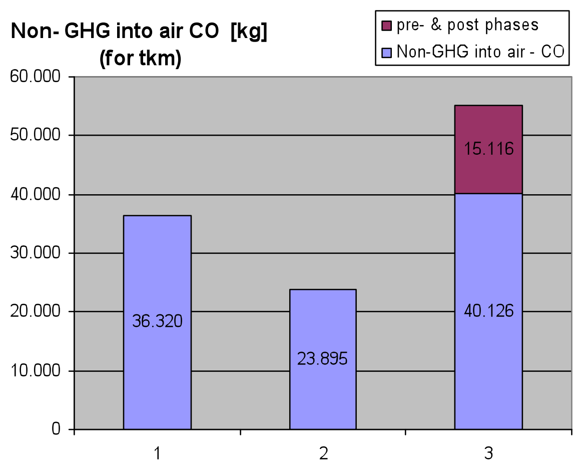
Table 3: Input data for calculation of emission in transport processes

	Unit	chain 1, chain 3 (40t)	chain 2 (60t)
SO_2 truck urban (loaded)	Kg/tkm	4,6784000E-07	3,8468400E-07
SO_2 truck urban (unloaded)	Kg/km	7,9603300E-06	8,6841300E-06
SO_2 truck highway (loaded)	Kg/tkm	2,7961000E-07	2,1200800E-07
SO_2 truck highway (unloaded)	Kg/km	5,1418500E-06	5,5876500E-06
SO_2 train (diesel)	Kg/tkm	1,7000000E-07	1,7000000E-07
SO_2 train (electric)	Kg/tkm	1,4865700E-05	1,4870000E-05
NOx truck urban (loaded)	Kg/tkm	5,8876558E-04	5,1022079E-04
NOx truck urban (unloaded)	Kg/km	9,8435176E-03	1,1818983E-02
NOx truck highway (loaded)	Kg/tkm	3,5548323E-04	2,7504948E-04
NOx truck highway (unloaded)	Kg/km	6,7789010E-03	7,3403779E-03
NOx train (diesel)	Kg/tkm	9,9708632E-05	9,9708632E-05
NOx train (electric)	Kg/tkm	6,4000000E-04	6,4000000E-04
CO truck urban (loaded)	Kg/tkm	4,5634861E-05	2,7041300E-05
CO truck urban (unloaded)	Kg/km	1,2865788E-03	1,2264468E-03
CO truck highway (loaded)	Kg/tkm	8,8073325E-06	6,7112802E-06
CO truck highway (unloaded)	Kg/km	1,8658747E-04	1,9494969E-04

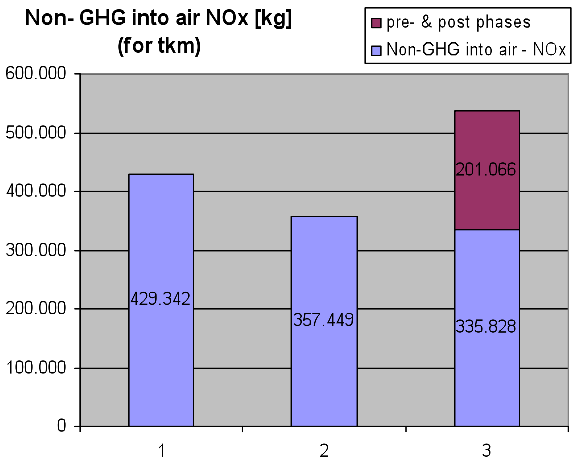
CO train (diesel)	Kg/tkm	1,9941726E-05	1,9941726E-05
CO train (electric)	Kg/tkm	8,1000000E-05	8,1000000E-05

Table 4 shows the results of the calculation of non-greenhouse gas emissions (CO, NOx, SO_2) and green house gas emissions (CO_2, CH_4, N_20, HFCs, PFCs, SF6, NF3, SF5CF3, halogenated ethers and other halocarbons) in kg, summed up for (total) tonne kilometers.
As shown, all non-greenhouse gas emissions and green house gas emissions (GHG) from machinery show the lowest values in chain two, in which it is assumed to transport 70% of the timer with a 60t truck (40t payload). Transporting timber with a 60t truck instead of a 40t truck saves more than 1/3 of all GHG from machinery (table 4d) compared to the actual situation which is reflected in chain one (65.573.810 kg CO_2 equivalents caused by 40t and 40.800.282 kg CO_2 equivalents caused by 60t truck). In chain two there are 71.893 kg less NOx (table 4b), 12.425 kg less CO (table 4a) and 70kg less SO_2 (table 4c) compared to chain one.
The values of the non-greenhouse gas emissions CO increase in chain three compared to chain one and decrease in chain two compared to chain one which leads to the conclusion that a shift to rail transport causes (in total) more non-greenhouse gas emissions CO than road transport (table 4a). It has to be taken into account that the distances for rail transport did not increase due to system boundaries of the case study.
The highest values of non-greenhouse gas emissions into air CO and NO_x can be observed both in chain three (36.320kg CO and 536.894 kg NOx). 27% (CO) and 37% (NOx) of the emission are caused by the pre- and post transport phases (15.116 kg CO and 201.066 kg NOx) (table 4a, 4b).
Using a 60t truck (chain two) instead of a transport system with 70% transport at rail reduces the emissions of CO, NOx and GHG significantly (31.347kg less CO; 179.445kg less NOx; 20.879.838 kg CO_2 equivalents).
The values of non-greenhouse gas emissions into air SO_2 are the highest in chain three (6.081 kg).Both alternative chains with 70% transport via road show relatively similar values (1.353. kg in chain 1 and 1.283 kg in chain 2). In chain three, less than 3% of all SO_2 emissions are caused by pre- and post transport phases. Due to these values, SO_2 seems to be caused more by rail transport than by truck. This result shows that SO_2 is highly influenced by the energy mix which is used for rail transport (table 4c). Opferkuch (2007) comes to similar results. Freight transportation mainly consumes diesel fuel from fossil energy sources consisting of 35% stone coal, 12% brown coal, 32% nuclear energy, 7% natural gasoline, 13% regenerative and 1% others (Opferkuch, 2007).

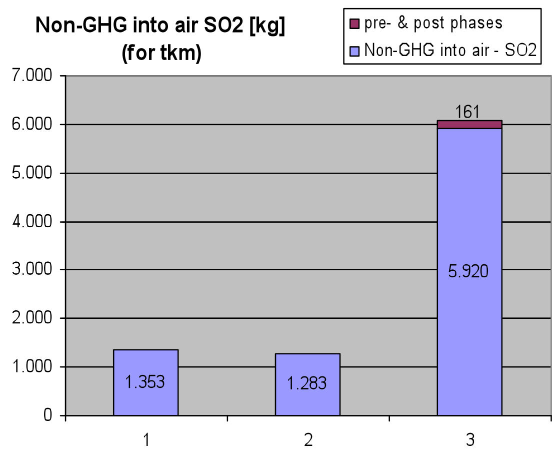
Table 4: Aggregated indicator results of the indicators "non greenhouse gas emissions SO_2, NOx, CO" and "greenhouse gas emissions from machinery" for alternative transport processes
a)



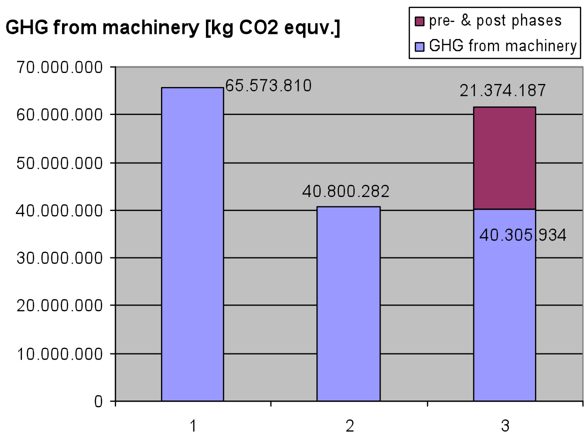
b)



c)



d)

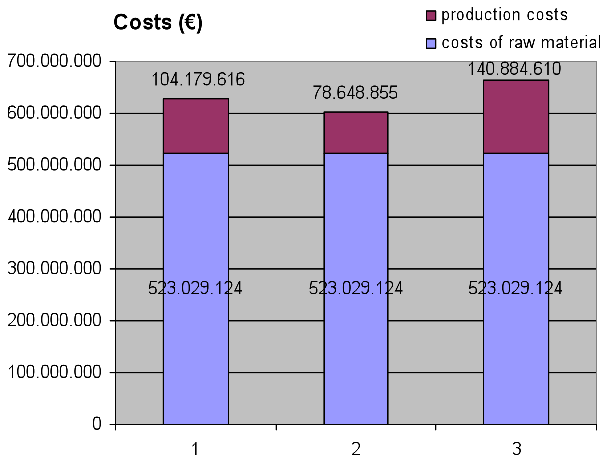


It can be seen in table 5 that in chain one and two there are in both cases less employees needed (408 in 1; 245 in 2) compared to chain three (438 in 3).

In table 6 the production costs of the different transport systems are presented. In all cases the costs for raw material from the forest wood chain are equal (523.029.124 €). Not regarding the costs for raw materials, in chain one the production costs are 104.179.616 €; in chain two costs are decreasing (78.648.855 €) and in chain three costs are increasing up to 140.884.609 €. The value is the highest in chain three which is caused by the pre- and post transport phases and the longer distances which are necessary to bring the timber to the cargo stations. The share of labour costs of the production costs is higher in chain 1 (23.8%) than in chain 2 (18.8%) and 20.1% in chain 3. Additional costs for the pre- and post transport are in average 5€/m³ and can be seen as main reason for the higher costs.

Table 5: Aggregated indicator results of the indicator "employment" (absolute number of persons in full-time equivalents)

Table 6: Aggregated indicator results of the indicator "production costs" which includes raw material costs from forest wood chain, labour costs, non productive costs, other costs and energy costs



5. Discussion

In the study, the concept of Sustainability Impact Assessment (SIA) was presented. An important step is the calculation of indicator values for a common set of sustainability indicators for every process step, related to the reference unit (in the study m³ under bark roundwood). Comparisons between two or more FWCs of different structures show the impacts of the related differences regarding economical, ecological and social indicators. In this study one forest wood chain which represents the current status quo of timber transport in Baden-Württemberg (2005) and two scenarios with either an increased share of rail

transport (and lower truck transport) or a higher payload of the truck were compared to each other. The results are only presented for the alternative transport processes, not for the overall forest wood chain.
Such comparisons are very important if technical improvements of processes are discussed or if political measures are evaluated as a basis for decision making. A holistic judgement of the "overall sustainability of the chain" is complex and therewith complicated.
The example of the non-greenhouse gas emissions and GHG of machinery show that there is a big impact if timber transport would be done with a total gross weight of 60t instead of 40t. Although the production costs (as well as fuel consumption of fossil fuel which was not presented) would decrease, at the same time it has to be considered that the total employment is decreasing, too, which may create social concerns.
Including pre- and post transport phases on the other hand would lead to an increase of employment, but also to an increase of non- GHG into air, GHG and production costs. In the study it was assumed that the infrastructure of the train cargo stations is available but the condition and availability of the train cargo stations is often criticised by logistic companies (Wellhausen, and Sliwinski, 2008). It has to be considered, too, that the presented results do not reflect realistic conditions for the scenario in Baden-Württemberg at this moment: there are neither enough cargo stations (also the location of the stations is unfavorable) nor enough containers to transport 70% of all timber on the rail. This problem leads to allocation problems and to the demand for coordinating centers.

When the results of SIAs are used to support decisions, there exist no exact mathematical or physical formulas or calculations to inform the decision-maker on an overall level which option is the best taking into account all three aspects of sustainability. SIA only provides numbers for every single indicator as results. A meaningful aggregation and interpretation of one single indicator along the whole chain is possible, but different stakeholders may have different opinions about the importance of one indicator compared to another. Nevertheless, the results of SIAs for single indicators can be processed and aggregated by further methods as e.g. the CBA (cost-benefit-analysis) or multicriteria analysis (MCA) as described in Ness et al. (2006). The outcome of these applications can be used to support a consistent decision of individuals or groups of individuals reflecting the relative importance of different indicators and facilitate a rational overall judgement about sustainability.

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