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Consequences of increasing payloads on carbon emissions – an example from the Bavaria State Forest Enterprise (BaySF)

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Abstract: To significantly reduce greenhouse gas emissions in general, and to substantially reduce the energy input specifically of wood products, is an overall accepted aim. Here, log transport significantly contributes within the wood supply chain, and the question arisesin which quantity the gross vehicle weight contributes to the related greenhouse gas emissions within wood transportation and the energy input in relation to the wood energy content of the transported goods.

The study uses a modelling approach, following the DIN EN 16258:2013-03 for calculating GHG emissions, and the energy consumption of transport services. To apply these calculations data of the transported log volume of the Bavaria State Forest Enterprise (BaySF) in 2010 were used.

Results show that the overall potential to reduce GHG emissions from log transports by increasing payloads is high. In particular, the reduction factor is 2.5 % per extra tonne of gross vehicle weight allocated to tonne-kilometer. In our sample study, the energy input was reduced from 404 to 352 MJ/ a, and the GHG emissions were decreased from 28,899 to 25,145 tCO_2eq/ a when increasing the gross vehicle weight by only 4 t up to 44 t per truck. For both categories this is a decrease of 13.0 %.

Key words: wood logistics, carbon emissions, environmental effects, payload increase, gross vehicle weight

INTRODUCTION

In the context of political efforts to substantially reducing greenhouse gas (GHG) emissions and carbon footprints, logisticsare a key driver, in particular for ecologically sensitive goods like wood products.

Transportation in general amounts to about 16 % of Germany's total GHG emissions in 2012 with the major contribution from the transportation of goods (BMUB 2014). The total emissions remained constant since 2006 at a level of approx. 151 tCO_2eq. (BMUB 2014). Without naming specific numbers, it is common understanding that the potential to reduce GHG emissions in the transportation sector is high in general. Therefore it is necessary to analyze existing supply chains, develop GHG emission calculation standards, and finally, optimize supply chains in terms of GHG emissions (BMVBS 2010). Hence this will contribute to smaller carbon footprints, specifically of wood products, and of production processes in the forest-wood-sector.

The economic perspective is basically compounded by usage-bounded costs, and consequently directly correlated to the effective driving distances, and gross vehicle weights. It is to assume that logistic costs will continue to increase when CO_2 emission limits for trucks will be introduced in the European Union (EU) or road taxes will be linked to emissions. However, up to today real CO_2 emissions from trucks or specifically for any kind of product are not known as they are too heterogeneous, depending on the type of truck and equipment (e.g. tires, gear boxes, engine), gross vehicle weight, road topography, driving performance, etc. In 2014 the EU launched the project VECTO to simulate, and assess data in this field (Savvidis 2014).

On a European level it is aim to set borders for equal, transparent, and comparable markets. However, sovereign states are able to set laws on own national interests. In particular, gross vehicle weights are varying significantly between 40 t per truck (e.g. Germany) and 60 t per truck (Sweden) within Europe (compare Table 1) (International Transport Forum 2013). In addition, some countries in the EU have set higher gross vehicle weights for log transport under certain circumstances (e.g. France up to 57 t) or for trials (e.g. Sweden and Finland, up to 80 t and 90 t, respectively). With a gross vehicle weightlimit of 40 t per truck Germany ranks at the bottom end in the European Union. Several reasons exist forsettingdiverse gross vehicleweight limits (Table 1), and each decision is influenced by e.g. existing national road infrastructure, truck design/age, population density or industrial interests. Additionally, in most cases of high permissible gross vehicle weights specific truck equipment (e.g. pneumatic suspension, double tires) is required.

However, the question can be raised, how much an increase in gross vehicle weight contributes to the reduction of GHG emissions in the transportation sector. Unfortunately, only a few studies try to answer this complex question, all using a modeling approach (Obkircher et al. 2013; Steckel 2007; Kienzler et al. 2000). Instead, no study is known that measures fuel consumption against gross vehicle weights of log trucks.

Themodeled GHG emission saving potential follows more or less a linear equation: 13.8 % for an increase of 4 t from 40 t to 44 t per truck (Obkircher et al. 2013), 18 % for an increase of 5 t to 45 t per truck (Steckel 2007), 28 % for an increase of 10 t to 50 t per truck (Steckel 2007), and 31 % for an increase of 12 t to 52 t per truck (Obkircher et al. 2013).

The aim of this study was to assess a GHG balance for the transportation of a specific biomass volume, and real transportation distances. It was in focus of the study to understand in which quantity the gross vehicle weight contributes to a reduction of GHG emissions. Similar to the existing studies we followed a modeling approach.

Table 1. Permissible maximum gross vehicle weights [t] of trucks in selected European countries, modified from International Transport Forum 2013

Country	Lorry 2 axles	Lorry 3 axles	Road Train 4 axles	Road Train 5 axles and +	Articulated Vehicle 5 axles and +
Austria	18	26	36	40	40
Belgium	19	26	39	44	44
Czech Republic	18	26	36	44	42/ 48
Denmark	18	26	38	42/ 54	42/ 54
Finland	18	26	36	44/ 60	42/ 48
France	19	26	38	40/ 44	40/ 44
Germany	18	26	36	40	40
Hungary	18	25	30	40	40/ 44
Italy	18	26	40	44	44
Netherlands	21.5	21.5/ 30.5	40	50	50
Norway	19	26	39	46/ 56	43/ 50
Poland	18	26	36	40	40
Slovakia	18	26	36	40	40
Sweden	18	26	38	48/ 60	48/ 60
Switzerland	18	26	36	40	40

MATERIALS AND METHODS

Our data set consisted of biomass log volumes of spruce, and pine of the BaySF that were supra-regional marked in 2010 (widely CPT, carriage paid to). Assortments were several types of industrial wood, in specificindustrial short logs (IS), industrial long logs (IL), stem wood long (L), stem wood short (LAS), stem wood palette (PAL). Additionally, we referred to transportation distances calculated within a logistic optimization project of the BaySF (Smaltschinski et al. 2011).

The GHG emission balance was assessed by following the DIN EN 16258:2013-03 'Methodology for calculation and declaration of energy consumption and GHG emissions of transport services', released in March 2013 (DIN DeutschesInstitutfür Normung e. V. März 2013). Strict system boundaries were set to limit the number of calculations, and to exclude uncertainties.

Investigations focused on a simple transport cycle driving from the log pile in the forest to mill gate, and return to the forest. Possible back freights were taken into accountindirectly by a fixed share of empty runs. In contrast additional driving for back freights are not taken into account. When more than one pile was loaded on a truck, driving between the piles was excluded from the calculations, because real distances between the piles were not known. Routes from the depot to the forest, and return after work were not considered either. Any emissions related to truck manufacturing or other equipment was not part of the study, and therefore also excluded.

Two different methods for GHG emission calculations were applied in line with the DIN EN 16258:2013-03 Tank-to-Wheel (TTW), whichonly refers to the consumption of fuel within the process, and Well-to-Wheel (WTW), where additional GHG emissions that occur during the production of the fuel are included.

Due to missing data of real measured fuel consumption, we decided to use an average value for the complete analyzed process (FVOS, fleet specific fuel consumption). Therefore a reference vehicle-operation-system (VOS) was prior determined. Based on the fuel consumption [l] calculated later, the related energy consumption [MJ] and the resulting GHG emissions [kgCO_2eq] were calculated using the conversion factors given in the standard (Table 2).

Finally, all results were allocated to (metric) tonne-kilometer [tkm].

Table 2. Conversion factors (DIN Deutsches Institutfür Normung e. V. März 2013), and assumptions made for the GHG balance

	Tree length	Short logs
Assortments	IL, L	IS, LAS, PAL
Type of wood truck	Truck with trailer axel; with crane; Euro-5	Truck with trailer or truck with semi-trailer; both with crane; Euro-5
Empty weight of trucks [t]	19.0	19.3
Empty weight of VOS [t]	19.19	
Empty runs back [%]	40.0	
Degree of capacity utilization [%]	100.0	
Fuel consumption at 40 t of VOS [l/ 100 km]	45.0	
Energy factor TTW [MJ/ l]	35.7[a]	
Energy factor WTW [MJ/ l]	44.2[a]	
GHG emission factor TTW [kgCO_2eq/ l]	2.51[a]	
GHG emission factor WTW [kgCO_2eq/ l]	3.16[a]	

Notes: [a] includes 6 % biodiesel; TTW = Tank-to-Wheel; WTW = Well-to-Wheel; IL = industrial wood tree length; L = stem wood tree length; IS = industrial wood logs; LAS = stem wood logs; PAL = palette

Assumptions on the empty weight of trucks were made to determine the VOS. For IL, and L assortments an empty weight of 19.0 t was assumed, including truck, trailer and crane (Borcherding 2007). For IS, LAS, and PAL assortments a slightly heavier truck with 19.3 t incl. crane was assumed (Borcherding 2007).The weight of the representative VOS was further calculated by the weighted sum of the assortment specific kilometers (product of volume per assortment, and single transport distance between forest and mill gate) as defined in DIN EN 16258:2013-03.

The specific fuel consumption was calculated based on the assumption that the fuel consumption against weight of wood trucks with crane behaves in the same way as the fuel consumption of standard road trucks (parallel translation of curves). Fuel consumption data for standard road trucks were derived from 'The Handbook Emission Factors for Road Transport' (HBEFA), which is a widely recognized database for emissions in transportation processes (Kranke et al. 2011). We assumed driving on flat terrain (1 % slope on average) outside city limits. All trucks – wood -, and road trucks – are ideally equipped with a modern engine, equal to emission category Euro V. An average fuel consumption of 45 l/100 km was set for the wood trucks (Obkircher et al. 2013).

The assumed annual degree of capacity utilization was 100 %, and the share of empty runs was set at 40 % in every case. Both values were discussed, and affirmed with the BaySF.

To keep the conversion of volume data [m^3 o.b.] into mass data [tair dry] easy, we chose an average conversion factor of 1.2 for both species, spruce, and pine (Table 3) (Lohmann and Blosen 2003).

The study focused on two scenario calculations. In the base scenario GHG emissions were calculated for the standard routing of the BaySF with 40 t per truck. All calculated numbers refer to this base scenario. In scenario 1 gross vehicle weights were changed to 44 t, 48 t, 50 t and 60 t per truck. Scenario 2 refers to the gross vehicle weights of scenario 1 with additional optimized transportation distances that are reported in Smaltschinski, Müller and Becker 2011 (Table 3). There, optimized transportation distances were calculated by solving a standard transportation problem (Hitchcock 1941) using the simplex algorithm (Dantzig 1951), a common method of linear programming. The dataset used included road distances between every single forest district and all customers, additional input data were the harvested log volume of specific assortments and the corresponding demand of the customers. The optimized distribution results in an 11.9 % reduction of transportation distances (Smaltschinski et al. 2011).

RESULTS

Based on the assumptions made, maximum payloads between 20.8 and 40.8 t per truck were calculated. Due to the assumed degree of capacity, empty runs, and empty vehicle weight, the average gross vehicle weights of a transport cycle ranged from 31.7 to 43.7 t per truck (Table 4).

Along with increased gross vehicle weights per truck (scenario 1) the number of runs decreases, as more logs can be carried at the same time. Overall the number of runs was reduced by 18,734 runs in scenario 1 from 116,209 to 97,475 runs by rising the gross vehicle weight from 40 to 44 t per truck. This is a reduction of 16.1 %. Consequently, the total distance traveled decreases in the same range from 20.3 Mio to 17.0 Mio km/a, in our example.

Table 3. Single transport distances, - volumes, and – weightsof the supra-regional wood supply of the Bavaria State Forest Enterprise in 2010; transportation distances modified from Smaltschinski, Müller and Becker (2011)

Tree species	Assortment	Single transport distance with standard routing	Single transport distance with optimal routing	Transport volume	Transport weight
		[km]	[km]	[m^3 o.b.]	[$t_{air\ dry}$]
Spruce	IL	146	127	88,600	73,833
	IS	123	110	151,300	126,083
	L	74	69	737,700	614,750
	LAS	75	64	1,142,300	951,917
	PAL	100	82	178,700	148,917
Pine	IL	183	175	95,600	79,667
	IS	101	101	4,800	4,000
	L	73	61	153,400	127,833
	LAS	99	86	255,200	212,667
	PAL	102	89	94,400	78,667

Notes: IL = industrial wood tree length; L = stem wood tree length; IS = industrial wood logs; LAS = stem wood logs; PAL = palette

Table 4: Payloads, and gross vehicle weights based on the assumptions made and resulting specific fuel consumption, energy consumption, and GHG emissions against the maximum permissible gross vehicle weight

Maximum permissible gross vehicle weight [t]	Maximum payload [t]	Average gross vehicle weight per transport cycle [t]	Specific fuel consumption per km [l/ 100 km]	Specific fuel consumption per tonne-kilometer [l/ tkm]	Energy consumption TTW [MJ/ tkm]	Energy consumption WTW [MJ/ tkm]	GHG emissions TTW [$kgCO_2eq$/ tkm]	GHG emissions WTW [$kgCO_2eq$/ tkm]
40	20.81	31.68	45.00	0.0216	0,7719	0,9557	0,0543	0,0683
44	24.81	34.08	46.68	0.0188	0,6717	0,8316	0,0472	0,0595
48	28.81	36.48	48.36	0.0168	0,5992	0,7419	0,0421	0,0530
50	30.81	37.68	49.20	0.0160	0,5701	0,7058	0,0401	0,0505
60	40.81	43.68	53.40	0.0131	0,4671	0,5783	0,0328	0,0413

Notes: first line (40 t gross vehicle weight) corresponds to the base scenario; other lines correspond to scenario 1

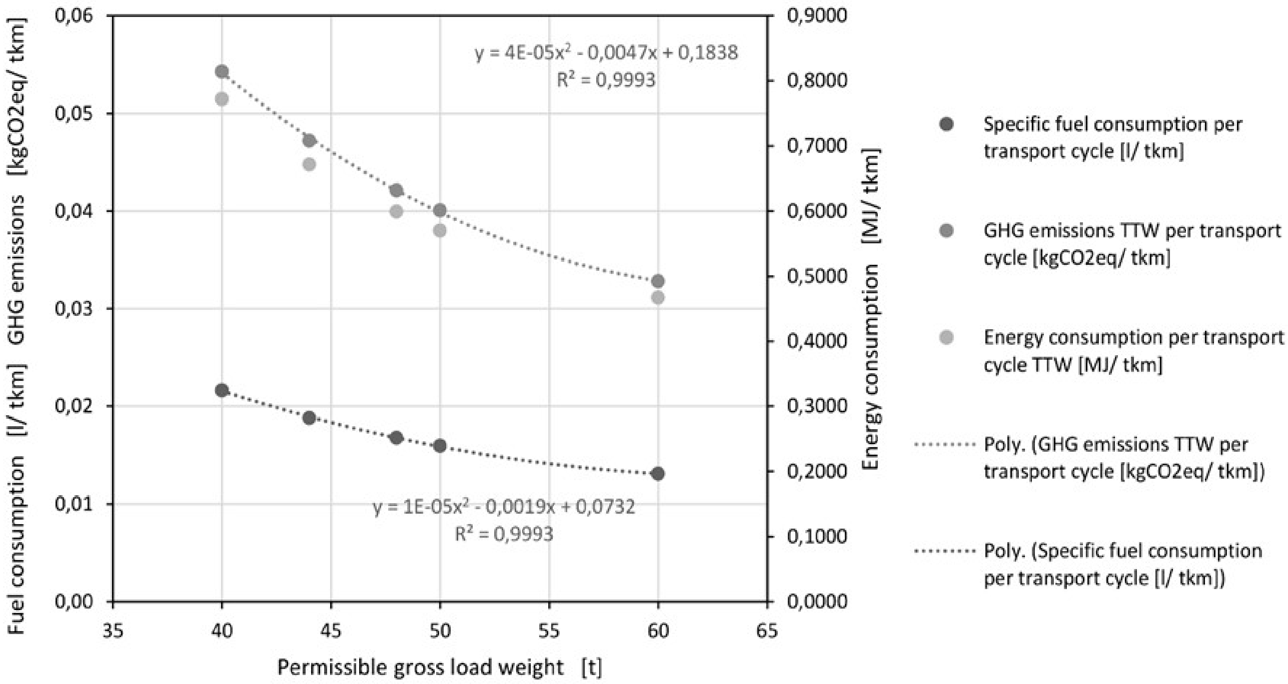

Figure 1. Specific fuel consumption per tonne-kilometer, and resulting energy consumption, GHG emissions per tonne-kilometer against the permissible gross load weight

A combination of increased gross vehicle weights and an optimized distribution (scenario 2) could strongly reduce the total travel distance. At 44 t gross vehicle weight the travel distances sums up to 15.0 Mio km/a, a decrease of 26.1 % compared to the base scenario, and still a decrease of 11.9 % compared to scenario 1. About 11.2 Mio km/a or 55.1 % could be saved in maximum, when applying optimal distribution, and 60 t gross load weight per truck.

The fuel consumption per kilometer increases arithmetically with increasing gross vehicle weights from 45.0 to 53.4 l/100 km (Table 4). More importantly, the specific fuel consumption per tonne-kilometer of a transportation cycledecreases in a non-linear way(Figure 1). Starting from the current permissible gross vehicleweight of 40 t per truck an increase of 4 t to 44 t per truck would result in a 12.9 % decrease of specific fuel consumption per tonne-kilometer. However, due to the non-linear expression of the fuel consumption per tonne-kilometer the decrease rate declinescontinuously. While the decrease of the specific fuel consumption is 3.3 % per extra tonne of gross vehicleweightfrom 44 t upwards, it is only 1.8 % when exceeding a 50 t limit. The energy consumption as well as the emissions follow the specific fuel consumption per tonne-kilometer (Table 4).

Referring to our sample calculations with the data of the transported logsof the BaySF in 2010 about 9.2 Mio l/a of diesel were required in the base scenario.Just increasing the gross vehicle weight per truck (scenario 1) by 4 t to 44 t per truck reduces the diesel consumption by 1.2 Mio l/ a, a reduction of 13.0 % (Table 5). A further increaseof the gross vehicle weight to 60 t per truck results in a reduction of 3.6 Mio l/a, a decrease of 39.5 %.

Regarding energy demand a combination of increasing gross vehicle weights, and optimal distribution (scenario 2) shows even greater saving potential (Table 5). Both concepts reach the aim of saving fuel well, in a similar range: by changing the gross vehicle weight to 44 t per truck, 13.0 % could be saved. An optimized distribution reduces fuel consumption by 11.9 %.

Because energy consumption is directly correlated to the fuel consumption, changes behave in the same way and the same range as those of fuel consumption (Table 5). The energy input to thelogs - and later on to wood products - that occurs through transportwas significantly reduced by increasingthe gross vehicle weight (scenario 1). At a gross vehicle weight of 44 t per truck the energy input was lowered by 42.4 Mio MJ/a (Tank-to-Wheel, TTW), and 52.5 Mio MJ/a (Well-to-Wheel, WTW), respectively, compared to the base scenario(Table 5). In general, every additional tonne of gross vehicle weight results in a decrease of energy input by 9 Mio MJ/a on average (TTW), and 11 MJ/a on average (WTW), respectively. In both cases the decrease is not linear. For a lower gross vehicle weight, the decrease is slightly bigger than for a higher gross vehicle weight.

The decrease of energy input that occurs from increased gross vehicle weights, and additionally optimizing the transport distribution (scenario 2) follows the overall decrease observed in scenario 1 (Table 5).

The allocated energy input only depends on the increase of gross vehicle weight. On average, with every additional tonne of gross vehicle weight the energy input is decreasing by 0.017 MJ/tkm (TTW), and 0.021 MJ/tkm (WTW), respectively.

Again, GHG emissions are directly correlated to the fuel consumption. In the base scenario GHG emissions of 22,955 tCO2eq/ a (TTW) occur. In the WTW calculations they are slightly higher, namely 28,899 tCO_2eq/a. Generally, TTW GHG emissionsrange about 79.5 % of the WTW GHG emissions.

Looking at the WTW GHG emissions in scenario 1 about 3,754 tCO_2eq/a ofGHG emissions can be saved by increasingthe gross vehicle weight up to 44 t per truck (Table 5). When minimizing total distance by an optimized distribution, andin parallelincreasingthe gross vehicle weight to 44 t (scenario 2) even 6,754 tCO_2eq/a (WTW) less are emitted to the atmosphere. This is a decrease of 23.4 % against the base scenario.

It is interesting to see that the GHG emissions saving potential is already high when only the gross vehicle weight is modified (Figure 2). An additional optimization of distribution is increasing the GHG saving potential by 79.9 %, 41.4 %, 33.7 %, and 18.3 % at 44 t, 48 t, 50 t, and 60 t per truck, respectively.

The allocation of GHG emissions shows a general non-linear decreasing trend against the increasing gross vehicle weight (Figure 3). Overall, the potential to reduce GHG emissions per tonne-kilometer is high, with an average reduction of 2.5 % per extra tonne of gross vehicle weight. A maximum of 39.5 % of GHG emissions can be reduced by increasing the gross vehicle weight from 40 t to 60 t per truck. However, with an increasing gross vehicle weight the saving potential is strongly decreasing, hence the ecological benefit from an additional increase is smaller.

DISCUSSION

Many assumptions had to be made to perform the study. First of all the empty vehicle weight of the two truck systems was set to 19.0 and 19.3 t, respectively. A representative average value is difficult to find due to the heterogeneity of the log transport sector and the assortment specific built of the vehicles. However, most logistic studies range the empty weight between 18.0 and 20.0 t per truck.

An estimation of the average fuel consumption for the vehicle-operating-system (VOS) is even more complex. We excluded loading and unloading phases in our calculation. Including those activities the average fuel consumption may increase to 52.0 l/100 km (Borcherding 2007). To conduct time studies in combination with fuel flow rate measurements and GPS logging will close this gap of information in the future.

Table 5. Fuel consumption, energy input, and GHG emissions of scenario 1 (increase of gross vehicle weight only), and scenario 2 (increase of gross vehicle weight additionally to an optimized distribution)

		Gross vehicle weight [t per truck]				
		40	44	48	50	60
Fuel consumption [1,000 l/ a]						
Base scenario		9,145				
Scenario 1		--	7,957	7,099	6,754	5,534
Scenario 2		8,054	7,008	6,252	5,948	4,874
Energy input, absolute [Mio MJ/ a]						
Base scenario	TTW	326				
	WTW	404				
Scenario 1	TTW	--	284	253	241	198
	WTW	--	352	314	299	245
Scenario 2	TTW	288	250	223	212	174
	WTW	356	310	276	263	215
Energy input, allocated [MJ/ tkm]						
Base scenario	TTW	0.77				
	WTW	0.96				
Scenario	TTW	--	0.67	0.60	0.57	0.47
	WTW	--	0.83	0.74	0.71	0.58
GHG emissions, absolute [tCO_2eq/ a]						
Base scenario	TTW	22,96				
	WTW	28,899				
Scenario 1	TTW	--	19,973	17,819	16,952	13,891
	WTW	--	25,145	22,434	21,342	17,489
Scenario 2	TTW	20,216	17,590	15,693	14,930	12,234
	WTW	25,452	22,145	19,757	18,796	15,402
GHG emissions, allocated [kgCO_2eq/ tkm]						
Base scenario	TTW	0.0543				
	WTW	0.0683				
Scenario	TTW	--	0.0472	0.0421	0.0401	0.0328
	WTW	--	0.0595	0.0530	0.0505	0.0413

Notes: TTW = Tank-to-Wheel; WTW = Well-to-Wheel

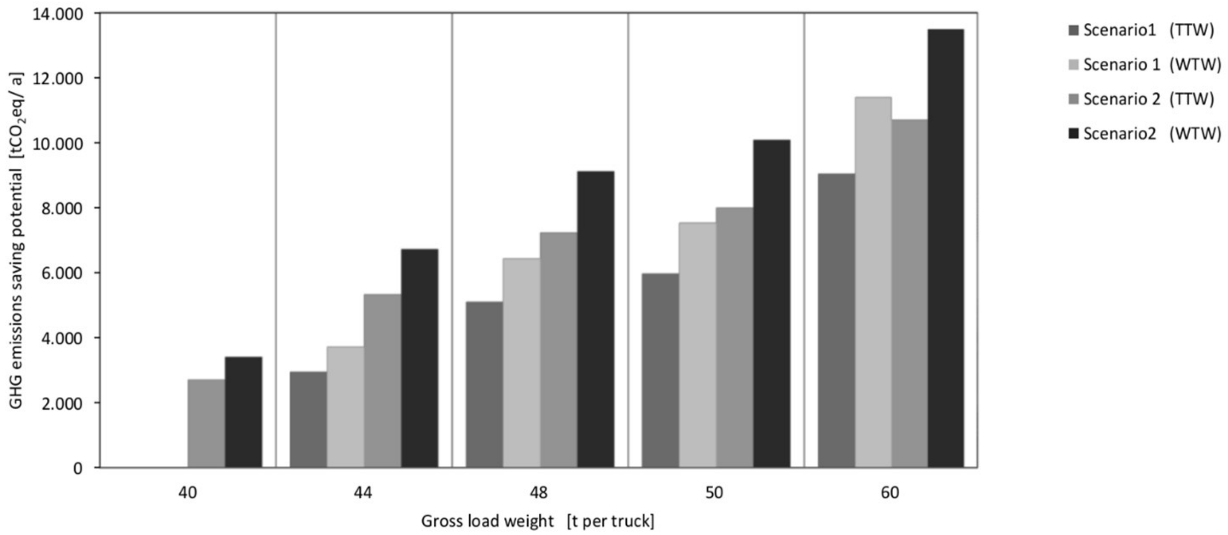

Figure 2. GHG emissions saving potential of scenario 1 (increase of gross vehicle weight only), and scenario 2 (increase of gross vehicle weight in addition to an optimized distribution) for the wood market of the BaySF in 2010; TTW = Tank-to-Wheel; WTW = Well-to-Wheel

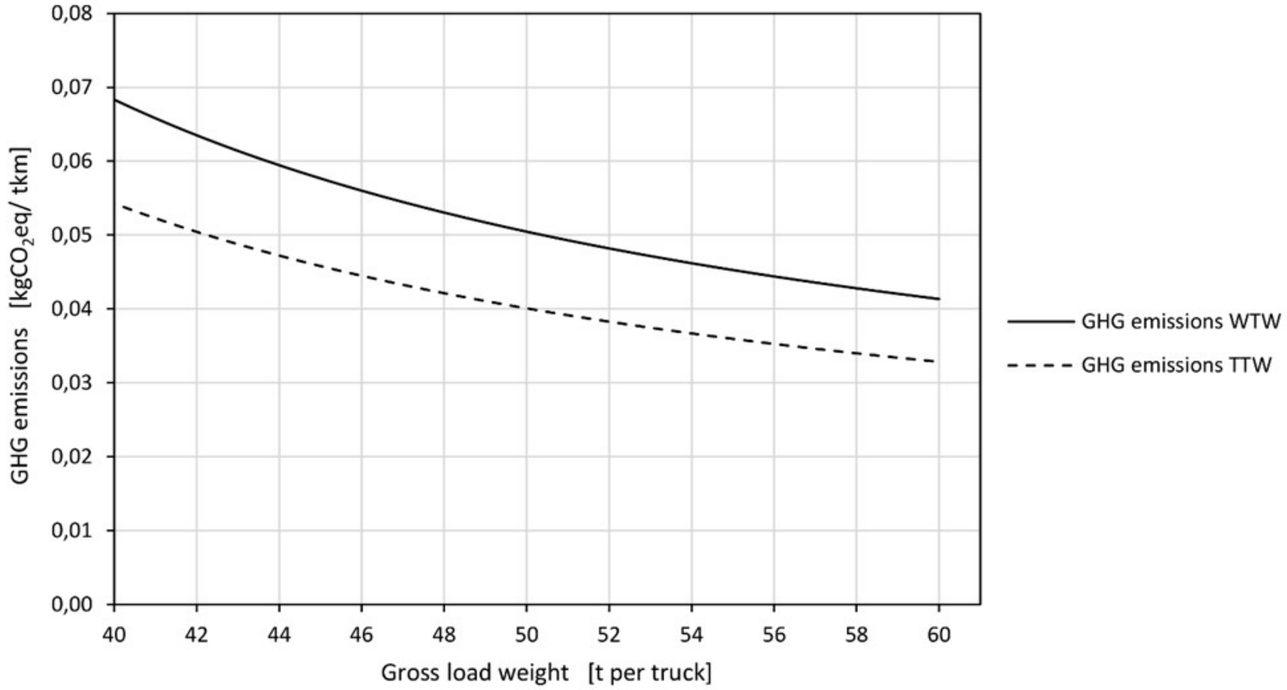

Figure 3. Allocated GHG emissions against gross vehicle weights; WTW = Well-to-Wheel; TTW = Tank-to-Wheel

Additionally, the fuel consumption was calculated in parallel to the consumption of a standard road truck of the emission class Euro V. This represents a compromise between modern trucks with Euro VI, and slightly older trucks with Euro IV.

The assumed empty run rate of 40 % is based on experience, and has been discussed and agreed with the BaySF. The value is low compared to other studies, where Baumann 2008, p. 151 measured 43 %, and Bodelschwingh 2006, p. 117 calculated 46 %. Of cause, higher rates of empty runs will increase the average fuel consumption per tonne-kilometer, resulting as well in higher GHG emissions.

A topography with an average ascending slope of 1 % was assumed. Naturally, some mountainous areas might have higher rates. An average ascending slope rate of 2 % would lead to 21 % higher fuel consumptions. Moreover, the type of road construction has huge influences. Generally, driving on paved high ways decreases the fuel consumption, while driving on dirt roads leads to increasing fuel consumption.

Saving fuel is an essential issue, not only from an ecological point of view, but also economically. We did not address this aspect, as it was not part of the study objective. However, it is easy to correlate fuel prices with the calculated fuel consumption to get economic information.

With this study, we do not want to support nor doubt any argumenton gross vehicle weights of trucks, specifically in Germany. The aim is to demonstrate the potential of GHG emissions savings in the wood supply chain. Of course, within the discussion about the permissible gross vehicle weight of trucks other essential aspects (e.g. road construction, - wearing, - damages, truck design) exist that have to be taken into account, and that have not been addressed here.

CONCLUSIONS

It was aim of the study to answer the question, how much the gross vehicle weight may contribute to a GHG emissions saving potential. Already a slight increase of gross vehicle weight by 4 t to 44 t per truck would result in a strong decrease of total travel distance (16.1 %), and related GHG emissions. This GHG emission saving potential is even higher than it could be realized with optimal distribution (11.9 %) as described in (Smaltschinski et al. 2011). Combining both actions, 23.6 % GHG emissions could be saved. This is an important contribution to the political aim of reducing Germanys GHG emissions by 40 % until 2020 (BMUB 2014).

The actual energy input is an important factor when processing wood especially for bio-energy, and with minor importance for solid wood products as well. Here limits between energy input/output are in political/social discussion or already in implementation. Easily reducing the energy input for logistics by 13.0 % by a slight increase in gross vehicle weight, could be an important step to optimize the overall energy efficiency of wood products.

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