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# Impacts of increasing maximum truck weight – case Finland



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## Abstract

Finnish government allowed in October 2013 operating high capacity vehicles (HCV) with a maximum weight limit of 76 t on Finnish roads. An analysis on how HCVs have affected the Finnish road freight transport sector is presented here based on a continuous time series data from 2013 to 2017. The analysis shows a significant increase in the average payload weight and a transition from 7-axle to 8- and 9-axle articulated vehicle combinations, which allow the higher weights. Truck mileage of 225 million km has been avoided from October 2013 until the end of 2017 and avoided mileage corresponded in 2017 to approximately 4% of total truck mileage in Finland. This equals around 126 million € cost savings in 2017 and 0.1 Mt of CO<sub>2</sub> emissions reduction in road freight, even after taking into account that there has been some modal shift from rail to road.

**Keywords:** High capacity vehicles, Road freight transport, CO<sub>2</sub> emissions, Transport costs

## 1 Introduction

Road freight transport is a significant contributor to global greenhouse gas (GHG) emissions and its importance in transport emissions is likely to increase as passenger vehicles are increasingly electrified. In addition to propulsion issues, also changes in consuming habits offer significant challenges, because more and more deliveries are made to customers' homes instead of local markets and shopping centres. Hence, each action, which could provide efficient improvements and emission reductions for transport sector must be considered. Without actual data and information it is impossible to determine which actions are good and influential and which are not. Hence studies as described in this paper are important for global battle against climate change.

Measures to decarbonise road freight transport are required in order to prioritize actions to mitigate climate change. One possible measure for reducing the GHG emissions and simultaneously decreasing the transport costs is using longer and heavier vehicles. This follows the basic principle that it is more efficient to transport large volumes consolidated into full truckloads, than to transport low volumes and part loads. Finland and Sweden have a long

tradition in using 25.25 m and 60 t articulated vehicles, commonly referred to as long and heavy vehicles (LHVs), while other countries in Europe and North America mostly use 18.75 m and 44 t vehicles, commonly referred to as heavy goods vehicles (HGVs). Finland and Sweden are also allowing and piloting even longer and heavier vehicles, referred to as high capacity vehicles (HCVs) or high capacity transport (HCT), with maximum weight of up to 104 t and maximum length of up to 34.5 m [1].

Finnish government allowed in October 2013 by amendment to Finnish legislation [2] the operation of high capacity vehicles (HCV) with gross vehicle weight (GVW) of 76 t on Finnish roads. On bridges and smaller roads, usage of HCV can be restricted with traffic signs, but otherwise HCVs can operate freely. This decision differs from general European legislation. By the new regulation the maximum weight limit of trucks increased to 76 t and the maximum height limit to 4.4 m from the previous limits of 60 t and 4.2 m, while maintaining the length limit at 25.25 m in accordance with the European modular system. New regulation affected both new vehicles and vehicles that were already in operation. Hence, there was no need for hauliers to invest in new vehicles in order to benefit from the larger payload. Only an alteration inspection for the old vehicles were needed to allow the operations with increased payload. The changes in the truck weight limits are presented in Table 1.

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**Table 1** Changes in the truck weight limits and payloads

Truck type	Maximum gross vehicle weight limit		Maximum payload weight		Increase in payload
	Old	New	Old	New	
4-axle truck without trailer	32 t	35 t	18 t	21 t	17%
5-axle truck without trailer	38 t	42 t	21 t	25 t	19%
8-axle articulated truck	60 t	68 t	37 t	45 t	22%
9-axle articulated truck	60 t	76 t	35 t	51 t	46%

In addition, the amendment in regulation included temporary weight increases, which were in force until the end of April 2018. The temporary increases were:

2-axle truck without trailer	18 t	20 t	26 t	28 t	18%
3-axle truck without trailer	26 t	28 t	16 t	18 t	13%
7-axle articulated truck	60 t	64 t	40 t	44 t	10%

In addition to these changes, hauliers in Finland have been allowed, with exemption permissions on certain roads, to test even larger articulated trucks of up to 104 t and 34.5 m long [1]. In spring 2018, there were altogether 50 pilot HCV combinations on Finnish roads, of which 32 were longer than 27 m and 18 were heavier than 76 t [3]. After successful trials, in January 2019 the longest permitted length was extended to 34.50 m from the previous 25.25 m on all roads in Finland [4].

*The purpose of this paper is to analyse how allowing the 76 t HCVs have affected the transport volumes, costs and CO<sub>2</sub> emissions of Finnish road freight transport sector.* The paper also includes a comparison, where predicted impacts (see [5]) are compared with the actual impacts. The focus is on the articulated vehicles in the 60 to 76 t range, i.e. the 7-, 8- and 9-axle vehicles. The maximum weight limits of trucks with 2–5 axles were also changed, but higher weight limits have not been utilised with these smaller rigid trucks. As for the over 76 t or over 25.25 m vehicles that have been operating in Finland, there is very limited amount of data available in general statistics so these vehicles are not considered in this study.

## 2 Literature review

Allowing the use of longer and heavier vehicles (LHVs) in Europe has been subject of active research during recent years and there has been some debate about the potential benefits and negative impacts. Most studies in Europe have focused on the transition from conventional heavy goods vehicles (HGV) with 18.75 m length and 40 t gross vehicle weight (GVW) to the European modular system (EMS) with 25.25 m length and 60 t GVW. Most studies agree that the larger the truck, the more efficient use of resources, meaning that using larger vehicles would increase transport efficiency (see [6–12]).

Sanchez Rodrigues et al. [12] note that the impacts of LHVs are usually estimated using road freight statistics,

because of the lack of empirical data, but in their case study six German companies tested EMS vehicle combinations and all six companies reported cost reductions. The companies were able to reduce fuel consumption per tkm by about 30%, but also negative outcomes were anticipated by some respondents, such as an increase in tyre costs and in vehicle maintenance costs. LHV trials in the Netherlands have resulted in reduced number of journeys and driven mileage, which are estimated to reduce 20 million kilometres annually and thus 0.016 Mt reduction in CO<sub>2</sub> emissions per year, according to Rijkswaterstaat [11]. Breemersch and Akkermans [7] estimated that allowing EMS operations in the EU could result in 2% reduction in CO<sub>2</sub> emissions from long haul transport by 2020.

The optimum size of vehicles has also received much attention in the LHV debate. Some studies claim that the largest vehicle combinations are risky and may cause more negative than positive impacts, although they agree that LHVs offer benefits [8, 13]. Lumsden [14] notes that for majority of long haul transport the dimensions of the vehicle are more important than the maximum weight. Galos et al. [15] highlight that it is also possible to increase the payload by reducing the own weight of the truck by using lightweight materials, hence giving the opportunity increase the efficiency of hauling weight restricted commodities.

Sweden has a long tradition of using EMS. Kyster-Hansen & Sjögren [16] outline a roadmap on permitting high capacity vehicle combinations on Swedish roads and give recommendations on stakeholder activities to support the implementation. Vierth & Haraldsson [17] and Örebro Regional Development Council [18] studied the shift from 60 t to 90 t trucks and report positive results with some notices. A shift from 60 t to 90 t could reduce the vehicle kilometres by about on third, according to Örebro Regional Development Council [18]. Pålsson et al. [19] estimated the effects of HCVs in Sweden and concluded that the net economic benefits of

implementing 25.25 m/74 t vehicles would total 2.9 to 7.4 billion € during 2018–2058, depending on the implementation scenario, but also require 1.1 to 1.3 billion € additional investments in road infrastructure. Freight transport in the forestry sector have been seen as a particularly suitable area of implementing HCVs. Haraldsson et al. [20] have estimated that replacing 60 t articulated trucks with 90 t combinations in Swedish round wood transport would reduce vehicle kilometres by 21%.

In Finland, Palander [21] analysed the actual effects of allowing HCVs in Finland using ERP data from a major Finnish pulp and paper company and concluded that operational reduction in fuel consumption was 6.2% 1 year after the mass limits were raised from 60 t to 76 t in 2013 and long-term reduction could be 15.5%, when hauliers are fully adjusted and implemented HCVs.

Most of the negative impacts of LHV's relate to concern a potential modal shift from rail to road, safety issues and the impacts on road infrastructure [10, 22]. TRL [23] estimates that LHV's would result in a significant modal shift and lead to an increase in CO<sub>2</sub> emissions. However, Steer et al. [24] conclude that empirical evidence shows lower actual modal shift than desk studies have estimated. Several studies conclude that there is no clear evidence that LHV's would decrease road safety, and LHV's might even improve safety due to reduced truck mileage [9, 25, 26]. The impact of LHV's on the road infrastructure depends on the axle weights, number of axles and tyres. Kalliainen et al. [27] and Kolisoja et al. [28] argue that road wear may increase. Furthermore, investments in bridges may be required to accommodate heavier vehicles. When estimating the possible benefits and negative impacts of HCVs, the development of technologies and vehicles should be acknowledged as these could offer solutions for some of HCVs' challenges.

### 3 Methodology

In this research, quantitative data is used to calculate the actual impacts of new maximum weight limits of articulated trucks in Finland. Data from the Goods Transport by Road survey (GTRS) by Statistics Finland [29] on national road freight transport in 2013–2017 is used as the main data source. The survey describes the transport operations of trucks registered in Finland based on a continuous sample survey in which annually 10,000 truck owners are asked to provide data on their trucks and operations over three or four consecutive survey days. The data include both domestic and international operations, but only domestic operations are considered here, because weight limit increases could not be utilized in international operations. This data source does not include data on fuel consumption. Hence, fuel consumption data from LIPASTO [30] and NTM [31] have been added to the analysis following the methodology outlined in Liimatainen & Pöllänen [32].

There are data from around 10,000 truck trips each year. The following key data, which is provided by the truck owners on all the operations of a lorry over three or four survey days, is used for each trip:

- trip length (km)
- number of axles in truck and trailer
- own weight (kg)
- maximum total weight (kg), i.e. weight limit of a fully loaded truck and trailer combination as defined in vehicle registration
- payload weight (kg)
- type of payload (originally 45 commodity types, here aggregated to 20 + forestry, according to the NST2007 commodity classification).

The following information is calculated based on the data:

- total vehicle kilometres
- total tonnes
- total tonne-kilometres
- total number of trips
- total fuel consumption and CO<sub>2</sub> emissions.

The following process is followed in order to analyse the benefits of the HCV implementation in Finland:

- each trip is checked to see if the maximum total weight is greater than the former weight limit for a truck with certain number of axles, e.g. greater than 60 t for 8-axle vehicle combination.
- if yes,
  - the old maximum payload weight is calculated as the difference of old weight limit and own weight,
  - the extra payload weight allowed by new weight limits is then calculated as the difference of payload weight and old maximum payload weight,
  - the extra tonne-kilometres are then calculated by multiplying the extra payload weight with the trip length,
  - the extra tonne-kilometres of each trip are then expanded to correspond the national total using the sample multipliers,
  - total extra tonne-kilometres are then divided by the old maximum payload weight of a truck, i.e. 40 t. This results in total vehicle kilometres saved using the new higher weight limits.
  - Then, total vehicle kilometres saved is multiplied with cost factors by vehicle type (Table 1) to get the cost savings. There are five vehicle types (part load, forestry, long-haul, tanker and bulk, construction), and commodities are assigned to these vehicle types as presented in Table 2. Cost factors are calculated

**Table 2** Operating cost used to calculate cost savings (based on Vierth et al. [33], except fuel consumption on laden trips calculated from GTRS data using methodology by Liimatainen & Pöllänen [32])

Vehicle type	Part load	Forestry	Long-haul distribution	Tanker and bulk	Construction
SEK/10 km	130	149	144	178	195
Share of personnel costs	36%	33%	44%	42%	38%
Share of fuel costs	30%	30%	26%	22%	22%
Share of other vehicle costs	35%	37%	30%	37%	40%
Exchange rate	1 SEK = 0.0984 EUR				
Personnel costs (€/km)	0.46 €	0.48 €	0.62 €	0.74 €	0.73 €
Fuel costs (€/km)	0.38 €	0.44 €	0.37 €	0.39 €	0.42 €
Other vehicle costs (€/km)	0.45 €	0.54 €	0.43 €	0.65 €	0.77 €
Total (€/km)	<b>1.29 €</b>	<b>1.47 €</b>	<b>1.42 €</b>	<b>1.77 €</b>	<b>1.92 €</b>
Fuel consumption (l/100 km) on laden trips	<b>30.3</b>	<b>66.7</b>	<b>37.5</b>	<b>46.5</b>	<b>58.1</b>

for each vehicle type based on the ones presented by Vierth et al. [33] and changing the currency from SEK to EUR using the conversion rate 1 SEK = 0,0984 EUR, which is estimated based on the EUR/SEK exchange rate during most of 2008 [34] and taking into account the changes in the freight transport cost index between 2010 and 2014 [35].

The resulting costs are presented in Table 2.

◦ Next, fuel savings and CO<sub>2</sub> emission reductions are calculated based on the total vehicle kilometres saved by using average fuel consumption on laden trips (presented in Table 2) calculated for each vehicle type using the methodology outlined in Liimatainen & Pöllänen [32]. The fuel consumption saved is calculated based on the average fuel consumption on trips in which extra capacity of HCVs was not used.

◦ Finally, CO<sub>2</sub> reductions are calculated by multiplying the fuel savings by the emission factor 2.66 kg CO<sub>2</sub>/litre

The results of the analyses are presented mostly by quarter in order to analyse the uptake of the 76 t vehicles combinations.

## 4 Results

### 4.1 Implementation and utilization of higher maximum payload

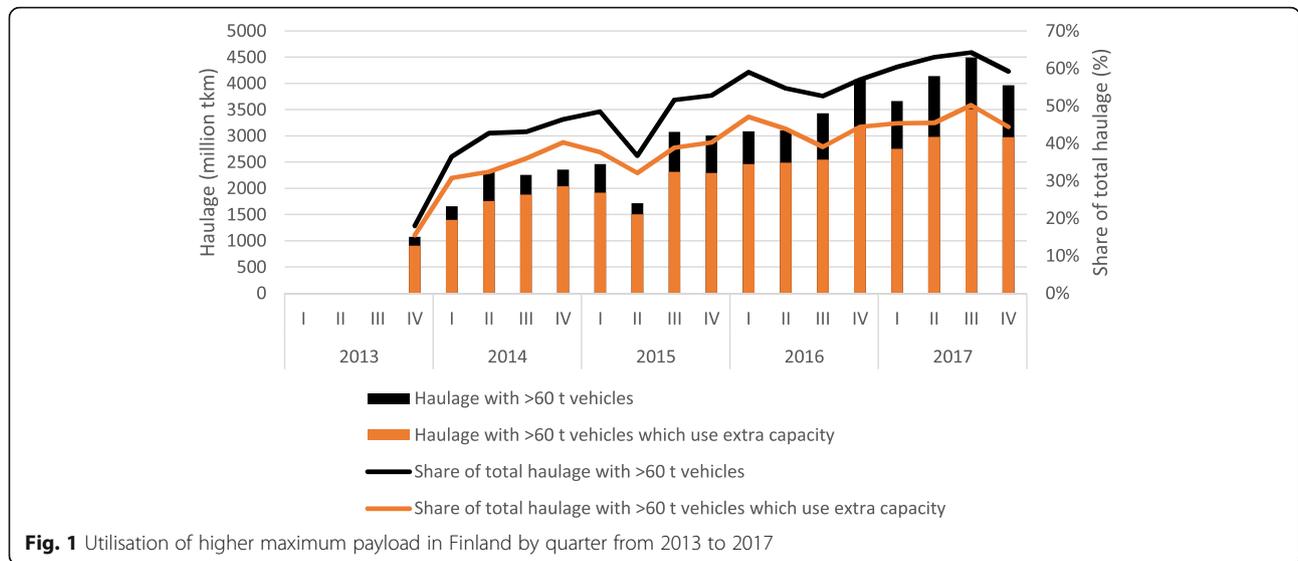
The higher weight limits, detailed above in Table 1, were introduced in the beginning of October, i.e. from the fourth quarter of 2013. An alteration inspection had to be done to an old truck or a new truck had to be registered to be able to benefit from the higher weight limits. Hence, the implementation of higher weight limits has progressed gradually, as evident from Fig. 1.

The over 60 t total weight vehicles have quickly gained a significant share of total haulage. However, the question arises, has the extra capacity actually been used? As

can be seen from Fig. 1, the extra capacity seems to have been used to a large extent. On average 79% (range of 72% to 88% between quarters) of haulage (tonne-kilometres, tkm) with over 60 t vehicles have used at least some of the extra capacity provided by the new regulation, i.e. the payload has been larger than previously possible.

Furthermore, the extra capacity is typically fully utilised. The maximum extra payload weights for articulated trucks with 7, 8 and 9 axles are 4, 8 and 16 t, respectively. Over the period from Q4/2013 until Q4/2017, the 7- and 8-axle vehicles have had average extra payloads of 3.6 t and 6.8 t, respectively, which are close to the maximum. However, the extra capacity is not as well utilized with the 9-axle vehicles, as extra payload average has been 12.6 t. This is likely due to the fact that the volumetric capacity is the same between the vehicles and to fully utilise the maximum weight of a 9-axle vehicle requires a very dense load. It is worth pointing out that this is one reason for allowing the longer than 25.25 m vehicle combinations in Finland in January 2019. The extra payload made possible by the new regulation has been on average 6.9 t (ranging from 4.4 to 9.6 between quarters).

When the uptake of over 60 t vehicles is analysed on a commodity level, it can be seen that the commodities in which the payload is limited by weight rather than cargo volume have implemented and utilized the extra capacity the most. In 2017, 46% of total haulage was made with over 60 t vehicles, which used the extra capacity. However, only four commodities out of 20 have a larger share than the average (Table 3). These commodities are forestry (91%), mining and quarrying (64%), chemical products (51%) and coke and petroleum products (61%). There are eight commodities (household and office removals; unidentifiable goods; mail; transport equipment; textiles; furniture; empty containers and packaging; other goods and empty) in which less than 10% of total



**Fig. 1** Utilisation of higher maximum payload in Finland by quarter from 2013 to 2017

haulage benefited from the extra capacity in 2017. For some commodities (e.g. food products; metal products; household and office removals; unidentifiable goods) there is a large variation between years and quarterly analysis on commodity level is not possible due to large variation in the amount of data.

**4.2 Effect on average payload and mileage**

As it was shown, the over 60 t articulated trucks have been taken into use and are utilized quite fully. A question then arises on effects of HCVs on the average payload of various vehicle types. Figure 2 shows an increasing trend of the average load on laden trips with

**Table 3** Share of haulage (of tkm) benefiting from the extra capacity by commodity group

Commodity group with NST number	Vehicle type	Q4/2013	2014	2015	2016	2017
Forestry	Forest raw material	53%	83%	86%	85%	91%
03 Mining and quarrying	Construction	13%	45%	42%	60%	64%
07 Coke and petroleum products	Tanker and bulk	0%	17%	39%	31%	61%
08 Chemical products	Tanker and bulk	13%	31%	56%	56%	51%
06 Wood products	Long-haul distribution	13%	36%	32%	43%	43%
14 Waste	Construction	3%	24%	22%	33%	39%
01 Agricultural products w/o forestry	Long-haul distribution	11%	22%	27%	22%	39%
09 Glass, other non-metallic mineral products	Long-haul distribution	13%	37%	33%	48%	38%
02 Coal	Tanker and bulk		100%	30%	39%	24%
04 Food products	Long-haul distribution	1%	9%	24%	17%	24%
10 Metal products	Long-haul distribution	9%	30%	19%	39%	22%
18 Grouped goods	Long-haul distribution	0%	10%	13%	18%	21%
11 Machinery and equipment	Part load	32%	1%	2%	2%	19%
15 Mail	Part load	0%	0%	0%	4%	8%
16 Empty containers, packaging	Part load	0%	0%	0%	0%	5%
17 Household and office removals	Part load	0%	0%	5%	37%	0%
19 Unidentifiable goods	Long-haul distribution	0%	0%	0%	26%	0%
12 Transport equipment	Part load	0%	1%	6%	2%	0%
05 Textiles	Part load	0%	0%	0%	0%	0%
13 Furniture	Part load	0%	0%	0%	0%	0%
20 Other goods and empty		0%	0%	0%	0%	0%
<b>ALL COMMODITIES</b>		<b>16%</b>	<b>35%</b>	<b>37%</b>	<b>43%</b>	<b>46%</b>

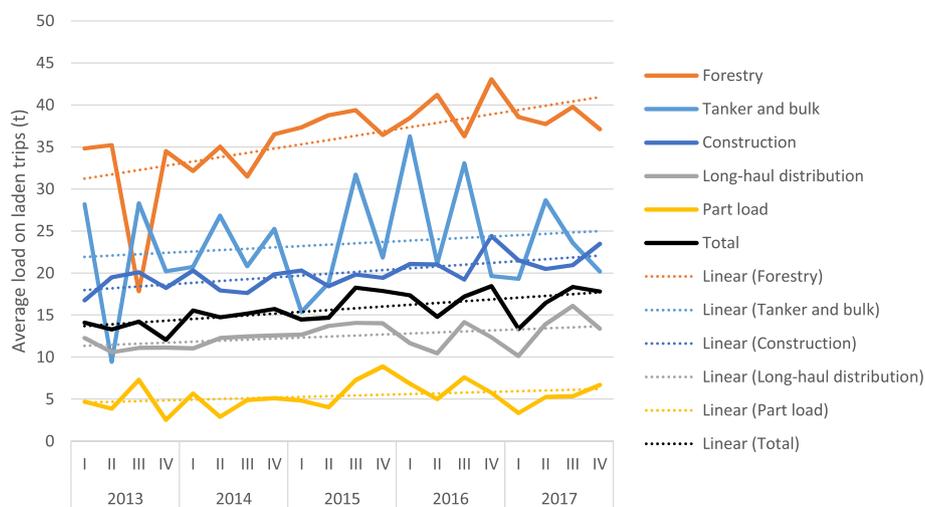
every vehicle type. However, this figure should be interpreted cautiously because there is great fluctuation between quarters depending on the amount of data that various commodities have had in the sample. The increase has been particularly steep with forest raw material vehicles, with which the average load has increased from 31 t to 41 t based on the linear trend line. Also for tanker and bulk vehicles the trend line shows steep increase from 22 t to 25 t. The total annual average payload increased from 13.3 t in 2013 to 15.3 t in 2014, 16.3 t in 2015, 17.0 t in 2016 and 16.5 t in 2017. This increase can be regarded as a positive impact from the energy efficiency perspective and it shows that the impact on average loads has been significant.

The utilization of the extra capacity has also led to significant vehicle mileage savings in Finland compared to a situation without the weight increases. If the haulage (tkm) now operated with over 60 t total vehicle weight would have been operated with the old maximum weight limit of 60 t GVW, in total 225 million additional vehicle kilometres would have been needed from October 2013 until the end of 2017. This is 2.9% more than the actual mileage. Figure 3 shows the increase in the amount of saved mileage. There was steady increase until the third quarter of 2014 and then saved mileage seemed to saturate around 12 million km and 2.5% of total truck mileage per quarter during 2015. Thereafter it increased again to around 3.5% and 15 million km per quarter in 2016 and first half of 2017, with a peak of 5% in Q3/2017. However, when comparing different years we must consider also general economic development, which has shown positive development from 2014 to 2017 and hence affected the total demand of freight transport (Fig. 4).

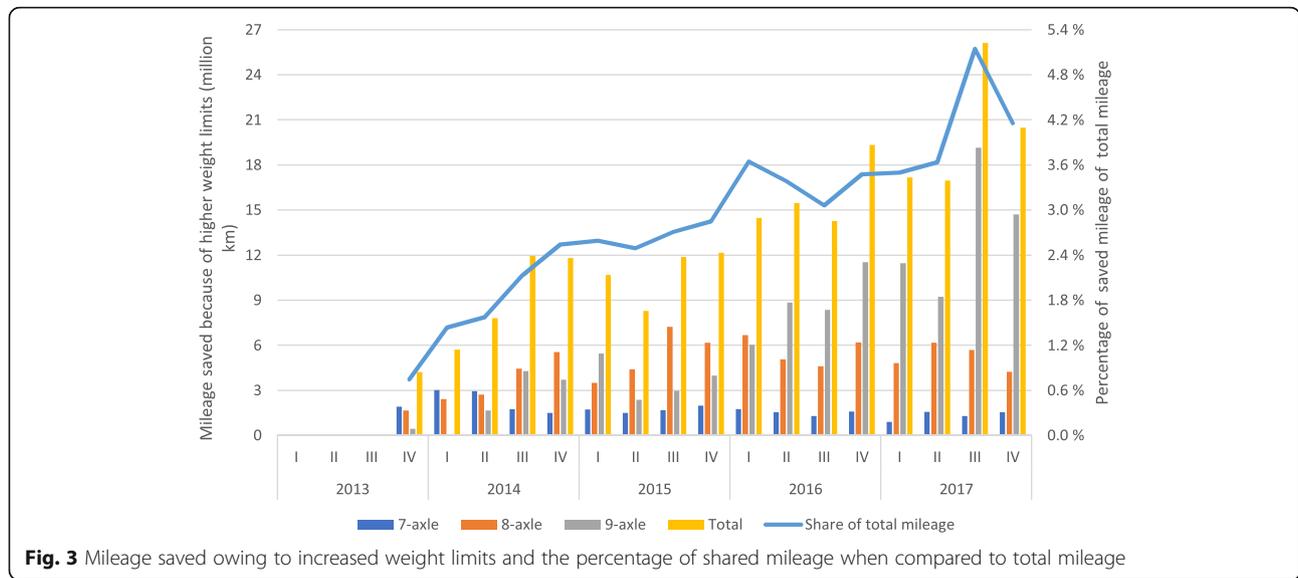
Before new regulation and the increase in the maximum vehicle weight, Nykänen and Liimatainen [5] estimated in a maximum impact analysis that 139 million km could be saved annually from 7- to 9-axle vehicles' mileage, if all suitable haulage with 7- and 8-axle combination would transfer to fully laden 9-axle vehicles. As can be seen from Fig. 3, there has been a significant transfer from 7-axle vehicles to 9-axle vehicles, but the savings in vehicle km were in total 81 million km in 2017, which is 58% of the estimated maximum saving. In 2017, the total mileage with 7- to 9-axle vehicles was 860 million km with 26%, 49% and 24% of that by 7-, 8- and 9-axle vehicles, respectively. The share of 7-axle vehicles decreased from 55% in Q4/2013, while shares of 8-axle and 9-axle vehicles increased from 43% and 2% in Q4/2013, respectively.

The 9-axle vehicles have been especially utilized in those sectors that have benefited from extra capacity as was seen in Table 3. Around 49% of mileage of forestry were carried with 9-axle vehicles in 2017. Hence, also the savings in vehicle kilometres come mainly from this weight-restricted commodity, as can be seen in Table 4.

Table 4 shows that by far the largest benefactor of the HCVs is forestry sector in which the saved vehicle kilometres are equal to 22% of actual vehicle kilometres driven in 2017. Forestry also represents 44% of the total vehicle kilometres saved if the saved empty running (which are included in the NST commodity '20 Other goods and empty') kilometres are assigned to other commodity types using the average empty running share of 21% of total haulage. However, the empty running share in forestry is likely to be greater than average [36] so forestry represents even larger share of total mileage savings.



**Fig. 2** Average payload weight on laden trips by vehicle type quarterly from 2013 to 2017

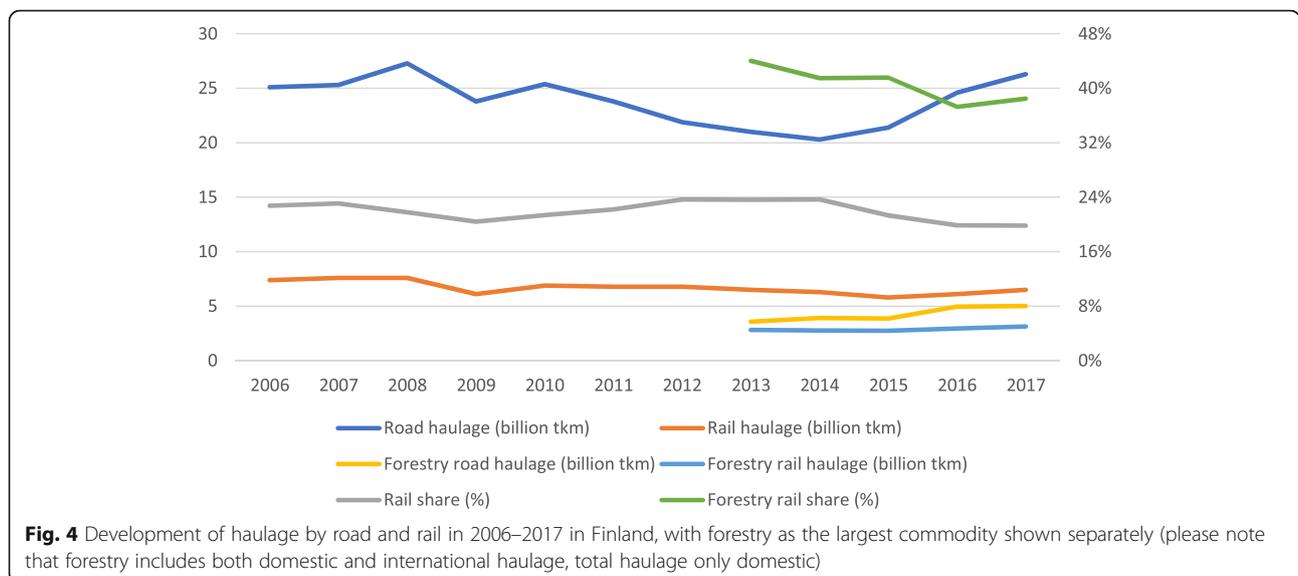


### 4.3 Economic effects

Finnish Ministry of transport and communications [37] estimated that cost savings of approximately 1.6–3.2 billion € could be achieved over a 20-year period due to the higher weight limits. The study by Nykänen and Liimatainen [5] estimated that the maximum savings could be 183 M€ annually and 3.4 billion € over a 20-year period. This was the absolute maximum estimate of the benefits, which could be achieved if all haulage carried out with 90% weight utilization rate would instead be carried out by fully using the new maximum weight limits. These estimates also included savings from the utilization of extra capacity in 2- to 5-axle trucks. However, we can now see that the utilization of higher weight limits have been

virtually non-existent with these trucks and these are hence not considered in this study. Based on the actual use of HCVs, the realized cost savings can now be calculated.

Table 5 shows that the cost savings have risen year-on-year from the reduced vehicle kilometres due to increased weight limits and reached 126 million € in 2017. The actual savings are thus much lower than the 183 M€ maximum savings estimated in Nykänen and Liimatainen [5], in which it was assumed that all weight-restricted haulage done with 7- or 8-axle vehicles would use 9-axle vehicles instead. In Nykänen and Liimatainen [5], there was a lower figure for costs per km, because the same costs, derived from Tervonen et al. [38], was used for all vehicle types. In this study, different costs for each of the



**Table 4** Vehicle kilometres saved by using HCVs in 2017 by commodity

Commodity group with NST number	Saved vehicle km (million km)	Total vehicle km (million km)	Saved vkm as % of total vkm
01 Agricultural products w/o forestry	2.8	70	3.9%
Forestry	26.4	122	21.6%
02 Coal	0.0	1	2.8%
03 Mining and quarrying	8.6	100	8.6%
04 Food products	3.1	244	1.3%
05 Textiles	0.0	17	0.0%
06 Wood products	4.5	135	3.3%
07 Coke and petroleum products	3.4	55	6.2%
08 Chemical products	2.4	54	4.6%
09 Glass, other non-metallic mineral products	2.8	81	3.5%
10 Metal products	1.0	85	1.2%
11 Machinery and equipment	0.6	42	1.3%
12 Transport equipment	0.0	42	0.0%
13 Furniture	0.0	10	0.0%
14 Waste	1.4	63	2.3%
15 Mail	0.0	56	0.1%
16 Empty containers, packaging	0.0	30	0.1%
17 Household and office removals	0.0	62	0.0%
18 Grouped goods	3.2	275	1.2%
19 Unidentifiable goods	0.0	9	0.0%
20 Other goods and empty	20.3	407	5.0%
<b>Total</b>	<b>81</b>	<b>1958</b>	<b>4.1%</b>

five vehicle types was used (Table 2). This further increases the difference between maximum estimated benefits and actual benefits of the use of HCVs.

Cost savings from the use of HCVs increased 24% from 2014 to 2015, 48% from 2015 to 2016 and 29% from 2016 to 2017. Part of the growth was due to increase in total haulage, but mainly the growth is due to 7-axle vehicles being replaced by 9-axle vehicles, as was presented in Fig. 3. The shares from different vehicle types has remained fairly stable as the share of cost savings of forestry has been 42–45% and long-haul distribution between 23 and 27%. This indicates that the rate of

replacing old 7- or 8-axle LHV with new 9-axle HCVs has happened at a similar rate with all vehicle types.

The total cost savings cumulatively from October 2013 to the end of 2017 are 348 M€. Figure 3 shows that the savings from extra capacity have grown somewhat continuously, although there is some variation between quarters. In order to analyse whether there still is potential for additional savings, the share of haulage within the various vehicle age groups are analysed. Of the total haulage in which extra capacity was utilized, 66% of the haulage by vehicles registered in 2014–2017 was carried by 9-axle vehicles, 33% by 8-axle vehicles, and 1% by 7-axle vehicles. Hence, the share of 9-axle vehicles seem to have reached its maximum at around 66% of the haulage benefiting from the weight limit increase. The savings are likely to increase further as all old 7-axle vehicles currently used to carry extra capacity are replaced by new 9-axle vehicles. In 2017, the 9-axle vehicles' share of the overall haulage benefiting from weight limit increase (12.2 billion tkm), was 47% (5.8 billion tkm). If 9-axle vehicles would have had the 66% share and 8-axle vehicles 34% share of this haulage (i.e. the shares the new 9- and 8-axle vehicles which have been registered after the weight limit increase have), approximately additional 2.3 billion tkm could transfer to 9-axle vehicles, of which 1.7 billion tkm from 7-axle vehicles and 0.6 billion tkm from 8-axle vehicles. With the current average load of 35.1 t for 7-axle vehicles, 37.2 t for 8-axle vehicles and 45.6 t for 9-axle vehicles, the shift of 1.7 billion tkm from 7-axle to 9-axle vehicles would save about 11 million km and shift of 0.6 billion tkm from 8-axle vehicles to 9-axle vehicles would save about 3 million km in addition to current savings of 81 million km. The total savings would then be approximately 95 million km (i.e. 14 million km more than actual savings in 2017), which would be about 4.9% of total truck mileage in 2017.

The maximum savings of using HCVs depends also naturally on the development of total haulage and particularly the haulage of the weight-restricted commodities and especially forestry (Table 4). In 2017 as much as 57% of haulage of forestry used 9-axle vehicles, so the share of HCVs might be saturating. However, the haulage of forestry is likely to increase in Finland because of investments in new pulp mills and biorefineries planned and made in 2017 and 2018 [39].

If the implementation of HCVs would saturate to around 5% of total mileage, the annual savings would be approximately 155 M€. Calculated with 1% inflation, the savings would then be approximately 2.6 billion € over the 20-year period. This is within the range of 1.6–3.2 billion €, which was estimated by the Finnish Ministry of Transport and Communications [37], although significantly less than the estimated theoretical maximum benefits (3.4 billion €) if all suitable haulage with

**Table 5** Cost savings of using HCVs in 2013–2017

	Part load	Forestry	Long-haul distribution	Tanker and bulk	Construction	Total	Savings as % of total
Vehicle kilometres saved (million km)							
2013/Q4	0.8	1.8	0.9	0.1	0.4	4.0	0,7%
2014	0.1	15.8	9.5	2.4	6.3	34.0	1,9%
2015	0.2	19.4	12.6	5.3	5.2	42.7	2,7%
2016	0.5	30.2	18.8	5.2	8.8	63.5	3,4%
2017	0.8	36.2	23.3	7.1	13.4	80.9	4,1%
Total	2.3	103.4	65.2	20.2	34.1	225.1	2,9%
Cost savings (million €)							
2013/Q4	1.0	2.6	1.3	0.2	0.7	5.9	0,7%
2014	0.1	23.2	13.4	4.3	12.1	53.1	2,0%
2015	0.2	28.4	17.9	9.4	10.0	66.0	2,8%
2016	0.6	44.2	26.7	9.3	16.9	97.9	3,6%
2017	1.0	53.1	33.0	12.6	25.8	125.5	4,4%
Total	2.9	151.6	92.3	35.7	65.5	348.0	3,1%

7- and 8-axle vehicles would transfer to fully laden 9-axle vehicles [5].

#### 4.4 Environmental effects

Based on the saved kilometres, the fuel savings and CO<sub>2</sub> emission reduction can also be calculated. Table 6 presents the results of these calculations. Fuel savings reached 44 million litres and CO<sub>2</sub> emission reductions 118 kt in 2017. The CO<sub>2</sub> reduction is about 3.6% of total road freight emissions (3.3 Mt, see [40]). The share of forestry haulage is larger in fuel savings and emission reductions (55%) than in vehicle kilometre savings (42%), because the fuel consumption per kilometre is higher due to worse aerodynamics and higher average load than in other vehicle types. Cumulatively in 2013–2017 HCVs have resulted in 123 million litre fuel savings and 0.3 Mt CO<sub>2</sub> reductions, which presents a valuable contribution towards achieving the emission reductions targets set in Finland for transport sector.

If the implementation of HCVs would increase by about 20% as estimated in the previous section, the fuel savings would be around 53 million litres and CO<sub>2</sub> reductions approximately 0.14 Mt annually. Over a 20-year period, the CO<sub>2</sub> reductions would be approximately 2.6 Mt.

#### 4.5 Modal shift

One of the main arguments against increasing the capacity of trucks is the possible adverse effect on rail freight transport and shift from rail to road. Figure 4 shows the development of domestic rail and road haulage and rail share of total haulage in 2006–2017. During this time, the rail share has been between 19.9 and 23.7% of total haulage. Both the highest and the lowest

share are from the period during which HCVs have been allowed, i.e. highest in 2014 and lowest in 2017. Hence, it seems that rail share has taken a downward step at the same time that HCVs have been in operation. There might be annual variation due to sample issues, but it seems that there has been a decrease in rail share, particularly in forestry haulage. This conclusion is further verified when both domestic and international haulage of forestry are analyzed.

In 2013, the domestic and international haulage of forestry by road and rail were 6.4 billion tkm and rail share was 44% while in 2017 the total haulage was 8.1 billion tkm and rail share had decreased to 38%. In other words, forestry haulage increased by 11% on railroads while increasing by 40% on roads. It is reasonable to assume this modal shift has occurred due to economic benefits of increased vehicle weight, but other factors may have had an effect as well, so longer term development of modal shares will be needed to see the actual effects. A study from Sweden analysed the long-term effects of previous truck weight increases and highlighted that weight increases did not have short-term effects, but the share of each mode continued its long-term development [41].

However, based on these numbers it is possible to estimate the effect of modal shift on the environmental benefits on HCVs. If the share of rail haulage would have remained the same in 2017 as it was in 2013, 450 million tkm of road haulage of forestry would have remained on railways. Assuming that these would have been hauled using the average loading (40 t on laden trips) and empty running (40% of total vkm) of forestry, the CO<sub>2</sub> emissions from the shifted forestry haulage would be about 17 kt, which is 14% of the CO<sub>2</sub> emission reduction in 2017 presented in Table 5. Hence, increasing the

**Table 6** Fuel and CO<sub>2</sub> savings of using HCVs in 2013–2017

Fuel consumption (l/100 km)							
	Part load	Forestry	Long-haul distribution	Tanker and bulk	Construction		
	30.3	66.7	37.5	46.5	58.1		
Vehicle kilometres saved (million km)							
	Part load	Forestry	Long-haul distribution	Tanker and bulk	Construction	Total	Savings as % of total
2013	0.8	1.8	0.9	0.1	0.4	4.0	0,7%
2014	0.1	15.8	9.5	2.4	6.3	34.0	1,9%
2015	0.2	19.4	12.6	5.3	5.2	42.7	2,7%
2016	0.5	30.2	18.8	5.2	8.8	63.5	3,4%
2017	0.8	36.2	23.3	7.1	13.4	80.9	4,1%
Total	2.3	103.4	65.2	20.2	34.1	225.1	2,9%
Fuel savings (million l)							
	Part load	Forestry	Long-haul distribution	Tanker and bulk	Construction	Total	Savings as % of total
2013	0.2	1.2	0.4	0.0	0.2	2.1	0,8%
2014	0.0	10.5	3.5	1.1	3.7	18.9	1,9%
2015	0.0	12.9	4.7	2.5	3.0	23.2	2,3%
2016	0.1	20.1	7.1	2.4	5.1	34.9	3,0%
2017	0.2	24.1	8.8	3.3	7.8	44.3	3,6%
Total	0.7	68.9	24.5	9.4	19.8	123.3	2,6%
CO <sub>2</sub> reduction (kt)							
	Part load	Forestry	Long-haul distribution	Tanker and bulk	Construction	Total	Savings as % of total
2013	0.7	3.2	0.9	0.1	0.6	5.5	0,8%
2014	0.0	28.0	9.4	3.0	9.8	50.3	1,9%
2015	0.1	34.4	12.6	6.5	8.1	61.7	2,3%
2016	0.4	53.5	18.8	6.5	13.6	92.7	3,0%
2017	0.6	64.2	23.3	8.8	20.8	117.7	3,6%
Total	1.8	183.3	65.1	24.9	52.8	327.9	2,6%

maximum weight of trucks has decreased the CO<sub>2</sub> emissions of freight transport, but there has been a rebound effect because of modal shift from rail to road.

## 5 Discussion and conclusions

Increasing the length and weight of trucks and widening the use of European modular system have been for quite some time a subject of policy debate and research interest in Europe. Research has highlighted the potential for mileage and fuel savings while noting the concerns about effects on safety and road infrastructure. Finland and Sweden have used the EMS for 25 years and are, encouraged by the good experiences, taking steps further to using vehicles longer than 25.25 m and heavier than 60 t. Finland increased in October 2013 the maximum weight of 7-, 8- and 9-axle vehicle combinations to 64, 68 and 76 t, respectively. This study analysed the results of that increase.

This study shows that the Finnish hauliers have implemented higher maximum weight mostly by replacing 7-axle vehicles with 9-axle vehicles. During 2017, the higher payloads have resulted in mileage savings of about 4% of the total truck mileage in Finland, or about 20 million km per quarter. In 2017, the HCVs resulted in cost savings of around 126 million € and CO<sub>2</sub> savings of at least 0.10 Mt (0.12 Mt without taking into account the effect of modal shift from rail to road which increased emissions by 0.017 Mt as a maximum estimate), which equals around 3% of total trucking CO<sub>2</sub> emissions in Finland. These savings are significant and within the range of possible savings estimated prior to the change. However, the savings do not come without infrastructure costs, which have been estimated to be around 850 million € over a 20-year period due to bridge alterations and increased pavement repairs [42]. This study estimates that the total benefits of increased truck weight could reach 2.6 billion € over a 20-year period, which

would make the change clearly beneficial for the Finnish economy. The effects of HCVs on road safety are likely to be minor in Finland because of the prior use of EMS vehicles. Hence, increasing the maximum weight of trucks seems to be on track to overall positive results.

Based on this study, there are major differences between commodities in the uptake of extra capacity and these differences should be taken into account when the costs and benefits of longer and heavier vehicles are estimated in other countries. Majority of the benefits in Finland came from one commodity, i.e. forestry. In other countries where forestry does not have such an important role in freight transport the benefits of longer and heavier vehicles may be significantly lower. Hence, commodity level approach is required in analysing the potential benefits of LHV or HCV. The effects of HCVs on traffic safety have not been analysed in this study, and there is not enough data for statistical analysis on the safety effects of larger trucks. The HCT combinations (longer than 25.25 m or heavier than 76 t) have been subject to careful scrutiny in Finland and although the combinations have been involved in a few incidents, the fact that the HCT combinations were longer and/or heavier than usual have had no impact on the situations [1].

Another important aspect requiring further research is the role of HCVs in achieving the ambitious CO<sub>2</sub> emission targets. There seems to be a growing interest by vehicle manufacturers to introduce battery electric semi-trailer trucks, but battery electric trucks are not suitable for LHV or HCV, at least not with current battery technology. Hence, Finland has very little opportunities for electric trucks compared to countries, which use semi-trailers [43]. In addition to propulsion development, another more technology-based road freight transport development path to intensify road transport is automation and especially platooning development. Platooning research has been focusing on semitrailers (HGVs), but LHV and HCV may provide similar benefits without the need for technological developments. Platooning could also be studied with LHV and HCV to gain additional benefits.

In the short-term HCVs seem to provide a very cost efficient measure for reducing CO<sub>2</sub> emissions, even when taking into account the infrastructure costs. However, the emission reduction costs through HCVs may increase in the future if electric HGVs become less expensive and the biofuels needed for CO<sub>2</sub> emissions reductions in HCVs become more expensive. Furthermore, HCVs seem to have caused modal shift from rail to road in Finland, but the general aim in the EU is to promote the opposite modal shift from road to rail. Hence, increasing the vehicle length and weight may become politically difficult in the future, even though the CO<sub>2</sub> emissions have decreased in total in Finland due to truck weight increase.

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#### Authors' contributions

HL was primarily responsible for writing the manuscript. MP and LN gave ideas, wrote short sections and commented. All authors read and approved the final manuscript.

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#### Availability of data and materials

The data that support the findings of this study are available from [third party name] but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available.

#### Competing interests

The authors declare that they have no competing interests.

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