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A short Literature Review on Sawlog and Pulpwood Transport Efficiency and Fuel Consumption

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Abstract

Timber transport is one of the main components of woody supply chain, which causes high costs and considerable emissions depending on truck size, type, transport distance, and payload. A cradle-to-gate life cycle assessment of Softwood plantations and regrowth hardwood native forests estimated that the most significant contributor to total greenhouse emissions per unit of wood production in softwood plantation was log haulage at 37%. For regrowth native hardwood forests, log transportation contributed 23% of greenhouse gas emissions. This research, built on existing literature, focused on how timber harvesting transportation costs and emissions to the environment can be reduced, specifically, the transport of the industrial timber logs from the Forest Stockpile to the processing facility or unloading points. The review summarized the data and highlighted that the efficiency and emissions data could be categorized into five themes: Higher Capacity Transportation (HCT), Road Networks & Surfaces, Logistics and Planning, Fleet Replacement, and Fuel efficiency technologies. Fuel efficiency improvements across these themes ranged from 3% to 43% within the reviewed case studies. Several studies researched the fuel efficiency of High Capacity Transport indicated that the fuel consumption in liters per ton kilometer was 8-11% lower in the 92-tonne combination HCT compared to a 72-tonne combination HCT due to the increased payload for High Capacity Transport. Road networks and the composition of the surfaces have been shown to have a strong correlation to emissions. Studies have shown a 16.7% increase in emissions from a network of predominantly highways to a higher proportion of Forrest and Gravel roads. Studies that included data on vehicle age found efficiency improvements of up to 26% when new vehicles' fuel consumption was compared to older vehicles. Newer truck fleets incorporate newer technologies, with reports showing fuel consumption improvements of up to 43% with less than a two-year payback period.

Keywords: Transportation, Sustainable, Timber haulage, Emission, Fuel Efficiency

1. Introduction

The Climate Change Bill 2022 outlines that Australia's target for greenhouse gas emissions reduction targets was 43% reduction from 2005 levels by 2030 and net zero by 2050. In the year to June 2022, the Land Use, Land Use Change and Forestry (LULUCF) sector accounted for -8.1% of Australia national Greenhouse gas emissions inventory, a net sink. Forestry is already seen as a green industry but there is a growing demand for promoting sustainably managed forests as included in the United Nations Sustainable Development Goals.

The life cycle process of a timber plantation can be summarized, beginning with the establishing the site and seeding & planting, managing forest including fertilizing and herbicides, and road construction-finally, the harvesting the timber and the haulage to the mill. A cradle-to-gate life cycle assessment of Softwood plantations and regrowth hardwood native forests (England et al., 2013) estimated that the most significant contributor to total greenhouse emissions per unit of wood production in softwood plantations was log haulage at 37%. For regrowth, native hardwood forests' log transportation contributed 23% of greenhouse gas emissions, the second highest only to the practice of slash and burned at 46%.

Transporting woody products by timber trucks is costly due to the long travel distances between plantations and mills (Acuna et al., 2012; Brown and Ghaffariyan, 2016; Brown, 2021). Transportation cost accounts for more than 25% of forestry costs (Svenson and Fjeld, 2016). Higher operating costs may occur due to increased fuel costs. Higher fuel usage will also cause significant emissions to the environment. Transportation is the most fuel-consuming element of a wood supply chain in Australia and other countries (Griffin and Brown, 2010; Ghaffariyan et al., 2018).

Modelling completed in Australia by the Commonwealth Scientific and Industrial Research Organization (CSIRO) in 2017 estimated 28 million trips

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over 25 years (2016-2041) would be required to transport about 800 million m^3 of timber at a total cost of $23 billion (Higgins et al., 2017). This project researched existing literature on how timber harvesting transportation costs and its emission to the environment can be reduced. The research focus did not cover all elements of the cradle to gate emissions of the transportation due to the limited time scale for the review, emissions generated through truck tire and road construction and wear were identified but considered outside of the research boundaries.

A short review of studies on the fuel consumption of timber trucks was published in 2018 (Ghaffariyan et al. 2018). Typically, the efficiency of transport is measured in liters per 100 km. Where load size varies, this needs to be factored into the comparison by adding the metric of payload tons transported per liter per kilometer. It is highlighted by wood transportation data analysis in Finland (Palander et al., 2020), where it was found that a 64 t vehicle combination consumed 4.9% less energy per kilometer than a 76 t combination vehicle; however, emissions actually decreased by 10.7% when the results are considered in ton-kilometers because of the reduced fuel consumption per transported unit. Emissions are typically measured in the amount of CO_2 emissions; hence, a metric utilized for transportation efficiency regarding emissions is CO_2 emissions in tons per ton of product per kilometer transported (gt t × km^{-1}).

The transportation of timber products can be defined by the following phases as defined in (Holzleitner et al., 2011)

- Driving Empty
- Loading
- Driving Loaded
- Waiting for acceptance
- Unloading

Many factors affect fuel consumption and emissions, including haul length, the maximum payload of the combination used, weather, road conditions, and operator experience. This study summarizes recent literature on fuel consumption and caused emissions in the timber haulage phase of the sawlog and pulpwood supply chain.

2. Material and Methods

The fuel consumption and findings on efficiency improvements for timber transportation were collected through a literature review of recently published research (focusing on the last 10 years). The search specifically focused on sawlog transportation with the following keywords used in the online search of literature: transportation, sustainable, timber haulage, emission, and fuel efficiency. The online search was conducted using a combination of ResearchGate and Google Scholar, with 34 research studies identified. Research studies were geographically spread around the globe, including Australia, Brazil, Canada, Croatia, the Czech Republic, Finland, Poland, Slovakia, Sweden, and Turkiye.

Work efficiency is defined using time study method where transport time (including productive and delay times) and work output (volume or weight of transported wood) are measured (Griliches, 1998; Magagnotti et al., 2012; Heinimann, 2021;). Different factors can impact the productivity of a truck, such as transport distance, load weight, road types, and truck configurations.

The fuel consumption of truck is usually measured in liters per 100 kilometers. In the research studies, several techniques were used to record data, including onboard computer data, manual measurements, data from corporation GIS Systems, and data from enterprise resource planning systems.

3. Results and Discussion

The results of the literature review have been summarized into key themes for fuel, cost, and emissions savings, including:

- Higher Capacity Transportation
- Road Networks & Surfaces
- Logistics and Planning
- Fleet Replacement
- Fuel efficiency technologies

3.1. Higher Capacity Transportation

A case study of laden timber truck combinations in Finland measured, modelled, and compared a 92 t HCT to a standard 72 t combination. Due to the increased payload, the fuel consumption in mL tkm^{-1} was 8-11% lower in the 92 HCT combination (Karha et al., 2023). It was also reported in an analysis (Palander et al., 2020) where it was found that a 64t vehicle combination consumed 4.9% less energy per kilometer than a 76t combination vehicle. However, emissions actually decreased by 10.7% when the results are considered in ton-kilometers because of the reduced fuel consumption per transported unit.

A network analysis based software, Network 2000 Program, was utilized in Turkiye to complete integrated planning for timber extraction and hauling activities (Akay and Sesen, 2021). The study compared 15-ton and 22-ton capacity size truck units. The unit cost of hauling was computed based on the hourly unit cost of the logging truck, the load capacity of the truck, and operating time. The scenario analysis found that the higher capacity truck reduced hauling costs by 8%.

An analysis of fuel consumption was published in 2019 based on data retrieved in between 2012 and 2013. The analysis compared two combinations: a conjugated vehicle with composition truck, semi-trailer and trailer PBTC 68.5 T and an articulated vehicle with composition of a tractor and semi-trailer with PBTC 48.5T. It was found that the articulated combination could transport an additional 11.3% for 1km per liter of fuel, referred to as the energy yield (Guimarães et al., 2019).

3.2 Road Networks and Surface

The study into the impacts of road infrastructure on the environmental efficiency of high-capacity transport focused on the make up of road network (Palander et al., 2021). The percentage of the network was summarized into three categories: Highway Category (H), Gravel Roads (G), and Forest Roads (F). The study calculated the impact on diesel and CO_2 emissions for different shares of each type of road for class 76 t and 92 t vehicles.

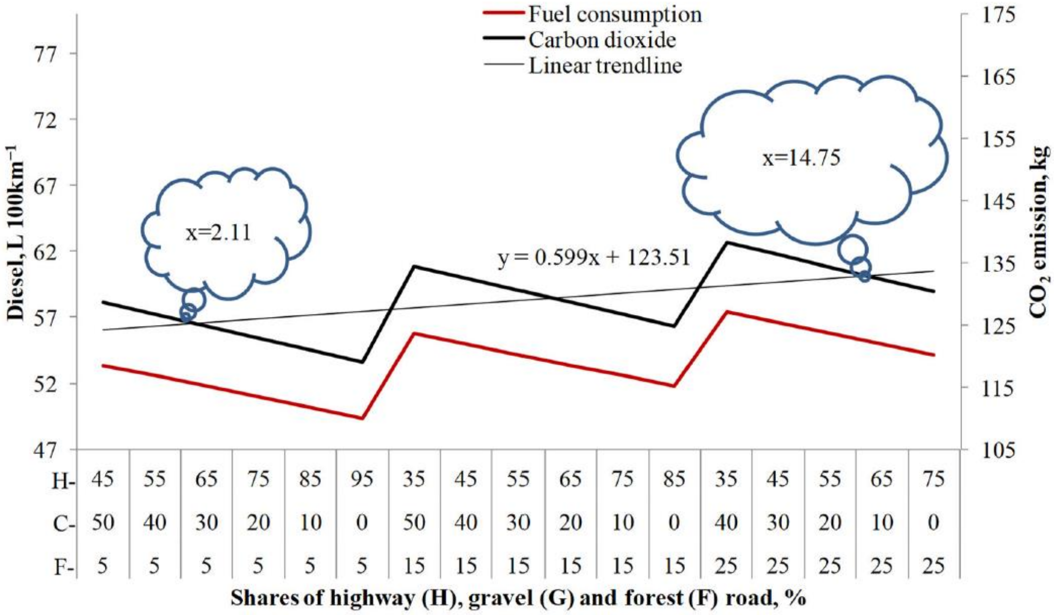

Figure 1. The effect of road-network setup on CO_2 emissions of 76 t vehicles in line-hauling transportation of renewable wood (Palander et al., 2021)

The calculations showed a 16.7% increase in emissions from a network consisting of 5% forest and 95% highway to the 25% forest, 40% gravel, and 35% highway network setups. Modelling completed by the CSIRO (Higgins et al., 2017) used a ground-up costing to model logging vehicle costs in Australia. An overview of the cost at varying travel speeds is below. The modelling shows lower average speeds are nearly three times the cost per km. At the same time, there is a significant variance in cost per km in type of truck under Australia's Performance Based Standards (PBS) for vehicle classification and limits.

Table 1. Overview of vehicle transport costs Australia

	Modelled cost ($AUD/km) per travel speed		
PBS Scheme	100 km/h	60 km/h	20 km/h
Level 1 (Semitrailer)	1.91	2.58	6.11
Level 2A (B-Double)	2.35	3.13	7.36
Level 3A (Type 1)	2.71	3.54	6.81
Level 4A (Type 2)	3.43	4.36	8.22

A study of three types of logging trucks in Slovakia defined two types of hauls as primary hauls (stems and long wood) from roadside landings to a conversion depot (6.4 km to 29.8 km) and secondary haulage of pulpwood from roadside landing or the depot to a paper mill (approx. 70 km). $C0_2$ emissions were estimated at 2.83 to 5.54 kg of CO_2 per m^3. The longer secondary haulage route causes the most emissions (Allman et al., 2021). As such, the authors state that it would be necessary to increase the maximum capacity allowed on the roads to improve efficiency.

3.3. Logistics and Planning

A study conducted in Brazil determined an average operating efficiency of 91.6%. (Lopes et al., 2016) The relatively short haul of 40km from harvest location to the mill meant that the loading and unloading made up a large proportion of the cycle, approximately 38%. With this increased focus on unloading and loading times, it was found that the loading and unloading time for longer logs were generally quicker. The detailed analysis also found queuing in loading and unloading, which could be improved by planning additional loaders or fleet management systems.

Several studies conducted sensitivity analysis and modelling to determine equations for estimated fuel consumption, for example, 0.74 liter per km (Guimarães et al., 2016). The driving factor for efficiency was haul distance, with high correlation, whereas the loading and unloading variables had lower correlation indicating large variances due to delays in unloading and loading processes.

3.4. Fleet Replacement

Research on fleet of 17 trucks in Croatia comprised trucks aged between 6 months and 24 years (Šušnjar et al., 2019). The study found that newer trucks consumed up to 10 liter/100 km less than the older 22 and 24-year-old trucks. The study also found that the truck fleet less than 10 years old had an operational availability ranging from 91 to 99%. In contrast, the older fleet from 10 to 24 years had 71 to 88% availability, with the number of days spent in breakdowns almost three times higher. An earlier study conducted by (Klvač et al., 2013), which had access to data over extended periods, highlighted fuel consumption savings of 0.5 liter/m^3 or 9% per 100 km due to a fleet renewal process.

3.5. Fuel Efficiency Technologies

The International Council on Clean Transportation published a study titled "European heavy-duty vehicles: cost-effectiveness of fuel efficiency technologies for long-haul tractor trailers in the 2025-2030 timeframe". The study estimated a 27% reduction in distance-based fuel consumption with technologies with payback periods generally less than one year (International Council on Clean Transportation, 2018). While the study is not specific to timber haulage, which would have lower average speeds impacting fuel consumption efficiency, such as aerodynamics, the technologies are transferrable. The below figure best summarizes fuel consumption technologies included and payback periods (Figure 2).

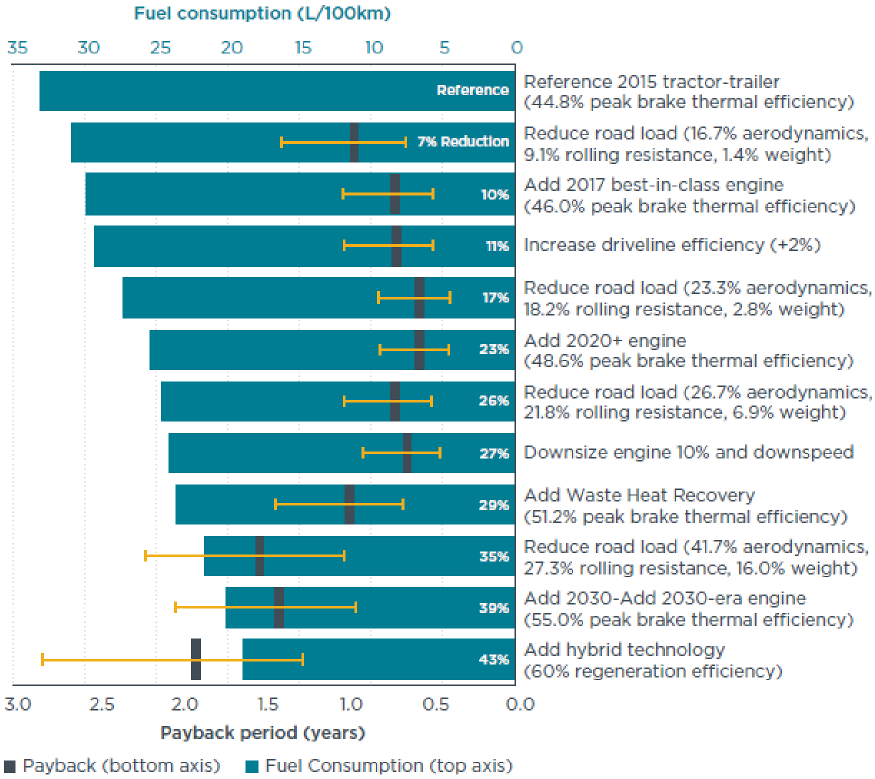

Figure 2. Cumulative fuel consumption impacts and associated 2030 payback periods for tractor trailer efficiency technologies

The Forest Engineering Research Institute of Canada (FERIC) completed an example case study for the application of technologies in 1999. The project, known as the Star Truck, involved improvements to the specifications of a new truck versus a standard control truck used by a haulage contractor. A truck with a tare weight of 3000 kg less than the fleet average was achieved through the specification of lightweight components. The truck was monitored for a year of operation compared to the control truck, and it was established that it could carry 9.8% more payload while consuming only 1% more fuel (Office of Energy Efficiency Natural Resources Canada, 2016).

A paper published in 2017 explored the benefits of Central Tire Inflation (CTI) as a transportation technology (Ghaffariyan, 2017). The paper discussed the strong correlation between road surface and truck mobility across multiple studies and findings showed that using CTI systems can increase fuel efficiency between 3-30%. Other improvements, such as tire life and improved safety, are highlighted along with fuel efficiency.

Australian scholars reviewed the fuel usage of timber trucks and created a data base for Australian, Canadian, and International studies. They developed fuel consumption prediction models depending on the payload (Figure 3). Their results indicated that payload significantly impacts the fuel consumption of timber trucks. Canadian truck fuel consumption model over predicted the fuel consumption compared with international model. They suggested that the Australian fuel consumption model for general trucks might be a guide for the forest industry to use.

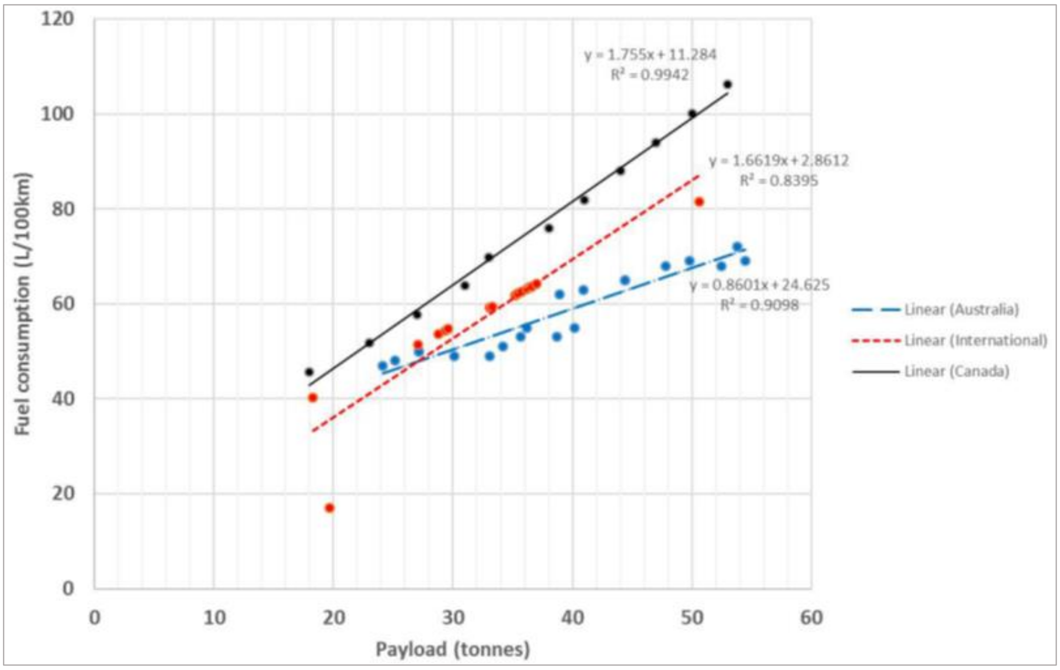

Figure 3. Fuel consumption as function of payload for international model (dash red line), Canadian model (solid black line) and Australian model (dash blue line) (Ghaffariyan et al., 2018)

More recently a collaboration between Scania and SCA (Europe's largest private forest owner) has developed the first electric timber truck with a capability of up to 80 tons of total weight. The truck is currently being trailed in Sweden and is expected to reduce carbon emissions by 55,000 kg annually (SCA, 2023).

3.6. Summary

A summary of the fuel efficiency improvements is presented in Table 2, with fuel efficiency improvements ranging from 3 to 43% for various improvement measurements, including central tire inflation, road network use, high vehicle capacity transportation, weight reduction strategies, and technology improvement.

The results of several studies on emissions calculations are summarized in Table 3. Recent literature has not converged on a single measure for emission efficiency, as some studies measure loads in m^3, but they do not specify the timber type for density data.

Table 2. Summary of transportation efficiency studies

Country	Fuel Efficiency	Improvement Measure	Combination	**Reference**
Finland	8-11%	Use of High Capacity Transportation	76t &92t	(Karha et al., 2023)
Finland	16.7%	Road Network Use	76t &92t	(Palander et al., 2021)
Croatia	10-26%	Age of Fleet	-	(Šušnjar et al., 2019)
Czech Republic	9%	Age of Fleet	-	(Klvač et al., 2013)
Canada - Saskatchewan	3 – 30% fuel consumption improvements	Central Tyre Inflation	-	(Ghaffariyan, 2017)
Canada - Ontario	6%	Central Tyre Inflation	-	(Ghaffariyan, 2017)
Canada - Quebec	5.8%	Various Weight Reduction initiatives	-	(Office of Energy Efficiency Natural Resources Canada, 2016)
EU	7-43%	Technology improvements	-	(International Council on Clean Transportation, 2018)

Table 3. Summary of Emissions Data

Country	Fuel Consumption (L/100km)	CO_2 Emissions	Reference
Croatia	66	185.9g/tkm	(Zoric et al., 2014)
Finland	58-73	27.1 to 35.1 g × tkm^{-1}	(Palander et al., 2020)
Poland	37.1	1.936 kg/m^3 61.53 g/m^3/km	(Lijewski et al., 2017)
Slovakia	38.8 to 82.37	2.83-5.54 kg/m^3	(Allman et al., 2021)

4. Conclusions

Existing literature on how timber harvesting transportation costs and emissions to the environment can be reduced have been reviewed and summarized into themes, including Higher Capacity Transportation, Road Networks & Surfaces, Logistics and Planning, Fleet Replacement, and Fuel efficiency technologies. The use of high capacity transport in recent literature as a means to reduce CO_2 emissions per ton of timber transported is well documented. Combining network modelling of routes and route type with fuel consumption equations can provide industry and government with valuable data to make investment decisions regarding emissions reduction infrastructure, such as upgrading forestry roads or bridges for high-capacity transport. It is recommended that the new technologies with regard to fuel consumption efficiencies be further studied and analyzed with respect to their application to the timber haulage industry to inform stakeholder decision-making processes.

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