Environmental properties and scenarios for future rail systems: infrastructure and operation of high-speed rail in Norway

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Abstract The environmental performance of high-speed rail is controlled by several interacting factors, including requirements for the infrastructure, operational properties of the rolling fleet, and load factors for infrastructure and train sets. Besides the technical components, deforestation and land use changes may represent significant portions of the environmental footprint of new rail sections. In this paper we describe the temporal sensitivity in these factors, and investigate their importance to life-cycle assessment of high-speed rail futures in Norway.

Prospective studies for railway need to consider scenarios for the future development of all system components, including market issues, technology and external factors. Energy use and energy technology is an issue treated in most strategic studies, for transport and other systems. However, given the large portion of renewables in the electricity market, life-cycle assessments for rail in the Scandinavian context have indicated that infrastructure dominates many of the impacts, especially climate change effects. The initial development of infrastructure must be made using current technology, but maintenance and operation of infrastructure represent major parts of the footprint and thereby provide important potentials for improvement through time. Moreover, traffic pattern and traffic demand is expected to change in the future, and these will affect both infrastructure load and efficiency in use of the rolling stock.

We present environmental properties and scenarios for future high-speed rail systems in Norway. The model inventory draws upon several recently completed reports for the environmental performance of rail in Norway, adjusted to represent intercity high-speed rail corridors in process life-cycle assessment. We describe scenarios for the temporal development of controlling factors and investigate their importance to the total environmental performance. Factors for evaluation include energy source and efficiency, fleet and infrastructure utilization, production

technology for infrastructure inputs (most importantly steel and concrete) and energy supply, as well as the external biogenic aspects.

1 Introduction

Norway is assessing the feasibility – financial costs, social and environmental impacts - of future high-speed rail (HSR). The size of potential market for HSR in Norway is assessed as much smaller than HSR markets already established in other countries such as France and Germany, but similar to that of Sweden [1]. VWI conducted a feasibility study conducted a feasibility study that showed several advantages for Norwegian HSR [2]; among them was reduced travel times, greenhouse gases (GHG) and exhaust emissions. Moreover, accessibility between major cities and regions will increase and HSR reduces air transport considerably thereby resolving future airport capacity problems.

Experiences from other European countries have shown that HSR in Norway will require three conditions to be filled. First, main markets should be concentrated on the major points on demand, and only a few numbers of intermediate stops should be taken in greater communities with sufficient traffic demand. Secondly, planning of infrastructure should aim for single track, where technically possible, for cost optimization. Third, additional regional services should play a feeder role for the high-speed network [2].From this, lines Oslo-Bergen and Oslo-Trondheim have been indicated as the most interesting connections in Norway for HSR [1,2].

High-speed means operational speed at 250 km/h or faster. A HSR concept integrates technologies for infrastructure, rolling stock and operation, with speed and marked set by population distribution, topography and stop scheduling. Operating at high-speed increases energy consumption per seat, and puts limits on the number of stops that can be served on a line [2]. Previous new HSR lines in Europe consist of a combination of existing and upgraded infrastructure [2], and this has been indicated as the probable case in Norway also [3].

Previous studies that have investigated environmental performance of conventional rail and HSR have concluded that the treatment of temporal considerations is important for many of the controlling factors, such as energy efficiency of whole trains, seat capacity per train and seat utilization [4,5]. Infrastructure also plays a key role, especially when the electricity mix used for operation has a low carbon footprint (CF) [4,6], which is the case in Norway. The development of energy supply for rail operation should also be included. Most HSR are operated with electricity, so the future electricity system therefore becomes a particularly sensitive model decision.

In this paper we build on the railway infrastructure inventory model made by MiSA for intercity and high-speed rail in Norway. We use SimaPro, and assume a backgound system according to ecoinvent (version 2.2). The aim of this study is not to compare HSR with other means of transportation, but to find out core factors for Norwegian HSR and to draw their likely development up to 2050 in a LCA perspective. Results presented here should therefore be interpreted for the importance of scenario parameters, rather than as indications of the absolute emissions from an expected HSR concept in Norway. Scenario development and sensitivity for each core factor is described further in the full report [7].

2 Core parameters for the environmental performance of high-speed rail

2.1 Core parameters from literature

The following core parameters have been identified in the literature, for the total environmental performance of high-speed rail, given conditions relevant for the Nordic countries and Norwegian conditions [4-6, 8-10].

Background system
Infrastructure (composition of sections: tunnel, bridges and open sections, and their construction and material use), steel, cement, extrudes polystyrene (XPS), use or more renewable energy in the steel/cement production process, use of more recycled steel/cement, deforestation

Foreground system
Electricity mixes, passengers per train, seat occupancy, maintenance, freight transport

2.2 Life-cycle model for high-speed rail (HSR-LCA)

The detailed model is described in the full report [7]. Our model builds on the data and structures in previously completed inventories for rail in Norway [8, 11], with adaptations to take into account the temporal development of core parameters. The corridor modelled here is generic and must not be interpreted as a specific line in

Norway. Results are aimed at quantifuying the importance of various parameters and the potential improvement in these towards a future HSR concept in Norway.

The inventory model consist of three main parts: infrastructure, rolling stock and operation. The infrastructure model links components, such as tunnels, bridges and open sections, with material and process inputs based on Norwegian planning data. Life-cycle of rolling stock is adapted from ecoinvent IC trains, normalized per seat. Energy use per passenger and environmental load from utilization of infrastructure depends on specific properties of each (e.g., energy efficiency of trains) as well as market potentials. Energy use data is based on reported values and potentials discussed in literature.The end model is unit process-based and parameterized, to accomodate investigation of scenarioparameters for single core factors and scenarios for the total HSR concept.

Background system inventories in ecoinvent have been updated to take into account the time span between the origal source data and 2010. Foreground data refers to specific data needed to model the system. The foreground system of HSR models consists of energy use for operation, corridor-specific factors for occupancy (load factors) and the composition of infrastructure for the major components (open section, tunnel, bridge).Figure 1 below shows results for the corridor, indicating the relative importance of each part of the HSR concept [7].

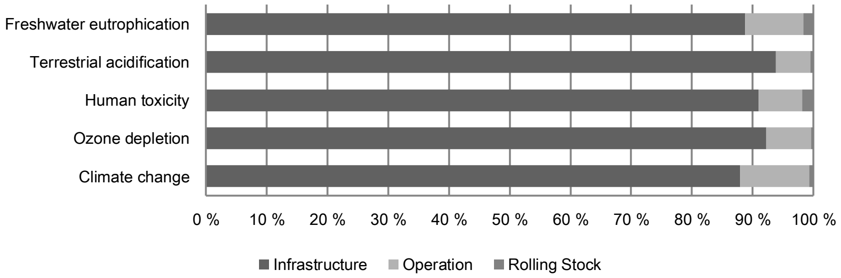

Fig.1: Results for Oslo-Trondheim (Infrastructure, Operation, Rolling stock) [7]

Infrastructure accounts for a large share of the emissions; from 88% for climate change to 94% for terrestrial acidification. It is not surprising to find a large amount for infrastructure since the electricity mix used for operation has a low CF (166 g CO2 eq per kWh). This corresponds with the findings for European settings [4, 5,10], that emphasize the larger share of infrastructure with a electricity mix with low CF for operation and the lower share of infrastructure with a electricity mix with high CF. For instance, a study for Euope found shares for infrastructure ranging from 9% with an el mix with high CF for operation to 31-85% for el mix with low CF [4]. Our results are in teh top end of teh scale in literature, for the importance of infrastructure. The main reason is the relatively low number of trains running on the infrastructure, leading to a low use of electricity for operation, a small total emissions for operation and thus a larger share for infrastructure.

2.3 Land use and land use changes

Land use and land use changes (LULUC) generate GHG emissions through deforestation and release of soil carbon from clearing of land. Significant indirect LULUC emissions may also be caused by drainage of wetlands through change of waterways or other. Two previous studies have estimated LULUC GHG emissions from developing track lines. For Norway, including soil carbon release from standing mass and parts of the soil removed, LULUC emissions were estimated at estimated 17.6 kg CO2 per average m2 transformed in railway construction [9]. Including only forest biomass, a Swedish study estimated 14.4 kg CO2e per m2 [12]. To compare, general inventory methods estimate a pulse of 6 (grass) -15 (forests) kg CO2e per m2 transformed to artificial land [13].
We will not model this issue further here, only point out that with the values above LULUC emissions are likely to represent within 10-20 % of GHG emissions from developing rail infrastructure. This is significant to the overall emissions from the HSR system. Alignment plans and line design should therefore be made with LULUC emissions and land management in mind. In Norway, forest area consists of almost 40% of the national landscape. The remainder is mountainous areas at 44% of the territory, and wetland, lakes and glaciers at 13% [14].

3 Scenario development

3.1 Parameter sensitivities

Parameters were tested separately, for the sensitivity towards scenario settings; cement (secondary material and secondary fuel in clinker), steel (use of scrap, increase in energy efficiency in the production process) and XPS (blowing agents used in the production process) in the background system. In the foreground system, for the sensitivity of the electricity mix used for operation, the load factor as well as the energy-per seat km as are investigated These are further described in the accompanying poster, and in the full report [7].

3.2 Collected scenarios for future HSR in Norway

The following scenarios are defined, to combine the likely development of core factors for the environmental performance of future HSR in Norway. Parameter settings for each are summarized in Table 1, with details for factors in the background and foreground systems discussed separately in the next section.

Tab.1: Scenarios development

			Units	2010	2050	2050+
Background	Cement	secondary material	%	5	37	60
		secondary fuel	%	18	37	60
	Steel	energy	% decrease in energy use	10	20	40
		quality	% chromium steel in rails	10	10	10
		recycling	% scrap	37	60	80
	XPS	blowing agent	% CO2	70	90	100
			%HFC-134	10	-	-
			%HFC-152a	20	10	-
Foreground	El mixes for operation		CF (g CO2 per kWh)	166	130	100
	Energy per seat-km		kWh per seat-km	0,041	0,035	0,035
	Load factor		%	55	70	80
	Energy per pass-km		kWh per pkm	0,075	0,050	0,044
	Passenger per day		person (share of HSR)	5223 (43%)	8685 (72%)	9899 (82%)
	Trains per day		-	38	49	49

2010

The data from the background system has been modified by the authors to take into account the time span between the modeling of the data from the database and their use in the HSR model.

2050

The background and foreground system have been modified. The numbers for the background system are based on literature studies for 2050. This is, this scenario is feasible, based on production technique and material available.

2050+

The background and foreground system have been modified. The numbers are based on scenario 2050. However, scenario 2050+ is beyond the average production techniques and quantity of material available by that time. To reach the goals set in 2050+, the organization running the train and the infrastructure in order to “deliver the transport service to meet the total transport demand” (functional unit) will have to dress a list of specific requirements to its suppliers and a active yield management. The requirements concern the materials and energy used in the production process. For instance, one could require from cement producers cement with 60% secondary material and secondary fuel. Concerning operation the objective could be to drive the trains with a “clean electricity mix”.

3.3 Scenario development for core parameters

Cement

5% secondary material and 18% secondary fuel correspond with the European cement industry in 2006 [15]. [16] predict a use rate of 37% for both secondary material and secondary fuel in 2050. The share of 60% for secondary material for in scenario 2050+ is based on Geopolymer cement [16] that make use of waste material from the power industry (fly ash, bottom ash) and the steel industry (slag). The share of 60% for secondary fuel for in scenario 2050+ is to reflect the share of secondary material.

Steel

The update of 10% in energy efficiency is based on the estimation of the authors. The 20% is based on the International Energy Agency that set the energy efficiency potential, based on today’s best available technologies to about 20% [17]. Nevertheless, by changing from open blast-furnaces to electric arc furnaces, the steel industry could also reduce its use of energy by 50% [18], leading to the number of 40% energy saving. Global scrap availability is today of about 0.4 ton of scrap per ton of crude steel produced. If by 2050 today’s level of crude steel production were to double, scrap availability is estimated to amount to about 0.6 ton per ton of crude steel [19]. “2050” has 60% recycled steel, based on scrap available in 2050. “2050+” has 80% recycled steel, implying that specific requirements have to be specified to suppliers.

XPS

Different blowing agents can be used to produce XPS (CO2, HFC-134, HFC-152a). The use of CO2 as blowing agent is increase in ordre to reduce the impact of ozone depletion.

Electricity mix for operation

The mix of scenario 2050 consists of 70% renewable (hydro), 16% fossils (8% coal, 8% natural gas) and 10% nuclear. The mix of scenario 2050+ consists of 80% renewable (hydro), 12% fossils (6% coal, 6% natural gas) and 10% nuclear. It is unlikely that these two electricity mixes will be representative of the average electricity mix offered by the market in 2050. Again, this objective will be achieved only if the organization running the trains will set as objective to drive the trains with a “clean electricity mix”.

Energy per seat-km

The numbers are based on the report by [20] that estimate green train energy consumption for high-speed rail operations.

Load factor

In 2004, the load factor was in the order of 55% for X2000 [21]. A recent study by [20] shows a further increase of the load factor for X200 to 60%, resulting mainly from a more active yield management. Furthermore, they note that the average load factor for future high-speed trains might even be higher. The 70% for scenario 2050 are an increase based on the estimation of the author from the load factor of 55% in 2010. To reach the 80% of scenario “2050+”, an active yield management will be required.

Energy per pkm

The energy per pass-km is obtained by dividing the energy per seat-km by the load factor.

Passengers per day

For scenario “2010”, the author of this project has based HSR-LCA on 5223 pday for HSR. This number is computed by a schedule of 1 train per hour, in both directions, from 6am to 12pm. This number is very close from the number found by [1] (2011), which found 4920 pday (scenario D: building of new separate HSR line). The original number of 12147 pday for all mode of transportation is kept and developed further in scenario 2050 and 2050+. In scenario 2050, HSR gains benefit from all mode of transport that loose 50% of their passengers. Additionally, in scenario 2050+, the airline Oslo-Trondheim is deleted.

Trains per day

Trains per day are increased by 30% (38 to 49) to satisfy the demand of the increased number of pday from scenario 2010 to scenario 2050+. Trains consist of 250 seats.

4 Results for future high-speed rail

Scenarios described above were implemented in the inventory model for HSR in Norway, for a predefined corridor with mostly open sections. Aggregated results are presented in Figure 2, as improvements for a selection of impact categories.

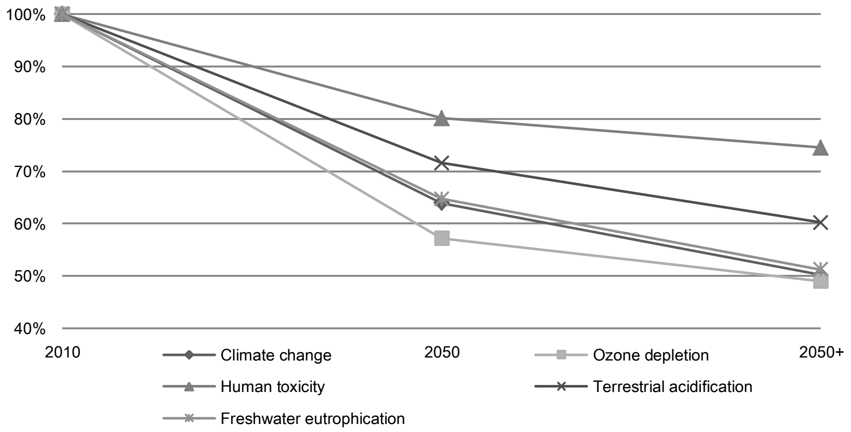

Fig.2: Scenarios results, per passenger-km by high -speed rail

Climate change

The decrease comes to a large extent from the use of secondary material in clinker production for cement. To a lesser extent, it comes from the increase in energy efficiency for steel of high and low quality and from the use of recycled steel for steel of low quality.

Ozone depletion

All the impact categories are following a general trend. Nevertheless, the slope for ozone depletion is sharper from 2010 to 2050. This is due to the shift of blowing agent in XPS production to a large extend and to the use of secondary fuel in clinker production and the increase in energy efficiency for steel of high and low quality to a minor extend.

Human toxicity

The major feedstock to produce recycled steel is ferrous scrap. Scrap can consist of scrap from inside the steel-works, cuts-off from steel product manufacturers (e.g. vehicle builders) and capital or post-consumer scrap (e.g. end of life products) [22]. Emissions of heavy metals depend largely on the scrap quality. For instance, cadmium is one of the main contributors of human toxicity. This heavy metal is principally consumed for the production of rechargeable nickel cadmium batteries; other end uses such as pigments, coatings and plating, and as stabilizers for plastics [23]. This is, a certain amount of cadmium is found in recycled steel, thereby increasing its human toxicity score [24].

Terrestrial acidification

The decrease comes mainly from the increase in energy efficiency for both steel of high and low quality and the increase rate of recycled steel for steel of low quality.

Freshwater eutrophication

The decrease comes mainly from the increase in energy efficiency and the increase rate of recycled steel for steel of low quality.

5 Environmental performance of future high-speed rail in Norway

Our results show that emissions are on average decreased by 32% in scenario 2050 compared to the current situation (2010), and by 57% for scenario 2050+. These improvements are attained through policy and technology measures found in the literature, achievable through specific requirements to suppliers and by having an active yield management. This shows a large potential for reducing emissions for HSR concepts in Norway.

Compared with previous studies for Europe, though not shown here, we clearly see the effect of the low number of trains per day for HSR lines in Norway. A typical European situation assumes both larger trains and more trains per day. What is considered a high occupancy and traffic in Norway [7], represents the low average for Europe [4].

For infrastructure, European results in person per km (pkm) vary between 2-67 g CO2e, with the lower number being a line with high traffic and mostly open section railway, while the high estimate represents a railway almost exclusively consisting of tunnel and bridge sections and with a much lower traffic rate. Our results are in the high end of the interval, around 35-60 g CO2e per pkm, depending on the traffic rates, even with relatively small portion of tunnels (17 %) on the line. Direct comparisons are not possible due to different modeling assumptions, but tthe differences indicated for the European and Norwegian results underline the specific challenges of future HSR in Norway. The environmental performance depends on the environmental properties of material inputs and the use pattern for the infrastructure.

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