Contribution of railroad transport into carbon footprint of the pulp and paper supply chains: case of Russia

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Abstract

This paper focuses on environmental impact of the rail transport as part of the pulp and paper supply chain. It draws attention to export from North-West Russia, and covers carbon dioxide emissions exhaled from dispatch to border crossing stations. We examine if the actual routing on the rail network corresponds to an optimal solution. We formulate the transshipment module and identify the differences.

Keywords: sustainability, carbon emissions, railway, vehicle routing problem, Russia

Introduction

Russia has one of the largest developed forestry sectors, which ensures supply of paper goods to many countries, and its role in the global economy is growing (Sarkis, 2010). Sustainability of the forestry sector in Russia is of great interest for the end-users in Europe (Leinonen et al. 2008). However, the country remains a mystery for many for its distinctive culture and language that make data collection difficult (Leinonen et al. 2008).

Klein et al. (2015) report finding no studies of life cycle assessment for the forestry sector for Eastern Europe and Russia during the last 20 years. Fromme (1996) emphasizes high energy saving potential of Russia. Korppoo et al. (2008) observe higher energy efficiency of the forestry sector in the North-West region of Russia resulting from structural change. However, none so far studied carbon footprint of exporting paper goods from the North-West region of Russia by rail, whereas it plays a great part in the pulp and paper (p&p) supply chains.

We contribute to the existing research presenting the first study on rail transport carbon emissions in the p&p supply chain answering the following research question: What is an optimal routing for exporting the p&p goods from Russia by rail?

The pulp and paper industry (PPI) is one of the most energy consuming and polluting industries, and hence, carbon emissions from this sector are worth paying attention to (Wang et al. 2016). We reveal how much carbon emissions the railway transport contributes to the p&p supply chains in Russia, and what is the optimal routing to reduce carbon footprint. We focus on dispatch of paper goods for export from the North-West Russia.

Literature review

Lopes et al. (2003) consider transportation subsystem as ‘circulation, between subsystems, of wood, softwood pulp, paper, wastepaper, chemicals and fuels by 16-tonne, 28-tonne and garbage trucks, ocean ships and electric trains” in their life cycle assessment of the pulp and paper sector in Portugal (Lopes et al., 2003, p. 54).

In case of paper products, nearly 50% of trade-related emissions come from transportation. In support for this, Lopes et al. (2003) conclude that transport is the second most important contributor to non-renewable resource depletion, due to consumption of diesel oil and heavy fuel oil throughout the paper life cycle.

Leinonen et al. (2008) highlight concern and mistrust of European end-users towards produce made of Russian timber. Wang et al. (2016) highlight that 60% of the total emissions in PPI result from energy consumption, with electricity being the major source followed by raw coal and coal products. In looking at sustainable p&p production, Helminen (2000) defines “eco-efficiency” as value added/environmental impact. Thus, eco-efficiency ‘refers to both economic and ecological efficiency’ (p. 197), where value added is determined by sales revenue, input costs and changes in inventory position, and environmental impact includes liquid effluents, emissions into the atmosphere and solid wastes.

PPI both uses and produces large amounts of energy. Korhonen et al. (2015) highlight that the pulp and paper is a transport-dependent industry. They suggest that sustainable transportation strategies could contribute to long-term competitiveness of the PPI, considering use of transportation biofuels. While Korhonen et al. (2015) cover maritime transport of Nordic paper products for export we focus on the rail.

Business case

The following companies lead the p&p production in Russia: Ilim Group, International Paper Company, and Mondi Group. Ilim Group is the biggest Russian company that has paper mills in Arkhangelsk, Irkutsk, Leningrad and Moscow Regions that produce containerboard, paper, pulp and corrugated packaging. For its market share, Ilim Group produces 75% of cellulose, 20% of board and 10% of paper in Russia. International Paper Company is an international company that owns 50% of Ilim Group in Russia.

Russian environmental legislation and environmental principles established by International Paper Company drive environmental policy of Ilim Group. In 2008, the company published its first Corporate Social Responsibility (CSR) report. For 2008 – 2015, Ilim Group declared their efforts in reducing air and water pollution, waste management and sustainable forestry. Reporting CO2 emissions from transportation is yet there to come.

The railway plays major role in safe transportation of freight across Russia. In 2013, the rail carried 43.2% of the total freight turnover in Russia. Several sub-railways operate the operational length of 85.3 thousand kilometers. The policy on sustainable development in Russia to 2030, which came into force in 2012, remains the main factor that drives corporate principles and regulations on sustainable development, energy-efficiency and innovations in on the railway network. They continuously invest into electric traction. However, only 50.4% of the railroad network is currently electrified in Russia, and hence, complete substitution of diesel locomotives with electric ones will happen in the long run. In some regions of Siberia and the Far East of Russia, use of eco-efficient fuels is not possible. The old locomotives in use do not correspond to present-day environmental standards. Hence, monitoring carbon footprint is of great importance. The railway network is continuously seeking ways to reduce carbon emissions from movable assets.

Data

We collected primary and secondary data. We used primary data extracted from the railway database and data from secondary sources such as corporate website and online calculator for railroad distances. The data was used to break up the threads[1] into transport legs. For each transport leg, we calculated: distance, lead-time, annual freight volume in tons, and carbon emissions, traffic restrictions.

The mathematical model

The general transshipment linear programming model may be written as presented in equations (1) to (6), where the arcs are the possible routes between different nodes and the decision variables x_{ij} determines the amount of transported goods between the nodes (see e.g. Anderson et al., 1976 pp. xxx). Note that in this paper we use three different objective

[1] **Threads –** the mapping of the movement of the train in a Cartesian coordinate system, where the X axis is the time axis, and the Y axis is the distance axis, i.e. fixed routes.

functions instead of one single criteria function. This will be discussed more in the results chapter.

(1) $\text{Min} \sum_{all\ arcs} c_{ij} x_{ij}$

(2) $\text{Min} \sum_{all\ arcs} l_{ij} x_{ij}$

(3) $\text{Min} \sum_{all\ arcs} e_{ij} x_{ij}$

s.t.

(4) $\sum_{arcs\ out} x_{ij} - \sum_{arcs\ in} x_{ij} \leq s_i$ Origin nodes *i*

(5) $\sum_{arcs\ out} x_{ij} - \sum_{arcs\ in} x_{ij} = 0$ Transshipment nodes

(6) $\sum_{arcs\ in} x_{ij} - \sum_{arcs\ out} x_{ij} = d_j$ Destination nodes *j*

$x_{ij} \geq 0$ for all *i* and *j*

where c_{ij} = CO2 emissions of transporting 1000 kg from node *i* to node *j*
l_{ij} = Lead time in days of transporting 1000 kg from node *i* to node *j*
e_{ij} = Distance in kilometers of transporting from node *i* to node *j*
s_i = supply at origin *i*
d_j = demand at destination *j*

Problem

The needed parameter values for the model are presented in the Tables 1 to 4. Table 1 illustrates the supply capacities of the nine dispatch stations.

Table 1. Freight stations dispatching p&p products in the North-West Russia

Origin nodes *i*	**Supply 1000 kg**
Dispatch st. 1	56069
Dispatch st. 2	42768
Dispatch st. 3	88819
Dispatch st. 4	140821
Dispatch st. 5	24099
Dispatch st. 6	115165
Dispatch st. 7	7135
Dispatch st. 8	41285
Dispatch st. 9	8254

Table 2 contains demand of the twenty border stations.

Table 2. Russian border stations processing the freight trains that export p&p goods

Destination nodes *j*	Demand 1000 kg
Border st. 1	57900
Border st. 2	16302
Border st. 3	137690
Border st. 4	29396
Border st. 5	1375
Border st. 6	5216
Border st. 7	9892
Border st. 8	3753
Border st. 9	1797
Border st. 10	716
Border st. 11	595
Border st. 12	8046
Border st. 13	27410
Border st. 14	933
Border st. 15	17596
Border st. 16	835
Border st. 17	2109
Border st. 18	38502
Border st. 19	30389
Border st. 20	7684

Table 3 presents the incoming routes (arcs) to the transshipment nodes, the lengths of the arcs in kilometers, the proportions of these, which are operated by electric, or diesel engines, and the durations of the transportation. The lengths of operated by electric, or diesel engines are used to calculate the CO2 emissions of transporting 1000 kg from node i to node j (c_{ij}) by multiplying the electric traction by 18 g/ton-km and diesel traction by 35 g/ton-km.

Table 3 – The incoming routes (arcs) to the transshipment nodes, the lengths of the arcs in kilometers, the proportions of these which are operated by electric or diesel ensigns', and the durations of the transportation.

Transshipment nodes	Arcs in	Distance, km e_{ij}	Electric traction, km	Diesel traction, km	Lead time days l_{ij}
Train st. 1	Train st. 11	1089	69	1020	5
	Train st. 20	405	0	405	2
Train st. 2	Train st. 29	170	170	0	1
Train st. 3	Train st. 17	64	64	0	1
Train st. 4	Train st. 29	377	99	278	2
Train st. 5	Train st. 3	317	317	0	2
Train st. 6	Train st. 7	267	5	262	1
Train st. 7	Train st. 15	855	6	849	4
Train st. 8	Train st. 11	69	69	0	0

Train st. 9	Train st. 6	292	251	41	1
	Train st. 10	996	996	0	5
Train st. 10	Train st. 21	884	884	0	4
Train st. 11	Train st. 21	206	206	0	1
Train st. 12	Dispatch st. 4	305	0	305	2
	Dispatch st. 6	26	26	0	0
Train st. 13	Train st. 1	57	0	57	0
Train st. 14	Dispatch st. 3	631	504	127	3
	Train st. 12	581	218	363	3
	Train st. 22	971	758	213	5
	Train st. 27	485	485	0	2
Train st. 15	Train st. 12	379	0	379	2
Train st. 16	Dispatch st. 9	26	0	26	0
Train st. 17	Train st. 2	131	131	0	1
Train st. 18	Train st. 9	305	10	295	1
Train st. 19	Train st. 8	107	0	107	1
Train st. 20	Train st. 8	591	0	591	3
Train st. 21	Train st. 2	248	248	0	1
Train st. 23	Dispatch st. 1	213	213	0	0
	Train st. 16	307	151	156	2
	Train st. 28	145	145	0	1
Train st. 25	Train st. 13	9	0	9	0
Train st. 26	Train st. 2	365	365	0	2
Train st. 27	Train st. 23	110	110	0	1
	Train st. 14	485	485	0	2
	Train st. 16	535	163	372	2
	Dispatch st. 5	345	345	0	2
	Dispatch st. 7	549	549	0	3
Train st. 28	Dispatch st. 2	28	28	0	0
	Train st. 24	66	66	0	0
Train st. 29	Train st. 14	207	207	0	1

Table 4 includes the same information than Table 3. The difference is that it presents the outgoing routes from the transshipment nodes and, in the last row the only direct arc between origin and destination.

Table 4 – The outgoing routes (arcs) from the transshipment nodes, the lengths of the arcs in kilometers, the proportions of these which are operated by electric or diesel ensigns', and the durations of the transportation.

Transshipment nodes	**Arcs out**	**Distance, km** e_{ij}	**Electric traction, km**	**Diesel traction, km**	**Lead time** l_{ij}
Train st. 1	Border st. 2	11	0	11	0
	Border st. 3	453	453	0	2
Train st. 4	Border st. 14	316	316	0	2

	Border st. 15	477	0	477	2
Train st. 5	Border st. 6	371	3	368	1
	Border st. 17	175	4	171	1
	Border st. 18	122	122	0	1
	Border st. 20	226	0	226	1
	Border st. 5	1408	1267	141	7
	Border st. 6	2015	643	1372	11
	Border st. 11	637	345	292	3
Train st. 10	Border st. 1	447	0	447	2
	Border st. 10	762	192	570	4
Train st. 18	Border st. 1	401	321	80	2
Train st. 19	Border st. 16	279	279	0	1
	Border st. 4	391	8	383	2
	Border st. 8	1013	1013	0	5
Train st. 23	Dispatch st 1.	29	8	21	0
	Border st. 9	17	17	0	0
Train st. 25	Border st. 12	8	0	8	0
	Border st. 13	646	159	487	3
Train st. 26	Border st. 6	548	0	548	2
	Border st. 7	258	0	258	2
	St Petersburg Sorting	113	113	0	1
Origin node					
Dispatch st. 1	Border st. 19	493	0	493	2

In addition to these parameters, all the decision variables are set to be grater or equal than zero.

Results

The optimal results using the three different models are presented in Tables 5 and 6. Table 5 shows the transportation arcs where the transported amounts differs from each other based on the objective function used.

Table 5 -

Arcs	**Min CO2 Emissions**	**Min lead time**	**Min distance**
Train st. 27 – Train st. 14	11253	4118	4118
Train st. 14 – Train st. 29	354088	296188	296188
Train st. 29 – Train st. 2	335559	277659	277659
Train st. 2 – Train st. 21	144358	86458	86458
Train st. 21 - Train st. 11	86458	86458	86458
Train st. 11 – Train st. 1	0	51758	0
Train st. 21 – Train st. 10	57900	0	0

Train st. 10 - Border st. 1	57900	0	0
Train st. 11 – Train st. 8	85742	33984	85742
Train st. 8 – Train st. 20	51758	0	51758
Train st. 20 - Train st. 1	51758	0	51758
Train st. 2 - Train st. 17	191201	185985	191201
Train st. 17 - Train st. 3	191201	185985	191201
Train st. 3 – Train st. 5	53511	48295	53511
Train st. 12 – Train st. 15	1970	59870	59870
Train st. 15 – Train st. 7	1970	59870	59870
Train st. 7 – Train st. 6	0	57900	57900
Train st. 6 – Train st. 9	0	57900	57900
Train st. 12 – Train st. 14	254016	196116	196116
Train st. 9 – Train st. 18	0	57900	57900
Train st. 18 - Border st. 1	0	57900	57900
Train st. 5 – Border st. 6	5216	0	5216
Train st. 2 –Train st. 26	0	5216	0
Train st. 26 – Border st. 6	0	5216	0
Train st. 22 – Train st. 14	0	7135	7135
Train st. 22 – Train st. 27	7135	0	0

Table 6 illustrates the objective values for the three different problems and for the current situation.

Table 6 -

Optimization problem / Objective function value	**Min CO2 Emission**	**Min lead time**	**Min distance**	**Current situation**
CO2 Emissions 1000 kg	19707,03	20826,21	20763,96	25069,56
Lead time in days*1000 kg	4233252	4170136	4175352	4903930
Distance km * 1000 kg	816705337	815454304	814055632	1004535489

It is easy to see from Table 6 that the current situation is not optimal. For example, the minimization of emissions results to solution where the emissions are only 79 %, the lead-time 86% and the length of the transportation legs 81 % from the current situation.

References

Anderson, D.R., Sweeney, D.J. and, Williams, T.A., 1976, *An introduction to Management Science – Quantitative Approach to Decision Making*, 7th Edition, West Publishing Company, New York.

Fromme, J. W. (1996), "Energy conservation in the Russian manufacturing industry: Potentials and obstacles", *Energy policy*, Vol. 24 No. 3, pp. 245-252.

Helminen, R. R. (2000), "Developing tangible measures for eco-efficiency: the case of the Finnish and Swedish pulp and paper industry", *Business Strategy and the Environment*, Vol. 9 No. 3, pp. 196-210.

Klein, D., Wolf, C., Schulz, C. and Weber-Blaschke, G. (2015), "20 years of life cycle assessment (LCA) in the forestry sector: state of the art and a methodical proposal for the LCA of forest production", *The International Journal of Life Cycle Assessment*, Vol. 20 No. 4, pp. 556-575.

Korhonen, J., Pätäri, S., Toppinen, A. and Tuppura, A. (2015), "The role of environmental regulation in the future competitiveness of the pulp and paper industry: the case of the sulfur emissions directive in Northern Europe", *Journal of Cleaner Production*, Vol. 108, pp. 864-872.

Korppoo, A., Luukkanen, J., Vehmas, J. and Kinnunen, M. (2008), "What goes down must come up? Trends of industrial electricity use in the North-West of Russia", *Energy Policy*, Vol. 36 No. 9, pp. 3588-3597.

Leinonen, T., Sungurov, R., Kolström, T., Sokolov, A., Žigunov, A., & Dorošin, A. (2008). Forest regeneration in Northern and Northwestern Russia in 1993–2004—methods, results and development needs. *Forest ecology and management*, *255*(3), 383-395.

Lopes, E., Dias, A., Arroja, L., Capela, I. and Pereira, F. (2003), "Application of life cycle assessment to the Portuguese pulp and paper industry", *Journal of Cleaner Production*, Vol. 11 No. 1, pp. 51-59.

Sarkis, J. (2010), "Benchmarking the greening of business", *Benchmarking: An International Journal*, Vol. 17 No. 3.

Wang, Y., Yang, X., Sun, M., Ma, L., Li, X., & Shi, L. (2016). Estimating carbon emissions from the pulp and paper industry: A case study. *Applied Energy*, *184*, 779-789.