Assessing obstacles to renewable energy in heavy haul traction

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ABSTRACT: Transport is a major contributor to climate change, directly by harmful emissions in exhaust gases, and indirectly by consuming energy derived from fossil fuels. Although rail is the most energy efficient transport mode in niches that it serves best, there is nevertheless still scope to substantially decrease energy consumption for heavy haul traffic. The objectives of this paper are to examine and identify the modalities. There is evidence that if heavy haul energy provisioning is aligned to renewable energy precepts, the two will naturally complement one another. The research design addressed the objectives through case studies. Vertical alignment profiles for selected heavy haul railways were derived from Google Earth and analysed regarding energy consumption attributes within mine-to-port-and-return systems. Three locomotive configurations examined across the selected alignment profiles demonstrated a potential 66% decrease in energy consumption and harmful emissions. It was found that electric traction supports the objectives because it can conduct energy off- and on-board to enlarge the load to balance instantaneous surplus and demand, or to store it. In this respect there is natural synergy between the intermittent energy use and regeneration of heavy haul railways and intermittent sources of renewable energy and their management.

1 INTRODUCTION

1.1 *General*

Motive power type has changed relatively little since heavy haul emerged as significant railway sub-mode in the 1970s. Diesel traction prevails in countries where it was originally implemented; so also electric traction. Since the 1980s, minimal electrification or de-electrification of existing heavy haul lines appears to have happened. In contrast, the consequences of finite fossil fuel reserves and the need to embrace renewable energy sources, as well as to decrease energy consumption to decrease harmful emissions, has escalated to a top level issue, including for railways. The authors examined aspects of positioning heavy haul railways to maximise their positive contribution to global climate change objectives.

1.2 *Climate change*

Transport is a major contributor to global warming and consequent climate change, directly by harmful emissions in exhaust gases from vehicles powered by fossil fuels, and indirectly by consuming electricity or liquid fuels derived from fossil fuels. Furthermore, despite policy interventions to decrease emissions, the global transport sector's contribution is increasing even as other sectors manage harmful emissions downward.

Rail is the most energy efficient of all transport modes (Barkan, 2007) in niches that its genetic technologies equip it to serve best. In the 2050 emissions decrease big picture, rail is predicted to achieve substantial shift from road, and even maritime traffic is shifting to rail where overland routes are workable. There is nevertheless still scope to substantially decrease energy consumption for traffic that rail already carries best, heavy haul being a prime example, and the objectives of this paper are to examine and identify the modalities.

Intended Nationally Determined Contributions to decrease harmful emissions were agreed at the United Nations' 2015 COP (Conference of Parties) 21 Climate Change Conference in Paris. Albeit with caveats, their generic format is *Decrease emissions by 25-65% on 1990-2005 levels by 2025-2030* (CarbonBrief, 2015), where the given percentages and periods capture the intents of the countries that are represented in the International Heavy Haul Association.

Note that the authors take no position on climate change mitigation targets, but simply note their existence and examine the extent to which heavy haul railways can potentially contribute to their achievement. Furthermore, they do not compare heavy haul railways with their respective countries' targets. That said, the targets are challenging and meeting them will likely require ongoing incremental change as well as fundamental repositioning.

1.3 *Some railway and renewables relations*

As trains traverse their natural sequence of rising and falling gradients, they may regenerate temporarily surplus energy on falling gradients that could be consumed on subsequent rising gradients. Storing and re-using such temporarily surplus energy can decrease emissions by decreasing overall energy consumption. Many heavy haul railways operate loaded in one direction and empty in the other: Where the elevation change in relation to haul distance is favourable, there is potential to usefully conserve energy and such cases are best treated as closed systems.

As the renewable share of total energy generated inevitably increases in response to climate change imperatives, it compounds the challenge of balancing demand and supply in real time. Despite well known limitations, maximum demand pricing and peak lopping have traditionally sufficed to manage demand. However, managing the dips and peaks of variable supplies is more complex. Balancing authorities are responding with a range of ancillary services that are able to respond to the amount and rate of change of instantaneous demand. Among other they require storing electric energy: Facilities range widely in scale from high-capacity slow-response hydro electric systems to batteries that can dispatch or store double digit megawatts in minutes. There is a trend to intervene close to the source of variance, to minimise disturbance to the transmission grid.

The systems and technologies that enable renewable energy sources to meet a worthwhile portion of aggregate demand have significant synergy with heavy haul railways. Both generate electricity and behave as independent power producers. The installed power of a heavy haul train is in the same league as that of a small town. The power they generate fluctuates within wide limits. Heavy haul railways can complement renewables, particularly wind, as both operate 24/7/365.

In the past electrified heavy haul railways were valued customers of electric utilities, but the amount of energy regenerated and constantly fluctuating temporal and geographic distribution made it difficult to sell back to the electric power grid (Fullerton & Dick, 2015). Nowadays, the tools to deal with that problem have become the stock-in-trade of smart grid system operators.

1.4 *Heavy haul's relation to greening road vehicles*

Despite addressing the same global challenge, superficially comparing heavy haul emissions reduction prospects with the approach by electric and hybrid road vehicles is not appropriate, because their objectives and requirements differ in many respects. The following material examines key differences and then sets the matter aside.

Electric and hybrid road vehicles are developing rapidly, with expectations of significant market penetration by 2020, while rail still seems a long way off. Although the scientific principles are the same, the practical implications, and the rate at which emerging technology can address them, differ substantially, as follows:

Table 1. Attributes that distinguish heavy haul railway and automotive approaches to decreasing emissions

Heavy haul railways	Electric, hybrid road vehicles
Steel on steel adhesion for braking and traction requires substantially flatter gradients	Rubber on road supports higher adhesion and therefore steeper gradients
Flatter gradients increase the distance between surplus and use cycles	Steeper gradients reduce the distance between surplus and use cycles
Low proportion of motored axles, in the range 2-3%	High proportion of motored axles, in the range 30-50%
Friction braking energy dissipated on high proportion of unmotored axles is unrecoverable	Minimal friction braking, high probability of regenerating kinetic and potential energy
Asymmetrical gradients from empty and loaded directions	Symmetrical gradients due to bi-directional traffic flow
Long round trips measured in hundreds or thousands of kilometers	Generally short, urban trips, constrained by battery capacity
It may be necessary to conserve energy from a loaded trip to power an empty trip	Opportunities exist to recharge or discharge during intermediate stops
Aerodynamic resistance much less than gravity component, therefore higher potential to regenerate potential energy	Aerodynamic resistance of same order as gravity component, therefore lower potential to regenerate potential energy

2 METHODOLOGY

2.1 *The research question*

The research question is: How does the energy quantum that potentially can be stored and reused, by connecting heavy haul locomotives to external loads and or storage devices through overhead catenary, relate to use of renewable energy and its ancillary services?

2.2 *Research design*

The world's heavy haul railways are relatively few in number, so statistical comparisons are not tenable. The research design therefore addressed the research question through case studies. Vertical alignment profiles derived from Google Earth were used to numerically analyse heavy haul railway energy consumption attributes within mine-to-port-and-return systems. In addition to six older lines for which profiles had previously been derived (Van der Meulen & Möller, 2013, 2014), the authors added to this paper two further Chinese heavy haul railways, Shenmu–Huanghua and Watang–Rizhao. Another new railway commissioned since then, Roy Hill in Australia, closely follows the BHP Billiton railway alignment already included in the 2013 and 2014 studies and was therefore not examined.

Note that this study considered changes in potential energy only. Its essential determinants are changes in elevation, dynamic and regenerative locomotive braking and tractive efforts, as well as the rolling resistance of empty and loaded trains. It did not examine running times and train dynamics, which in principle depend on locomotive traction and braking power rather than effort or force. The vertical alignments were reduced to elevation changes over one kilometer, to support the analysis presented in Table 3.

2.3 *Country-cases examined*

The railways examined were selected for their topographical features, and their potential for decreasing energy consumption. They were taken at face value as real life examples of solutions to moving large quantities of bulk commodities across natural obstacles. There was no intent to examine existing operations on these lines or to make recommendations in the light of the findings. The following eight pit-to-port railways were examined: Australia, Newman–Port Hedland (AU); Brazil, Itabira–Vitória (BR); China, Datong–Qinhuangdao (CN 1), Shenmu–Huanghua (CN 2) and Watang–Rizhao (CN 3); Nordic, Kiruna–Narvik; South Africa, Ermelo–Richards Bay (ZA 1) and Sishen–Saldanha (ZA 2).

Flattish average gradients do not offer serious potential for energy management. A fair-sized battery, perhaps with due development, should allow locomotives to minimise energy consumption over moderate undulations. Serious energy conservation needs to start with routes that have some self sufficiency. This requires an average falling gradient of steeper than approximately 1 in 460 for 32.5 tonnes per axle and 6:1 load:tare ratio: It assumes that curvature is compensated, all braking energy is regenerated and not dissipated as heat, and that round-trip efficiency between regeneration and reuse is 80%.

The previous paragraph explains why the following cases might appear to have been missed. Brazil's Carajás railway meanders in an elevation band below 300m over its 892km length, an average falling gradient of approximately 1 in 3200. This is flatter than the rolling resistance of a loaded car. Similarly, the United States' Powder River Basin coal mines are situated in the 1270-1470m elevation range, and fuel some 40 power plants situated at an average elevation of 380m with an average haul of 1680km. The average falling gradient is 1 in 1580 (derived from Powder River, 2017 and Google Earth), again flatter than the rolling resistance of a loaded car. In principle such situations require traction all the way, except for relatively short undulations where hybrid locomotives, if they were commercially available, could be useful, but they attract little interest from a systemic energy management perspective.

2.4 *Rolling stock considerations*

It is evident that diesel and electrified heavy haul railways are diverging regarding preferred motive power configuration. While high tractive effort on six axles and moderate power characterise heavy haul diesel locomotives, high traction motor power on four axles and moderate tractive effort characterise heavy haul electric locomotives. The foundation of scientific research is examination of differences: These two poles-apart solutions were therefore used to define the three motive power options examined, using only their tractive and braking efforts for analytic purposes. Thus the first case, *High TE diesel* in Table 3 is represented by the *High tractive effort, moderate power* column in Table 2. The second case, *High TE electric* in Table 3, is also represented by the *High tractive Effort, moderate power* column in Table 2, but with ability to regenerate energy and export it for alternative use or for storage. The third case, *Hi-power electric* in Table 3 is represented by the *High power moderate tractive effort* column in Table 2, also with ability to regenerate energy and export it.

The high tractive effort case typifies a North American diesel locomotive. The high power case typifies a China Railways' HXD2f locomotive (CRRC, 2016).

Table 2. Essential locomotive parameters

Parameter	High tractive effort, moderate power	High power moderate tractive effort
Axles, no.	6	4
Axle load, t	32.7	30.0
Traction Power, kW*	3275	4800
Tractive effort, kN**	673	346
Tractive adhesion, %	35.0	29.4
Braking effort, kN***	520	510
Braking adhesion, %	27.1	43.3
*at wheels, **continuous, ***regenerative		

Noting that the COP21 basis for decreasing emissions goes back to 1990, the *High TE diesel* locomotive was included to represent a time when all diesel locomotives, as well as many electrics, were equipped with dynamic braking only. Without the ability to regenerate back to the supply, all braking energy, whether dynamic or by brake block friction on train wheels, was dissipated as heat. This is the base case for the analysis in Table 3.

The present analysis assumed that regenerative braking could be prioritised, to maximise the amount of energy regenerated. This implies electronically controlled pneumatic graduated release train braking to avoid losses due to direct release brakes in situations where they cannot or should not be released.

Previous research by the authors (Van der Meulen & Moller, 2013, 2014) found a moderate sensitivity to car gross axle load, due to rolling resistance decreasing with increasing axle load. However, after committing to examining three types of locomotives in the present study, they decided that retaining axle load as variable would introduce undue complication without delivering commensurate insight, so 30 tonnes/axle gross and 5 tonnes/axle tare were used across the board.

The basic calculations in Table 3 were done on a per car basis, so that the outcome can be multiplied out for any number of cars or any throughput tonnage per unit time.

3 RESULTS

Table 3, presented in Parts 1 and 2, shows the outcome of the analysis.

The results are presented for each of the route cases, in three columns for the three motive power options considered.

Lines 3-10 report the key determinants of energy consumption that were derived from Google Earth. The vertical profiles in Figure 1 show elevation against distance for each route[1], with 0km at the mine.

Lines 11-13 show key rolling stock parameters used to calculate the energy consumption stages.

Line 14 presents the height component of the potential energy irrecoverably dissipated by dynamic and or friction braking. It is interesting to compare it with the aggregate fall in Row 4 and note how large a portion of the initial potential energy can simply be wasted without ability to store and reuse it. For purposes of meeting emissions decrease targets, and depending on where a country currently finds itself with respect to its target emissions decrease, this could be the base case for determining decreases in respect of COP21.

Lines 15-18 present the outcomes of the energy consumption stages to arrival of a train at the port. Note that the values are calculated per car, to enable them to be applied to whatever train length is under consideration.

Line 19 shows the energy required for a loaded trip to the port. If the number is positive, it represents a surplus available for the empty trip. If the number is negative, it represents a deficit to be carried forward to the empty trip.

Line 20 shows the quantity of energy available to be stored.

Line 21 converts the quantity of energy to be stored to kWh, to give a real life appreciation of the quantum involved. Round-trip storage efficiency has been set at 80%, and the resultant 20% loss is subtracted from Line 19.

Line 23 shows the quantity of energy available at the port for the empty trip, with 80% of the stored energy added back where applicable.

Lines 24-27 derive the energy required for the empty trip.

Line 28 calculates the net energy required for the mine-port-mine round trip by subtracting Line 27 from Line 23. A negative number indicates that the system is not self-sufficient, and therefore requires energy to be input from outside the system. It is the final outcome, from which conclusions were drawn.

Line 29 converts Line 28 to kWh, again to give a real life appreciation of the quantum involved.

Line 30 is the cardinal finding. Using the net energy consumption of Line 29 and the *High TE diesel* locomotive as base, it calculates the percentage decrease in energy consumed by the *High TE electric* and *Hi-power electric* locomotive options.

Line 31 puts the quantum of energy to be stored, from Line 21, into the context of, for example, a 200-car train. The Ermelo–Richards Bay operation represents the highest value in the table, at 50MWh.

Lines 32 and 33 place the net energy required from Line 29 into the context of a 100 million tonnes per annum throughput.

Line 34 shows the impact of using high powered locomotives vis-á-vis high tractive effort locomotives. Across the routes examined, a high power locomotive requires nearly twice the number of locomotives to haul a given train in return for an energy consumption decrement of 5-35% (in Line 30), with an average of 15.6%.

4 ANCILLARY SERVICES

Having developed the scope of the heavy haul railway emissions reduction challenge, it is now useful to examine some of the ancillary services that balancing authorities need to operate smart grids within regulatory obligations.

Grid energy storage, where whoever wants, consumes, and whoever generates, provides, leaving the system operator to take care of resultant imbalances, is an attractive proposition. From an electric heavy haul perspective it would be valuable to have such capability.

[1] The formatting template for this paper required black and white figures: A clearer full-colour version is available at http://www.railcorpstrat.com/databases.html.

There are limits to relying on diversity to smooth the overall variation, so energy storage options are proliferating within the following upper limits; batteries 100MW and 1000MWh; thermal storage 1000MW and 10000MWh, and hydroelectric or pumped storage 10 000MW and 100 000MWh. Without augmenting diversity from other participants, a standalone heavy haul railway would fall into the lowest category.

Battery technology has not yet advanced to the point where on-board storage is feasible in terms of wh/kg and wh/m^3, and finite life must also be taken into account. Currently, one 12m container stores 1MWh. Round trip loss is at best 20%, and could be higher. Unsurprisingly, alternative electromechanical systems with indeterminate life in the range 100MW and 200MWh to near pumped storage capacity are in the works, and would comfortably accommodate heavy haul railways (ARES, 2017).

Energy storage does incur losses, so it could be preferable to use temporarily surplus energy directly rather than store it. However, that would incur transmission losses. The challenges of stabilising a high voltage transmission system are greater than stabilising a local distribution system, so the preference is to manage fluctuation at the lowest economically viable level.

5 PROBABLE INTEGRATED SOLUTIONS

It would not be necessary to accumulate temporarily surplus energy from individual loaded trains on falling gradients until they reach the port, because storage facilities could be placed en route at long, steep falling gradients. This would be preferable to keeping it on board until the return journey, as the total surplus for the loaded trip would be so much greater.

Electric traction supports these objectives because it is possible to conduct energy off- and on-board to enlarge the load to balance instantaneously surplus and demand, or to store it. In this respect there is natural synergy between the intermittent energy use and regeneration of heavy haul railways and intermittent sources of renewable energy.

At face value the authors may appear to prefer electric traction over diesel traction. If so, the more fundamental issue is that, despite great advances in traction and energy storage technologies, the ability to store energy on board a locomotive, or even in a realistic number of tenders, still seems far off. Furthermore, for the foreseeable future, renewable energy appears to come in the form of electricity.

Hence electrification seems to be an essential element of heavy haul railways. Perhaps intermittent or selective electrification will provide a pragmatic solution. One can conceive of diesel locomotives with AC-DC-AC power electronics, with a pantograph on the DC link and catenary connected to a storage system, or to a regional grid with its storage system, a solution that minimises cost and maximises benefits.

6 DISCUSSION AND CONCLUSIONS

In conclusion, Table 3 demonstrates that ability to transfer temporarily surplus energy off a locomotive opens a substantial opportunity to decrease energy consumption for the same output task. Line 30 demonstrates an average 66% decrease in energy consumption, and hence harmful emissions, between the base high tractive effort diesel and the high tractive effort electric locomotive, across the cases examined.

Beyond that, also in Line 30, there is on average a further 13% energy consumption decrease to be gained by the use of high power locomotives. At face value, a 13% energy consumption decrement that requires twice as many high adhesion locomotives would seem to require further analysis. Reduced cycle time due to higher power-to-mass ratio could contribute offsetting benefits.

As rail grows its share of the global transport task, it will no longer be sufficient to see rail as the pre-eminent transport mode for low energy consumption and low emissions. Its greater stature will no longer bear comparison with other modes, but will need to measure itself against its own potential for improvement.

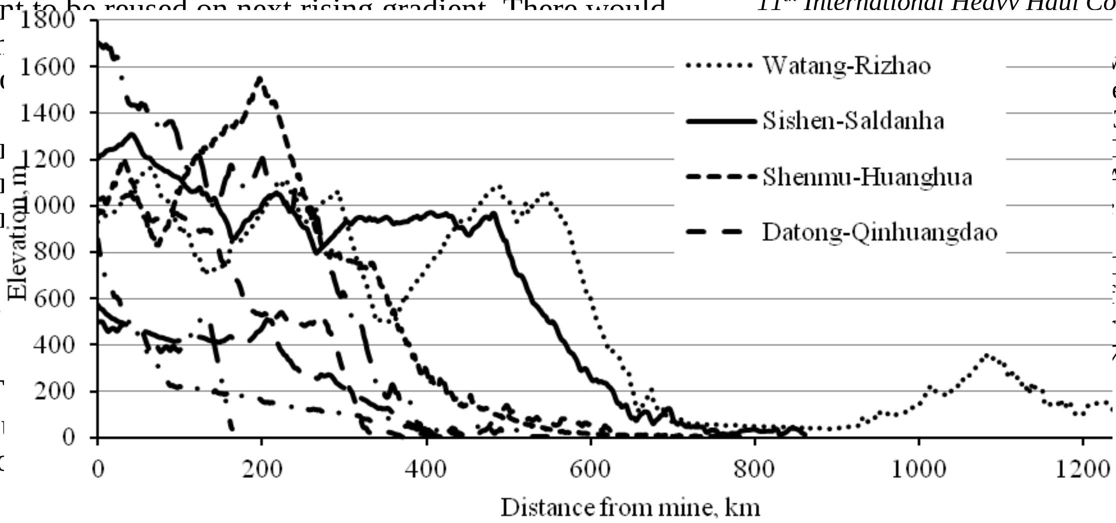
Using exceptionally high (43%) wheel-rail adhesion for regenerative braking and more modest (29%) traction adhesion in conjunction with high-power traction motors is an interesting approach to addressing asymmetry between rising and falling gradients in the loaded direction. It is of course not readily possible to reduce existing asymmetry except where alignment needs to be changed, or where a new line needs to be built anyway. Thus for many real life situations a high power locomotive has value. Whether doubling the number of locomotives is viable is something that the market will resolve in due course.

Appreciate that in all cases both electric locomotive options incur irrecoverable losses on falling gradients where the regenerative braking effort is insufficient to balance the gravity component and it is necessary to apply train braking to maintain a safe, steady speed. To regenerate all potential energy, it would be necessary to design vertical alignment to optimise the relationship between traction and braking adhesion, as well as rising and falling gradients, not losing sight of rolling resistance and curve resistance.

It appears that the percentage decrease in energy consumption compared to the base case could potentially support COP (Conference of Parties) 21 targets. The relative timing of the base year and the commissioning year would determine the extent to which the value can be realised. The combination of electric traction with lineside storage is attractive. The amounts of energy to be stored at such sites appear manageable with existing technology that achieves 1MWh per 12m container. The cost of own storage versus the cost of grid storage would need to be compared.

The need for some sort of energy management system is moderated by the topography of the terrain through which the railway line passes.

On undulating terrain with a flattish trend line, one would be looking for dynamic braking energy to be stored in sufficient capacity on one falling gradient to be reused on next rising gradient. There would



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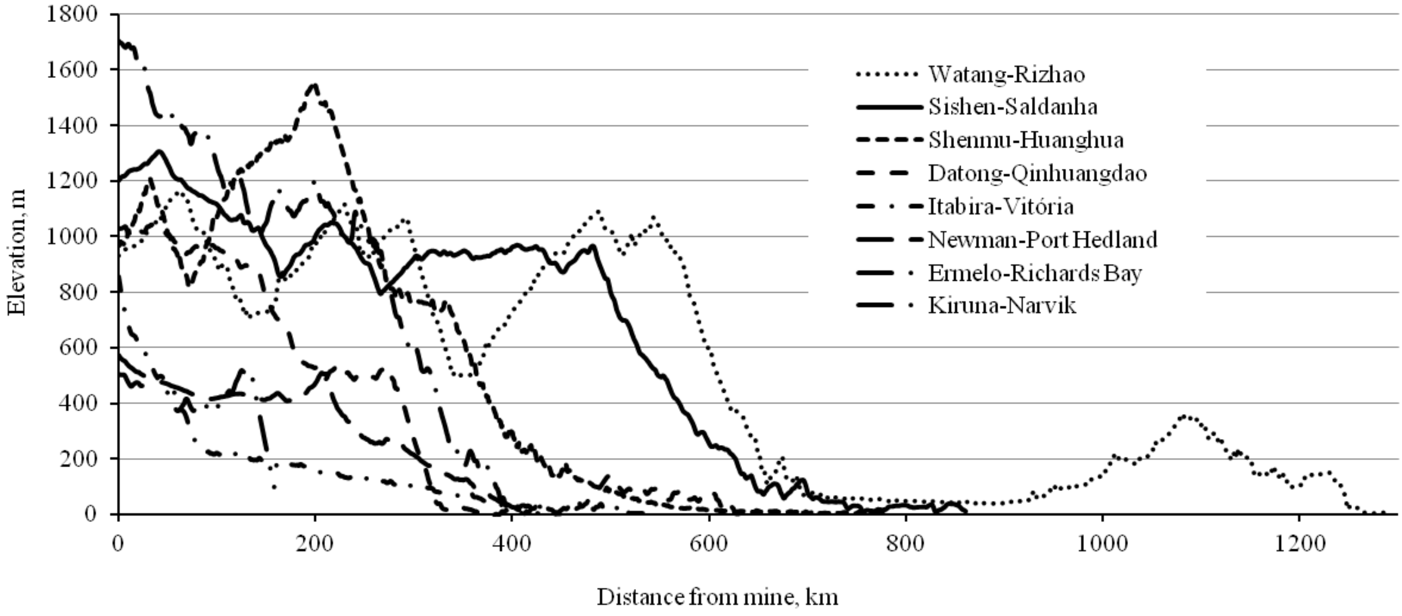

Figure 1.Vertical alignments of the eight heavy haul cases

Table 3, Part 1. Input parameters and energy balance for heavy haul railway cases AU, BR, CN 1 and CN 2

1	Site (ISO-2 code)	AU Newman–Port Hedland			BR Itabira–Vitória			CN 1 Datong–Qinhuangdao			CN 2 Shenmu–Huanghua		
2	Locomotive (TE = tractive effort)	High TE diesel	High TE electric	Hi-power electric	High TE diesel	High TE electric	Hi-power electric	High TE diesel	High TE electric	Hi-power electric	High TE diesel	High TE electric	Hi-power electric
3	Route distance, km	426			547			641			782		
4	Aggregate fall, m	754			1208			1685			2699		
5	Aggregate rise, m	186			354			659			1737		
6	Net elevation change, m	568			854			1026			961		
7	Average fall gradient, ‰	2,30			3,20			4,10			5,80		
8	Average rise gradient, ‰	1,90			2,08			2,87			5,48		
9	Ruling grade, loaded, ‰	0,67			0,38			0,85			1,00		
10	Ruling grade, empty, ‰	1,05			0,51			1,06			1,07		
11	Car tare mass, tons/axle	5			5			5			5		
12	Car gross mass, tons/axle	30			30			30			30		
13	Locomotive mass, tonnes	196	196	120	196	196	120	196	196	120	196	196	120
14	Elevation dissipated by braking, m	445	56	19	891	407	204	1317	237	17	2255	716	108
15	*Per loaded car per loaded trip:*												
16	Fall energy, MNm	481	481	483	963	963	956	1492	1492	1481	2637	2637	2618
17	Braking energy loss, MNm	-533	-67	-23	-1069	-488	-245	-1580	-285	-20	-2653	-859	-131
18	Rise energy, MNm	-349	-349	-351	-644	-644	-646	-1088	-1088	-1092	-2493	-2493	-2503
19	Energy required for loaded trip, MNm	-402	65	109	-750	-169	64	-2668	119	369	-5146	-714	-15
20	Energy to be stored, MNm	0	65	109	0	0	64	0	119	369	0	0	0
21	Energy to be stored, kWh	0,00	18,0	30,3	0,00	0,00	17,7	0,00	33,2	102	0,00	0,00	0,00
22	Round-trip energy loss @ 20%, MNm	0	13	22	0	0	13	0	24	74	0	0	0
23	Energy available for empty trip, MNm	-402	-402	-402	-402	-402	-402	-402	-402	-402	-402	-402	-402
24	*Per empty car per empty trip:*												
25	Fall energy, MNm	48	48	49	77	77	79	65	65	66	-92	-92	-94
26	Rise energy, MNm	463	463	473	607	607	621	743	743	759	1014	1014	1036
27	Energy required for empty trip, MNm	512	512	523	684	684	699	807	807	825	921	921	942
28	Net energy required, MNm	-913	-460	-436	-1435	-853	-648	-3475	-712	-530	-6067	-1636	-957
29	Net energy required, kWh	-254	-128	-121	-398	-237	-180	-965	-198	-147	-1685	-454	-266
30	Decrease compared to diesel, %	0,0	49,7	52,3	0,0	40,5	54,8	0,0	79,5	84,7	0,0	73,0	84,2
31	Energy storage/200-car train, MWh	0,00	3,61	6,07	0,00	0,00	3,55	0,00	6,63	20,5	0,00	0,00	0,00
32	Round trips per 100Mtpa, number	1000000			1000000			1000000			1000000		
33	Energy consumed/100Mtpa, GWh	254	128	121	398	237	180	965	198	147	1685	454	266
34	Cars/train high TE locomotive/high power locomotive	1,98			1,96			1,99			1,99		

Table 3, Part 2. Input parameters and energy balance for heavy haul railway cases CN 3, Nordic, ZA 1 and ZA 2

1	Site (ISO-2 code)	CN 3 Watang–Rizhao			Nordic Kiruna–Narvik			ZA 1 Ermelo–Richards Bay			ZA 2 Sishen–Saldanha		
2	Locomotive (TE = tractive effort)	High TE diesel	High TE electric	Hi-power electric	High TE diesel	High TE electric	Hi-power electric	High TE diesel	High TE electric	Hi-power electric	High TE diesel	High TE electric	Hi-power electric
3	Route distance, km	1285			163			417			861		
4	Aggregate fall, m	3735			761			2508			2143		
5	Aggregate rise, m	2814			299			810			951		
6	Net elevation change, m	921			462			1699			1192		
7	Average fall gradient, ‰	5,81			7,93			8,65			4,25		
8	Average rise gradient, ‰	4,38			4,47			6,38			2,67		
9	Ruling grade, loaded, ‰	0,52			0,68			0,63			0,40		
10	Ruling grade, empty, ‰	1,19			2,00			1,52			1,00		
11	Car tare mass, tons/axle	5			5			5			5		
12	Car gross mass, tons/axle	30			30			30			30		
13	Locomotive mass, tonnes	196	196	120	196	196	120	196	196	120	196	196	120
14	Elevation dissipated by braking, m	3149	1786	950	666	334	171	2215	1120	478	1642	738	265
15	*Per loaded car per loaded trip:*												
16	Fall energy, MNm	3651	3651	3624	789	789	783	2635	2635	2615	1921	1921	1906
17	Braking energy loss, MNm	-3777	-2143	-1144	-799	-401	-206	-2657	-1344	-576	-1969	-886	-320
18	Rise energy, MNm	-4203	-4203	-4220	-445	-445	-447	-1135	-1135	-1140	-1602	-1602	-1608
19	Energy required for loaded trip, MNm	-7981	-2695	-1740	-1245	-57	130	-3792	156	900	-3571	-567	-21
20	Energy to be stored, MNm	0	0	0	0	0	130	0	156	900	0	0	0
21	Energy to be stored, kWh	0,00	0,00	0,00	0,00	0,00	36,2	0,00	43,3	250	0,00	0,00	0,00
22	Round-trip energy loss @ 20%, MNm	0	0	0	0	0	26	0	31	180	0	0	0
23	Energy available for empty trip, MNm	-7981	-2695	-1740	-1245	-57	104	-3792	125	720	-3571	-567	-21
24	*Per empty car per empty trip:*												
25	Fall energy, MNm	-32	-32	-33	-5	-5	-5	-62	-62	-63	116	116	119
26	Rise energy, MNm	1402	1402	1433	254	254	260	813	813	831	927	927	948
27	Energy required for empty trip, MNm	1370	1370	1400	249	249	255	751	751	768	1044	1044	1067
28	Net energy required, MNm	-9350	-4065	-3140	-1494	-306	-151	-4543	-626	-48	-4615	-1611	-1088
29	Net energy required, kWh	-2597	-1129	-872	-415	-85	-42	-1262	-174	-13	-1282	-447	-302
30	Decrease compared to diesel, %	0,0	56,5	66,4	0,0	79,5	89,9	0,0	86,2	99,0	0,0	65,1	76,4
31	Energy storage/200-car train, MWh	0,00	0,00	0,00	0,00	0,00	7,24	0,00	8,67	50,0	0,00	0,00	0,00
32	Round trips per 100Mtpa, number	1000000			1000000			1000000			1000000		
33	Energy consumed/100Mtpa, GWh	2597	1129	872	415	85	42	1262	174	13	1282	447	302
34	Cars/train high TE locomotive/high power locomotive	1,97			1,98			1,98			1,96		