ENERGY REQUIREMENTS AND CO2-EMISSIONS FROM MANUFACTURING AND MAINTENANCE OF LOCOMOTIVES AND TRAINS

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Energy consumption factors

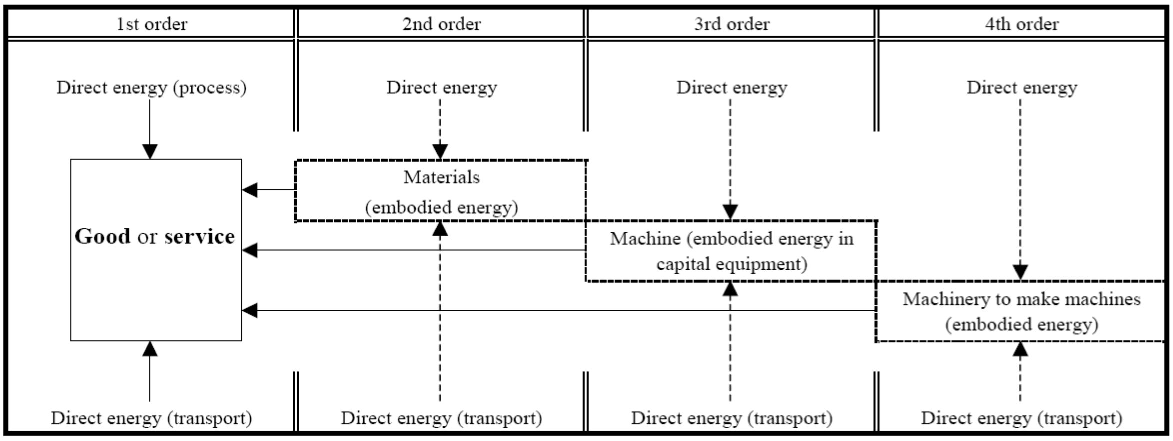
This document analyses the energy requirements for manufacturing of locomotives and trains. We will look at two locomotives (one electric and one diesel-driven) from Bombardier, one six-car commuter train from Alstom and train manufacturing estimates [1] for BART and Caltrain railway systems in USA. In addition, we will look at estimates for train manufacturing presented in the literature. We will analyse the energy requirements both for manufacturing and maintenance of the different railway equipment.

In order to calculate the energy requirements for locomotives from Bombardier and commuter trains from Alstom, we will start with a material decomposition of the railway equipment in question. By applying factors for energy use and emissions pr kg of the most significant materials we will build up a total energy and emission estimate for the manufacturing of the relevant equipment.

Energy use factors can be developed in several ways. We will first look at GER-values. Then we will contrast these GER-values with estimates from a German LCA-database [2].

According to FAO (Food and Agriculture Organization of the United Nations) a GER-value measures the "total amount of energy required for a product" [3]. FAO gives an example of what a GER-value is by referring to milk which has a GER-value of 5.2 MJ/pint in the United Kingdom. This GER-value includes the energy required to "..produce fertiliser, grow the grass, feed the cows, process the milk in the dairy, and energy for transport" . A doctoral thesis from University of Groningen in the Netherlands [4] defines GER-values as: "The amount of energy source which is sequestered by the process of making a good or service." We will use the term energy use factors with the same meaning as GER-values.

Figure 1 GER-values [5]



[1] Horvath,A. , Chester, M. ,: Environmental Life-cycle Assessment of Passenger Transportation: A Detailed Methodology for Energy, Greenhouse Gas and Criteria Pollutant Inventories of Automobiles, Buses, Light Rail, Heavy Rail and Air v.2, http://repositories.cdlib.org/cgi/viewcontent.cgi?article=1015&context=its/future_urban_transport

[2] ProBas, a database for "process oriented data for environmental management instruments" developed by Deutsche Bundesumweltsamt and Institut für Angewandte Ökologie,.

[3] See http://www.fao.org/docrep/u2246e/u2246e02.htm

[4] Lensink, S.M., " Capacity Building for Sustainable Transport" http://dissertations.ub.rug.nl/FILES/faculties/science/2005/s.m.lensink/thesis.pdf

[5] ibid., page 30.

Figure 1 is reproduced from the thesis. The figure shows energy requirements of different orders included in the energy use values. As can be seen from the figure, first order requirements include the direct manufacturing energy needed to manufacture a good or service as well as the direct energy needed to transport it to the end user. Higher order requirements include the energy needed to mine, fabricate and transport materials as well as manufacturing and transport machines used in the manufacturing process of the service or good in question. Figure 1 shows that the manufacturing process is a chain with many links, of which the direct manufacturing at plant is one.

Note that for transport, only *direct* energy is included. This means that energy for producing, transporting, refining and distributing fuel for transport is not included. This energy we call the *gross direct energy*. The energy for manufacturing the transport mean or for constructing, operating and maintain the infrastructure is also not included in the energy use factors. This last type of energy we call *indirect energy*[6].

By applying energy use factors for different materials used in locomotives and trains, we will try to produce an estimate of the total energy required to manufacture the train equipment. The product declaration from the manufacturer include energy values for production, but these values only relate to the direct employment of energy at the manufacturing plant. Our energy use factors include energy required to extract and fabricate materials, the machines involved in this process, as well as the transport required in these processes.

One problem with this approach is that not all materials in the relevant train equipments are referred to in the product declaration. Since the dominant materials are included, we will regard this source of error as a negligible one. Product declaration from both Bombardier[7] and Alstom[8] are published according to the standards of ISO 14025. Product declarations from both companies are made in accordance to EMAS, a management tool for environmental assessment developed by the EU which is open to all production sectors since 2001.

TRAXX is a locomotive platform from Bombardier. The locomotives have 4 axles and are run both on electricity and diesel. All locomotives on the platform are built in a modular fashion allowing for reuse of components across different locomotive types. The locomotives are used both for passenger and freight transport across Europe. They are designed to comply with different standards in different European countries. The European Train Control System (ETCS) are available on locomotives from this platform.

Bombardier F140 MS

The TRAXX 4 F140 MS is a locomotive based on Class 185 from Bombardier. The power of this locomotive varies according to the voltage system on which the locomotive is run. For voltage systems between 15 and 25 kilo-voltage in AC-systems the power capacity of the locomotives are

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6 Høyer, K.G. and Heiberg, E. (1993): *Persontransport – konsekvenser for energi og miljø* (Passenger transport – an assessment of energy and environmental impacts), Report 1/93 (Sogndal: Western Norway Research Institute).

7 Bombardier: Environment Product Declaration for TRAXX F140 MS, http://www.bombardier.com/files/en/supporting_docs/TRAXX_MS_EMAS.pdf

8 Alstom: CORADIA LIREX Commuter Train. http://www.se.alstom.com/home/about_us/ecopolicy/_files/file_32236_59941.pdf

5 600 kW. For voltage systems with 3 kilo-voltage in DC-systems the power capacity is also 5 600 kW while the capacity for voltage systems of 1,5 kilo-voltage in DC-systems is 4000 kW.

The TRAXX 4 F140 MS can run on 4 different voltage systems (15kV / 25 kV AC, 1.5kV / 3kV DC) [9], hence the abbreviation MS which stands for multiple systems [10]. Maximum speed for TRAXX F140 MS is 140 kilometre pr hour. The letter F means that this locomotive is used for freight transport [11]. The locomotives are used by the Swiss railway cargo division, among others. The total weight of the locomotive is 84,7 tonnes. Its loading capacity is 1 260 tonnes giving a gross tonnes weight (load+vehicle weight) of 1 344,7 tonnes.

Table 1 Production site of different locomotive parts by country

Part	Place	Country
Carbodies and bogie	Wroclaw	Poland
Traction converter and auxiliary converter	Mannheim	Germany
Bogies	Siegen	Germany
Drive	Hennigsdorf	Germany
Cooling tower	Stuttgart	Germany
Brake system	Munich	Germany
Transformer	Geneva	Switzerland
HVAC (heating, ventilation and air conditioning)	Korneuburg	Austria

Table 1 shows in which country the different parts of the locomotive are produced. Table 2 shows its material decomposition as well as energy use factors for the materials. The factors are obtained from the German LCA-database ProBas [12]. The documentation of these factors are discussed elsewhere.

Table 2 Material decomposition of Bombardier TRAXX 4 F140 MS [13]

Material	kg	MJ/kg	Total energy (GJ)
Steel [14]	58 059	22,8	1 324
Aluminium	5 009	175,9	881
Copper	7 867	48,9	385
PVC	2 958	56,2	166
Total	73 893		2 756

[9] http://railwiki.com/TRAXX+F140+MS/
[10] http://www.ferroequinologist.de/en/photos/Innotrans+2008+-+Bombardier+TRAXX+F140+MS
[11] ibid.
[12] Fro ProBas, a database for "process oriented data for environmental management instruments" from Deutsche Bundesumweltsamt and Institut für Angewandte Ökologie. The database includes all relevant information for a cradle-to-grave environmental assessment of a material or product, such as excavation and fabrication of raw materials as well as transport. See http://www.probas.umweltbundesamt.de/download/uba_bewertungsmethode.pdf page 1
[13] http://www.bombardier.com/files/en/supporting_docs/TRAXX_MS_EMAS.pdf , page 8
[14] Energy use factor for hot rolled steel sheets.

One problem with the analysis above is that only 71 tonnes of the total weight of 84 tonnes is accounted for (excluding PVC). Consequently, some energy is also not accounted for. The rest of the materials are grouped in larger categories. Polymers is one group with 2 958 kg. We will use a energy use factor of 56,2 MJ/kg for PVC obtained from ELCD [15] as representative for polymers. We refer to the discussion of energy use factors elsewhere for justification of this factor. Using this estimate, we estimate an additional 166 GJ bringing the total estimate to 2756 GJ for manufacturing of F140 MS.

The energy use factors applied above include energy used by the process of mining raw material (i.e. iron ore) and transport it for further processing as well as fabrication of raw material to the end-material (i.e. hot rolled steel sheets). Our energy use factors do *not* include energy used at the manufacturing plant for the locomotive F140 MS.

The product declaration from Bombardier gives estimates for material requirements arising from use of the locomotive. These are equivalent to maintenance requirements. Table 3 shows the maintenance material decomposition for F140 MS for its total lifetime.

Table 3 Material decomposition for maintenance of Bombardier TRAXX 4 F140 MS

Material	Kg	MJ/kg	Total energy in GJ
Steel	13 676	22,8	312
Aluminium	515	175,9	91
Copper	11	48,9	1
Total	14 202		403

We estimated the manufacturing energy to be 2756 GJ. By adding the maintenance energy requirements we get a total estimate of 3 159 GJ for F140 MS over its entire lifetime.

The product declaration also gives an overview of different primary energy resources used in the manufacturing of the locomotive. This energy do presumably not include indirect energy from material excavation, material fabrication, machine fabrication and transport as do the energy use factors employed in this analysis. We assume that the figures for primary energy resources only include direct energy used at the manufacturing plant. These numbers will anyhow tell us what energy mix is used at the manufacturing plant as well as give us a picture of how big the amount of direct energy is relative to the indirect energy used in other stages of the manufacturing process.

The use of primary energy sources is measured pr tonne-km. In order to give an estimate of total primary energy use over the lifetime of the locomotive we need to make two assumptions. One is for the total lifetime of the locomotive, the other is for the vehicle length travelled in km each year with a specified average load. The product declaration from Bombardier uses a lifetime for the locomotive of 30 years and a yearly travelled length of 150 000 km. The average load used is 1 260 tonnes. The locomotive itself weighs 84,7 tonnes so the average gross mass of the locomotive in use is 1 344,7 tonnes (load +vehicle weight)[16].

[15] ELCD is a LCA-database developed by EU for core materials, energy carriers and transport. Each estimate is represented by a "data set". Each data set is developed and approved by relevant industrial organizations in EU, http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm

[16] http://www.bombardier.com/files/en/supporting_docs/TRAXX_MS_EMAS.pdf , page 8.

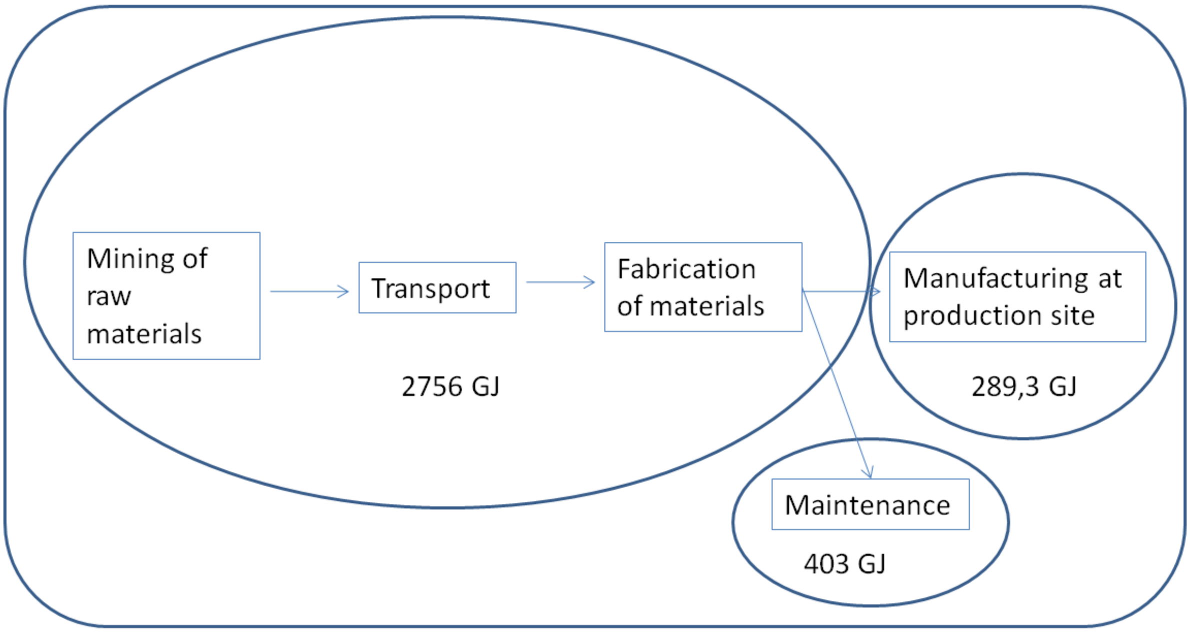
Table 4 shows use of primary energy resource pr tonne kilometre for manufacturing of the locomotive Bombardier F140 MS. The leftmost column shows the values for total energy use pr energy source with the assumptions given. The values for primary energy use are calculated for the entire lifetime of the locomotive. All in all, it is assumed that the locomotive during its lifetime produces 1344,7*150000*30=6 051 150 000 tonne kilometres.

Table 4 Use of primary energy source for manufacturing of Bombardier TRAXX 4 F140 MS

Primary energy source	Wh/ tonne-km	Total energy in GJ
Oil	0,00094	20,5
Coal	0,00416	90,6
Nuclear power	0,00409	89,1
Natural gas	0,00181	39,4
Hydro power	0,00228	49,7
Total		289,3

The total energy use for all primary energy sources is calculated as 289,3 GJ in Table 4. This is only for manufacturing the train at the production site. Previously we have calculated total energy use for fabrication of the materials used in this production. This energy is calculated as 2 756 GJ. We add the energy used at production plant and get 3 045,3 GJ as an estimate for the total energy use for manufacturing of the locomotive. This figure includes energy for the whole production chain, from mining and transport of raw materials, to fabrication of raw materials to materials and finally to manufacturing of the locomotive at production site. If we add energy for maintenance to this estimate we get a total of 3448,3 GJ. Figure 2 shows the chain (with maintenance included) with each node represented as boxes with edges between them representing the links between the nodes.

Figure 2 Energy chain for manufacturing and maintenance of locomotive F140 MS



How much CO_2 is emitted from manufacturing of Bombardier F140 MS? The product declaration gives an estimate of 0,000052 kg CO_2-equivalents for each tonne km performed by the locomotive. According to the product declaration, this is a "cradle-to-gate" estimate including the materials and energy needed for manufacturing of the locomotive [17]. Using 6 051 150 000 tonne km over the lifetime of the locomotive, we estimate a total emission of 315 tonnes CO2-equivalents for manufacturing the locomotive.

Presumably this is emission from the manufacturing plants. The product declaration is unclear at this point. It states that an LCA analysis has been performed, without clearly stating what this analysis include. In addition to the emissions estimated in the product declaration, we will estimate the CO_2-emissions from the materials used in manufacturing the locomotive. We will produce an estimate of the total emission following from the production chain for the locomotive *until* assembly in the production plants based on material distribution. We can produce this estimate by looking at emission factors for the main materials used in the locomotive from Table 2. This will account for approximately 85% of the total weight of the locomotive.

Emission factors for different materials are obtained from ProBas. We refer to the documentation of these factors elsewhere. ProBas gives estimates for CO_2-equivalents including all greenhouse gases such as methane, nitrus-oksid, perfluorkarbones, hydrofluorcarbones and sulphur hexafluorid in addition to CO_2.

Table 4 CO2-emission from materials used in manufacturing of Bombardier F140 MS

Material	Emission factor (tonne CO2 equivalents/tonne material)	Tonnes of material used in manufacturing	Tonnes of CO2 emitted from manufacturing F140 MS
Steel	1,7 [18]	58,1	98,8
Aluminium	16,9 [19]	5,01	84,7
Copper	4 [20]	7,9	31,6
PVC	2,7[21]	3	8,1
Total		74	223,1

All in all, excavating, fabricating and transporting the materials used in the manufacturing of the Bombardier F140 MS cause emission of 223,1 tonnes of CO_2-equivalents. This is the emission of CO_2-equivalents in the production chain until assembly at the production plants. The estimate from the product declaration is 315 tonnes . It is not clear from the product declaration what is included in this estimate. We assume that the estimate covers energy use for manufacturing at the production site.

[17] http://www.bombardier.com/files/en/supporting_docs/TRAXX_MS_EMAS.pdf , page 9.
[18] Estimate for hot rolled steel sheets from ProBas, internal name Stahl-DE-WarmWalz-2005
[19] Estimate for aluminium from ProBas, internal name Aluminium-mix-DE-2005
[20] Estimate for copper from ProBas, internal nameKupfer-DE-mix-2005
[21] ELCD, European Reference Life Cycle Database, http://lct.jrc.ec.europa.eu/projects/eplca/deliverables/elcd-database-1/elcd-database

We therefore add the 223,1 tonnes and end up with an emission of 538,1 tonnes of CO_2-equivalents for manufacturing of Bombardier F140 MS.

In addition, materials are used for maintenance of the locomotive. Table 5 shows emission of CO2-equivalents for materials used in maintenance and manufacturing of the Bombardier F140 MS. The emission estimate does not include energy used for assembling at the manufacturing plants. Emission from maintenance alone is 31,7 tonnes. Adding up emissions from manufacturing and maintenance we estimate the total emission of CO_2-equivalents for Bombardier F140 MS to be 561,8 tonnes of CO_2-equivalents pr tonne for the locomotive.

Table 5 Emission of CO2 from materials for maintenance and manufacturing of Bombardier F140 MS

Materials for maintenance	Tonne	Tonne CO_2-equivalents pr tonne material	Emission of CO2-equivalents from maintenance (tonne)	Emission of CO2-equivalents from materials used in manufacturing (tonne)	Emissions of CO2-equivalents from manufacturing (tonne)	Total manufacturing and maintenance (tonne)
Steel	13,7	1,7	23,3	98,8		122,1
Aluminium	0,5	16,9	8,5	84,7		93,2
Copper	0,0	4,0	0,0	31,6		31,6
PVC	3	2,7		8,1		
Total	14,2		31,7	223,1	315,0	569,8

Figure 3 Total emissions of CO2-equivalents from manufacturing and maintenance for Bombardier F140 MS

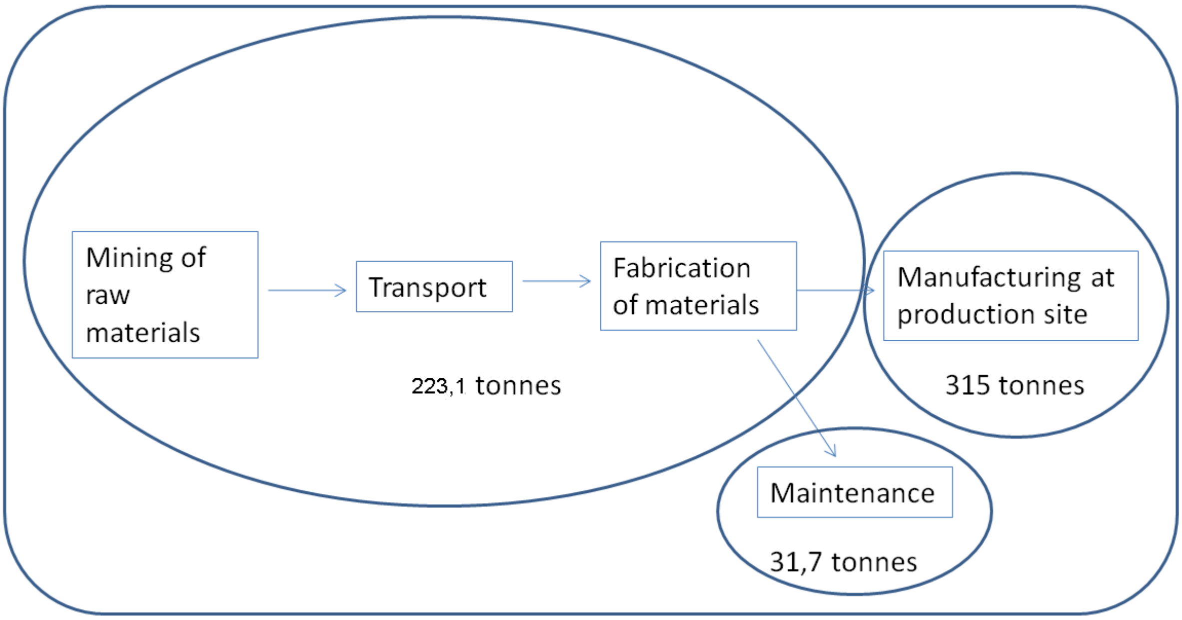


Figure 3 shows a breakdown of the estimate of CO2-equivalents arising from manufacturing and maintenance of F140 MS.

Bombardier P160DE

In this section we will look at energy requirements for manufacturing another Bombardier locomotive, the P160DE. This is a locomotive for passenger transport with a maximum speed of 160 km/hour. The locomotive runs on diesel power. It shares the car body, bogies, traction motors, driver's cabs, locomotive layout and communication system with the locomotive F140 MS. This also means that they share the same energy mix for the manufacturing of the locomotive. The P160 DE can run on different voltage systems as can F140 MS. The P160DE locomotive has a power capacity of 2 200 kW in all voltage systems. The power capacity of the P160DE is therefore less than the F140 MS in all voltage systems. The locomotive weighs 88 tonnes .

The material decomposition for P160 DE is shown in Table 5. The energy use factors used are the same as for F140 MS with the same specifications. We use the same approach for polymers for P160 DE as for the freight locomotive F140 MS. We assume that all polymers are PVC for isolation, dashboards and tightening. The total weight estimated above for P160 DE is greater than the total weight given for the locomotive in the product declaration., where the total weight is set to 81 tonnes. The amount of steel, aluminium and copper alone given in the environment profile exceeds the total weight. We will use the weights from the environment profile as the total weight estimate for P160 DE.

Table 5 Material decomposition of Bombardier TRAXX 4 P160 DE

Material	Kg	Energy use factor (MJ/kg)	Total energy in GJ
Steel	76 672	22,84	1 751
Aluminium	7 950	175,9	1 398
Copper	3 045	48,9	149
Polymers	1 314	56,2	74
Total	88 981		3 372

The product declaration for the locomotive P160 DE also has a material decomposition for materials required for *maintenance* of the locomotive over its lifetime. Table 6Table 6 shows this decomposition along with the energy requirements estimated by using relevant energy use factors for the different materials. Adding the energy requirements for maintenance we get a total estimate for energy requirements for P160 DE of 3 891 GJ over the train's lifetime.

Table 6 Material decomposition for maintenance of Bombardier P160 DE

Material	Kg	Energy use factor (MJ/kg)	Total energy in GJ
Steel	14 547	22,8	332
Aluminium	1 049	175,9	184
Copper	38	48,9	2
Total	15 634		519

The product declaration for the P160 DE covers primary energy used at the manufacturing plants. Table 7 shows the energy consumption. The locomotive P160 DE is for passenger transport. The load used in calculations in the product declaration is 226.2 tonnes which includes passenger and passenger coaches. In addition the locomotive itself weighs 81,2 tonnes. The locomotive runs 175 000 km each year in 30 years. In total, this yields 1 613 850 000 tonne km for the lifetime of the locomotive. Using numbers pr tonne-km as given in the product declaration, we can estimate the total consumption of energy resources over the lifetime of the locomotive. As Table 7 shows, we estimate this consumption of primary energy resources to be 288,8 GJ.

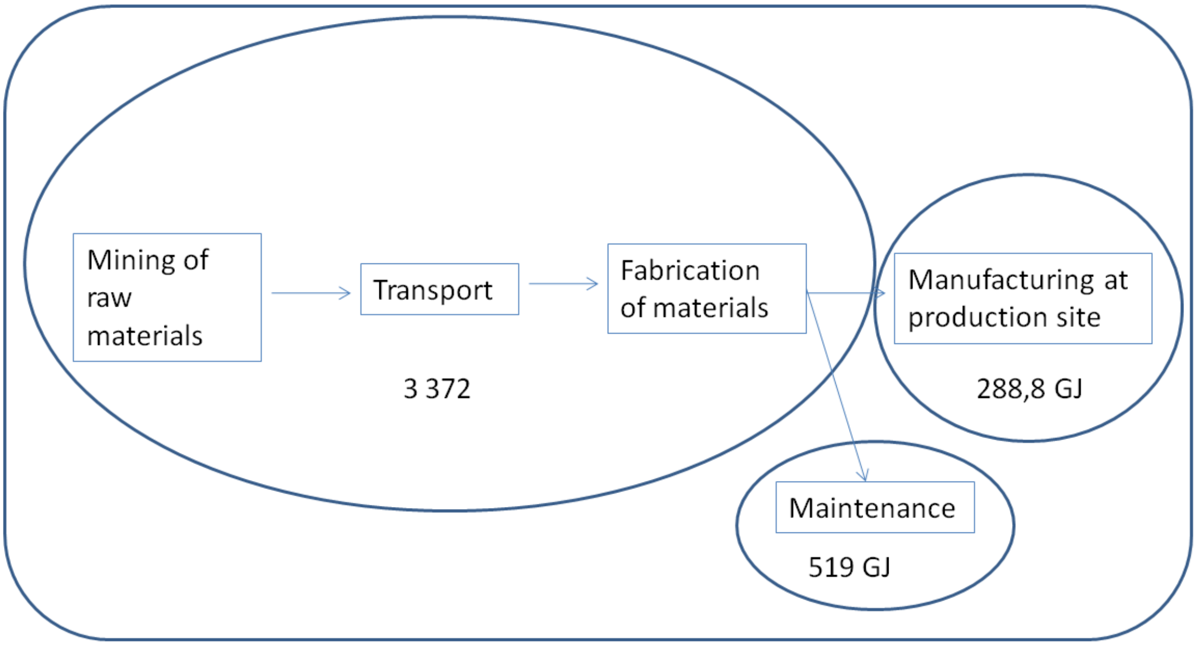
Table 7 shows energy resources used at the production plants. The estimates given in Table 5 and Table 6 shows energy embedded in the materials used. We add the energy used at the manufacturing plants and get a total energy requirement estimate of 4 179,8 GJ for manufacturing and maintenance of the locomotive. Excluding maintenance, we get an energy estimate of 3 660,8 GJ.

Table 7 Primary energy resources used at the manufacturing plants.

Primary energy resource	Wh pr tonne-km	GJ
Oil	0,0035	20,3
Coal	0,0156	90,6
Nuclear power	0,0153	88,9
Gas	0,0068	39,5
Hydropower	0,0085	49,4
Total		288,8

Figure 4 shows energy used in the production chain (including maintenance) for manufacturing of the locomotive P160 DE.

Figure 4 Energy chain for manufacturing and maintenance of locomotive P160 DE



We can calculate the emission of CO_2-equivalents from manufacturing of the locomotive P160 DE as we did for locomotive F140 MS. The product declaration [22] gives an estimate for materials and energy used in manufacturing of 0,000190 kg pr tonne-km. With 1 613 850 000 tonne-km as estimated above this yields 306,7 tonnes of CO_2-equivalents for manufacturing of the locomotive at the production site. We assume, as above, that this estimate does not include embedded CO2 from excavation and fabrication of materials before final assembly and fabrication at the manufacturing plants.

We will use emission factors for the materials used in manufacturing in order to arrive at an estimate of embedded CO_2-emission in the materials. We refer elsewhere to the documentation of these factors. As mentioned above, we assume that all use of polymers is in the form of PVC insulation material.

Table 8 Emission of CO2-equivalents from materials used in manufacturing of Bombardier P160 DE

Material	Tonnes	Tonne CO2-equivalents pr tonne material	Tonnes of CO2-equivalents
Steel	76,7	1,7	130,3
Aluminium	8,0	16,9	134,4
Copper	3,0	4,0	12,2
PVC	1,3	2,7	3,5
Total	89,0		280,4

[22] http://www.bombardier.com/files/en/supporting_docs/TRAXX_DE_EMAS.pdf

We add the total estimate from Table 8, 280,4 tonnes of CO2-equivalents, to the 306,7 tonnes CO2-equivalents given in the product declaration. This gives us emission of 587,1 tonnes of CO2-equivalents for manufacturing of the Bombardier P160 DE.

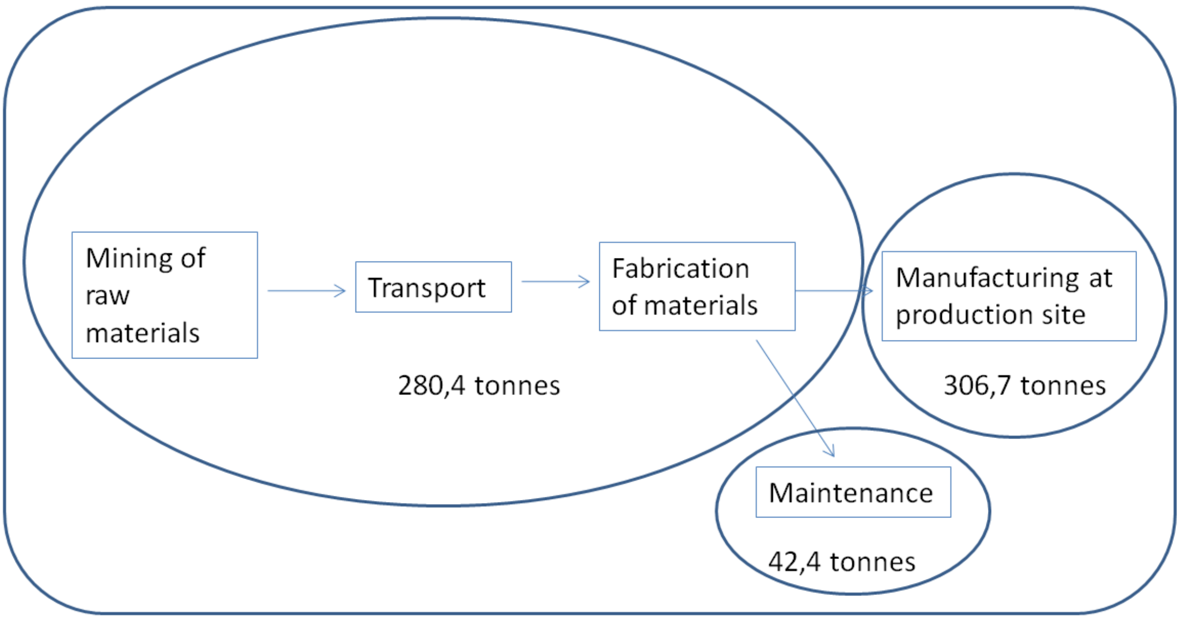
Materials are also used for maintenance of the locomotive P160 DE. Table 9 shows materials used in maintenance and the corresponding factors for emission of CO_2-equivalents and the total emission due to maintenance. Corresponding numbers for manufacturing are included in the table to give an overview of the total emission for each of the listed materials. PVC is only used in manufacturing of the locomotive, not in maintenance of it.

Table 9 Emission of tonnes of CO2-equivalents for manufacturing and maintenance for Bombardier P160 DE

Materials for maintenance	Tonne	Tonne CO_2-equivalents pr tonne material	Emission of CO2-equivalents from maintenance	Emission of CO2-equivalents from materials used in manufacturing	Emissions of CO2-equivalents from manufacturing	Total
Steel	14,5	1,7	24,7	130,3		155,0
Aluminium	1,1	16,9	17,7	134,4		152,1
Copper	0,0	4,0	0,0	12,2		12,2
PVC				3,5		
Total	15,6		42,4	280,4	306,7	629,5

As Table 9 shows, maintenance operations add 42,4 tonnes of CO_2-equivalents to the total emission for the locomotive P160 DE. Adding emissions from maintenance to emissions from manufacturing (including emissions from fabricating materials), we end up with a total emission of 629,5 CO2-equivalents for manufacturing and maintenance of the Bombardier locomotive P160 DE. Figure 5 shows a breakdown of the estimate of CO2-equivalents arising from manufacturing and maintenance of P160 DE.

Figure 5 Total emissions of CO2-equivalents from manufacturing and maintenance for P160 DE



Alstom Coradia Lirex

Coradia Lirex is a train operating in the Greater Stockholm area operated by Storstockholms Lokaltrafik (SL). The train has six cars, weighs 206 tonnes and has a maximum speed of 160 km/hour. It has 374 seats and a total passenger carrying capacity of 918 passengers. The operator ordered 71 train sets which were all delivered before 2008. The train is manufactured by Alstom which has published an environmental product declaration with an LCA analysis conforming to ISO 14040-14043 Standard. Alstom also has an environmental policy conforming to the EU Management and Audit System (EMAS) [23].

Table 10 shows the material decomposition of the Coradia Lirex. The table uses the energy use factors used above in order to estimate the energy requirements for manufacturing of the train. We refer to the documentation of these energy use factors elsewhere. For cast iron we use the energy use factor for primary steel. For steel the energy use value for hot rolled steel is used. All in all the material decomposition in Table 10 accounts for 183,3 of the train's total weight of 206 tonnes which is about 89% of total weight.

The remaining 23 tonnes are mainly plastics and chemicals. We do not have energy use factors (or CO_2-emission factors) for aggregate material categories like plastic or chemicals, only for materials at a more specified level. We do not know the exact properties of the remaining 26 tonnes, which makes it impossible to calculate the energy requirements and emission from these materials. Since they make up a minor part (11%) of total material composition we regard this source of error as negligible. The product declaration states explicitly that plastic is not composed of PVC since this material is "..avoided from the beginning" [24].

Table 10 Material decomposition for Coradia Lirex

Materials	Tonne	Energy use factors MJ/kg	Total energy GJ
Metals			
Steel	82,4	22,8	1 882
Stainless steel	42,3	53,0	2 242
Cast iron	23,7	19,9	472
Aluminium	18,0	175,9	3 166
Copper	10,5	48,9	513
Rubber	2,6	36,6	95
Glass	3,8	12,0	45
Total	183,3		8 415

As Table 10 shows, our estimate for energy requirements for the manufacturing of Coradia Lirex is 8415 GJ. This is energy used for excavation and transport of raw materials and fabrication of materials. This energy estimate does not include primary energy resources used at the manufacturing plant. There is no estimate for this energy use in the product declaration. From the discussion of the Bombardier locomotives, we can estimate this energy to be approximately 10% of

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[23] Alstom: *CORADIA LIREX Commuter Train. A Presentation of Quantified Product Information on the Life Cycle of the CORADIA LIREX Commuter Train for Stockholm/Sweden*, http://www.se.alstom.com/home/about_us/ecopolicy/_files/file_32236_59941.pdf

[24] ibid., page 4

the energy estimated from the GER-values. Using this as a rough estimate we add another 841,5 GJ for the manufacturing of Alstom Coradia Lirex and get a total estimate of 9256,5 GJ.

The estimate is close to 2,5 times bigger than the estimate for the energy requirement for manufacturing the locomotive P160 DE from Bombardier, and 3,3 bigger than the corresponding estimate for the locomotive F140 MS which is for freight transport. Given that Coradia Lirex is a six-car passenger train set, these differences are reasonable. The total weight of Coradia Lirex is about 2,4 bigger than the weight for the locomotive P160 DE.

The product declaration for Coradia Lirex does not include an estimate for energy used for maintenance of the train set. For the Bombardier locomotives F140 MS and P160 DE, the relative proportion of this energy to energy used for mining, transportation and fabrication of materials is around 15,5%. Using the same relative proportion for Coradia Lirex, we estimate 1304 GJ for maintenance of the train during its total lifetime. Total energy for manufacturing (including materials) and maintenance will then be 10 561 GJ.

Figure 6 shows the energy used for the whole production chain for Coradia Lirex, including maintenance as estimated above.

Figure 6 Energy chain for manufacturing and maintenance of Coradia Lirex

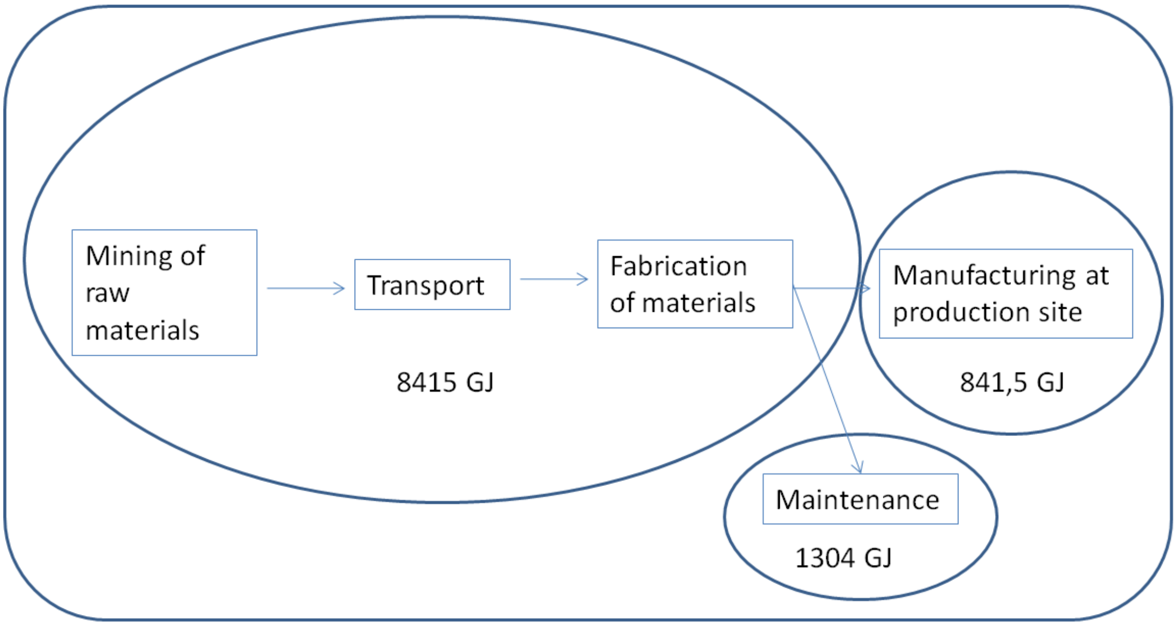


Table 11 Emission of CO2-equivalents from manufacturing of Coradia Lirex

	tonne CO2-equivalents
Production of raw materials	720
Production of six-car unit at Salzgitter site	880,5
Maintenance	56,2
Sum	1656,7

The product declaration contains information on emission of CO2 from the manufacturing of the train set. Table 11 shows the results. All in all, according to the product declaration, 1 600 tonnes of CO2-equivalents are emitted for manufacturing, including excavation, fabrication and transport of materials. In addition, about 56 tonnes are emitted during maintenance of the train.

We can check this estimate by using the emission factors given for main materials in the section above on the Bombardier locomotives. The factors are obtained from ProBas.

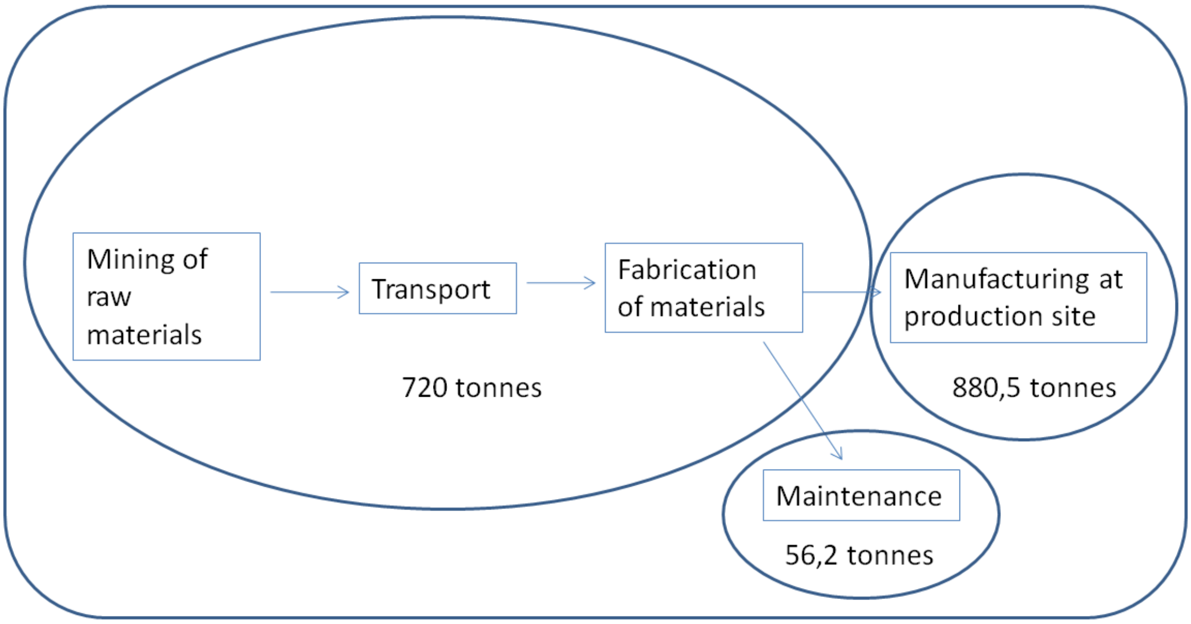
Table 12 Emissions of CO2-equivalents from material use in manufacturing of Coradia Lirex

Materials	Tonne	CO2-equiv.	Tonnes of CO2-equiv.
Metals			
Steel	82,4	1,71	140,9
Stainless steel	42,3	3,6	152,3
Cast iron	23,7	1,52	36,0
Aluminium	18	16,9	304,2
Copper	10,5	4,04	42,4
Rubber	2,6	3,18	8,3
Glass	3,8	1,13	4,3
Total	183,3		688,4

Table 12 shows en estimate of emission of CO_2-equivalents from excavation and fabrication of materials for the Coradia Lirex. The estimate is based on approximately 89% of the total weight of the train. The estimate should be comparable to line 1 in Table 11 except that 11% of the total weight is not accounted for. The difference of 31,6 tonnes of CO_2-equivalents is negligible.

Figure 7 shows the total emissions of CO2-equivalents during the whole production chain for Coradia Lirex, including maintenance of the train.

Figure 7 Emissions of CO2-equivalents from manufacturing and maintenance for Coradia Lirex



Overview

Table 13 shows energy requirements and CO2-emissions from manufacturing and maintenance of the locomotives and trains discussed in this document. Information about maintenance of Alstom Coradia Lirex is not given in the product declaration.

Table 13 Overview of energy use and CO2-emissions for manufacturing and maintenance of different locomotives and trains

		Bombardier F140 MS	Bombardier P160 DE	Alstom Coradia Lirex
Weight in tonnes		84,7	88,0	206,0
Materials	Energy GJ	2 590	3 372	8 415
	tonnes CO2-equiv	215,0	280,4	720,0
Manufacturing	GJ	289	289	842
	tonnes CO2-equiv	315,0	306,7	880,5
Sum manufacturing/materials	GJ	2 879	3 661	9 257
	tonnes CO2-equiv	530,0	587,1	1 600,5
Maintenance	Energy	403	519	1 304
	tonnes CO2-equiv	31,7	42,4	56,2
Total	Energy	3 282	4 179	10 561
	tonnes CO2-equiv	561,8	629,5	1 656,7
	GJ pr tonne	38,7	47,5	51,3
	CO2 pr tonne	6,6	7,2	8,0

As can be seen from the table, the energy and emission estimates fit reasonably well together when we look at GJ pr tonne or CO2-equivalents pr tonne. This also gives strength to the assumption that estimates for CO_2-emissions and energy requirements from the Bombardier product declaration only include energy and emission from the manufacturing plants.

Comparable estimates

Table 14 shows some estimates for locomotive and train manufacturing from other sources.

Table 14 Estimates from manufacturing of locomotives and trains

		Weight in tonnes	Energy GJ for manufacturing	GJ/tonne	Tonnes CO2-equivalents	tonne CO2/tonne train
Jonsson [25]	Locomotive intercity train		4032			
Heiberg [26]	Locomotive	72,2	3168	43,9		

[25] Jonsson, D.:*Indirekt energi för svenska väg- og järnvägtransporter*, Totalförsvarets Forskningsinstitut 2005, isbn 1650-1942, <http://www.infra.kth.se/fms/pdf/FOI-R--1557--SE_v.2.pdf> , table B19, page 90

[26] Heiberg, E.: Indirekte energibruk i persontransport, VF-rapport 20/92, 1992, page 33-34.

BART[27]	Train-set, long distance	220	18000	81,8	1100	5,0
Caltrain	Train-set, long distance	360	30000	83,3	1800	5,0
F140 MS	Freight locomotive	84,7	2 879	44,9	557	6,6
P160 DE	Passenger locomotive	88	3 661	48,5	623,6	7,1
Coradia Lirex	Train set, local and regional	206	9 257	41,8	1656,7	8

BART (Bay Area Rapid Transit System) is a heavy rail system in San Francisco and Caltrain is a diesel-powered heavy rail from Gilroy to San Francisco. The average BART train has 8 passenger cars, while the Caltrain has 3. Train-sets for Caltrain and BART are estimated by using SimaPro, a database and software for LCA analysis based on process analysis. The Caltrain and Bart systems are calculated as long-distance rail with a Californian energy mix.

As can be seen from the table, the estimates for BART and Caltrain are high in terms of energy compared to other estimates if we look at energy consumption pr tonne. Even though BART is partly subway the energy requirement pr tonne for manufacturing is roughly the double than what is the case for Coradia Lirex which is an intercity train for Stockholm. The same is true for Caltrain. The estimates from Heiberg and Jonsson fit better with the estimates presented in this document.

If we look at emissions of CO2, the estimates for BART and Caltrain are closer to the estimates presented above. Actually, in terms of emission, estimates from BART and Caltrain are lower pr tonne than for the Bombardier locomotives and Coradia Lirex.

[27] Horvath,A. , Chester, M. : Environmental Life-cycle Assessment of Passenger Transportation: A Detailed Methodology for Energy, Greenhouse Gas and Criteria Pollutant Inventories of Automobiles, Buses, Light Rail, Heavy Rail and Air v.2, http://repositories.cdlib.org/cgi/viewcontent.cgi?article=1015&context=its/future_urban_transport, page 47-54