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"Towards the Eco-design of a tilting train in Korea: Applying Life Cycle Assessment to design alternatives"

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Abstract

Within the development of a Korean Tilting train including new composite materials, EPFL is contributing to its new design by providing in a consistent way the manufacturing costs assessment and its related environmental impacts. Such environmental expertise is issued from Life Cycle Assessment methods with an innovative Impact Assessment methodology. The Korean Titling Train[1] is one of the first applications of composite materials to structural pieces of a train. This Life Cycle Assessment study is comparing the potential environmental impacts of 1 car-body of a regional train over 25 years made in composite (Carbon fibers) versus the conventional current alternatives based on steel or aluminium. Preliminary results allow to identify major processes determining the life cycle impacts of this one car-body and allow to investigate the advantages of introducing composite in trains.

Setting the alternative scenarios for the regional Korean train

The functional unit is one car body for the Korean Tilting Train express, with a life time of 25 years and used over 7'500'000 km. This car body is formed by the Under Frame, the Panel structure (side, roof and end structure) and in the case of Composite scenario, an Inner Frame to maximise strength properties. The system boundaries include all the processes necessary for the realisation of the system function. All the processes for the raw material extraction, manufacturing and use of the car body are taken into account, except for the infrastructure demand, maintenance and machines fabrication because they are supposed to be the same for all scenarios. Three car bodies scenarios based on real scenarios are proposed and compared in this study (Table 1). A fourth one is also studied which is a full composite car-body. This last option allows to stretch the analysis to its theoretical limit by eliminating the Steel inner frame.

[1] Project undertaken for the KRRI (Korean Railroad Research Institute)

	Hybrid Composite car-body 8,76 tonnes	**Steel car-body 11.50 tonnes**	**Aluminium car-body 9,00 tonnes**
Under Frame	Stainless Steel: 5.3 tonnes	Stainless Steel: 4.2 tonnes	Stainless Steel: 4.2 tonnes
Side, roof, end structure	Composite: 1.75 tonnes - 0.35 tonnes Aluminium Honeycomb - 1.4 tonnes CFRP : • 0.84 tonnes carbon fibres • 0.56 tonnes Epoxy resin Bondex: 0.216 tonnes	Stainless Steel: 7.3 tonnes	Aluminium: 4.8 tonnes
Inner Frame	Stainless Steel: 1.5 tonnes	No Inner Frame	No Inner Frame

Table 1: Description of car-body scenarios

This LCA has been done in accordance with ISO14040 standards. Korean data have been used as much as possible and when not available, but still appropriate, European data (from Ecoinvent 1.1 Database and IDEMAT database for the carbon fibres production phase) have been used.

- Raw materials extraction and production phase inventory (Primary Energy, CO_2 and NOx) has been modelled with European data for raw materials and autoclave production performances. Korean assumptions have been used for train car-body dimensions and characteristics and for car-body manufacturing base-line scenario for the different scenarios proposed.
- Use phase inventory has been modelled with Railnet II train running model, developed by the LITEP (Laboratory for Intermodality, Transport and Planning) based on the specific train run characteristics (length, number of stop, slopes, limitations of speed) and Train Motor mechanical performances. Concerning the electricity production emissions, the Korean electricity production mix (37% hard coal, 15% gas, 8% oil, 38.9 % nuclear, 1.3% hydropower) has been used assuming European electricity production technology.

The composite car body alternative is the best scenario

Composite scenario is the most environmental friendly scenario in terms of primary energy: composite hybrid scenario appears to be, with 22.10^6 MJ-eq, 3% and 25% less energy demanding than the steel and Aluminium scenario (see figure 1). Such results are largely explained by the lower energy demand over the use phase for the composite scenario because of a much lighter design.

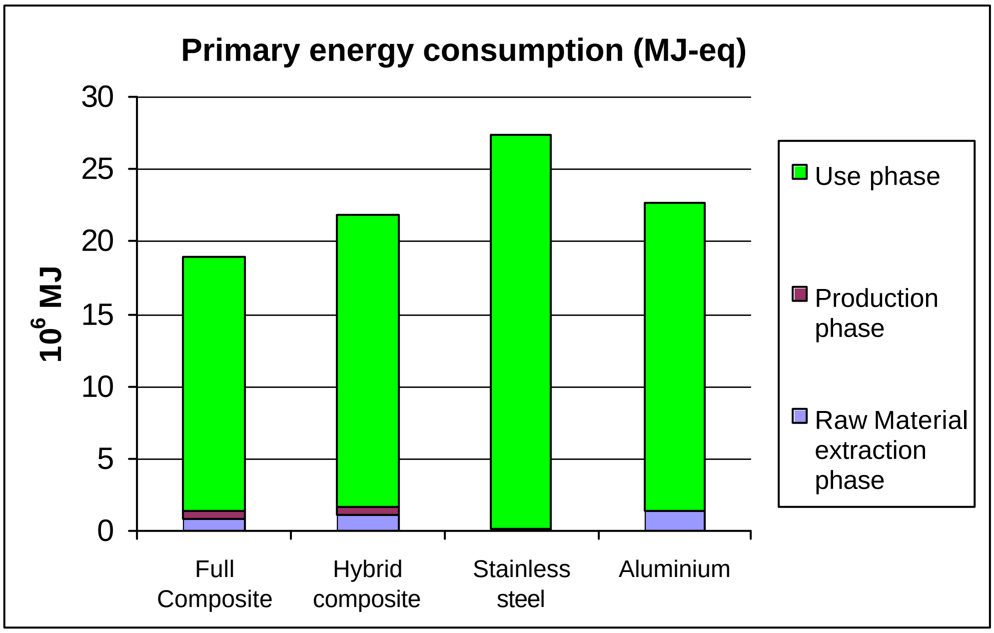

Figure1: Primary energy over the whole life cycle (10^6 MJ-eq)

CO_2 emissions assessment results show the same trend for the composite scenarios. The Hybrid composite scenario is the best alternative, with 0.9 tonne of CO_2, which are 5% and 26% lower than Aluminium and Stainless steel scenarios, respectively (figure 2). Concerning NO_x emissions, hybrid composite scenario appears to be also the most environmental friendly, with 2.07 10^3 kg emitted. Compared to Aluminium and Stainless steel scenario, these emissions are 3% and 25% respectively lower (Figure 3).

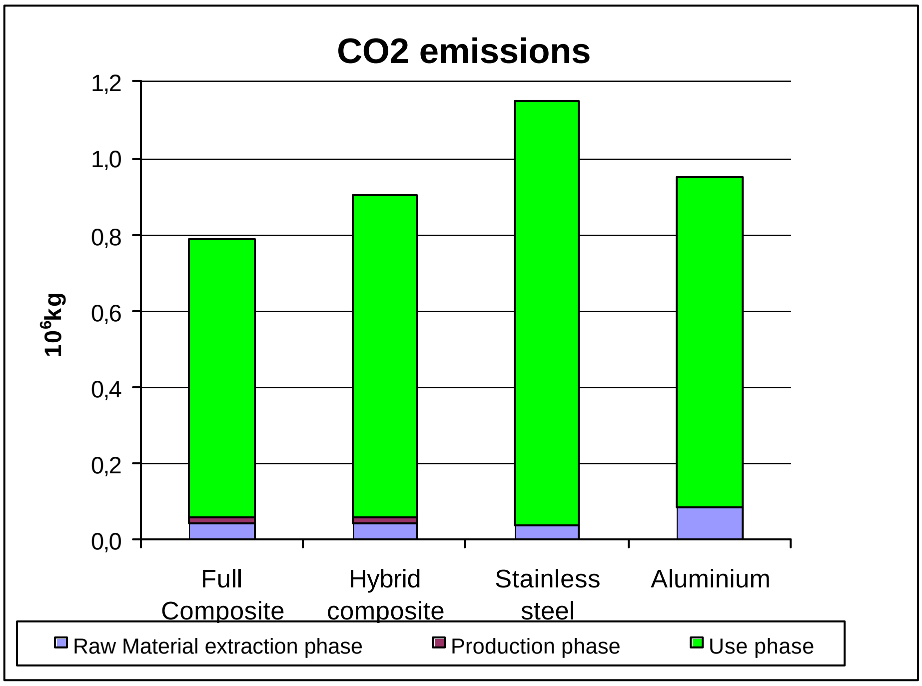

Figure 2: CO_2 emissions (10^6 kg) over the whole life cycle

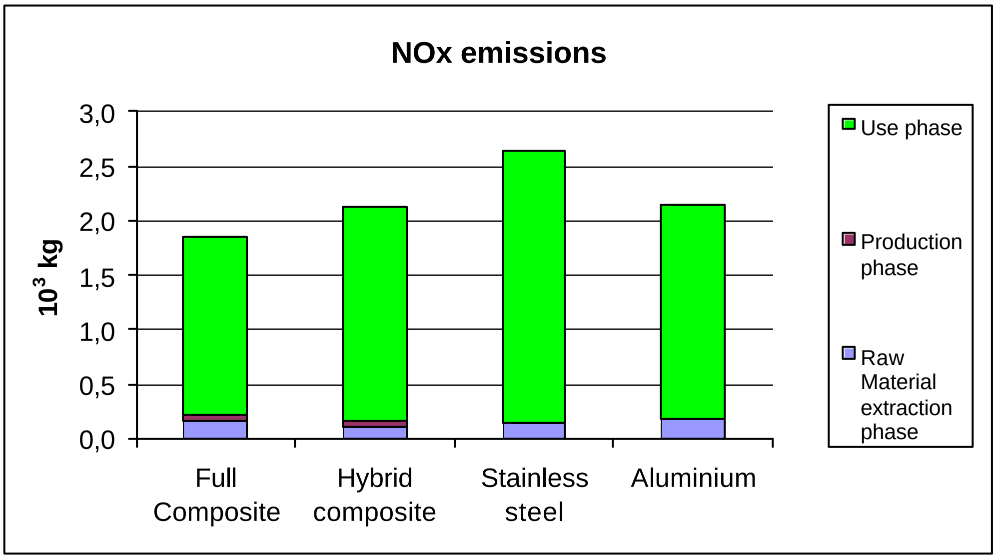

Figure 3: NOx emissions (10^3 kg) over the whole life cycle

Weight is a key factor for reducing energy consumption over the use phase

Weight is a key factor to consider when aiming at reducing the energy consumption for the use phase: a weight increase for the car-body of one tonne implies an increase for the primary energy demand of 0.0259 kWh/tonne.km for this specific Korean regional train. Considering this energy issue over the use phase, the composite scenarios do represent a good design option.

Impact assessment results and discussion

Impact assessment has been performed using Impact 2002+ approach [1]. Fifteen mid-points categories have been defined with this approach which are related to the Inventory results. These fifteen mid-points categories are structured into 4 damage categories: Human health, Ecosystem Quality, Climate Change and Resources depletion. They are normalised according to their global effect on these damage categories. Figure 4 allows the comparison of the scenarios for the regional Korean car body.

- Respiratory in-organics (related to Human Health category), Global warming (related to Climate change) and Non-renewable Energy (related to resource depletion) are the 3 mid-points categories worth to analyse when comparing the 4 scenarios. These mid-point categories reveal significant differences between the different options.
- **Resources depletion** appears to be the most important endpoint category, representing 44% of the whole impacts. Resources depletion is completely dominated by Non-renewable energy consumption (mineral extraction not actually operative).

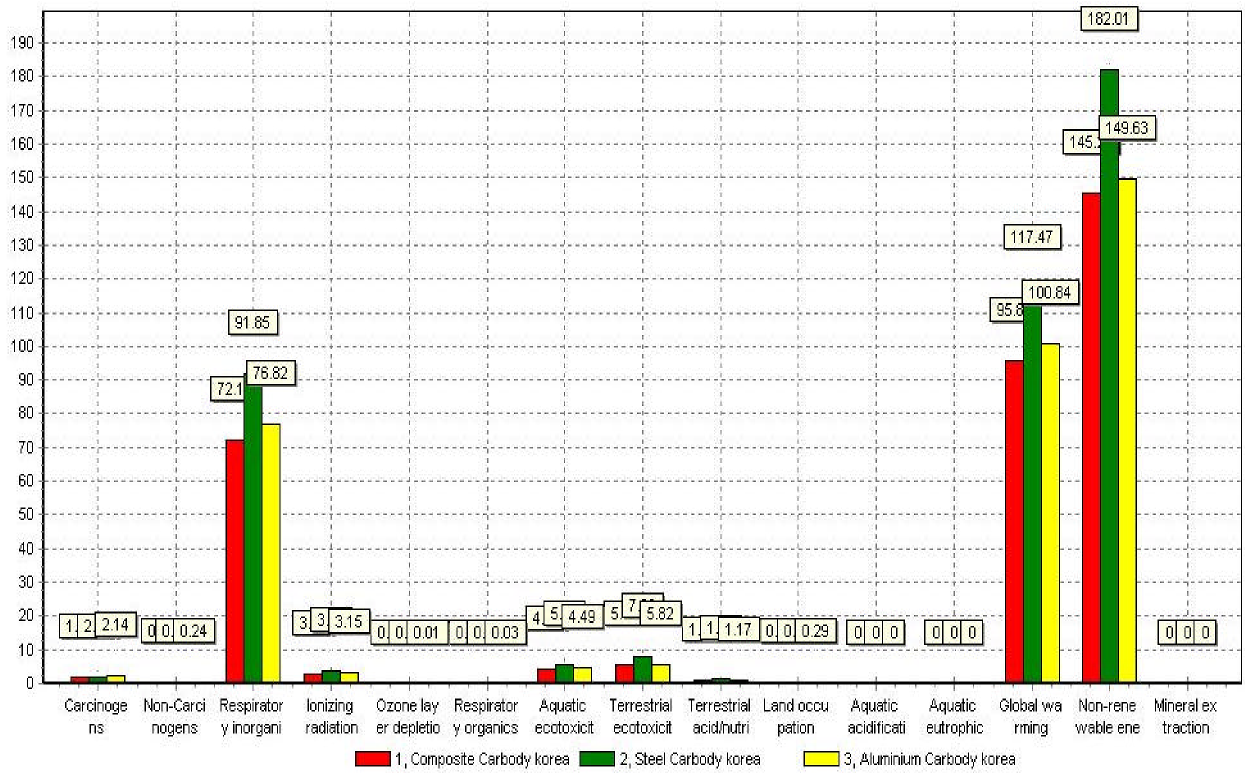

Figure 4: Normalised midpoint categories impact for the whole life cycle (Method 2002+v2.0)

- **Climate change** also represents a great percentage of the whole impacts, representing 29% of the whole impacts. Climate change is mainly dominated by CO_2 emissions produced on the electricity production for the use phase.
- **Human health** is the last endpoint category with important normalised impact (26%). Human health is mainly dominated by Respiratory in-organics, which are mainly dominated by NO_x, SO_2 and Particulates.
- Finally, **Ecosystem quality** only represents 2% of the whole life cycle impacts. As a consequence of the fact that Aquatic acidification and eutrophication are not yet included in Impact 2002+, Ecosystem quality is possibly underestimated.
- Composite scenarios are the ones with less impact compared to steel and aluminium options for Respiratory in-organics, Global warming and non renewable energy categories. These results are obviously in accordance with the inventory results previously reported for No_x, CO_2 and primary energy.

Once these impacts are normalised, the composite scenarios do show a superiority in terms of design options. Such analysis has been performed by considering the life cycle over the raw material extraction phase, the production phase and the use phase of one car-body of this Korean regional train operated over 25 years. However this study should be completed by performing sensitivity studies on several parameters such as the life length of the train. Quality of the inventory data is also a major issue and the carbon fibre production has to be thoroughly analysed and checked if relevant within to the Korean context. Finally completing the study by including end of life scenario is also necessary.

References

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