A LIFE CYCLE ASSESSMENT OF FIBRE OPTIC SUBMARINE CABLE SYSTEMS

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Abstract: Life Cycle Assessment (LCA) methodology is used to evaluate the *potential* environmental impact of fibre optic submarine cable systems by considering a *cradle-to-grave* approach. The system boundary is drawn at the limits of the terminal, wherein all significant components and processes have been modelled to account for the flow of resources, energy, wastes and emissions. The results show that seven grams of carbon dioxide equivalents (7g CO_2e) are potentially released for every gigabit of data sent ten thousand kilometres (10,000Gb·km). Furthermore, electricity use at the terminal station and cable ship fuel consumption have the largest *potential* environmental impact over a 13 year expected lifetime.

1. INTRODUCTION

Submarine cables carry over 97 percent of our transcontinental voice and data traffic [1]. Yet, research reveals that little is known about the *potential* environmental impacts of a fibre optic submarine cable system from a life cycle perspective [2]. Life Cycle Assessment (LCA) methodology is used to collect specific system data and evaluate the potential environmental impacts of a system by using a *holistic* approach within a single consistent framework [3]. A *cradle-to-grave* process is considered, which begins with the extraction of raw materials from the natural environment and ends with the recycling of materials or the return of wastes back to the environment. LCA as a method, however, should not be considered a full environmental assessment as it addresses only those environmental issues specified in the goal and scope [4]. Furthermore, environmental impacts are described as *potential* impacts as they are not fixed in time and space and are related to the defined functional unit. Therefore, LCA should be considered an analytical tool to be used in conjunction with other evidence in order to support decision making [5].

The background research to this paper [2] considered 10 common environmental impact categories. This paper focuses solely on *climate change* or the Global Warming Potential over a 100-year time horizon (GWP100), which relates to anthropogenic emissions of greenhouse gases (GHGs). The characterisation model, developed by the Intergovernmental Panel on Climate Change (IPCC), measures GHG emissions against the reference unit of kilograms of carbon dioxide equivalents (kg CO_2e). Emission of methane, for example, is known to cause greater radiative forcing and is assigned a factor of 24:1 [3].

2. GOAL AND SCOPE DEFINITION

The goal of the study was to undertake an LCA of a fibre optic submarine cable system in order to assess the potential environmental impact of sending data over the cable network. To evaluate these impacts, the modelled flows within the system must be related to a quantifiable function of the system, described as the *functional unit* [6]. In this case the functional unit was chosen as ***Ten thousand gigabit kilometres (10,000Gb.km)***, which is a scalable unit and can be interpreted as, for example, 1.25Gb of data sent over 8,000km of submarine cable. The technological system boundary is defined as the limits of the land terminal station and includes all significant components within the terminal, the submarine cable and the submarine repeaters. The temporal boundary is based on a commercial service lifetime of 13 years [7] and the average system capacity of 11 systems installed on or after year 2000 [8]. The geographical boundary is based on a generic system in a global perspective.

3. LIFE CYCLE INVENTORY

Detailed data of the flows within, and crossing, the system boundary are collected during the inventory stage. Using a cradle-to-grave approach, five life cycle phases were identified. Each phase was further divided into cable (including repeaters) and terminal station sub-models, as shown in Figure 1.

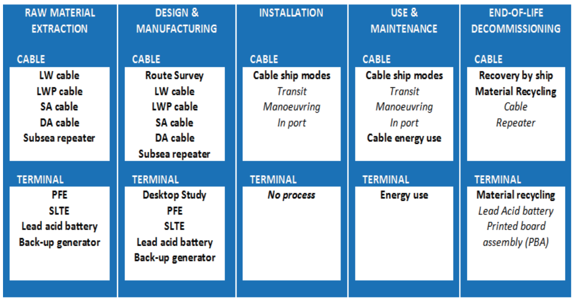


Figure 1: Life cycle phases of a submarine cable

Key processes are electricity generation and the production and combustion of marine fuel. Energy sub-models were developed for both. Electricity was modelled using previous LCA studies, with generation averaged for China, Japan, Europe and the US [2]. Production of marine fuel was determined from standard LCA databases using US and EU production figures for Heavy Fuel Oil (HFO). Transportation sub-models included shipping emissions from the combustion of marine fuel during various engine loads, which were determined by previous research in the field [9] and road and air transportation from standard LCA databases.

Raw material extraction and manufacturing for the cable was based on the quantities of four principal cable types determined from 4 systems representing 40,000km of cable, as shown in Table 1.

Lightweight (LW)	Lightweight Protected (LWP)	Single Armour (SA)	Double Armour (DA)
70%	14%	13%	3%

Table 1: Average ratio of cable types

The raw material extraction and manufacturing for a repeater was based on the weight of a beryllium copper housing and assumptions for the internal components. For the terminal, this was based on previous LCA studies of equivalent components. Vessel operations for typical route survey and installation missions (normalized to 1000km) were based on operational reports and are given in Table 2. Fuel consumption was based on vessel specification sheets, with emissions calculated from engine load and fuel type.

Vessel Operations	In Port (days)	Manoeuvring (days)	Transit (days)
Route Survey	2.7	12.1	-
Installation	13.3	10.3	10.6
Annual Maintenance	3.6	1.7	2.1

Table 2: Typical mission length per 1000km

Use and maintenance is divided between electricity used at the terminal and cable ship maintenance. Typical total energy consumption at the terminal, including equipment, climate control and lighting, was calculated from two stations at 191kW. A total of 127 gigawatt hours

(GWh) of electricity is used, given the lifetime of 13 years, with 90 percent of this being consumed during the use & maintenance phase. Maintenance, normalized to 1000 km of cable, was averaged from the operations of four standby vessels and is given in Table 2. An annual fault factor of 0.37 was calculated, being consistent with other research [10]. A total of 179 ship days per 1000 km of cable was calculated, resulting in the combustion of 1515 tons of fuel. Of this, 54% is consumed during the use & maintenance phase, with 19% consumed during the installation and end-of-life recovery phases. While it is not common to recover decommissioned cable, the end-of-life decommissioning scenario considers that the cable is recovered by cable ship and recycled for the mechanical materials, such as plastic, steel and copper. Recycling of these particular mechanical materials is highly efficient and a "closed-loop" recycling process is modelled, which assumes that 90 percent of the virgin material input is offset by the recycled materials.

Generic system length was based on 24 transoceanic cables giving an average of 16,200 km with 8.5 terminal stations. System capacity was based on the average of 11 systems installed from 2000 onward, giving an estimated lit capacity of 400Gbps. Research shows that bandwidth usage is, on average, only 25% of lit capacity [11]. Therefore, assuming bandwidth usage approximates data traffic, a total of 100Gbps actual data traffic is estimated.

4. RESULTS

The results show that a total of seven grams (7g) of carbon dioxide equivalents (CO_2e) are released for every 10,000 Gb.km. This figure can be placed into context by comparing a telepresence meeting utilizing the fibre network, to a face-to-face meeting requiring air travel. Consider a meeting between Stockholm and New York with an approximate distance of 8000 km. A telepresence meeting requiring a bandwidth of 18Mbps would potentially release 355 g CO_2e per hour. Expanding this to a 2 day meeting of 16 hours, results in a potential release of 5.7 kg of CO_2e. By comparison, this same 2 day meeting in a face-to-face setting would require 16,000 km of air travel per person, resulting in a release of 1920 kg of CO_2 [12]. This represents a saving of almost 2 ton of CO_2 and is equivalent to driving the average passenger car approximately 12,000 km [13]. Table 3 presents the above comparison.

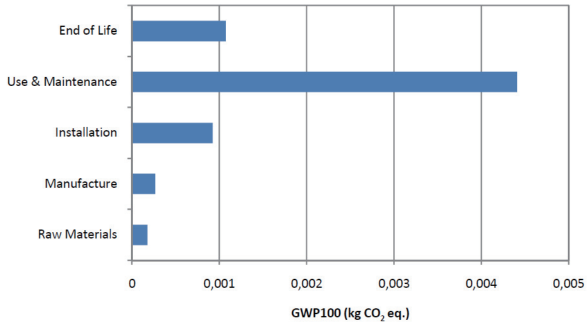
Factor	Data Transfer Telepresence System*	Air Travel
Impact	5.7 kg CO_2e	1920 kg CO_2
Utility	16 hours @ 18Mbps	16,000 km
Saving	**Approximately 2 ton of CO_2**	

* Represents 8,000km of terminal-to-terminal submarine cable data transfer only.

Table 3: Climate change impact comparison

It should be noted that this example is for comparison purposes and considers only the impact of sending data via the submarine cable system and not the telepresence system or the terrestrial network as a whole.

Graph 1 presents a more detailed analysis of the LCA results by life cycle phase and reveals that the *use & maintenance* phase clearly dominates the climate change impact at 64%.

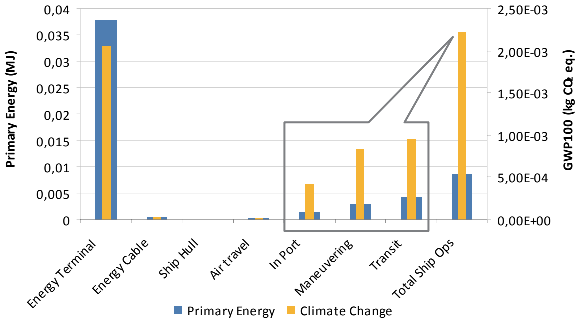


Graph 1: Climate change potential per 10,000 Gb.km

Emissions of carbon dioxide (CO_2) to air are the significant contributor resulting from the generation of the electricity used at the terminal and the combustion of marine fuel consumed during cable maintenance. Emissions of other GHGs are insignificant by comparison. These two energy resources, therefore, appear to be the key processes influencing the environmental performance of a submarine cable system.

The installation and end-of-life phases present an impact of 13 and 16 percent respectively and are influenced by the combustion of marine fuel during cable ship operations.

Further analysis of the *use & maintenance* phase shows that the emissions of CO_2e are equally shared between electricity use at the terminal (47 percent) and cable ship operations during maintenance (53 percent), as shown in Graph 2.

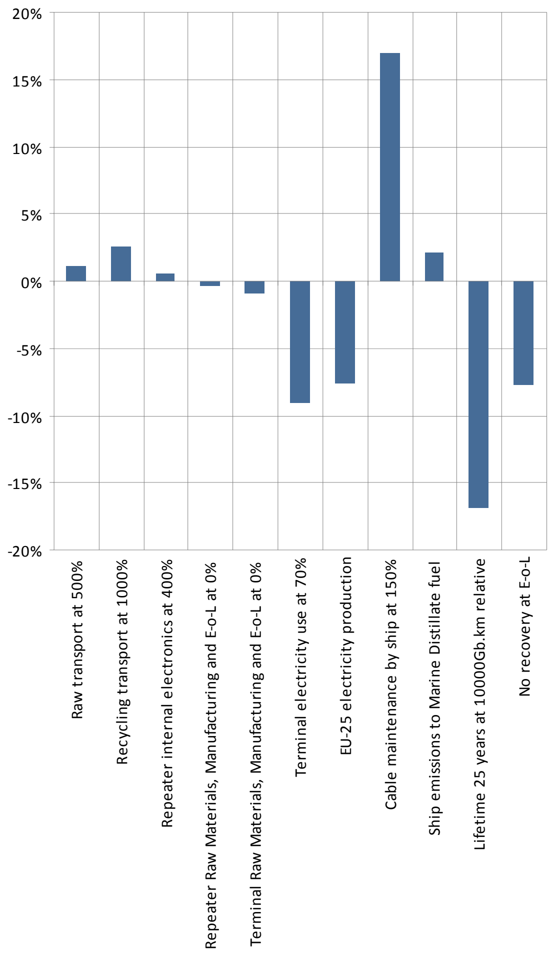


Graph 2: Primary energy consumption vs. climate change potential per 10,000 Gb.km

However, what is more interesting is the magnitude of the impact per unit of primary energy. Graph 2 shows that the combustion of marine fuel has a far greater impact on climate change, per unit of primary energy, than the impact from electricity use, highlighting the disparity in the environmental impact of electricity verses fossil fuel consumption.

5. DATA QUALITY ANALYSIS

The limitations of the study affect the final result, therefore, as recommended by the ISO 14040 series guidelines, a sensitivity analysis has been undertaken to estimate the effect of data gaps, assumptions and methodological choices [4]. The submarine repeaters and terminal components are two sub-models affected significantly by data gaps and assumptions. However, by changing parameters within these sub-models, the sensitivity analysis shows that they have little effect on the final result. This indicates that the LCA model is relatively unaffected by the greatest uncertainties and is, therefore, robust. Results of the sensitivity analysis based on data gaps and assumptions are shown in Graph 3 (columns 1 to 5).



Graph 3: Data sensitivity analysis

Methodological choices include the use of database models for the production of electricity and heavy fuel oil (HFO) and for the combustion of HFO. The sensitivity analysis shows that methodological choices affect the final result no greater than 20 percent. The choice to use emissions factors for heavy residual oil (RO) fuels was particularly conservative; however, the analysis shows (Graph 3, column 9) that no great change in the climate change impact is observed between RO and the lighter cleaner marine distillates (MDs). Results of the sensitivity analysis based on methodological choices are shown in Graph 3 (columns 6 to 11).

6. DISCUSSION

The function of the system is based on usage, or the actual used bandwidth, as opposed to the design capacity, or present technological limitations at the terminal. Research shows that bandwidth usage is approximately 25 percent of current lit capacity. If this gap between usage and lit capacity was reduced, notwithstanding technical and commercial limitations, then a subsequent gain in environmental performance per data unit would be achieved. However, it should be noted that the overall environmental impact over the system lifetime remains unchanged. Similarly, increased total data traffic through a longer service life, reduces the resulting impact per unit of data. From a life cycle perspective, the longer a cable remains in service, the superior the environmental performance. Used capacity and service life therefore have a significant effect on determining the results based on the chosen functional unit.

Overall the *use & maintenance* phase is the area where the greatest gains could be made, particularly, electricity use at the terminal and the emissions from the cable ships. If the aim is to reduce the overall environmental impact of cable systems further, then cable owners could direct their focus on these two particular areas. Perhaps, electricity produced from renewable resources could be considered, along with other measures to reduce vessel fuel consumption or emissions.

Finally, when interpreting the results, it is also important to remember that an LCA model is a simplification of reality.

7. CONCLUSIONS

- The *use & maintenance* phase dominates the potential climate change impact.
- Key processes are electricity use at the terminal station and the combustion of marine fuel during the cable maintenance.
- Maintenance has the greatest impact per unit of primary energy.
- Seven grams CO_2e are released per 10,000 Gb.km.
- Increasing the commercial lifetime or data traffic, reduces the environmental impact per unit of data.

8. REFERENCES

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