A life cycle based Eco design consideration for the Rainbow Warrior III

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1 Introduction

Greenpeace has asked Gerard Dijkstra & Partners (hereafter 'GDNP') to design a new ship for Greenpeace. During the design of the new Greenpeace ship TNO is to provide advice on the best choice of options from an environmental point of view. This advice is based on the results of environmental life cycle assessment calculations.

The environmental impact of options is compared over the full life cycle of the ship:

- influence on **production** of raw materials, production processes, including upstream processes (the production processes up to mining of raw materials)
- influence on the **use phase**: energy consumption (diesel) and maintenance (antifouling, epoxy coating, etc.)
- influence on **end-of-life**: at the end of the life of the ship it will be dismantled and some materials will be reused

The impact on the environment has been calculated using EcoScan[1] software and the results are expressed in Eco-indicator 99 points[2]. The Eco-indicators have been developed for designers by commission of the Dutch Ministry of VROM (Housing, Spatial Planning and the Environment) and in cooperation with European scientists. This method is recommended and used by designers all over the world (for example at Philips, BiC, the furniture industry) and supported by governmental organisations (for example in the Netherlands, the Ministry of VROM, SenterNovem), Universities, Universities of Professional Education etc. The Eco-indicator 99 method and life cycle assessment calculation is described in Annex A.

This report discusses several topics in relation to the environment that have been considered during the project. These topics are:

- comparison of a steel versus an aluminium hull
- comparison of a ship with sail propulsion or engine propulsion
- use of anti-fouling paint (details not included in this paper)
- measures for emission reductions (details not included in this paper)

[1] www.ecoscan.nl Quickscan tool for Eco-design developed by TNO

[2] The Eco-indicator 99. A damage-oriented method for Life Cycle Impact Assessment. Manual for Designers. Ministry of Housing, Spatial Planning and the Environment, October 2000.

2 Summary of results

2.1 Steel hull versus aluminium hull

Compared to a steel hull, an aluminium hull has a lower environmental impact over the life cycle of the vessel. This is the net result of a small increased impact in the production/disposal phase, and a slightly reduced impact in the use phase (due to a lower weight of the ship and resulting reductions in fuel consumption when sailing with engine assistance).

Looking at the full life cycle of the ship, including all impacts for production, use and end-of-life, the difference caused by choosing aluminium instead of steel is small: 1.21% less impact for a ship with an aluminium hull over the full life cycle compared to a ship with a steel hull. The hull contributes little to the environmental impact of the ship. Most impact comes from using the engine in the use phase, with limited influence from the hull weight on fuel consumption.

Considering global warming only, a steel hull is preferred. A ship with an aluminium hull causes more CO_2 emissions over the full life cycle of the ship compared to a ship with a steel hull.

2.2 Sail propulsion versus engine propulsion

The new build has been designed as a sailing ship. A comparison has been made in order to get an idea of the reduction of the environmental impact by selecting a sailing ship instead of a ship with an engine. This shows that a ship with an engine of the same dimensions, same engine installation and operational profile, would have a 61% higher environmental impact compared to the sailing ship.

The environmental impact of the production and maintenance of sails is very small compared to the environmental impact of the (saved) fuel.

2.3 Antifouling

Under the pressure of stricter legislation progress has been made in the development of anti-fouling coatings that do not leach toxic substances, such as fouling release coatings. This type of coating has been applied for some time on Greenpeace ships. The new generation Fouling Release Coating (Intersleek 900) will be applied to the new build Greenpeace ship. Compared to toxic containing anti-fouling coatings, fouling release coatings have the following environmental advantages:

- no release to water of toxic substances
- as a result of a longer lifetime the coating needs to be applied less frequently. The frequency of coating application does also depend on the maintenance requirements of the ship owner.

Claims made by the manufacturer that the disadvantages of silicone fouling release coatings have been overcome are promising[3], but these new paints need to prove themselves in practice.

In the use phase attention needs to be paid to repair (as a result of mechanical damage) and to cleaning of the underwater hull - by high-speed sailing, or by diver or robot cleaning. The cleaning frequency and method are related strongly to the desired use pattern (weeks without sailing). TNO recommends that a cleaning protocol for the new build should be prepared.

In the future, when other fouling release coatings may be selected, attention needs to be paid to additives such as silicon oil, as these may leach out of the coating. Leaching is undesirable as the components may cause environmental damage.

2.4 Measures for emission reduction

The new build will be equipped with a wet scrubber (Ecosilencer). This emission reduction measure will result in the reduction of sulphur dioxide, particulate matter (dust) and a small amount of NO_x. As far as particulate matter is concerned, independent studies show that wet scrubbers are not as effective at reducing small particles - mainly larger particles are removed from air emissions. As a result, due to the increased fuel consumption (2.5%) the net environmental effect of the wet scrubber, as calculated using Eco-indicator 99, is a small increase in environmental impact. The increased fuel production and consumption causes more environmental damage compared to the benefit gained from decreased emissions.

Other emission reduction measures can be taken to improve the impact of emission reduction. Soot filters in combination with a de-NO_x installation will reduce the environmental impact by 32% over the life cycle of the ship, if all engines are equipped with this reduction technology.

Soot filters dedicated to the reduction of small particles are not yet fully developed for marine application. The technology has not yet been demonstrated to be robust over a period of several years. However, it can be expected that possible problems will be tackled in the next few years as a result of coming legislation, and besides this, cost reduction and efficiency improvements might be achieved. It is recommended to wait until soot filters are fully developed and to facilitate the new build for retrofit, e.g. by reserving space required for soot filters and/or buying engines with an engine-management system that is already designed for soot filtration.

[3] According to the manufacturer, this new generation Fouling Release Coating has less overspray and less abrasion resistance, and can be used on vessels that have a lower speed (10 knots) and are inactive for longer periods of time. Source: http://www.international-marine.com/include/Intersleek900_Brochure.pdf

3 Steel hull versus an Aluminium hull

3.1 Differences over the life cycle

The hull of the ship can be made out of steel or out of aluminium. The steel hull is taken as reference for the comparison. The differences resulting from choosing aluminium instead of steel are shown in Table 1. Aluminium is produced in a different way to steel, and also has a different impact in the end-of life phase. When the ship is no longer used, it will be dismantled and valuable materials, such as metal, will be recycled. Recycling reduces the need for the production of new material (i.e. mining is not necessary) and the saved environmental impact is expressed as a bonus. As the production of aluminium gives more impact compared to the production of steel, the bonus for recycling aluminium will be higher compared to the bonus for recycling steel. The aluminium hull weighs less and needs more insulation and less paint. Due to the lower weight, less diesel fuel is consumed for propulsion by diesel engine (see GDNP report on Hull Material study[4]).

Table 1 Differences resulting from material choice for hull

		Steel hull	Aluminium hull	Difference of aluminium compared to steel
Production and end-of-life	Hull	236,520 kg	191,250 kg	-19%
	Insulation	18,000 kg	22,000 kg	+22%
	Paint	6,750 kg	4,725 kg	-30%
Use phase: fuel consumption	Economic sailing	63 tons fuel /year	61 tons fuel /year	-3.2%
	Max. speed sailing	120 tons fuel /year	116 tons fuel /year	-3.2%

3.2 Results

Figure 1 shows the environmental impact of the ship. More Eco-indicator points [Pt] mean more environmental impact (indicated in red). ‘Negative’ points represent an environmental bonus (in green). As a reference, 1000 Eco-indicator points represent the environmental impact of 1 European citizen during one year. More references of the environmental impact expressed in Eco-indicator points can be found in the Annex (Table 5).

[4] Gerard Dijkstra & Partners. Hull Material Study. Amsterdam, December 2006. By commission of Stichting Marine Services / Greenpeace International

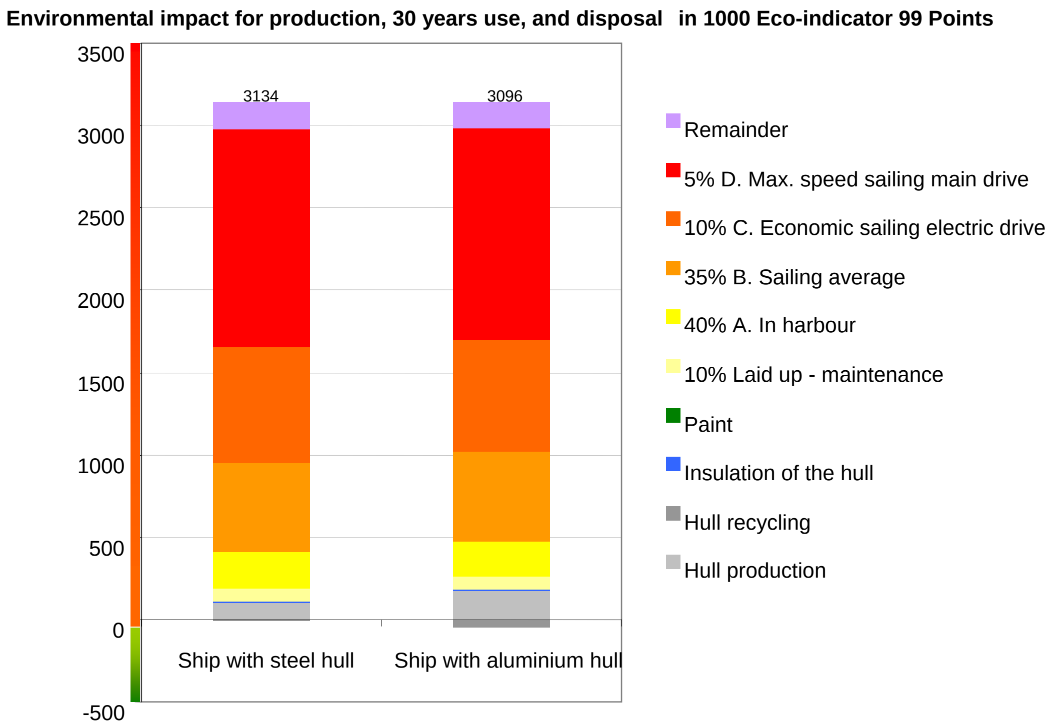

Figure 1 Environmental impact for the production, 30 years use and disposal expressed in Eco-indicator 99 points of a ship with a steel hull and a ship with an aluminium hull

Table 2 Environmental impact for the production, 30 years use and disposal expressed in 1000 Eco-indicator 99 points of a ship with a steel hull and a ship with an aluminium hull

	Ship with steel hull [1000 Eco-indicator Pt]	Ship with aluminium hull [1000 Eco-indicator Pt]	Difference of aluminium compared to steel	
			[1000 Eco-indicator Pt]	Compared to total of steel ship [%]
Hull production	104	171	67	2.14%
Hull recycling	-8	-48	-40	-1.28%
Insulation of the hull	6	7	1	0.04%
Paint	3	2	-1	-0.03%
10% Laid up - maintenance	78	78	0	0.00%
40% A. In harbour [5]	218	218	0	0.00%
35% B. Sailing average	545	545	0	0.00%
10% C. Economic sailing electric drive	700	678	-22	-0.72%
5% D. Max. speed sailing main drive	1327	1285	-42	-1.34%
Remainder	161	160	-1	-0.02%
Total	**3134**	**3096**	**-38**	**-1.21%**

[5] Electricity is needed when the ship is in harbour. The environmental impact is calculated for the scenario where shore power is used 80% of the time, and electricity is generated with the engines on board the ship 20% of the time. The environmental impact increases if the ship is producing more of its own electricity in harbour (as the environmental profile of shore power is more favourable).

As the hull contributes relatively little to the overall environmental impact of the ship, a closer look will be taken at the differences resulting from the hull material choice, leaving out all impacts that are the same for a ship with a steel or aluminium hull. The results focussing on the differences are displayed in Figure 2 and in Table 2.

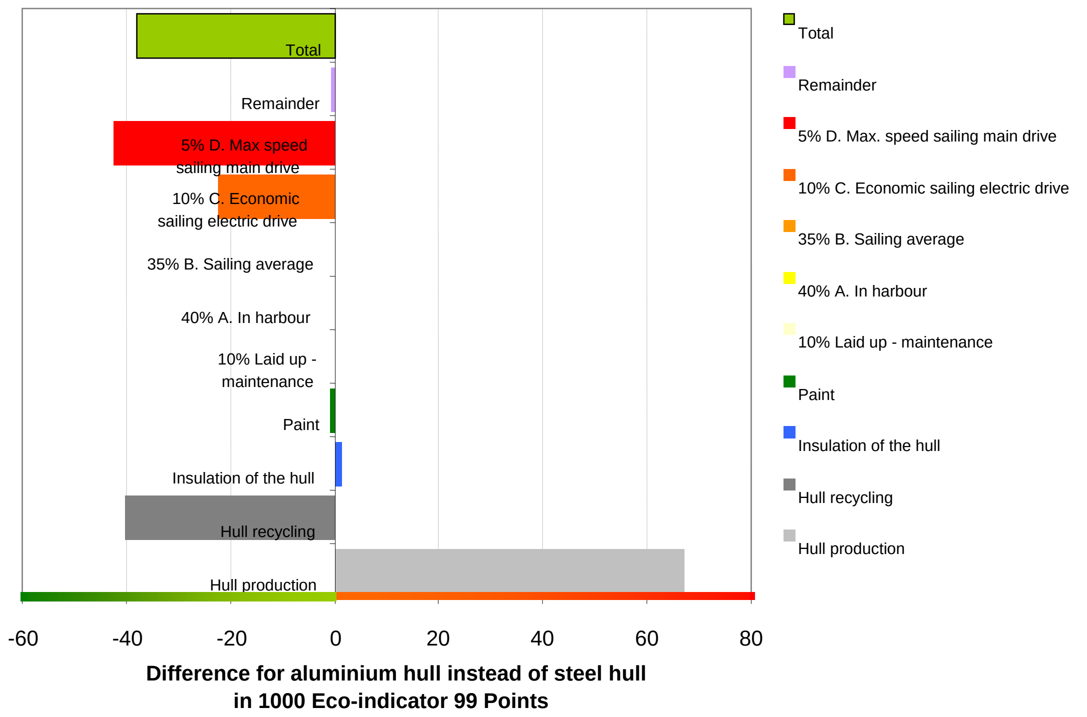

Figure 2 Difference in environmental impact as a result of choosing an aluminium hull instead of a steel hull, expressed in Eco-indicator points

3.3 Discussion of results

Compared to the steel hull an aluminium hull has a lower impact over the life cycle. There is only a small difference between the environmental impact of a ship with a steel hull and a ship with an aluminium hull: over the life cycle there is only a difference of 1.2% (3,134,000 Pt for the life cycle of a ship with a steel hull versus 3,096,000 Pt for a ship with an aluminium hull). This conclusion holds for other use patterns of the ship: more sailing increases the advantage of an aluminium hull. If the ship was sailing using the engine all the time (never on sail, never in the harbour) the advantage of aluminium increases up to 3% compared to a ship with a steel hull. The steel hull would only have an advantage compared to aluminium when the sailing time using the engine is reduced by a factor of 2 (2.5% max. speed and 5% economic sailing).

The hull production and recycling, and the other differences resulting from choosing aluminium instead of steel, contribute little compared to the other impacts that are not affected by the material choice for the hull. The impact of the ship is dominated by the fuel consumption for sailing and other fuel consumption. The fuel consumption in the use phase contributes 91.5% (2,868,000 Eco-indicator 99 Pt) to the total life cycle impact of the steel ship (3,134,000 Pt) and for aluminium the fuel consumption in the use phase contributes 90.5%.

The reduction in the environmental impact when choosing an aluminium hull instead of a steel hull is a result of:

- **Increased impact of production/disposal.** This difference is caused by an increase of 67,000 Pt for production (see the light grey bar for hull production in Figure 2). Although the hull weighs 19% less compared to steel, the environmental impact of the production of aluminium is a lot higher per kg compared to steel. On the other hand, recycling of aluminium gives a larger bonus (– 40,000 Pt, see Figure 2) compared to steel. Recycling saves metal production and thus saves more impact for aluminium. The net difference resulting from production and disposal is (67,000 - 40,000) = 27,000 more Eco-indicator 99 points for aluminium compared to steel; i.e. producing an aluminium hull has more environmental impact.
- **Decreased impact in the use phase** due to saving of 3.2% fuel when sailing on the engine as a result of reduced weight of an aluminium hull compared to a steel hull. In the use phase 63,000 Eco-indicator Pt are saved (-22,000 Pt for economic sailing and -41,000 Pt for maximum speed) compared to the fuel consumption for the heavier steel hull.

A ship with an aluminium hull needs 40% less paint over the full life cycle of the ship as the function of the paint on an aluminium hull is mainly decoration (instead of protection). The decrease in environmental impact is more or less compensated by the increased impact related to more insulation, but both impacts are very small.

Beside a calculation using Eco-indicator 99, covering many environmental aspects, an analysis has also been made for the global warming potential. Looking at global warming only, a steel hull is preferred. A ship with an aluminium hull contributes more to CO_2 emissions over the full life cycle compared to a ship with a steel hull.

4 Sail propulsion versus motor propulsion

In an early stage it was decided that the new build Greenpeace ship had to be a sailing ship. Using sails saves a lot of fuel as the energy for transport is provided by the wind. An environmental comparison of the new build with a similar ship with motor propulsion is made in this chapter. For this comparison, the production of the sails[6] has been subtracted, and the time of economic sailing has been increased (see Table 3). The results of the environmental impact are shown in Figure 3 and Table 4.

Table 3 Use pattern of ship with sails and fictive use pattern for ship without sails.

Activity	Ship with sail propulsion		Ship with motor propulsion	
	Hours /year	Percentage	Hours /year	Percentage
Laid up maintenance	876	10%	876	10%
A. In harbour	3504	40%	3.504	40%
D. Sailing	3066	35%	0	0%
C. Economic sailing	876	10%	3942	45%
D. Max. speed	438	5%	438	5%
Total	**8760**	**100%**	**8760**	**100%**

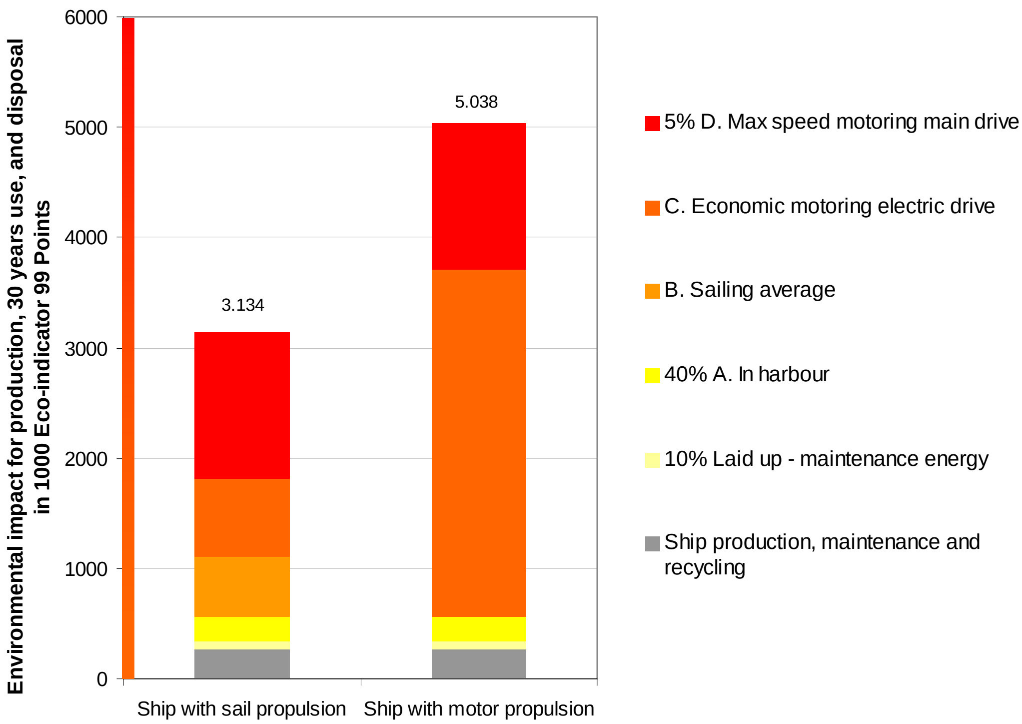

Figure 3 Environmental impact of the production, 30 years use and disposal expressed in Eco-indicator 99 points of a ship with sail propulsion, and a ship with motor propulsion

[6] Production of the sails includes the sails for replacement during the use of the ship (maintenance)

Table 4 Environmental impact of the production, 30 years use and disposal expressed in 1000 Eco-indicator 99 points of a ship with sail propulsion and a ship with motor propulsion

	Ship with sail propulsion [1000 Eco-indicator Pt]	Ship with motor propulsion [1000 Eco-indicator Pt]	Difference between sail and motor propulsion	
			[1000 Eco-indicator Pt]	Compared to ship with sail propulsion [% of Total]
Ship production, maintenance and recycling	266	263	-3	0%
10% Laid up - maintenance energy	78	78	0	0%
40% A. In harbour	218	218	0	0%
35% B. Sailing average	545	0	-545	-17%
10% C. Economic sailing electric drive	700	3152	2452	78%
5% D. Max. speed sailing main drive	1327	1327	0	0%
Total	**3134**	**5038**	**1904**	**61%**

4.1 Discussion of the results

A comparable ship with motor propulsion instead of sail propulsion will have 61% more environmental impact. The environmental impact of production and maintenance of sails is very small (three thousand Eco-indicator points) compared to the environmental impact of the (saved) fuel).

The same conclusion can be drawn when looking at the global warming potential only: a ship without sails would have caused 61% more CO_2 emissions over the full life cycle compared to a ship with sails.

A Annex: Eco-indicator 99

The environmental impact of the life cycle of a ship is calculated in two steps.
Data is collected on resource consumptions, emissions to air, water and soil, and waste (including processing of waste) for the ship production, use and end-of life. A large database is used for production of materials, energy etc. for this first step.
The pressure on the environment is calculated in the second step, using the Eco-indicator 99 impact assessment method[7]. For example, how each toxic emission moves through the environment, and what the uptake is by humans, is calculated in Eco-indicator 99. The uptake results in a health effect.

[7] The Eco-indicator 99. A damage-oriented method for Life Cycle Impact Assessment. Manual for Designers. Ministry of Housing, Spatial Planning and the Environment, October 2000.

Environment is defined by three types of damages in Eco-indicator 99:

- damage to human health expressed as the number of life years lost and the number of years lived disabled due to environmental causes. The effects included here are climate change, ozone layer depletion, carcinogenic effects, respiratory effects and ionising (nuclear) radiation
- ecosystem quality: effects on the diversity of species, especially on vascular plants and lower organisms. The effects included are ecotoxicity, land-use, acidification and eutrophication
- resources: the surplus energy needed in the future to extract lower quality mineral and fossil resources

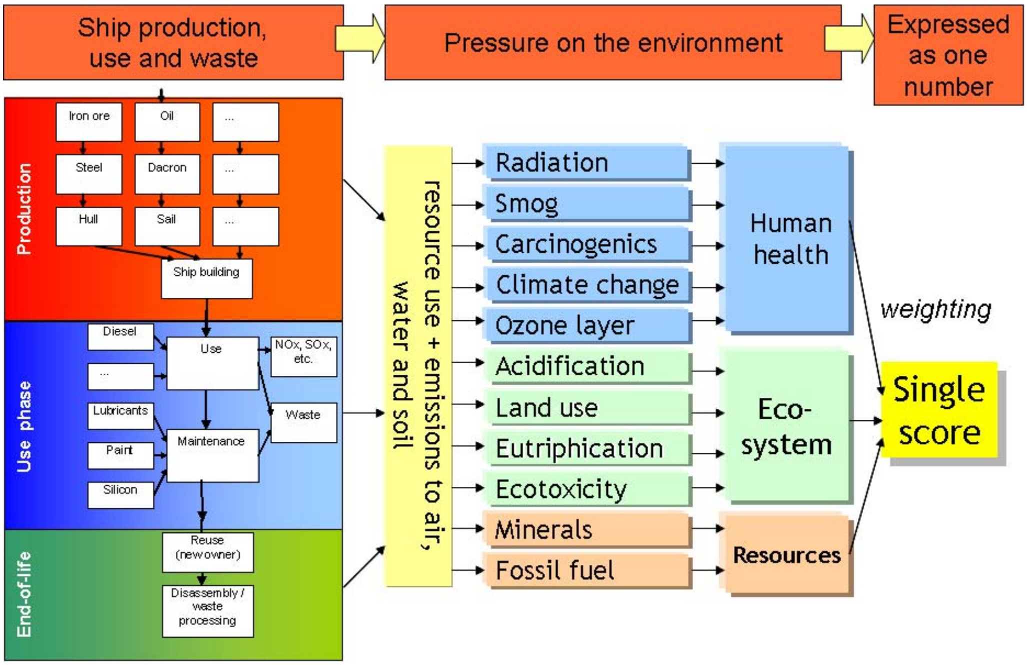

Figure 4 Schematic overview of calculation of Eco-indicator points

Four steps are needed for the calculation of the damage (pressure on the environment):

1. **Fate analysis**: when a chemical substance is released, it finds its way through the environmental compartments of the air, water and soil. Where the substances will go and how long they will stay depends on the properties of the substance and of the compartments. A soluble substance will be collected in the water compartment while a substance that will easily bind to organic particles may end up in specific types of soil. Another aspect is the degradability as most organic substances have a limited lifetime. The transfer between compartments and the degradation of substances is modelled in fate-analysis models. The concentrations in the air, water and soil is calculated as a result.
2. **Exposure**: based on calculated concentrations it is determined how much of a substance is taken in by humans, plants and other life forms.
3. **Effect analysis**: once the exposure is known, diseases (frequency and duration) and other effects are predicted.

4. **Damage analysis**: the predicted disease is expressed in damage units. For instance, if a certain exposure results in additional cases of cancer, the average age that people will get this type of cancer, the duration of the illness and the life years lost are determined.

Other damage models are used for land use and resource depletion. The effects of land use are based on field observations on the diversity of species for different uses of land. For resource depletion the energy needed for extraction is related to ore grade (for mineral resources) and to the quality of the fossil resources. Models for declining resource quality in the future are linked to the energy for extraction, to calculate the additional energy required in future to extract the same amount of resource.

The damage analysis results in three scores: one for human health, one for ecosystem quality and one for resources. The three scores are totalled to give one value, using weightings determined by a panel of environmental specialists:

- 40% to human health
- 40% to ecosystem quality
- 20% to depletion of resources

The result is a dimensionless score: Eco-indicator Points. Of course, the chosen weighting is subjective. The most used, and therefore accepted, weighting set has been applied here.

It is important to pay attention to the uncertainties in the methodology that is used to calculate Eco-indicators. There are two types of uncertainties.

1. Uncertainties about the **correctness of the models** used. This includes value choices such as the time horizon in the damage model, and the question whether an effect should be included even if the scientific evidence is incomplete. Eco-indicator 99 is available in three different conceptual models regarding the time horizon, the inclusion of effects, and the weighting of the three types of damage. The default (and most used) method in which there is a balance between the short term and the long term, and in which effects are included based on consensus among scientists, has been selected here.
2. **Data uncertainties**. These uncertainties refer to difficulties in measuring or predicting the environmental effects. These uncertainties are expressed in ranges and can be included in the calculation of results by applying a statistical Monte Carlo analysis. This uncertainty analysis will not be carried out in this project as resources are limited. The focus is on design options instead of LCA methodology.

The life cycle calculation results in Eco-indicator 99 points. More points represent a higher environmental impact. As points are a rather abstract result Table 5 shows the environmental impact of several activities expressed in Eco-indicator 99 points which can be used to form an idea about the magnitude of Eco-indicator 99 points. These references can also be used to compare the environmental impact of activities: for example, a household's annual laundry causes the same environmental impact as driving 2100 km in a car.

Table 5 Environmental impact of activities expressed in Eco-indicator 99 points

Activity	Environmental impact expressed in Eco-indicator points [Pt]
Annual environmental impact of one European citizen during one year	1000 Pt
Electricity consumption (for all household activities) per household per year (3350 kWh)	94 Pt
Electricity consumption for laundry (washing and drying) per household per year (736 kWh)	21 Pt
1000 km driving in a private car	10 Pt
Production and use of 1 barrel of oil as fuel, including emissions (159 litres of oil)	35 Pt