Swedish Environmental
Research Institute

Life Cycle Assessment of Volta Greentech's Factory 02

Performed within the AlgAIe project

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Summary

This report describes a Life Cycle Assessment of Volta Greentech's upcoming algae production facility, Factory 02. It was performed within the AlgAIe project, with the purpose of assessing the environmental impacts of Factory 02 and to highlight hotspots for potential improvement.

The lowest possible impact of all combined choices was 4.05 kg CO2eq/kg DW algae when salt additions were reduced and rapeseed oil was eliminated. In comparison with LCA results of Factory 01, all scenarios had lower GWP impacts.

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1 Introduction

Volta Greentech is a Swedish company, producing the seaweed Asparagopsis armata for use as a feed supplement for ruminant livestock. The purpose of the feed supplement is to reduce methane emissions of ruminants.

As part of a Vinnova founded research project called 'AlgAIe - Optimization of Algae Cultivation using AI to Significantly Reduce Methane Emission from Cattle' a life cycle assessment (LCA) of Volta Greentech's "Factory 02" seaweed cultivation system was performed. Factory 02 is designed to produce 18000 kg of seaweed (dry weight) annually. The assessment was done in collaboration with Volta Greentech.

1.1 Aim and problem formulation

The aim of this study was to assess the environmental impacts of the planned facility "Factory 02" by employing LCA, to pinpoint hotspots of the system and to discuss these hotspots. The study also evaluates several improvement options.

1.2 Research overview

Previous research by Nilsson and Martin (2022) examined the pilot facility "Factory 01", then in the planning stages. In this study, a LCA was performed with Volta Greentech resulting in the climate impact per kg of seaweed (dry weight, DW) of roughly 9.2 kg CO2e/kg seaweed. They found that rock salt contributed 48% of total greenhouse gas emissions (GHG). Exchanging the rock salt with sea salt, imported from France, reduced total emissions to 5.8 kg CO2e/kg seaweed. Great improvements were also found when increasing the rate of water recycling or the growth rate. Heating in different parts of the cultivation system was also a significant contributor to total climate impact, contributing roughly 16% of total GHG emissions. Heating was used to heat seawater entering the facility, to heat the facility, and for drying the seaweed after harvest. The type of heating system (district heating, natural gas, or electric heat pump) also had significant influence on total impact, influenced by the choice of renewables as source for electricity in the case of the heat pump.

2 Methodology

2.1 LCA scope and inventory

The system boundary included a cradle-to-gate assessment of the seaweed cultivation system. This assessment did not include an analysis of the potential for reductions in enteric methane emissions originating from feeding the seaweed to ruminants.

The functional unit (FU) was defined as 1 kg DW (dry weight) seaweed at the factory gate. However, it should be noted that the final product is mixed with rapeseed oil, which was considered as an input material distributed to the functional unit.

As in the previous assessment, much of the infrastructure was modelled using material datasets due to the lack of available datasets for similar equipment. See appendix 2 for information about the material modelling.

Transport distances were assumed to be 100 km for delivery of all equipment and material inputs, using Euro 6 truck transport. For salt delivery, ocean shipping was added from either France (sea salt) or Denmark (rock salt).

One of the assessed heat sources, district heating sourced from the nearby oil refinery, was assessed, and allocated using physical allocation based on energy content of the refinery's output flows. The internal allocation balance was assumed to be the same as in the study by Nilsson and Martin, though the datasets were updated from Ecoinvent 3.6 to Ecoinvent 3.9, incurring small changes in the impacts. As the new facility may be located at another location, heat sourced from municipal waste incineration was included as an alternative. Electricity was modeled based on the Swedish energy mix or Swedish renewables.

As in the previous assessment, CO_2 from the oil refinery, used for supplementation was assumed to have no economic value, therefore carrying no environmental burden of its production. However, impacts for flue gas cleaning and compression to liquid CO_2 were added. Impacts of CO_2 originating from ethanol production were also assessed, which included mass-based allocation of impacts, and energy expenditures for compression to liquid CO_2. For comparison with the zero-burden oil refinery sourced CO_2, an additional calculation was made only including the compression energy. For comparison with these custom datasets, a dataset for liquid carbon dioxide from Ecoinvent was also included.

This assessment assumes all input water to be freshwater (tap water). This leads to a larger addition of salt per liter of water than the previous study of the pilot plant. Salt sourcing was modeled as in the previous study, using either Danish rock salt or French sea salt.

Wastewater from the system is cleaned through a reverse osmosis filtration system (ROFS). The water from the ROFS is reused in the cultivation system, while the saline brine generated is dried with an evaporator. The resulting saline solids are considered a waste. Treatment of this waste was modeled based on municipal waste incineration or landfilling.

Previously, the seaweed was dried post-harvest and then packaged. As has been shown in research, the shelf-life of the seaweed itself is, however significantly improved when it is mixed with vegetable oils (Magnusson et al., 2020). Thus, the system assessed herein includes the input of rapeseed oil and mixing equipment, which was not previously included. For rapeseed oil, inventory data from a Latvian LCA study of rapeseed oil production was used (Fridrihsone et al., 2020), modified by changing the electricity source to the Swedish mix. A dataset for rapeseed oil (global) from Ecoinvent was included for comparison. The assessment of reduced impacts from reduced oil use do *not* include an alternative processing line, which might be necessary if packaging is performed differently.

2.2 Life cycle impact assessment

Ecoinvent 3.9 was used for all Life Cycle Inventory (LCI) data, while the impact assessment method used was Environmental Footprint version 3.1, the latest at the time of writing. Impact categories included in this paper are listed in Table 1. The same impact categories as in Nilsson and Martin (2022), who motivated these impact categories, suggesting:

"These were chosen to represent relevant indicators to assess the local and global environmental implications caused by seaweed production. Climate impact was chosen since the main purpose of the product assessed is to reduce the climate impact of ruminant husbandry. Resource depletion in terms of minerals and metals, energy, and water were assessed since high resource use is connected to land- based aquaculture systems. Marine eutrophication since this indicator represents marine impact and may therefore be valuable when compared to offshore cultivation systems." (Nilsson and Martin, 2022)

These are only five of the available 25 environmental impact categories of the EF 3.1 method. The results for the remaining indicators can be found in Appendix 1 (LCIA Results).

Table 1: Impact indicators assessed in this study

Indicator	Unit of impact
Climate impact (GWP)	kg CO_2-eq
Resource depletion – minerals and metals	kg Sb-eq
Non-renewable energy resources depletion	MJ
Water use - user deprivation potential	m3 eq. deprived
Eutrophication – marine	kg N-eq

2.2.1 Scenarios

The different scenarios investigated are listed below. The different parameters influencing each scenario (all others equal) are shown in table 2.

- A scenario assuming the facility to be located close to an oil refinery, as the first facility, Facility 01. Uses heat and CO_2 from the oil refinery and Swedish rapeseed oil.

- A scenario assuming a new location, with datasets customized for Swedish conditions, sea salt, CO_2 sourced from ethanol fermentation, and either hydropower or nuclear power as electricity source. These two electricity sources were chosen as they both represent significant shares of the Swedish electricity production, as well as being the electricity sources with the lowest GWP impacts. Other impact categories differ between hydropower and nuclear power, which is described in the results section.

Table 2: Description of the differences in modeling of the various scenarios

Parameter	Oil refinery	New Location
CO_2 source	Oil refinery, flue gas cleaning and compression only	Ethanol plant impacts mass allocated, and compression
Salt source	Rock salt, Denmark	Sea salt, France
Rapeseed oil source	Rape seed from Ecoinvent, process with Swedish electricity	Rape seed from Ecoinvent, process with Swedish electricity
Electricity source	Swedish mix	Hydropower or nuclear
Heat source	Oil refinery, energy allocated	Municipal waste incineration
Salt waste treatment method	Landfill	Landfill

The effects of reducing the amounts of salt and rapeseed oil are also investigated. The reason for modeling reduced salt addition is the internal goal of Volta to increase salt reuse. The reduced input of salt is accompanied by a reduced output of salt waste. The logic behind removing the rapeseed oil is that this oil is added to the final product for shelf-life reasons, however, it is not necessary to produce the algae itself. Packaging of the final product could theoretically be done without the oil. Alternative packaging processes necessary if packaging were not modeled for. As the rapeseed oil becomes part of the feed formulation for the animals consuming the algae product, the oil does contribute to the nutritional value of the feed. The effect of this is however considered outside of the scope of this study. An additional calculation for ethanol fermentation-sourced CO_2 shows the total system impact of modelling the CO_2 impact with only compression and transport. This was done to show the effect of modeling this CO_2 as the oil refinery-sourced CO_2 was modelled.

3 Results

3.1 Greenhouse gas emissions

Shares of impact per scenario originating in different system processes are shown in Fig A. Global warming potential in CO_2eq/kg DW algae for the scenarios are shown in fig. B. Origins of impacts shared by all scenarios, 1.87 kg CO_2eq/kg DW algae are shown in table 3. The variants of inputs or modelling is shown in table 4-9. The variants of choice lead to a variable impact between 1.85 and 12.91 kg CO_2eq/kg DW algae.

Replacing rock salt with sea salt reduces impact per kg DW algae by 0.59 kg CO_2eq/kg DW algae. Reducing the salt addition by 50% reduces impacts to 0.47 kg CO_2-eq for rock salt and 0.17 kg for sea salt. Landfilling of salt waste carries less impact than municipal waste incineration at 1.25 kg CO_2eq/kg DW algae as compared with 2.34 kg.

The Ecoinvent dataset for rapeseed oil contributes 3.09 kg CO_2eq/kg DW algae, which is reduced to 1.89 kg CO_2eq when employing the custom modelled oil.

When the rapeseed oil is removed, salt is reduced by 50% and nuclear power is used as electricity source, impacts were found to be 4.05 kg CO_2eq/kg DW algae. GHG emissions associated with the ethanol-plant sourced CO2 were higher than those of the oil-refinery sourced CO2, yet lower than the Ecoinvent dataset GWP impact. If only electricity consumption for compression and transport of ethanol-plant CO2 were included, total GHG emissions are reduced by ~0.3 kg CO2eq/kg DW algae, giving a theoretical lowest possible total of 3.73 kg CO2eq/kg DW algae, should the sourced CO2 be a waste product, only needing compression and transport before use.

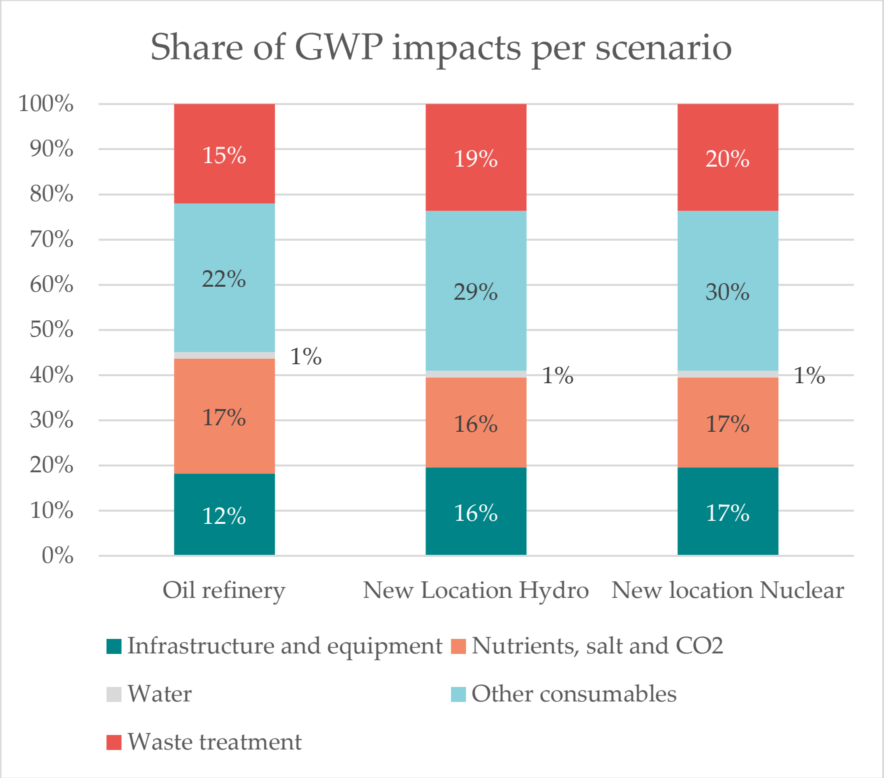

Fig A: Share of GWP impacts originating in different system processes

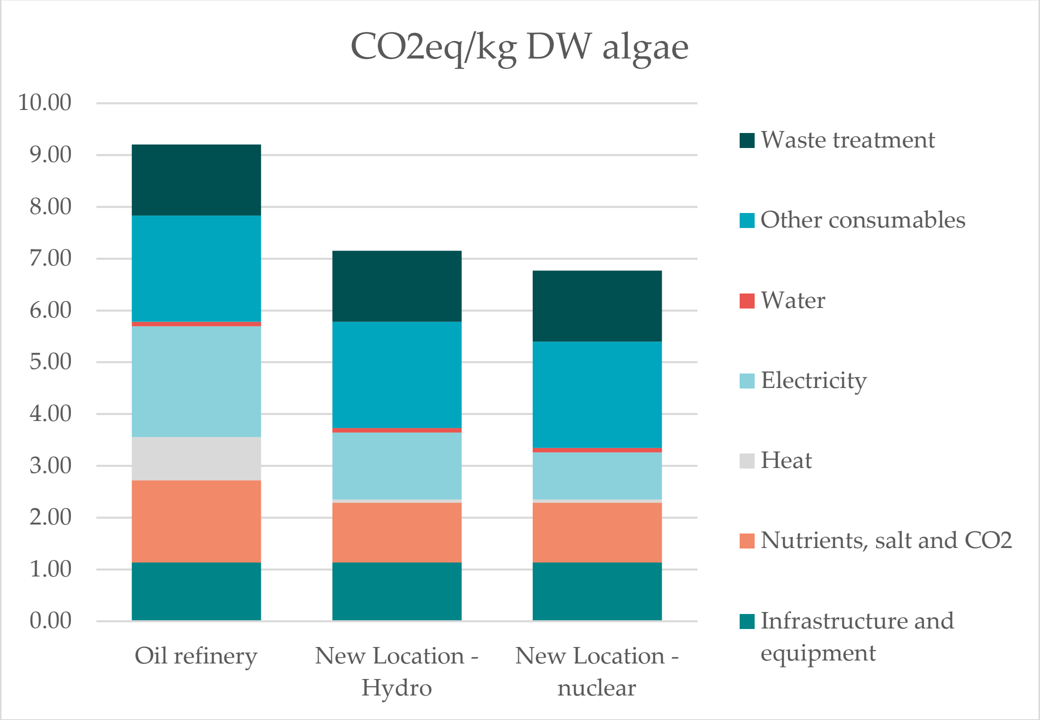

Fig B: GWP in kg CO_2-equivalents per kg DW algae

Table 3: Impacts shared by all scenarios

Common impacts	Infrastructure & Equipment	Nutrients	Misc inputs	Waste treatment
CO2eq/kg DW algae	1.13	0.41	0.24	0.08

Table 4: Impacts of the different salt choices

Salt	Rock salt	Sea salt	Rock salt -50%	Sea salt -50%
CO2eq/kg DW algae	0.94	0.35	0.47	0.17

Table 5: Impacts of the different salt waste treament choices

Salt waste treatment	Waste incineration	Salt waste landfill	Incineration, if -50% salt	Landfill, if salt -50%
CO2eq/kg DW algae	2.34	1.25	1.17	0.63

Table 6: Impacts of the different CO_2 sourcing and modeling choices

CO2 source	Oil refinery	Ecoinvent	Ethanol fermentation	Ethanol fermentation – zero burden
CO2eq/kg DW algae	0.21	1.71	0.21	0.05

Table 7: Impacts of the different heat sources.

Heat	Oil refinery heat	Municipal waste incineration
CO2eq/kg DW algae	0.83	0.07

Table 8: Impacts of the different electricity sources.

Electricity	Swedish mix	Swedish hydro	Swedish nuclear
CO2eq/kg DW algae	2.14	1.29	0.91

Table 9: Impacts of the different rapeseed oil sources.

Rapeseed oil	Ecoinvent	Swedish production
CO2eq/kg DW algae	3.09	1.89

3.2 Other impact categories

The impacts of the other investigated environmental impact categories are presented in Fig C as comparisons with the oil refinery scenario as index. Fossil energy resources depletion is increased for the nuclear power case compared to the oil refinery scenario, while this impact is very low in the hydropower scenario. Water use and marine eutrophication is elevated for both the hydropower case and the nuclear power case. Water that flows through run-of-river hydropower is calculated as water use, therefore the hydropower using scenario has the highest water use.

When rapeseed oil is omitted, marine eutrophication is reduced as well as water use. Marine eutrophication (nitrogen) and water use are both significant impacts of agriculture, so removing the rapeseed oil naturally reduces the total system impact in these categories.

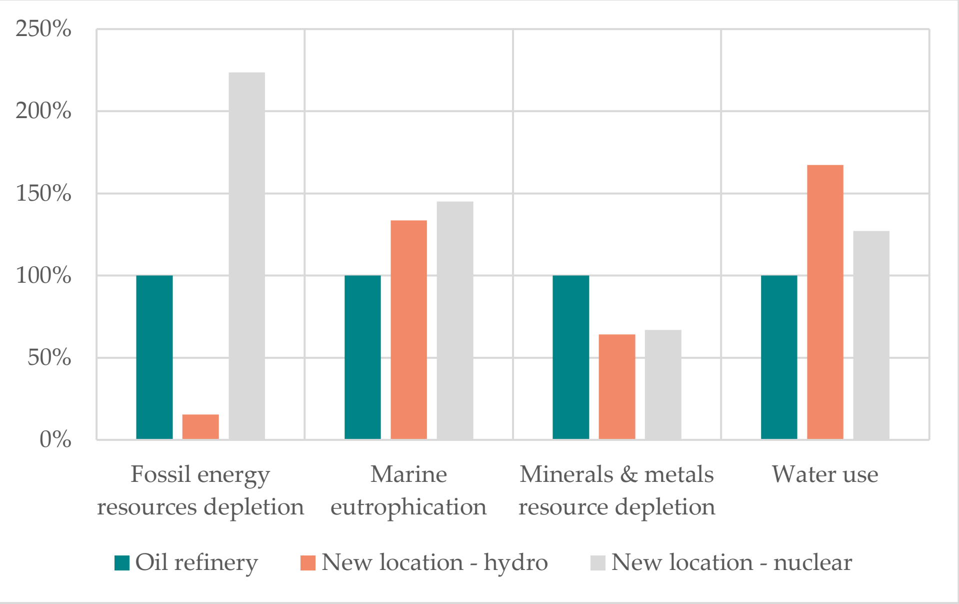

Fig C. Relative impacts of the other assessed impact categories, compared with the oil refinery scenario as index.

4 Discussion / Analysis

As shown in the results section, the main hotspots of this system in terms of GWP impact include rapeseed oil, energy (heat and electricity), salt (input and waste treatment), fertilizer, and LED light system. In comparison with the results from Nilsson & Martin (2022), the total climate impacts per kg DW seaweed are lower than those reported in the said study, i.e., 9.2 kg CO2eq/kg, for all scenarios except the baseline scenario.

Rapeseed oil carries noticeable burden in terms of total climate impacts, and removing the rapeseed oil from the calculation significantly reduces impact. However, the use of rapeseed oil does increase the shelf life of the product, potentially decreasing the risk of waste.

The CO_2 produced as a co-product of ethanol fermentation, carries a share of the burdens from ethanol production, i.e., it is allocated a share of the burdens from ethanol production based on mass. The CO_2 from the oil refinery is considered a waste product without economic value, thus the impact for that CO_2 is modeled solely on flue gas cleaning and energy expenditure for gas compression. This leads to the oil refinery-sourced CO_2 having a lower climate impact than that sourced from ethanol fermentation. This presents an interesting case of modeling choices and results giving the renewable source a higher impact. However, the ethanol-sourced CO_2 was found to have a much lower impact when modelled with the zero-burden approach used for the oil refinery-sourced CO_2. For all sources of CO_2, the carbon cannot be claimed to be "captured" in the seaweed, as the carbon will re-enter the atmosphere after moving through the feed, food, and waste chain.

An alternative that may be interesting to investigate for future CO_2 sourcing is direct air capture (DAC) through locally placed DAC equipment, although this likely requires a significant investment. Another option could be co-location with industries generating CO_2 (for example biorefineries or ethanol fermentation plants), where transports would be reduced and the need for gas compression may be eliminated or reduced. An example of this is found in the Netherlands, where piping is directed from CO_2-producing industries to greenhouses (Horti Daily, 2023). A third option could be a local CHP plant, from which the system could use both heat, electricity, and CO_2. Alternatives for heat sourcing beyond district heating from the oil refinery and municipal waste incineration are not considered in this assessment. Locations where residual heat is abundant could be interesting for future facilities. This heat could possibly be modeled with a zero-burden approach, lowering the impacts of algae production even further, granted it is not currently utilized for any other purpose.

For electricity, replacing the Swedish mix with nuclear power or hydropower reduces impacts in several categories, though hydropower increases water use, while nuclear power increases the fossil energy resources depletion and water use, as well as ionizing radiation (see appendix 1). These tradeoffs are important to consider in order to not suboptimize the system.

4.1 Conclusion

The impacts of the assessed system, Factory 02, are generally lower per kg (DW) produced algae when compared with Factory 01. Several alternatives for reducing the impacts of GWP hotspots were evaluated including salt sourcing and salt waste disposal method, source of CO_2 for supplementation, source of electricity, rapeseed oil and heat. The lowest GWP impact among the scenarios was 6.77 kg CO_2eq/kg DW algae for the new location - nuclear power scenario. The lowest summed GWP impact employing the assessed improvements was 4.05 kg CO_2eq/kg DW algae for the new location – nuclear power scenario amended for zero rapeseed oil usage and a 50% reduction in salt use. If only electricity consumption for compression and transport of ethanol-plant CO_2 were included for supplemental CO_2, total GHG emissions are reduced by ~0.3 kg CO_2eq/kg DW algae. This gives a theoretical lowest possible total of 3.73 kg CO_2eq/kg DW algae, should the sourced CO_2 be a waste product, only needing compression and transport before use.

For future research, it would be highly interesting to follow up on real-life production figures from factory 02, as well as assess the impacts of possible future changes in operations or system design.

5 Reference list

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Appendices

Appendix 1 – Impact assessment results – per kg DW algae

Total impact - per kg DW algae	Unit	Oil refinery	New location - hydro	New location - nuclear
acidification - accumulated exceedance (AE)	mol H+-Eq	8.5E-02	7.5E-02	1.0E-03
climate change - global warming potential (GWP100)	kg CO2-Eq	9.2E+00	7.2E+00	7.7E-02
climate change: biogenic - global warming potential (GWP100)	kg CO2-Eq	5.4E-02	8.1E-02	6.8E+00
climate change: fossil - global warming potential (GWP100)	kg CO2-Eq	8.9E+00	6.6E+00	1.4E-02
climate change: land use and land use change - global warming potential (GWP100)	kg CO2-Eq	2.2E-01	5.2E-01	6.7E+00
ecotoxicity: freshwater - comparative toxic unit for ecosystems (CTUe)	CTUe	1.2E+02	1.1E+02	4.0E-02
ecotoxicity: freshwater, inorganics - comparative toxic unit for ecosystems (CTUe)	CTUe	6.8E+01	4.9E+01	1.1E+02
ecotoxicity: freshwater, organics - comparative toxic unit for ecosystems (CTUe)	CTUe	5.5E+01	6.2E+01	5.3E+01
energy resources: non-renewable - abiotic depletion potential (ADP): fossil fuels	MJ, net calorific value	4.2E+02	6.3E+01	6.2E+01
eutrophication: freshwater - fraction of nutrients reaching freshwater end compartment (P)	kg P-Eq	3.7E-03	2.6E-03	9.1E+02
eutrophication: marine - fraction of nutrients reaching marine end compartment (N)	kg N-Eq	4.1E-02	3.7E-02	2.8E-03
eutrophication: terrestrial - accumulated exceedance (AE)	mol N-Eq	2.7E-01	2.7E-01	4.0E-02

Total impact - per kg DW algae	Unit	Oil refinery	New location - hydro	New location - nuclear
human toxicity: carcinogenic - comparative toxic unit for human (CTUh)	CTUh	1.1E-08	9.3E-09	2.7E-01
human toxicity: carcinogenic, inorganics - comparative toxic unit for human (CTUh)	CTUh	6.3E-09	5.4E-09	9.5E-09
human toxicity: carcinogenic, organics - comparative toxic unit for human (CTUh)	CTUh	9.0E-09	3.9E-09	5.7E-09
human toxicity: non-carcinogenic - comparative toxic unit for human (CTUh)	CTUh	2.7E-07	2.4E-07	3.8E-09
human toxicity: non-carcinogenic, inorganics - comparative toxic unit for human (CTUh)	CTUh	2.5E-07	2.3E-07	2.6E-07
human toxicity: non-carcinogenic, organics - comparative toxic unit for human (CTUh)	CTUh	1.6E-03	1.2E-08	2.5E-07
ionising radiation: human health - human exposure efficiency relative to u235	kBq U235-Eq	2.6E+01	3.8E-01	1.2E-08
land use - soil quality index	dimensionless	5.1E+02	4.8E+02	6.5E+01
material resources: metals/minerals - abiotic depletion potential (ADP): elements (ultimate reserves)	kg Sb-Eq	2.5E-04	1.6E-04	4.9E+02
ozone depletion - ozone depletion potential (ODP)	kg CFC-11-Eq	1.3E-03	1.4E-07	1.7E-04
particulate matter formation - impact on human health	disease incidence	9.5E+00	6.1E-07	1.5E-07
photochemical oxidant formation: human health - tropospheric ozone concentration increase	kg NMVOC-Eq	3.1E-02	2.7E-02	8.0E-07
water use - user deprivation potential (deprivation-weighted water consumption)	m3 world eq. deprived	2.3E+01	3.1E+01	2.9E-02

Appendix 2 – Material modeling

For much of the infrastructure and equipment used in Factory 02, no adequate ready-made datasets were available. Thus, the material composition of the unit was considered. In cases were a majority of the unit consisted of one single material, a representative dataset for that material was used. An example of this is the water tanks made from primarily High Density Polyethylene, modeled on datasets for that material. When the unit was composed of several materials of importance, a mass ratio of these materials was adapted. An example of this is the LED Grow lights, modeled as a combination of aluminum, wiring, diodes and HDPE. Likewise, the combined micronutrient fertilizer was modeled on contents of its individual components, for all components where datasets were available. A few components of the micronutrient fertilizer did not have available datasets, but these were deemed insignificant due to the very small amounts used.

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This report has been reviewed and approved in accordance with IVL's audit and approval management system.