LCA Comparison of Centralized Water Treatment Systems and In-Home Ceramic Water Filters in Bendekonde, Suriname

Luke Moilanen

Ashlee Vincent

Rabi Gyawali

Dr. John Gierke

May 18, 2012

Michigan Technological University

Department of Civil and Environmental Engineering

Scholarships- Science, Technology, Engineering, and Mathematics

Contents

Introduction ... 3
Objectives ... 3
Methods ... 4
  Boundary Conditions ... 4
  Life Cycle Inventory ... 4
  Functional Unit ... 5
  Impact Inventory ... 5
Results and Discussion ... 6
  Global Warming Potential ... 6
  Cumulative Energy Demand ... 6
  Ecosystem Damage Potential ... 7
Conclusions ... 8
Outcomes ... 8
References ... 9
Appendix A: SimaPro Outputs ... 10
Appendix B: SimaPro 7.3 Inputs ... 21

Introduction

Suriname is a small country situated on the northern shoreline of South America. Much of Suriname's population resides on the northern coast, but there are also rural communities located in the interior of the country. The village of Bendekonde, Suriname, is located along the Upper Suriname River and is representative of these rural communities. It contains a population of approximately 150 people and lies roughly 100 miles from the nearest developed town, Pokigron (Menke, 2000). Lack of development in communities like Bendekonde has provided motivation for aid efforts in different forms, of which there has been varying degrees of effectiveness. An example of one of these forms of aid is the addition of centralized water treatment technology to specific communities. The design implemented in Bendekonde is typical of the centralized water treatment systems that have been installed in several communities, but it is one of only a small number of centralized water treatment systems to continue to be in operation. A United Nations Children's Fund (UNICEF) survey reported that 75% of the 28 systems surveyed no longer function (Webster and Roebuck, 2001). This technology has various aspects to be considered when deciding upon implementation of such a system, one of which to be considered in conjunction with reliability is environmental impact as compared with other water treatment technologies currently available. One of the most technologically appropriate alternatives to centralized water treatment systems for implementation in the interior Suriname is the utilization of ceramic filters in individual homes of the community.

Economics might suggest that point-of-use ceramic filters would be financially advantageous over centralized water treatment. Differences in environmental impacts are less obvious. On one hand, a centralized system requires more materials but the energy requirements are low (solar) and practically have no emissions. Ceramic filters require firing a kiln and mining and processing clay, which would cause recurring emissions. A Life Cycle Assessment (LCA) was performed to quantitatively measure environmental impacts for the creation, transport, use, and disposal of a given product or process. The goal of the LCA was to analyze individual steps in the product life cycle to provide an overall quantitative measure such as energy consumption and/or global warming potential, as well as serve as a mechanism from which individual steps within the product life cycle can be compared to determine which particular step contributes the largest amount to the overall total.

Objectives

This LCA was performed to provide a comparison between two water treatment technologies available for use in Bendekonde. The first alternative, represented by the system currently in place in Bendekonde, is a solar-powered centralized water treatment system consisting of rapid and slow sand filters coupled with an ultraviolet disinfection system. The alternative to the centralized system that will be analyzed is the use of in-home ceramic filter units. The results of this LCA are to be utilized by Ashlee Vincent in her Master's Report, "Treatment Effectiveness and Cost Comparison of Two Water Treatment Options in Suriname, South America," which has not yet been completed.

Methods

The general steps that were taken for each LCA include the determination of scope/boundary conditions, generation of life cycle impact inventory, determination of functional unit, running of impact analysis, and interpretation of LCA results. SimaPro version 7.3 LCA analysis software (PRe Consultants, Amersfoort, Netherlands) was utilized to inventory input data and analyze environmental impacts for both the ceramic filters and centralized water treatment system. Input data for the centralized water treatment system was based on project documentation for the Bendekonde system (Course on Inland Water Systems, 2005), and input data for ceramic filters was based on accepted design practices with site-specific data utilized when available.

Boundary Conditions

The scope of this LCA includes:

Ceramic Filters:

- production of ceramic filter materials
- production of packaging materials
- assembly of ceramic filter parts
- transport of all materials
- energy for curing filters
- use of filters
- disposal of filters

Bendekonde Water Treatment System:

- production/collection of all materials
- production of packaging materials
- assembly of system components
- transport of all materials
- use and maintenance of system

The disposal of the Bendekonde system would likely entail little more than cannibalizing any usable parts off the system, and allowing it to sit idle. Given this likelihood, a disposal scenario for the Bendekonde system was omitted. Omission of the disposal of ceramic filters was considered as well, but the disposal scenario contributed negligibly to the environmental impacts of the life cycle and so it was not excluded.

Life Cycle Inventory

Information regarding materials, quantities, and processes used in the Bendekonde system were gained from the 2005 Bendekonde system construction manual (Course on Inland Water Systems, 2005). Specific information regarding make and model of controllers, solar panels, batteries, and UV treatment unit was given, while quantities of materials required for concrete works, metal scaffolding, and plastic reservoirs was estimated based upon the volume specified for each item in the manual. Additional information such as piping lengths and number of public taps was gained from site photographs and interviews with individuals who had been onsite. In an effort to provide a mid-range estimate of LCA impacts, all materials, processes, and quantities related to the Bendekonde system that required estimation were approximated using mid-range parameter values.

Information regarding the materials, production, and firing of ceramic filters was gained from the Best Management Practices (BMPs) outlined by Potters for Peace (The Ceramics Manufacturing Working Group, 2011). There is some variability in the ceramic filter-making process. Clay/sawdust ratios vary by clay type, application of silver nitrate differs between regions, and firing times vary based upon clay/sawdust ratio. In these instances moderate values were assumed to create an LCA that is representative of a 'moderate' ceramic clay filter, and minimize error present from assuming extreme values in materials or production.

Functional Unit

The functional unit is a unit of measure that normalizes inputs and impacts between products or processes. It is necessary to provide an adequate comparison between technologies that may have different life spans, energy inputs, and disposal considerations. The functional unit used as the basis for this comparison is per village for the expected lifetime of the Bendekonde system. The functional unit balances the comparison between ceramic filters and the Bendekonde system as follows:

Bendekonde:

Ceramic Filter:

Impact Inventory

This report discusses three methods from which LCA impacts are evaluated: global warming potential (GWP), cumulative energy demand (CED), and ecosystem damage potential (EDP). Global warming potential is a measure of the mass (in kg) of CO_2 equivalents produced during the life cycle, and contains climate change factors determined by the Intergovernmental Panel on Climate Change with a time frame of 100 years. Cumulative energy demand measures the total energy consumed through the life cycle in megajoules (MJ). Ecosystem damage potential is a point-system method for characterizing land occupation and transformation as a result of the LCA.

Results and Discussion

Different patterns emerged between the three methods that were used in SimaPro to determine impact of ceramic filters and the Bendekonde system. In this comparison, impacts associated with the addition of a chlorine drip are added as a third comparison to both ceramic filters and the Bendekonde system. It is assumed that widespread use of ceramic filters in Suriname would be implemented first at a regional level, since firing kilns and other infrastructure would be needed. A detailed discussion of measured impacts for each method used in the analysis is provided, with emphasis on the difference in impact magnitude between the regional filter and Bendekonde system scenarios. Profile-specific SimaPro outputs for all analyses are provided in Appendix A, and overall impact scores of all four scenarios and the three calculation set-ups utilized are listed in Table 1.

Table 1: Overall LCA Results

	System Scores			
Impact Inventory	**Regional Filter**	**Local Filter**	**Chlorine Drip**	**Bendekonde System**
IPCC 2007 GWP (kg CO_2 equiv.)	4355	2370	2180	15400
Cumulative Energy Demand (MJ)	104000	74000	35600	313000
Ecosystem Damage Potential (Pts)	1955	1940	10.35	359

Global Warming Potential

The life cycle of the Bendekonde system resulted in the production of 19,300 kg of CO_2 equivalents, the highest among the scenarios analyzed. While not as predominant as in the CED profile, HDPE production and processing contributed significantly (3,810 kg, 25% of total) to greenhouse gas production. Additional processes that strongly influenced CO_2 production were the manufacture of metal framework and production of cement. Required mass of cement was based upon estimated concrete volume requirements from site photographs and standard ratios for concrete mixing.

Usage of regionally-manufactured ceramic filters resulted in the production of 4,355 kg CO_2 equivalents. Travel by canoe for filter transport accounted for 68% of CO_2 equivalents produced in this scenario. Local ceramic filter manufacture resulted in a GWP of 2,370 kg CO_2 equivalents, thus it can be observed that a significant reduction in greenhouse gas production can be gained through the usage of ceramic filters versus centralized water treatment systems, with additional GHG reduction through local filter production. Because the majority of CO_2 equivalent emissions for both filter scenarios and the chlorine drip scenario were resultant from petrol combustion in canoes during transport, chlorine drip does not provide significant improvement over locally-produced ceramic filters in terms of GWP.

Cumulative Energy Demand

The Bendekonde System yielded a CED value of 313,000 MJ, which is approximately three times the CED of regionally constructed filters, and is over quadruple the CED of locally constructed filters. The largest energy sink is the usage of HDPE storage tanks in the system; the processes involved with HDPE usage are the production of HDPE granulate and injection moulding process to form the tanks. Together these inputs attribute to approximately 123,600 MJ, over one-third the total. The UV treatment system, an anticipated major energy sink in the system, contributes 32,000 MJ to the Bendekonde CED.

Regional ceramic filter production resulted in a CED of 104,000 MJ, from which the largest contributors are the burning of petrol to transport filters via outboard-equipped, dugout canoe to Bendekonde (52% of total CED), and the burning of hardwood logs in the firing kilns during filter production (37% of total CED). This illustrates that in the case of regionally-constructed ceramic filters, processing far outweighs material production in energy consumption; feedstock materials (clay, sawdust, and water) accounted for less than 1% of the CED. It was assumed that while ceramic filters were replaced every two years throughout the life cycle, the HDPE bucket used would last throughout the entire life cycle and thus in the SimaPro model only one bucket was used at each household.

Filters constructed locally in Bendekonde provide a 29% reduction in CED due to the reduction in required canoe travel. The major contributor to CED in the locally-produced scenario is the burning of hardwood logs for firing (38,000 MJ, 51% of total) and petrol combustion in canoes (27,200 MJ, 37% of total). As was anticipated, chlorination of drinking water yielded the lowest value for CED due to low processing and materials requirements. The largest contributor to CED within the chlorine drip profile is the burning of petrol during transportation of the bucket and chlorine to Bendekonde by river.

Ecosystem Damage Potential

The Bendekonde system resulted in an EDP of 395 pts, lower than both of the ceramic filter scenarios. The injection moulding process used to create the HDPE storage tanks and cement plant packing process accounted for the largest inputs, with values of 133 points, and 54 points, respectively. In contrast to evaluation through CED or GWP, transportation via canoe does not have a large contribution on EDP point total. It is also notable that while injection molding contributed 34% of the total EDP points, no material or process dominated the SimaPro results as significantly as was observed in the CED and GWP methods.

Ecosystem damage potential results for regionally-produced ceramic filters and locally-produced ceramic filters were essentially the same: 1,955 pts and 1,940 pts, respectively. These values represent an EDP nearly five times greater than that from the centralized treatment system. The burning of hardwood logs in the firing kiln contributed to the vast majority of EDP points for both ceramic filter scenarios. Moderate values for wood consumption were used in the LCA based upon estimations provided in the BMPs outlined by Potters for Peace. No other input to the SimaPro profile contributed significantly towards EDP point total.

This analysis advances the triple bottom line of sustainability by providing information relevant to decision-making regarding drinking water technology implementation in rural Suriname. The Bendekonde system selected for this LCA comparison is typical of many of the centralized treatment systems that have historically been installed, and use of ceramic water filters is spreading around the globe. Through social, economic, and environmental valuation, the most appropriate technologies can be selected for a given region.

Conclusions

As evidenced in this LCA comparison, magnitude of environmental impact of a technology is dependent on the criteria on which that given technology is being analyzed. While in comparison to ceramic filters the Bendekonde system was shown to have relatively high values for GWP and CED, the Bendekonde system had a significantly lower impact in regards to EDP. To say that implementation of one technology is more environmentally responsible than implementation of the others requires some qualification as to the basis on which the technologies are being evaluated. One method used to classify improved water systems is through a measure of embodied energy (Held et al., 2012); in this comparison, which involved two methods of high embodied energy (ceramic filters and centralized water treatment) and a method of low embodied energy (chlorine drip), impacts from the low embodied energy method were not significantly lower in one of the three calculation setups. Chlorine drip was used as a baseline in this comparison and not as an ideal alternative to centralized water treatment systems because of the potential social and health impacts associated with implementation of such a system which are outside the scope of this LCA.

The difference in method used to valuate LCA results is significant to the intended purpose of the LCA. As previously discussed, there were contrasting trends between ceramic filters and the Bendekonde system in regards to EDP versus GWP and CED. This could be particularly relevant in a heavily forested area such as central Suriname, or in other regions in South America where deforestation is prevalent and land use changes must be considered when creating governmental policy. It is also important for the LCA to reflect as closely as possible the real-life practices in the region in which it is designated to be used. This was the basis of splitting ceramic filter use into regionally-produced and locally-produced filters. It is likely that any initial infrastructure constructed to produce ceramic filters would be constructed in Paramaribo. Significant environmental advantages of producing filters locally could be weighed against social and economic factors to influence policy towards encouraging filter production in rural areas.

Outcomes

Several potential applications for this LCA comparison exist. The results of this LCA can be used in future design consideration by NGOs and communities when making decisions regarding water treatment system alternatives, as well as illustrate opportunities for improvement of specific life cycle processes for both centralized water treatment systems and ceramic water filters. This LCA can also be used as a tool for product marketing and project evaluations for the centralized treatment system and ceramic filters.

References

Fuchs, V. J., J. R. Mihelcic, and J. S. Gierke. "Life cycle assessment of vertical and horizontal flow constructed wetlands for wastewater treatment considering nitrogen and carbon greenhouse gas emissions." *Water Research*. 45.5 (2011): 2073-2081. Print.

Held, B. R., Q. Zhang, and J. R. Mihelcic. "Quantification of human and embodied energy of improved water provided by source and household interventions." *Journal of Cleaner Production*. (2012) Print.

Menke, Jack. United Nations Childrend's Fund. *Suriname Multiple Indicator Cluster Survey*. 2000. Print.

Smith, G., J. S. Gierke. "Rural Water System Sustainability: a Case Study of Community Managed Water Systems in Saramaka Communities." M.S. Report, Department of Civil & Environmental Engineering, Michigan Technological University, 2011.

Webster, T., and L. Roebuck. United States. Army Corps of Engineers, Mobile District and Topographic Engineering Center. *Water Resources Assessment of Suriname*. 2001. Print.

Course on Inland Water Systems 2005. *Course on Decentralized Water Systems in Inland Suriname*. Amsterdam: Municipality of Amsterdam Water Company, 2005. Print.

The Ceramics Manufacturing Working Group (2011). Best Practice Recommendations for Local Manufacturing of Ceramic Pot Filters for Household Water Treatment, Ed. 1. Atlanta, GA, USA: CDC

Appendix A: SimaPro Outputs

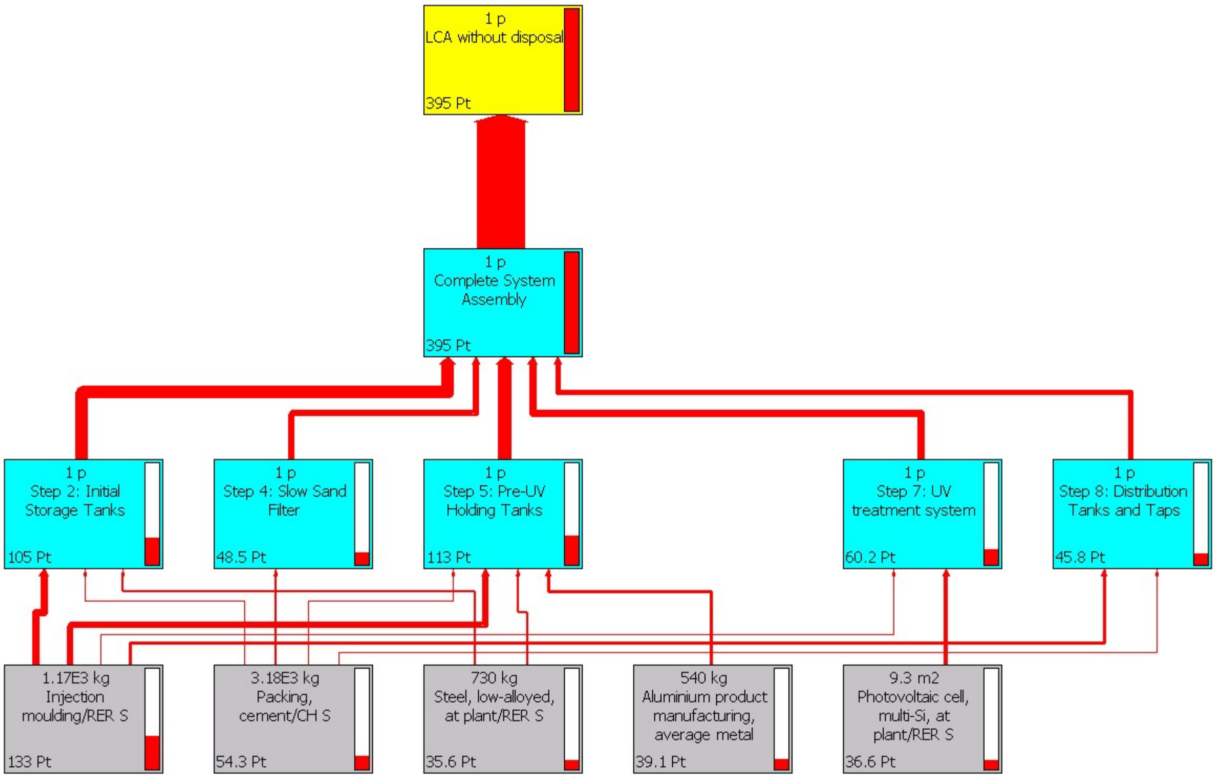

Figure A.1: SimaPro results for Bendekonde EDP.

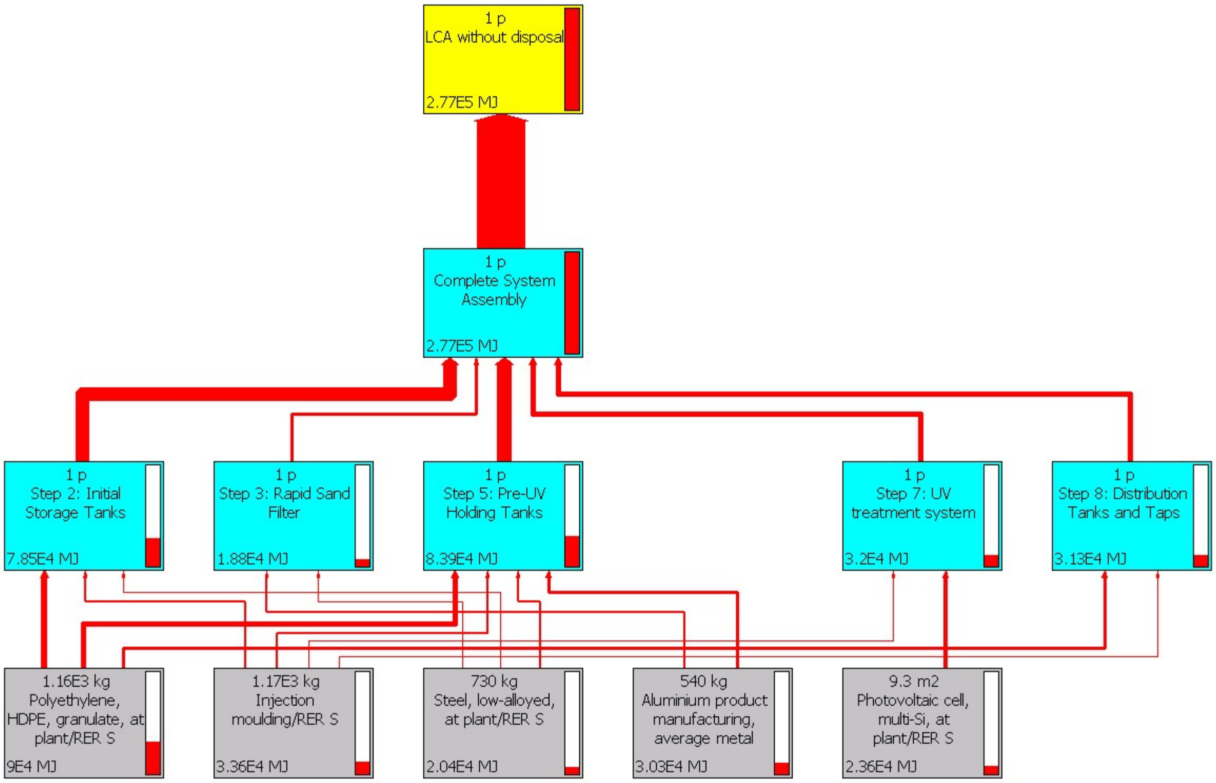

Figure A.2 SimaPro results for Bendekonde CED.

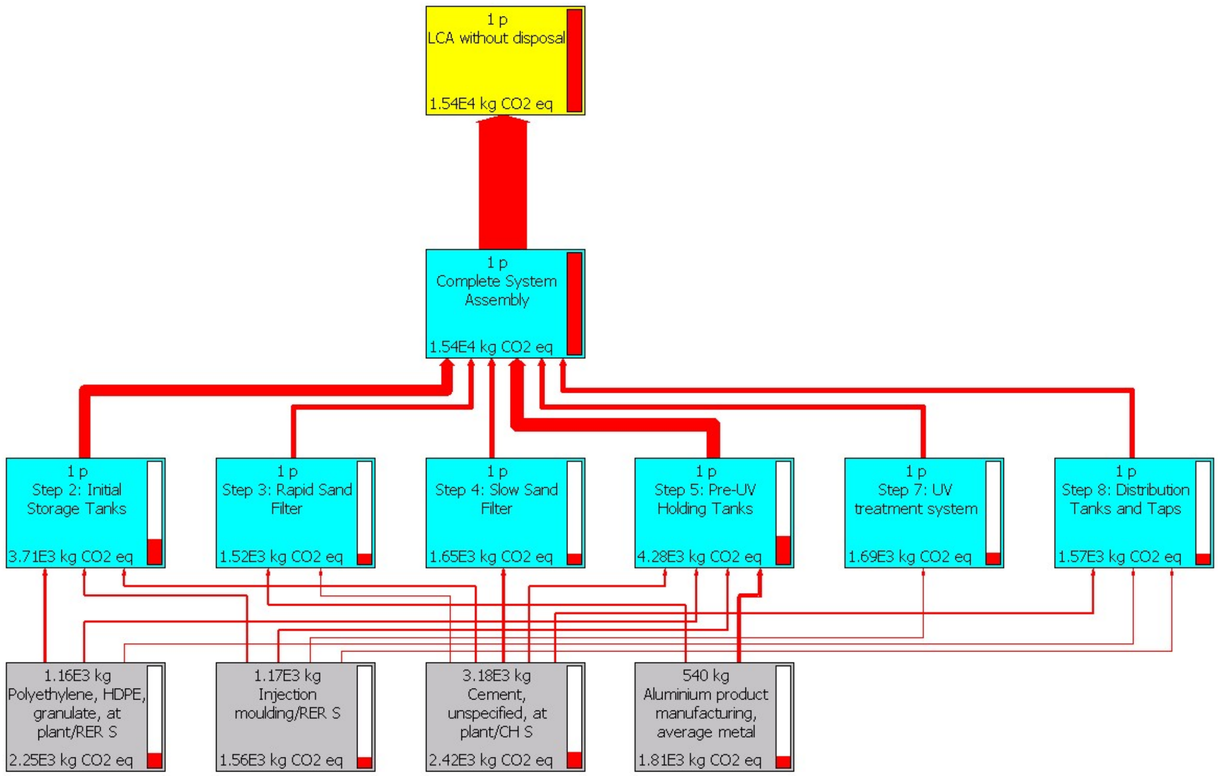

Figure A.3: SimaPro results for Bendekonde GWP.

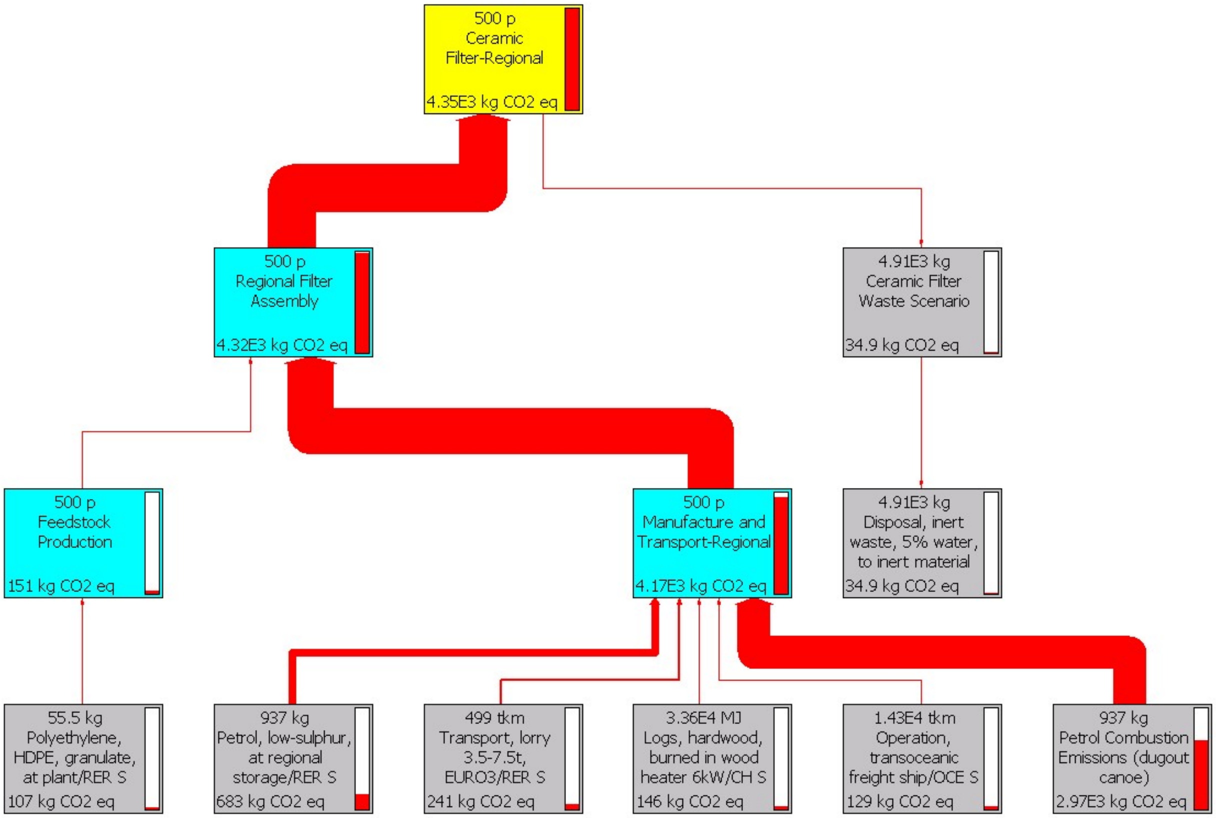

Figure A.4: SimaPro results for regional ceramic filter GWP.

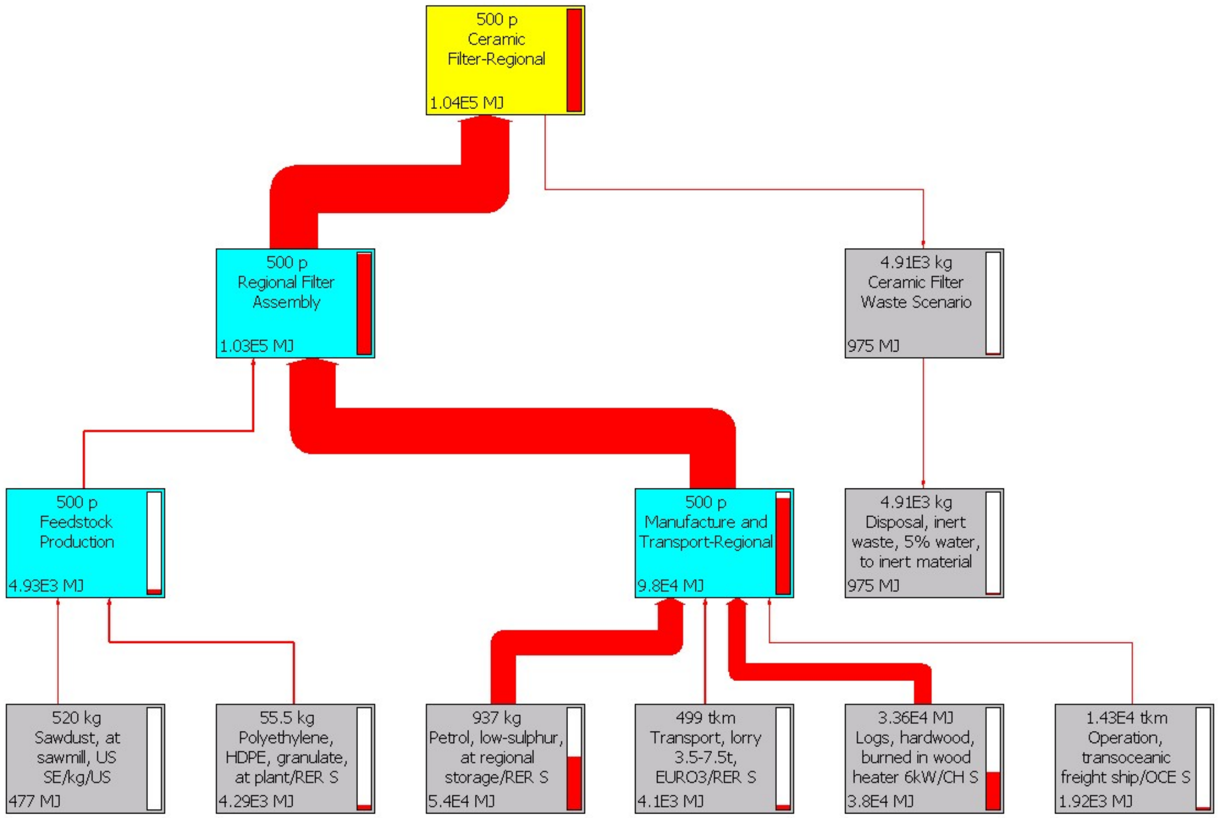

Figure A.5: SimaPro results for regional ceramic filter CED.

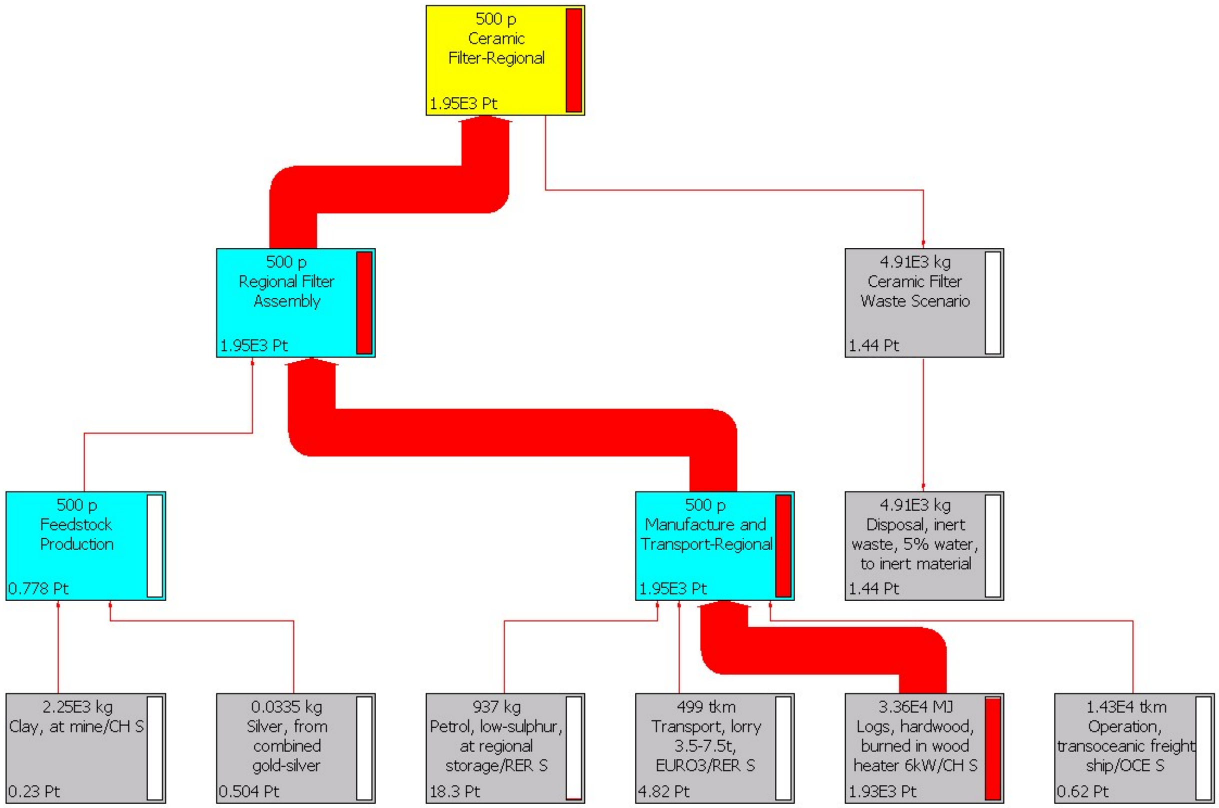

Figure A.6: SimaPro results for regional ceramic filter EDP.

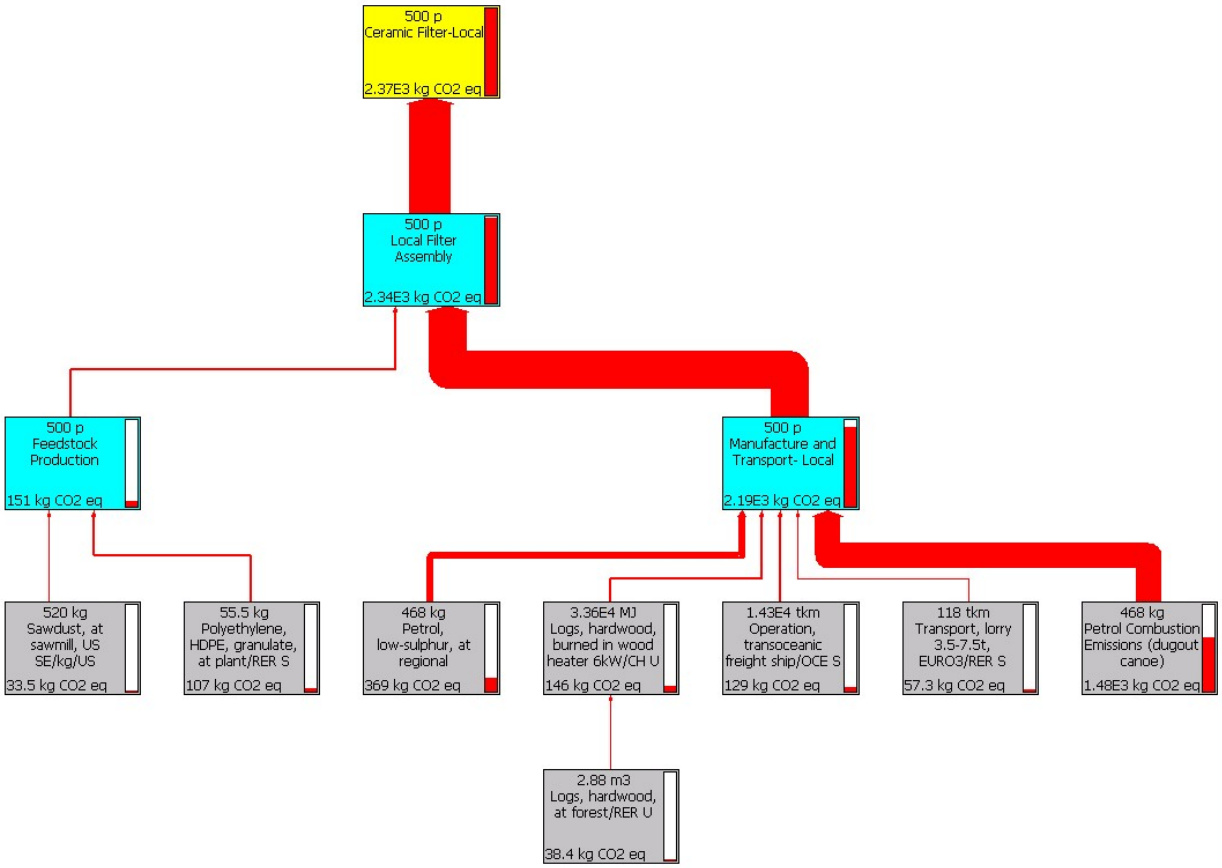

Figure A.7: SimaPro results for local ceramic filter GWP.

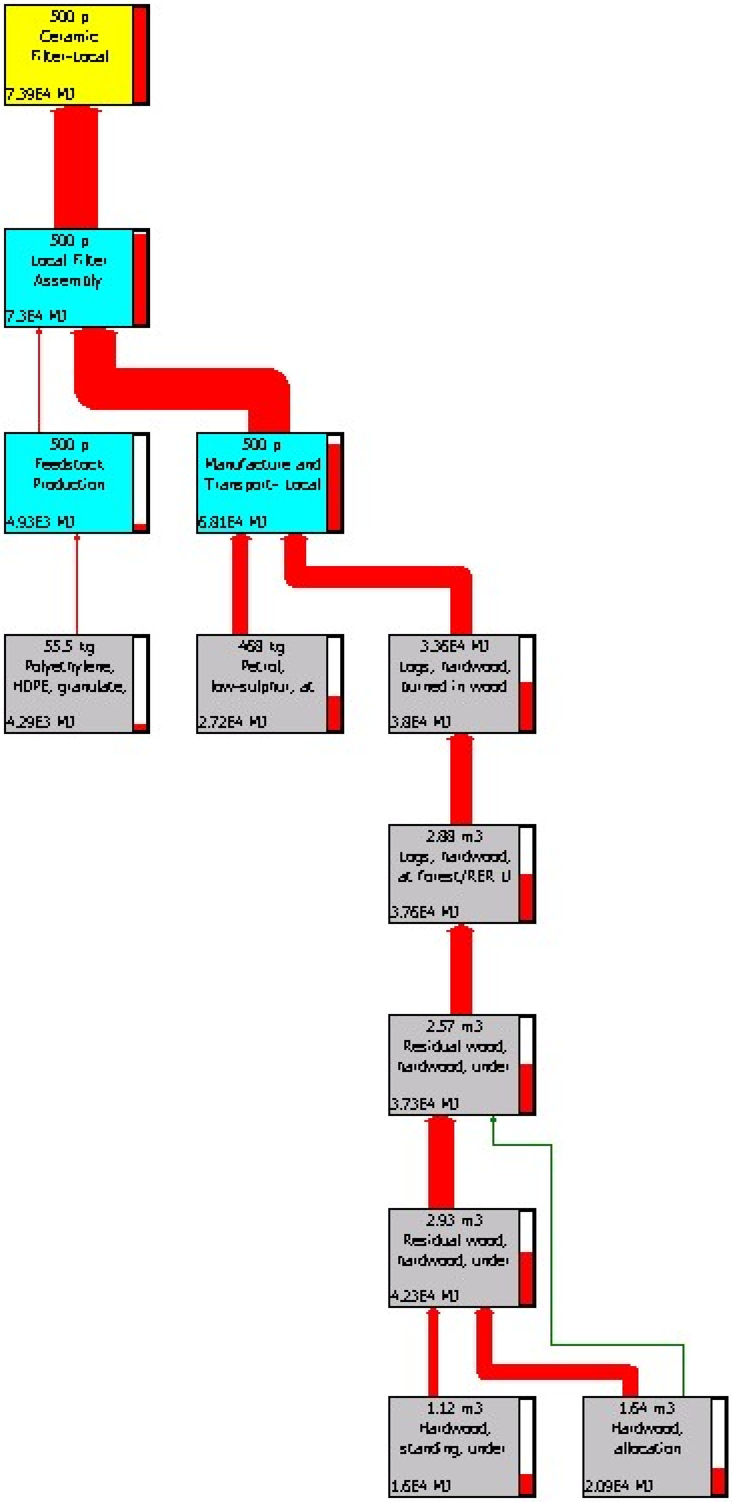

Figure A.8: SimaPro results for local ceramic filter CED.

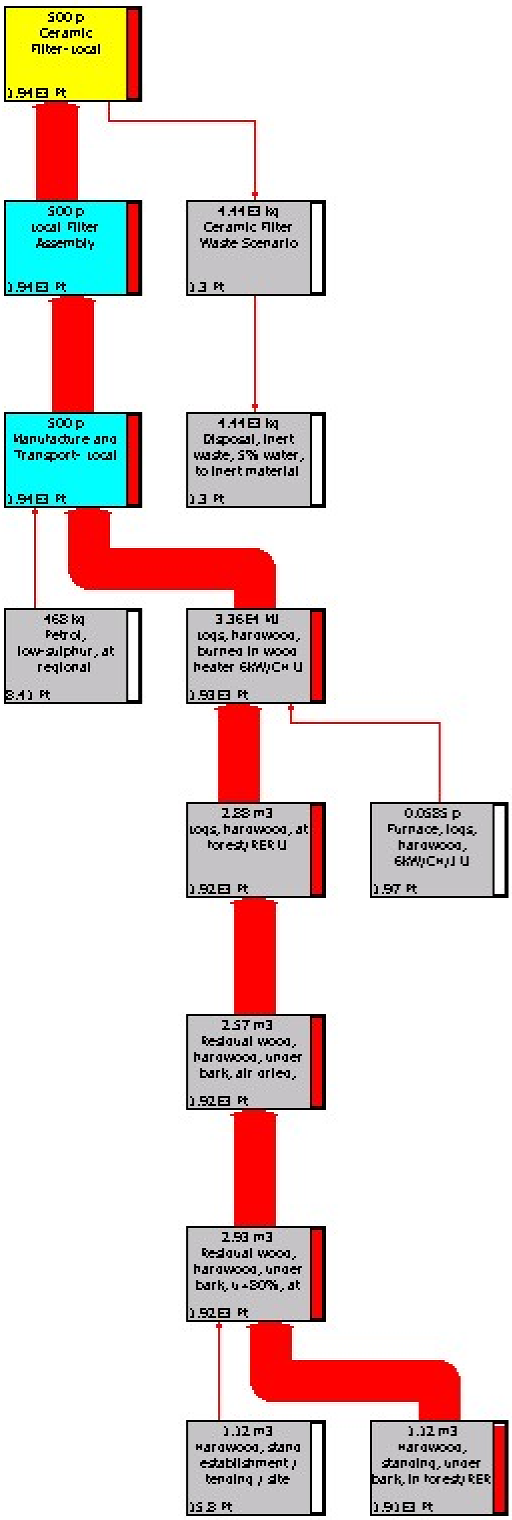

Figure A.9: SimaPro results for local ceramic filter EDP.

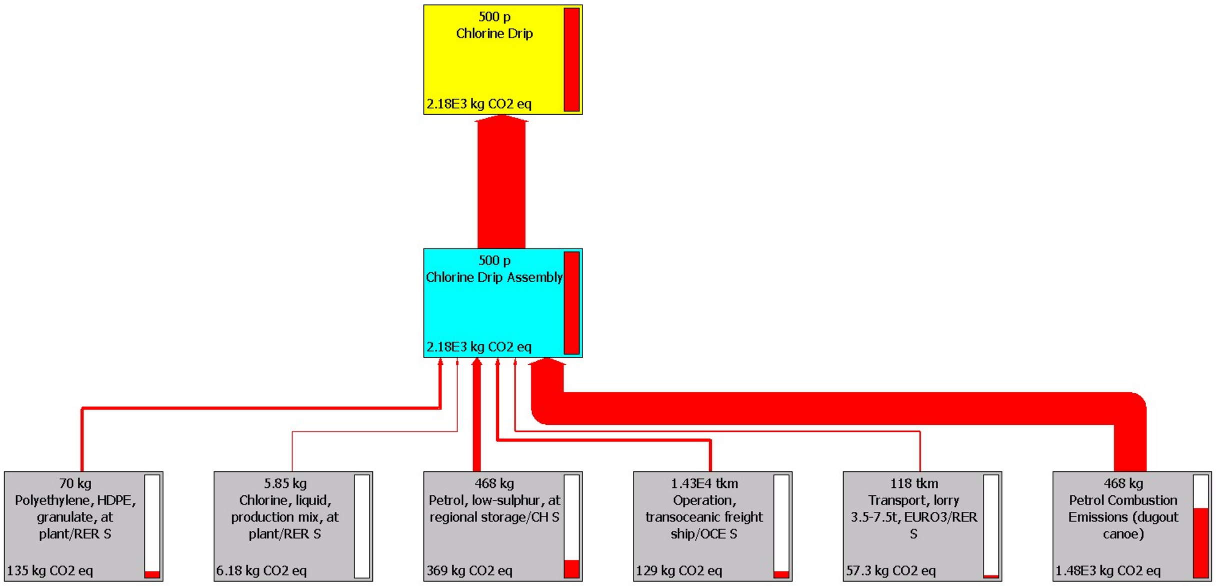

Figure A.10: SimaPro results for chlorine drip GWP.

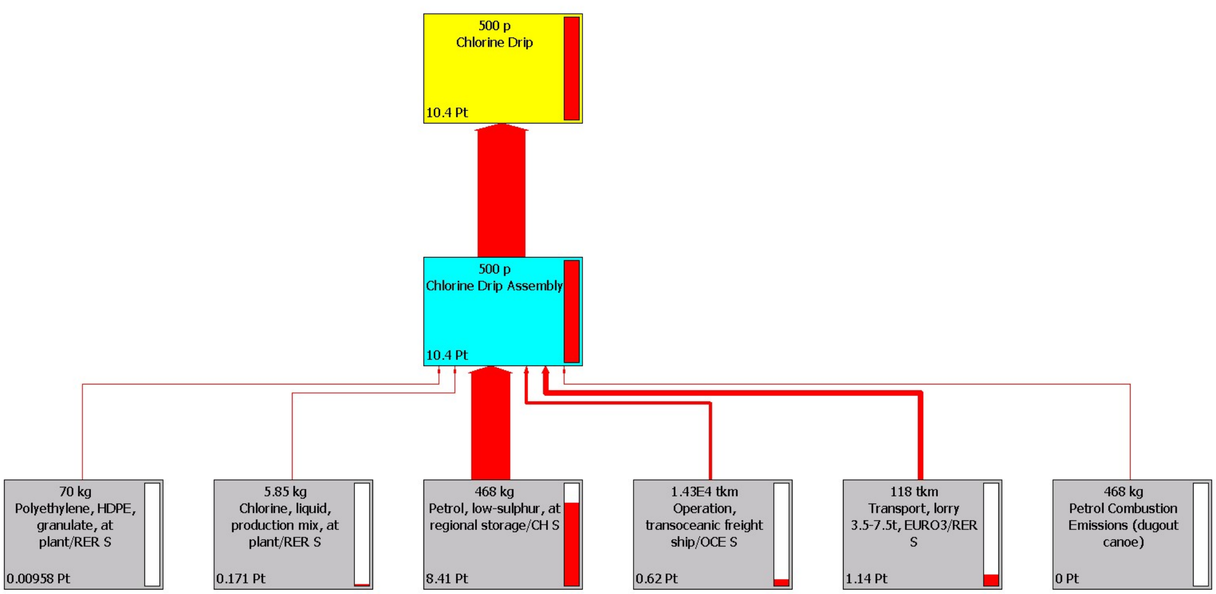

Figure A.11: SimaPro results for chlorine drip EDP.

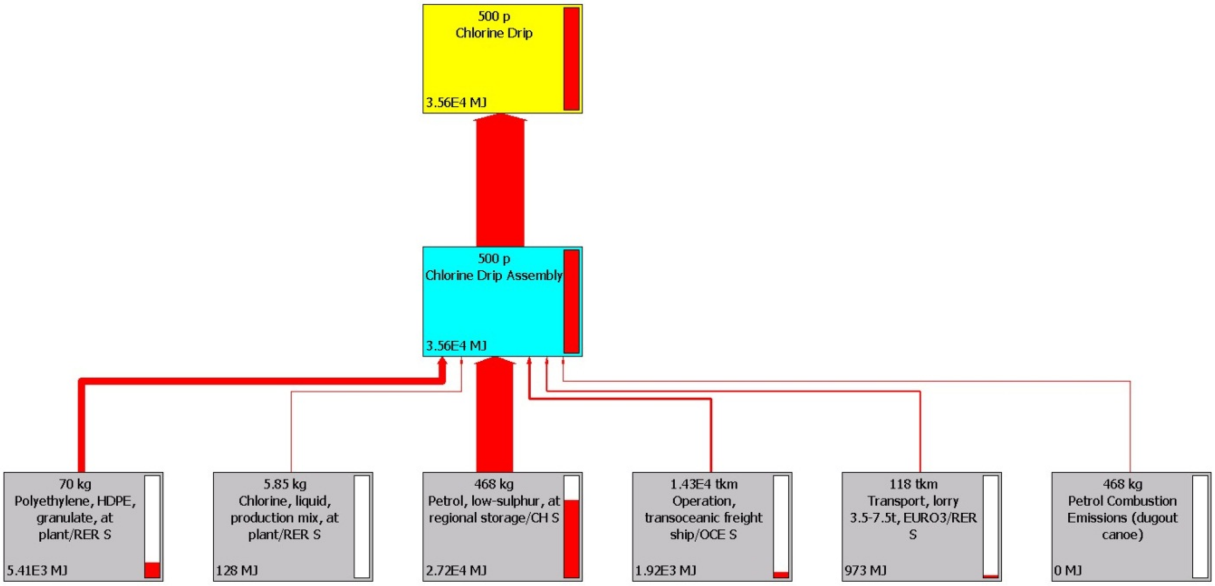

Figure A.12: SimaPro results for chlorine drip CED.

Appendix B: SimaPro 7.3 Inputs

Bendekonde System:

No	Process	Project	Unit
1	Alumina, at plant/US	USLCI	kg
2	Aluminium product manufacturing, average metal working/RER S	Ecoinvent system processes	kg
3	Aluminum ingot, production mix, at plant/US	USLCI	kg
4	Aluminum recovery, transport, to plant/RNA	USLCI	kg
5	Aluminum, primary, ingot, at plant/RNA	USLCI	kg
6	Aluminum, primary, smelt, at plant/RNA	USLCI	kg
7	Aluminum, secondary, ingot, at plant/RNA	USLCI	kg
8	Anode, at plant/RNA	USLCI	kg
9	Bauxite, at mine/GLO	USLCI	kg
10	Bituminous coal, at mine/US	USLCI	kg
11	Bituminous coal, combusted in industrial boiler/US	USLCI	kg
12	Brass, at plant/CH S	Ecoinvent system processes	kg
13	Casting, brass/CH S	Ecoinvent system processes	kg
14	Cement, unspecified, at plant/CH S	Ecoinvent system processes	tn.lg
15	Crude oil, at production/RNA	USLCI	kg
16	Diesel, at refinery/l/US	USLCI	cu.in
17	Diesel, combusted in industrial boiler/US	USLCI	cu.in
18	Dummy Energy (recovered)	ELCD	MJ
19	Dummy Hydrogen, gaseous	ELCD	mg
20	Dummy_Disposal, ash and flue gas desulfurization sludge, to unspecified reuse/US	USLCI	kg
21	Dummy_Disposal, BOF dust, to unspecified treatment/US	USLCI	kg
22	Dummy_Disposal, BOF slag, to unspecified treatment/US	USLCI	kg
23	Dummy_Disposal, lignite coal combustion byproducts, to unspecified reuse/US	USLCI	g
24	Dummy_Disposal, slag, to unspecified treatment/US	USLCI	kg
25	Dummy_Disposal, solid waste, unspecified, to municipal incineration/US	USLCI	g
26	Dummy_Disposal, solid waste, unspecified, to sanitary landfill/US	USLCI	kg
27	Dummy_Disposal, solid waste, unspecified, to underground deposit/US	USLCI	kg
28	Dummy_Disposal, solid waste, unspecified, to unspecified landfill/US	USLCI	g
29	Dummy_Disposal, solid waste, unspecified, to unspecified treatment/US	USLCI	kg

30	Dummy_Electricity, at cogenerating unit, unspecified/US	USLCI	MJ
31	Dummy_Electricity, at wind power plant, unspecified/US	USLCI	kJ
32	Dummy_Electricity, fossil, unspecified, at power plant/US	USLCI	kJ
33	Dummy_Electricity, from renewable source, unspecified/US	USLCI	kJ
34	Dummy_Electricity, geothermal, unspecified/US	USLCI	kJ
35	Dummy_Electricity, hydropower, at power plant, unspecified/US	USLCI	GJ
36	Dummy_Electricity, photovoltaic, unspecified/US	USLCI	kJ
37	Dummy_Galvanized steel scrap, at plant/US	USLCI	kg
38	Dummy_Transport, pipeline, coal slurry/US	USLCI	kgkm
39	Dummy_Transport, pipeline, unspecified/US	USLCI	tkm
40	Electricity, alumina refining regions/US	USLCI	MJ
41	Electricity, aluminum smelting and ingot casting regions/RNA	USLCI	GJ
42	Electricity, at grid, US/US	USLCI	MJ
43	Electricity, bauxite mining regions/GLO	USLCI	kJ
44	Electricity, biomass, at power plant/US	USLCI	MJ
45	Electricity, bituminous coal, at power plant/US	USLCI	MJ
46	Electricity, diesel, at power plant/RNA	USLCI	MJ
47	Electricity, lignite coal, at power plant/US	USLCI	MJ
48	Electricity, natural gas, at power plant/US	USLCI	MJ
49	Electricity, nuclear, at power plant/US	USLCI	MJ
50	Electricity, residual fuel oil, at power plant/US	USLCI	MJ
51	Electronics for control units/RER S	Ecoinvent system processes	kg
52	Fuel grade uranium, at regional storage/US	USLCI	mg
53	Galvanized steel sheet, at plant/RNA	USLCI	kg
54	Gasoline, at refinery/l/US	USLCI	cm3
55	Gasoline, combusted in equipment/US	USLCI	cm3
56	Glass fibre, at plant/RER S	Ecoinvent system processes	g
57	Gravel, unspecified, at mine/CH S	Ecoinvent system processes	tn.lg
58	Injection moulding/RER S	Ecoinvent system processes	tn.lg
59	Lead, at regional storage/RER S	Ecoinvent system processes	kg
60	Lignite coal, at surface mine/US	USLCI	g
61	Lignite coal, combusted in industrial boiler/US	USLCI	mg
62	Limestone, at mine/US	USLCI	kg
63	Liquefied petroleum gas, at refinery/l/US	USLCI	cm3
64	Liquefied petroleum gas, combusted in industrial boiler/US	USLCI	cm3
65	Metal product manufacturing, average metal working/RER S	Ecoinvent system processes	kg
66	Metallurgical coke, at plant/RNA	USLCI	kg

67	Natural gas, at extraction site/US	USLCI	m3
68	Natural gas, combusted in industrial boiler/US	USLCI	m3
69	Natural gas, processed, at plant/US	USLCI	m3
70	Packing, cement/CH S	Ecoinvent system processes	tn.lg
71	Petrol Combustion in Canoes	Bendekonde System	kg
72	Petroleum coke, at refinery/kg/US	USLCI	kg
73	Photovoltaic cell, multi-Si, at plant/RER S	Ecoinvent system processes	m2
74	Polyethylene terephthalate (PET) granulate, production mix, at plant, amorphous RER	ELCD	kg
75	Polyethylene, HDPE, granulate, at plant/RER S	Ecoinvent system processes	tn.lg
76	Polypropylene resin E	Industry data 2.0	kg
77	PVC pipe E	Industry data 2.0	kg
78	Quicklime, at plant/US	USLCI	kg
79	Residual fuel oil, at refinery/l/US	USLCI	cu.in
80	Residual fuel oil, combusted in industrial boiler/US	USLCI	cu.in
81	Sand, at mine/CH S	Ecoinvent system processes	tn.lg
82	Silica sand, at plant/DE S	Ecoinvent system processes	kg
83	Sodium chloride, at plant/RNA	USLCI	kg
84	Sodium hydroxide, production mix, at plant/kg/RNA	USLCI	kg
85	Stainless steel hot rolled coil, annealed & pickled, elec. arc furnace route, prod. mix, grade 304 RER S	ELCD	kg
86	Steel product manufacturing, average metal working/RER S	Ecoinvent system processes	kg
87	Steel, low-alloyed, at plant/RER S	Ecoinvent system processes	kg
88	Sulphuric acid, liquid, at plant/RER S	Ecoinvent system processes	kg
89	Synthetic rubber, at plant/RER S	Ecoinvent system processes	mg
90	Tin, at regional storage/RER S	Ecoinvent system processes	g
91	Transport, barge, average fuel mix/US	USLCI	tkm
92	Transport, barge, diesel powered/US	USLCI	tkm
93	Transport, barge, residual fuel oil powered/US	USLCI	tkm
94	Transport, combination truck, average fuel mix/US	USLCI	tkm
95	Transport, combination truck, diesel powered/US	USLCI	tkm
96	Transport, lorry 3.5-7.5t, EURO3/RER S	Ecoinvent system processes	ktkm
97	Transport, ocean freighter, average fuel mix/US	USLCI	tkm
98	Transport, ocean freighter, diesel powered/US	USLCI	tkm
99	Transport, ocean freighter, residual fuel oil powered/US	USLCI	tkm
100	Transport, train, diesel powered/US	USLCI	tkm

101	Transport, transoceanic freight ship/OCE S	Ecoinvent system processes	ktkm

Ceramic Filters:

No	Process	Project	Unit
1	Seedlings, at greenhouse, US SE/US	USLCI	p
2	Reforesting, high intensity site, US SE/US	USLCI	m2
3	Reforesting, low intensity site, US SE/US	USLCI	m2
4	Reforesting, medium intensity site, US SE/US	USLCI	m2
5	Dummy_Electricity, photovoltaic, unspecified/US	USLCI	J
6	Dummy_Electricity, geothermal, unspecified/US	USLCI	kJ
7	Dummy_Electricity, at wind power plant, unspecified/US	USLCI	kJ
8	Dummy_Electricity, fossil, unspecified, at power plant/US	USLCI	kJ
9	Dummy_Energy, unspecified/ US	USLCI	kJ
10	Electricity, biomass, at power plant/US	USLCI	MJ
11	Electricity, lignite coal, at power plant/US	USLCI	MJ
12	Dummy_Electricity, hydropower, at power plant, unspecified/US	USLCI	MJ
13	Electricity, residual fuel oil, at power plant/US	USLCI	MJ
14	Electricity, at grid, US/US	USLCI	MJ
15	Electricity, natural gas, at power plant/US	USLCI	MJ
16	Electricity, nuclear, at power plant/US	USLCI	MJ
17	Electricity, bituminous coal, at power plant/US	USLCI	MJ
18	Electricity, at grid, Eastern US/ US	USLCI	MJ
19	Logs, hardwood, burned in wood heater 6kW/CH S	Ecoinvent system processes	MWh
20	Dummy_Potassium fertilizer, production mix, at plant/US	USLCI	µg
21	Fuel grade uranium, at regional storage/US	USLCI	mg
22	Dummy_Disposal, chemical waste, unspecified, to sanitary landfill/US	USLCI	mg
23	Dummy_Disposal, inert solid waste, to inert material landfill/ US	USLCI	mg

24	Lignite coal, combusted in industrial boiler/US	USLCI	mg
25	Bituminous coal, combusted in industrial boiler/US	USLCI	g
26	Dummy_Disposal, lignite coal combustion byproducts, to unspecified reuse/US	USLCI	g
27	Silver, from combined gold-silver production, at refinery/PE S	Ecoinvent system processes	g
28	Dummy_Lubricants, unspecified, at plant/US	USLCI	g
29	Phosphorous fertilizer, production mix, at plant/US	USLCI	g
30	Dummy_Disposal, ash and flue gas desulfurization sludge, to unspecified reuse/US	USLCI	g
31	Dummy_Disposal, solid waste, unspecified, to sanitary landfill/US	USLCI	g
32	Dummy_Disposal, wood waste, to residual material landfill/US	USLCI	g
33	Lignite coal, at surface mine/US	USLCI	g
34	Dummy_Disposal, solid waste, unspecified, to unspecified treatment/US	USLCI	g
35	Nitrogen fertilizer, production mix, at plant/US	USLCI	g
36	Dummy_Disposal, solid waste, unspecified, to underground deposit/US	USLCI	kg
37	Bituminous coal, at mine/US	USLCI	kg
38	Crude oil, at production/RNA	USLCI	kg
39	Polyethylene, HDPE, granulate, at plant/RER S	Ecoinvent system processes	kg
40	Water, deionised, at plant/CH S	Ecoinvent system processes	kg
41	Sawdust, at sawmill, US SE/kg/US	USLCI	kg
42	Petrol Combustion Emissions (dugout canoe)	Moilanen Term LCA	kg
43	Petrol, low-sulphur, at regional storage/RER S	Ecoinvent system processes	kg
44	Tap water, at user/RER S	Ecoinvent system processes	ton
45	Clay, at mine/CH S	Ecoinvent system processes	tn.lg
46	Ceramic Filter Waste Scenario	Moilanen Term LCA	tn.lg
47	Disposal, inert waste, 5% water, to inert material landfill/CH S	Ecoinvent system processes	tn.lg
48	Dummy_Transport, pipeline, coal slurry/US	USLCI	kgkm
49	Transport, barge, diesel powered/US	USLCI	kgkm

50	Transport, barge, residual fuel oil powered/US	USLCI	kgkm
51	Transport, barge, average fuel mix/US	USLCI	kgkm
52	Transport, ocean freighter, diesel powered/US	USLCI	tkm
53	Dummy_Transport, pipeline, unspecified/US	USLCI	tkm
54	Transport, train, diesel powered/US	USLCI	tkm
55	Transport, ocean freighter, residual fuel oil powered/US	USLCI	tkm
56	Transport, ocean freighter, average fuel mix/US	USLCI	tkm
57	Transport, combination truck, average fuel mix/US	USLCI	tkm
58	Transport, combination truck, diesel powered/US	USLCI	tkm
59	Transport, lorry 3.5-7.5t, EURO3/RER S	Ecoinvent system processes	tkm
60	Operation, transoceanic freight ship/OCE S	Ecoinvent system processes	ktkm
61	Dummy_Kerosene, combusted in industrial boiler/US	USLCI	cm3
62	Liquefied petroleum gas, at refinery/l/US	USLCI	cm3
63	Liquefied petroleum gas, combusted in industrial boiler/US	USLCI	cm3
64	Gasoline, at refinery/l/US	USLCI	cm3
65	Gasoline, combusted in equipment/US	USLCI	cm3
66	Residual fuel oil, combusted in industrial boiler/US	USLCI	cm3
67	Diesel, combusted in industrial boiler/US	USLCI	cm3
68	Residual fuel oil, at refinery/l/US	USLCI	cm3
69	Diesel, combusted in industrial equipment/US	USLCI	cu.in
70	Diesel, at refinery/l/US	USLCI	cu.in
71	Softwood logs with bark, harvested at high intensity site, at mill, US SE/US	USLCI	dm3
72	Natural gas, combusted in industrial boiler/US	USLCI	dm3
73	Softwood logs with bark, harvested at low intensity site, at mill, US SE/US	USLCI	dm3
74	Softwood logs with bark, harvested at medium intensity site, at mill, US SE/US	USLCI	dm3
75	Softwood logs with bark, harvested at average intensity site, at mill, US SE/US	USLCI	dm3

76	Natural gas, processed, at plant/US	USLCI	m3
77	Natural gas, at extraction site/ US	USLCI	m3

Chlorine Drip:

No	Process	Project	Unit
	Total of all processes		MJ
1	Petrol Combustion Emissions (dugout canoe)	Moilanen Term LCA	MJ
2	Chlorine, liquid, production mix, at plant/RER S	Ecoinvent system processes	MJ
3	Transport, lorry 3.5-7.5t, EURO3/RER S	Ecoinvent system processes	MJ
4	Operation, transoceanic freight ship/OCE S	Ecoinvent system processes	MJ
5	Polyethylene, HDPE, granulate, at plant/RER S	Ecoinvent system processes	MJ
6	Petrol, low-sulphur, at regional storage/CH S	Ecoinvent system processes	MJ