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Environmental assessment of the Sotenäs Industrial Symbiosis Network

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Executive Summary

On the west coast of Sweden, an evolving network of industrial actors is being developed to create green, local jobs while contributing to a sustainable future. Industrial symbiosis (IS) is being promoted by the Sotenäs Symbioscentrum (Sotenäs Symbiosis Center) to develop synergies between industrial actors involved in renewable energy, food production, aquaculture, algae production and marine technology in order to improve material and energy efficiency in the region. It is anticipated that the current, developing and future synergies will lead to environmental benefits for the region and ensure a sustainable seafood and marine industry in the region. Therefore, this study aims to assess and review the environmental implications of the IS network in the Sotenäs region by outlining the potential environmental benefits and impacts of the evolving IS network.

In order to review the environmental implications of the Sotenäs IS network, life cycle assessment (LCA) was used and applied to the network. The assessment of the environmental impacts (and benefits) of the industrial symbiosis network follows the methodology outlined in Martin et al. (2015) for LCA of IS networks. Using this method allows for the review of both the impacts from the network (as a whole) and the benefit for individual firms in the network.

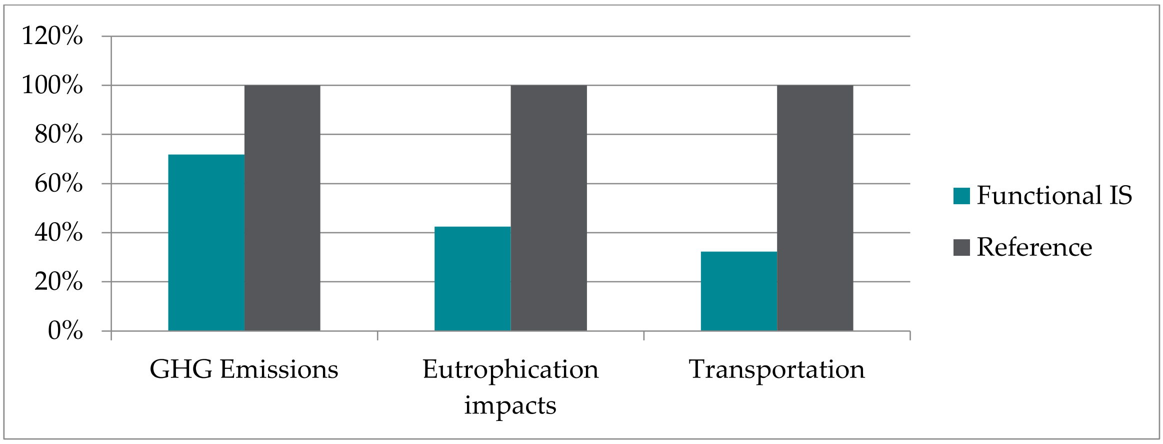

Figure 1: Comparison of the reference system to the planned IS Network

The results of this study suggest that the Sotenäs IS network has potential to significantly reduce environmental impacts for the production system currently being developed, when compared to a reference system. Large reductions in greenhouse gas emissions and local impacts, namely eutrophication impacts are possible. Examples include large impact reductions from land based salmon production compared to conventional salmon farming and adding value to fish industry waste through biogas, and thereafter biofertilizer, production.

The extent of the reductions include:

- A ***reduction of nearly 60 million kg*** CO_2***-eq emissions***
- Eutrophication impact ***reductions of 388 thousand kg*** PO_4***-eq***
- ***Reduction of over 19 million tonne-km*** in transportation of wastes and other products

All firms within the network were shown to benefit from the sharing of resources and energy, thus highlighting the importance of the IS network for improving the performance of the firms involved

and the products being produced. In addition to reduced impacts, there is a significant potential for reduction in transportation from the firms due to integration.

It is also important to note the significance of the nutrient recycling of the network by cascading wastes and wastewater to extract nutrients and reduce local impacts. With Sotenäs being a fishing community, the symbiotic network thus improves the use of sea-based resources and reduces the potential impacts to the aquatic and natural environment. Central to the system, the biogas plant act as an "upcycling tenant" in the IS network to further improve environmental benefits through wastewater and by-product handling in addition to replacing and supplying tradition forms of heat and fertilizer.

Results from the project will be important to spread to further municipalities in order speed up their local work with facilitating industrial symbiosis and to understand how these networks can be assessed both quantitatively and qualitatively from a number of important aspects.

Acknowledgements

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1 Background

The municipality of Sotenäs in Sweden together with partners from businesses, academy and other actors, have been actively working towards implementing and developing an industrial symbiosis (IS) network since 2013.The overall goal has been to create green local jobs while contributing to a better environment and sustainable future both locally and globally; which led to the development of the Sotenäs Symbioscentrum.

Since the start of the Sotenäs Symbioscentrum, a number of synergies between industrial actors in the industrial symbiosis network have been realized, and several exchanges are awaiting permits in order to implement the necessary infrastructure to allow for the exchanges to ensue. These include renewable energy, food production, aquaculture, algae production, marine technology and innovative products upcycling waste heat, fish industry waste and other wastes from the neighboring sea to create value added products and processes. More specifically, the network is revolves around several fish processing industries, pilot projects for algae production, an upcoming biogas project and salmon farm. It is anticipated that the current, developing and future synergies will lead to environmental benefits for the region and ensure a sustainable seafood and marine industry in the region. Therefore, this study ***aims*** to assess and review the environmental implications of the IS network in the Sotenäs region by outlining the potential environmental benefits and impacts of the evolving IS network.

This project is part of a larger assessment of the development, potential and verification of the work in the Sotenäs region of the evolving industrial symbiosis network in the Re:Source project "Industrial Symbiosis in Sotenäs." As such, to other reports also provide details on the socio-economic impact of the IS network and a review of the facilitation and maturity. In this report, and s part of this project, Dr. Michael Martin at IVL has led a work package to assess the potential environmental and socio-economic benefits of the system. The results presented in this report review the environmental assessment led and conducted by Dr. Martin with data input from Peter Carlsson of Sotenäs Symbioscentrum.

2 Method

The following sections provide a review of methodology, data and assumptions used for the environmental assessment and scenario development and analysis.

2.1 Assessing the Environmental Implications using Life Cycle Assessment

It is often presumed that industrial symbiosis networks create environmental and economic benefits. Furthermore, these benefits are assumed to be distributed between all actors, through so called “win-win” situations. In order to review the environmental implications of the Sotenäs IS network, life cycle assessment (LCA) was used and applied to the network. LCA is typically used to review and assess the environmental sustainability of products and services as it allows for reviewing and understanding the possible environmental impact tradeoffs of decisions made between production stages and on other systems. However, there are few examples of the use of LCA to review the environmental implications of industrial symbiosis networks in the literature (Martin, 2013; Martin et al., 2015; Mattila et al., 2012; Chertow and Lombardi, 2005; Sokka et al., 2011). However, Mattila et al. (2012) and Martin et al. (2015) have extended the framework and provided guidance on the use of LCA for reviewing IS networks.

The assessment of the environmental impacts (and benefits) of the industrial symbiosis network follows the methodology outlined in Martin et al. (2015) for LCA to IS networks. Using this method allows for the review of both the impacts from the network (as a whole) and the benefit for individual firms in the network. Furthermore, the method allows for an “equal distribution” of benefits created by replacing conventional products, through the shared use of resources, i.e. in the outlined 50/50 method. This method is advantageous when, and if, no other LCA is mandatory in policy and to review the symbiotic system as an arrangement of actors benefiting from one another. Otherwise, it is difficult to partition the benefits, and impacts, between producers and actors in the IS network; see Figure 2 below.

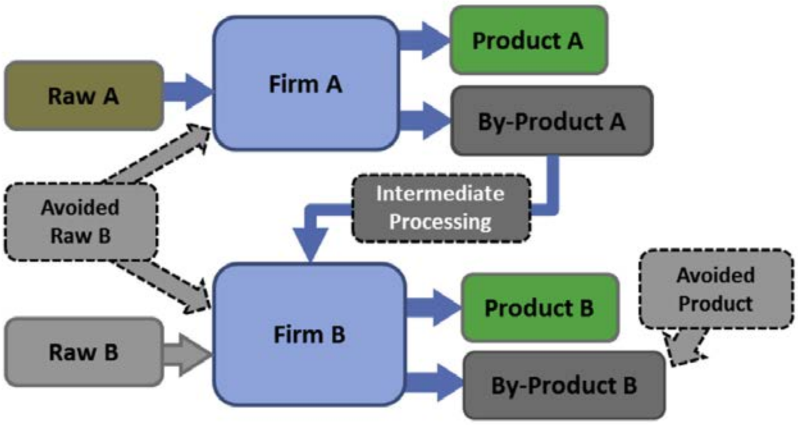

Figure 2: Illustration of methodology using the 50/50 method. Illustration from Martin et al. (2015)

Figure 2 above, illustrates the approach for a simple exchange between Firms A and B. The “fair” distribution of credits from the avoidance of Raw B is produced by providing Firm A and B a share

(50%) of the credit for the equivalent amount of Raw B avoided. As to not double-count the benefits and to model changes to the system by removal of Raw B, Firm B is provided a burden/impact for the production of Raw B; thus Firm B would only receive 50% of the impact of Raw B in total. Furthermore, by-products leaving the system are still avoided, according to the use of system expansion methodology. Intermediate processing is also possible, and the impacts of such a step are to be distributed between the firms involved in the exchange following the same 50/50 logic; this can include distributing impacts from upgrading and transport between the different companies involved in an exchange.

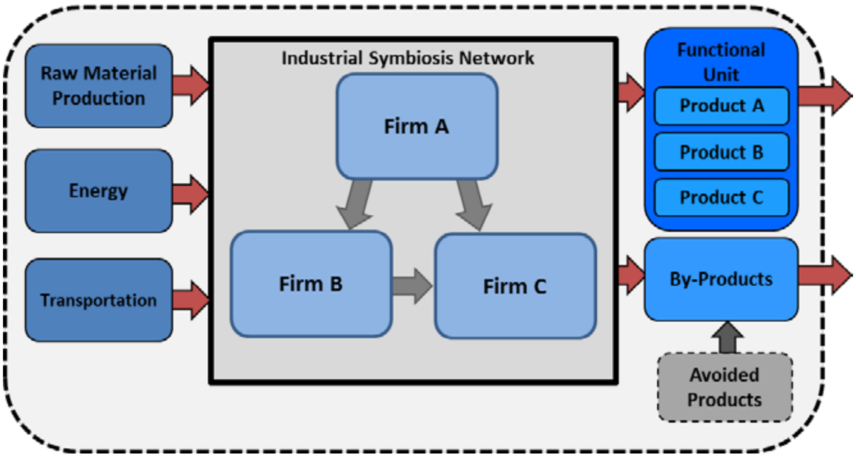

Figure 3: Illustration of methodological choices and data for reviewing an IS network, as outlined in Martin et al. (2015)

Furthermore, the approach of Martin et al. (2015) also outlines the selection, and potential impacts, of methodological considerations used for the quantifications including e.g. the choice of reference systems, allocation methods, system boundaries and functional unit(s); see Figure 3. The following sections provide more details on the methods, scenarios, boundaries and function of the system.

2.2 Scenarios Assessed

In order to review the development of the IS network of Sotenäs, several scenarios were developed to review the implications of the evolution of the network. These included a scenario to review the performance of a developed industrial symbiosis network in the near future and comparing this to a reference system where no IS network in place.

As several authors suggest (see e.g., Martin et al., 2015; Sokka et al., 2012; Mattila et al., 2012) the selection of a reference system is of utmost importance to review potential benefits of an IS network, i.e. compared to a current or future system. This is due to the fact that the reference system is normally chosen as the counterfactual system producing the same function as the studied symbiosis system (Martin et al., 2015). As such, the assumptions made for the reference system will determine the overall benefit compared to other scenarios.

In the case of the Sotenäs Symbioscentrum, several pilot cases exist, making the choice of reference system more transparent, but at the same time, less apparent. Again, in this case, the full operative IS network is not fully functional, and thus many assumptions were made (see the next section) based on prognoses from the companies currently involved. As such, the current system was chosen not as an actual review of symbiotic relationships. In order to allow for a comparison of the "evolution" of the system, the functional equivalence is important. Thus, the functional unit is reviewed in the analysis to understand this evolution and comparisons are done based on main product outputs from the Sotenäs IS network; see Figure 5.

2.2.1 Functional IS Network

In the next five years, it is envisioned that the IS network of Sotenäs will be in full operation; at least through some exchanges of materials and energy currently being realized through pilot projects. Thereafter, in ten years the network will be developed and include improved system and new synergistic exchanges (not currently reviewed). The functional IS scenario labelled ***Functional IS*** reviews the system in the near future, assuming that the symbiotic network develops fully from the current visions and pilot systems in place. The following subsections provide information on the modelling of firms which were modelled in "clusters." These included fish/food, waste treatment and energy, algae, salmon farming and sea recycling. Figure 4 below provides a representation of this system. The subsections below describe the exchanges and assumptions used in more detail. See also Figure 5 for a review of the functional unit used to compare the different scenarios.

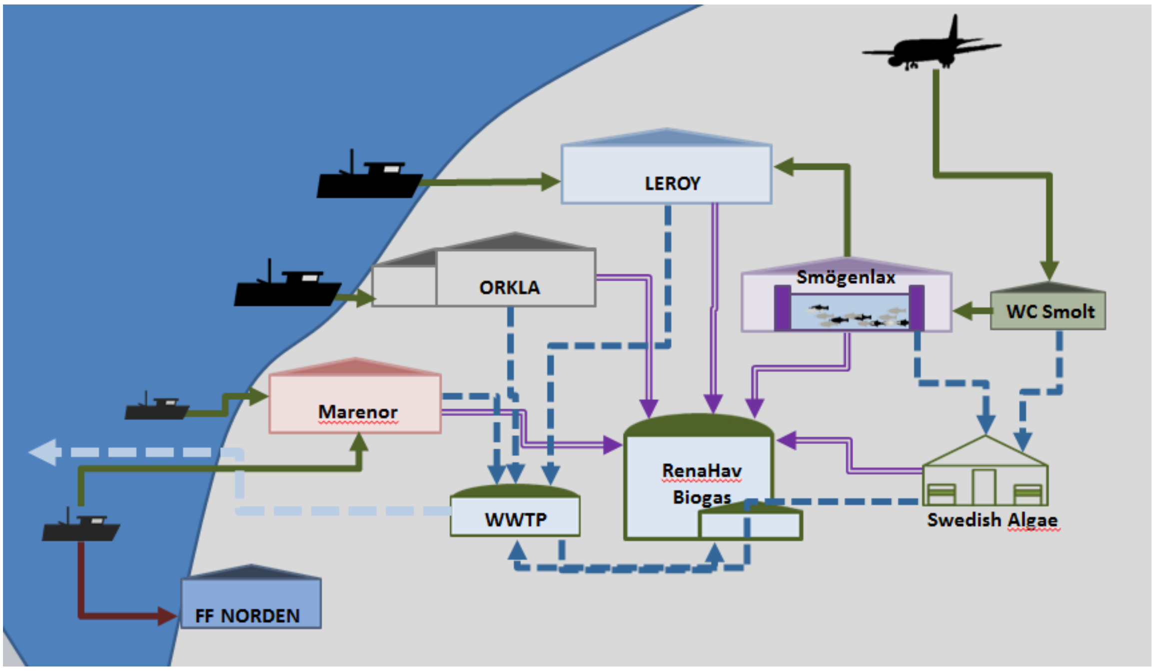

Figure 4: Synergies between different firms reviewed in the Functional IS scenario. Flows of wastewater are denoted with dark-dashed arrows. Flows of biowaste are denoted with double lined arrows. Flows of primary biomass are denoted with dark arrows. A light arrow from the WWTP denotes the discharge of wastewater to the sea. Finally, a dark arrow into FF NORDEN denotes the flow of wastes from the sea.

2.2.1.1 Biogas and WWTP Plants

Modeling of the biogas plant inputs and outputs was based primarily on information provided by Rena Hav (2014). This included inputs such as the total amount of fish wastes from the different fish processing plants and land based salmon farm sites. Biogas production from fish wastes were developed based on data provided by SGC (2009). In order to model the replacement of conventional fertilizers from biogas digestate, digestate nutrient content was taken from Martin et al. (2017). Modelling of the biogas system, e.g. energy inputs per output of biogas was developed from data Martin et al. (2015) for co-digestion plants. It is assumed that all fish wastes are transported by truck a short distance to the biogas plant from other plants; a distance of 5 km total was assumed to include transport to the facility and other maintenance[1]. Further information was adapted from Kaal (2017) and Shavalieva (2016), which earlier developed models for the coming biogas system. It was assumed that there is a 1% methane slip and there is no flaring of biogas. The biogas is used to produce both heat and electricity. For this system, the electricity was assumed to be the main product of the system, similar to assumptions made in Martin et al. (2015). The WWTP inputs and outputs were also developed based on information provided by Rena Hav (2014). These included the amount of wastewater sent to the WWTP and thereafter used in the biogas plant. Emissions for the Rena Hav WWTP were obtained from EcoInvent v. 3.3. (Ecoinvent, 2015). Once again, all LCI data used and their sources are outlined in aforementioned sections and in the Appendix.

Table 1: Inputs and Outputs for the Rena Hav Biogas and WWTP

Rena Hav							
		Flow	**Origin/ Class.**	**Amount**	**Unit**	**Use/ Destination**	**Transp.**
Inputs	Material	Fish Waste (Orkla)	Input-Symbios (Fish/Food)	198 00	Tonne	-	0.5
		Fish Waste (Leroy)	Input-Symbios (Fish/Food)	3 110	Tonne	-	0.5
		Fish Wastes (Marenor)	Input-Symbios (Fish/Food)	4 950	Tonne	-	2.5
		Fish Wastes Smogenlax Öde	Input-Symbios (Smögenlax)	2 900	Tonne	-	2.5
		Fish Wastes Smogenlax Haga	Input-Symbios (Smögenlax)	60.4	Tonne	-	2.5
		Water	Input-Symbios (WWTP)	0.0	m^3		0.0
	Energy	Electricity	Energy	2.1	GWh	-	0.0
		Heat	Energy	1.3			0.0
Outputs	Material	Biofertilizer	By-Product	30 000	Tonne	Market	100
		Methane Slip	By-Product	12 400	kg	-	0.0
	Energy	**Electricity (F.U.)**	**Main Product**	**7.50**	**GWh**	**Market**	**-**
		Heat	By-Product	8.40	GWh	District Heat	-
Rena Hav WWTP							
		Flow	**Origin/ Class.**	**Amount**	**Unit**	**Use/ Destination**	**Transp.**
Inputs	Material	WW Orkla	Input-Symbios (Smögen Lax)	150 000	m^3	-	-
		WW Leroy	Input-Symbios (Smögen Lax)	50 000	m^3		-
		WW Marenor	Input-Symbios (Smögen Lax)	30 000	m^3		-
		WW Smogenlax	Input-Symbios	55 150	m^3	-	-

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[1] Those firms sharing a by-product have been allocated 50/50 share of the transportation burden..

			(Smögen Lax)				
	Energy	Electricity	Energy	-	GWh	-	-
Outputs	Material	**Treated Wastewater (F.U.)**	**Main Product**	**228 120**	**m³**	**-**	**-**
		Water to Biogas	By-Product	46 000	m³	IS-Biogas Plant	-
	Energy	-	-	-	GWh		-

2.2.1.2 Salmon Farming

Salmon Farming for the Smögenlax plants at Ödegård and Hagaberg were modelled based on Recirculating Aquaculture Systems (RAS), and using information from Smögenlax (2015), in addition to the information available in (Colt et al., 2008; d'Orbcastel et al., 2009). Fertilized roe are assumed to be flown to Sweden from Iceland (Carlsson, 2017). It was assumed that salmon farming requires 1.1 tonne feed per tonne salmon live weight, i.e. fish feed conversion ratio (FCR).

Table 2: Inputs and Outputs for Salmon Farming Cluster

Smögenlax Ödegård							
		Flow	**Origin/ Class.**	**Amount**	**Unit**	**Use/ Destination**	**Transp.**
Inputs	Material	Smolt	Input Symbiosis (WC Smolt)	129	Tonne	-	0.5
		Fresh Water	-	200 000	m3	-	-
		Salt Water	-	200 000	m3	-	-
		Fish Feed	-	5 714	Tonne	-	100
		Plastic Packaging	-	10	Tonne	-	100
	Energy	Electricity	Energy	7	GWh	-	-
		Heat	Energy	3	GWh	-	-
Outputs	Material	**Salmon (F.U.)**	**Main Product**	1 645	Tonne	Market	100
		Salmon (Leroy)	Main Product	2 355	Tonne	IS-Leroy	2.5
		Fish Wastes (Process)	By-Product	1 195	Tonne	IS-Biogas Plant	2.5
		Slam Fesces	By-Product	1 709	Tonne	IS-Biogas Plant	2.5
		Wastewater	By-Product	39 760	m³	IS-WWTP	-

		Wastewater	By-Product	240	m^3	IS-Algae	2.5
	Energy	-	-	-	-	-	-
Smögenlax Hagaberg							
		Flow	**Origin/ Class.**	**Amount**	**Unit**	**Use/ Destination**	**Transp.**
Inputs	Material	Smolt	Input Symbiosis (WC Smolt)	55.1	Tonne	-	0.5
		Fresh Water	-	51 000	Tonne	-	-
		Salt Water	-	100 000			-
		Fish Feed	-	1 429	Tonne	-	100
		Plastic Packaging	-	2.6	Tonne	-	-
	Energy	Electricity	Energy	2.0	GWh	-	-
		Heat	Energy	1.0	GWh	-	-
Outputs	Material	**Salmon Gutted (F.U.)**	**Main Product**	455	Tonne	Market	100
		Fish Wastes (Process)	By-Product	299	Tonne	IS-Biogas Plant	2.5
		Slam Fesces	By-Product	427	Tonne	IS-Biogas Plant	2.5
		Wastewater	By-Product	15 100	m^3	IS-WWTP	-
		-	-				
	Energy	-	-	-	-	-	
West Coast Smolt							
		Flow	**Origin/ Class.**	**Amount**	**Unit**	**Use/ Destination**	**Transp.**
Inputs	Material	Roe	Iceland	0.35	Tonne	-	2 130
		Fodder	-	202	Tonne	-	100
		Water	-	530	Tonne	-	-
		Plastic	-	1.0	Tonne	-	100
	Energy	Electricity	Energy	2.0	GWh	-	-

		-	-	-	GWh	-	-
Outputs	Material	**Smolt**	**Main Product (IS)**	**184**	**Tonne**	**IS-Smögen Lax**	**0.5**
		Biowaste	By-Product	6.9	Tonne	IS-Biogas Plant	2.5
		Fecal wastes	By-Product	54		IS-Biogas Plant	2.5
		Wastewater	By-Product	530	Tonne	IS-WWTP	2.5
	Energy	-	-	-	GWh		-

[a]-Air Freight

2.2.1.3 Food/Fish Industry

The production of fish products at Orkla, Leroy and Marenor were based primarily on LCI data for fish products from e.g . Buchspies et al. (2011). Further data for canning, smoking, etc. were taken from Norden (2015) and applied where applicable. No data on the exact operations for Orkla, Leroy and Marenor were available. However, the main inputs and outputs to the system were provided by a number of references including Rena Hav (2014) and Norden (2015). As it was assumed that the production systems at Orkla, Leroy and Marenor do not change dramatically between the reference and Functional IS scenarios, the exact impacts from production processes at the firms were not modelled in detail.

Table 3: Inputs and Outputs for Food/Feed Cluster

Orkla							
		Flow	**Origin/ Class.**	**Amount**	**Unit**	**Use/ Destination**	**Transp.**
Inputs	Material	Herring	-	6 500	Tonne	-	50
		Roe	-	1 300	Tonne	-	50
		Anchovies	-	3 300	Tonne	-	50
		Whitefish	-	1 700	Tonne	-	50
		Mackerel	-	10 200	Tonne	-	50
	Energy	Electricity	Energy	9.0	GWh		-
Outputs	Material	**Fish Products (F.U)**	**Main Product**	10 200	Tonne	Market	200
		Fish Wastes	By-Product	19 800	Tonne	Biogas Plant	0.5
		Wastewater	By-Product	150 000	m³	WWTP	-

	Energy	-	-	-	-	-	-
Leroy							
		Flow	**Origin/ Class.**	**Amount**	**Unit**	**Use/ Destination**	**Transp.**
Inputs	Material	Salmon	Input-Symbios (Smögenlax)	2 400	Tonne	-	2.5
		Other Fish	-	1 200	Tonne	-	50
		Crustasceans	-	1 200	Tonne	-	50
	Energy	Electricity	Energy	2.0	GWh	-	-
Outputs	Material	**Fish Products (F.U.)**	**Main Product**	1 600	Tonne	Market	200
		Fish Wastes	By-Product	3 100	Tonne	IS-Biogas Plant	0.5
		Wastewater	By-Product	50 000	Tonne	IS-WWTP	-
	Energy	-	-	-	-	-	-
Marenor							
		Flow	**Origin/ Class.**	**Amount**	**Unit**	**Use/ Destination**	**Transp.**
Inputs	Material	Cod	-	2 500	Tonne	-	400
		Herring	Input-Symbios (FF Norden)	2 500	Tonne	-	2.5
		Other Fish	Input-Symbios (FF Norden)	2 500	Tonne	-	2.5
	Energy	Electricity	Energy	3	GWh	-	-
Outputs	Material	**Fish Products (F.U.)**	**Main Product**	2 550	Tonne	Market	200
		Biowaste	By-Product	4 950	Tonne	IS-Biogas Plant	2.5
		Wastewater	By-Product	30 000	Tonne	IS-WWTP	-
	Energy	-	-	-	GWh		-

2.2.1.4 Plastic Recycling

It was assumed that fishing boats delivering nets and other wastes from the sea, also delivered fish (main products of these systems). It was assumed that these boats supply the Marenor operations with herring and other fish. It was assumed that only those boats supplying fish to the aforementioned firm provide all the recycled sea wastes. Wastes were assumed to replace mixed plastics and steel.

Table 4: Inputs and Outputs for FF Norden

FF Norden							
		Flow	**Origin/ Class.**	**Amount**	**Unit**	**Use/ Destination**	**Transp.**
Inputs	Material	Fish	Fishing	5 000	Tonne	-	200
Outputs	Material	Herring	Main Product	2 500	Tonne	IS-Leroy	2.5
		Other Fish	Main Product	2 500	Tonne	IS-Leroy	2.5
		Mixed Plastic	By-Product	29	Tonne	Market	100
		Mixed Metals	By-Product	5.4	Tonne	Market	100

2.2.1.5 Algae

Information on algae production was obtained from Swedish Algae Factory (2017). Other information on nutrient demands for algae production (diatoms) were obtained from Shavalieva (2016) and Kaal (2017).

Table 5: Inputs and Outputs for Swedish Algae Factory

Swedish Algae Factory							
		Flow	**Origin/ Class.**	**Amount**	**Unit**	**Use/ Destination**	**Transp.**
Inputs	Material	Nutrient Rich Wastewater	Input Symbiosis (Smögenlax)	240	Tonne	-	2.5
	Energy	Electricity	Energy	0.0037	GWh	-	-
		Heat	Energy	0.0004	GWh	-	-
Outputs	Material	**Silicon (F.U.)**	**Main Product**	**1.1**	**Tonne**	**Market**	100
		Biomass	By-Product	7.7	Tonne	Market	100
		Organic Fraction	By-Product	6.6	Tonne	Market	100
		Lipids	By-Product	1.3	Tonne	Market	100
		Wastewater	By-Product	240	m^3	IS-WWTP	-
	Energy	-	-	-	-	-	-

2.3 Crediting Firms for Synergies

Following the approach outlined in Martin et al (2015), credits and impacts were allocated to firms exchanging material and energy. Figure 5 below provides a review of the exchanges, credits (shown as "avoided" products and processes) and allocated impacts.

Furthermore, as shown, the Functional Unit (F.U.) of the system is shown with dark arrows leaving the system boundary. This includes the collected output of fish products from the Fish Industry cluster, electricity from the biogas plant, wastewater output, salmon from the salmon farming operations and raw material input for silicon production from the algae farm.

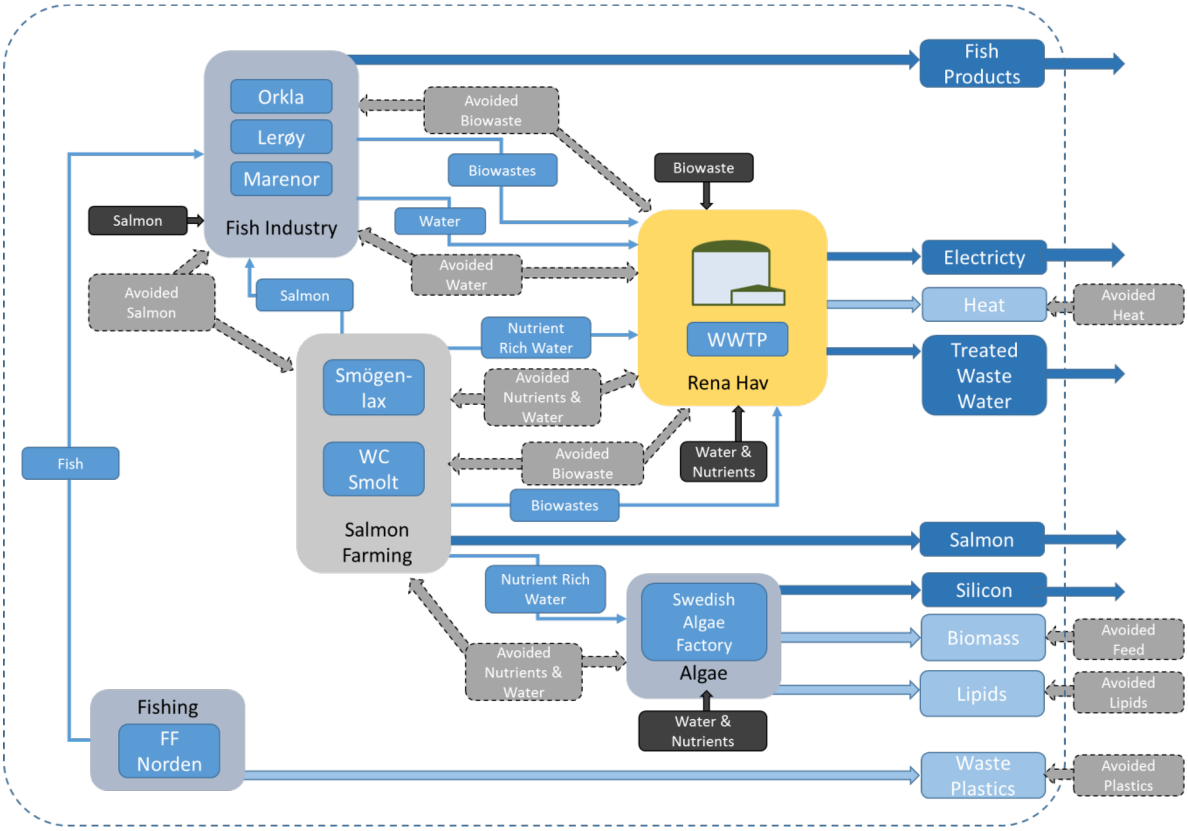

Figure 5: System description reviewing input and outputs out of the different clusters of firms. The dashed boundary represents the system boundary of the study. Other boxes and arrows denote main outputs (dark blue arrows out of the boundary), avoided products and processes (gray dashed boxes and arrows), by-products (light blue boxes), applied impacts (dark gray boxes and arrows) and exchanges (thin blue arrows).

Again, using the aforementioned approach, firms providing a product, utility or process receives a credit for the exchange. Firms on the receiving end however, receive both a credit and an impact (or burden) for the exchange so as not to receive a product with negative impacts. As such, the overall burden is only half that of the conventional input used.

2.4 Reference Scenario

The reference system was chosen to review a system of similar function using conventional processes with no symbiotic links between the different firms. In order to do so, the outputs were set equivalent to the Functional IS scenario. Conventional processes were modelled instead of the current innovative systems. For example, data for traditional salmon farming in off shore systems were used instead of land-based recirculating systems. Using information from current waste handling of fish wastes, the reference scenario also included shipping of fish wastes roughly 250 km to biogas plants outside the region. In the reference scenario the wastewater from the fish processing firms was also assumed to be processed through a basic WWTP plants and thereafter released to the sea (as it is currently done). Data for the nutrient content within this wastewater was developed from Rena Hav (2014) and Smögenlax (2015).

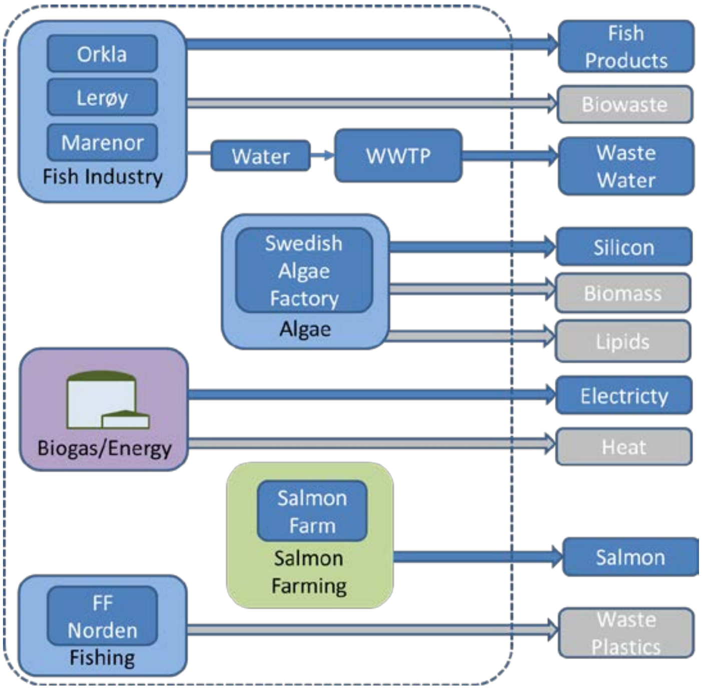

Figure 6: Review of the separate clusters (with no synergies) in the reference scenario.

For the reference system, it was assumed that a biogas plant would operate without synergies with neighboring firms and relies on import of substrates from outside the region and delivering digestate to farms outside the region. Sensitivity to data choices and reference scenario selection are also outlined in the analysis in subsequent text. See also the Appendix for a review of the inputs and outputs for the Reference system.

2.5 LCI Data

In order to model the environmental impacts of the system, life cycle inventory (LCI) data was primarily developed based on datasets provided in the LCI database Ecoinvent v. 3.3. Other datasets were also used to develop the flows or material and energy for the different firms; details are outlined in Table 6 and in the Appendix.

Table 6: LCI data review

Flow	Name	Reference
Electricity	market for electricity, medium voltage | electricity, medium voltage	Ecoinvent (2015)
Heat	heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 | heat, district or industrial, other than natural	Ecoinvent (2015)
Herring	Herring	Buchsspies (2010)
Whitefish	Whitefish	Buchsspies (2010)
Anchovies	Herring	Buchsspies (2010)
Salmon	Salmon	Buchsspies (2010)
Mackerel	Mackerel	Buchsspies (2010)
Mixed Plastics	market for waste plastic, mixture | waste plastic, mixture	Ecoinvent (2015)
Metal	market for steel, low-alloyed | steel, low-alloyed	Ecoinvent (2015)
Transport-Truck	Transport, freight, lorry 16-32 metric ton, EURO5	Ecoinvent (2015)
Transport-Fishing Vessel	transport, freight, inland waterways, barge with reefer, cooling | transport, freight, inland waterways, barge with reefer, cooling	Ecoinvent (2015)
Water	market for tap water | tap water	Ecoinvent (2015)
N-fertilizer	market for nitrogen fertiliser, as N	Ecoinvent (2015)
P-fertilizer	market for phosphate fertiliser, as P2O5	Ecoinvent (2015)
Biogas	treatment of biowaste by anaerobic digestion | biowaste	Ecoinvent (2015)
Packaging Plastic	market for packaging film, low density polyethylene | packaging film, low density polyethylene	Ecoinvent (2015)
Heat-Avoided	market for heat, district or industrial, natural gas | heat, district or industrial, natural gas	Ecoinvent (2015)
Lipid/Oil	market for vegetable oil, refined | vegetable oil, refined	Ecoinvent (2015)
Salmon Conventional (Ref 3)	Salmon, Norway	Pelletier et al. (2009)
Heat (Reference)	market for heat, district or industrial, natural gas | heat, district or industrial, natural gas	Ecoinvent (2015)
CHP-Electricity (Ref 2)	heat and power co-generation, natural gas, 1MW electrical, lean burn | electricity, high voltage	Ecoinvent (2015)
Fish Feed	Fish feed (Norway)	Pelletier et al. (2009)

3 Results and Analysis

Overall, the results suggest that there is a large benefit from the industrial symbiosis network due to reducing transportation, wastewater nutrient cascading and other synergies between the industries involved in the Sotenäs IS network. The following sections provide details of the impacts and benefits created.

3.1 Reviewing the Implications for the Symbiosis Network

The Sotenäs IS network can lead to a reduction of roughly 59 million kg CO_2-eq emissions through the sharing of resources. The largest reductions apparent stem from differences in the reference system for food and salmon farming cluster; i.e. changes in the inputs and outputs for food producers and the apparent emissions from the land based salmon production. In the Functional IS scenario, the largest GHG emissions derive from the food production, i.e. from the fish processing plants (which dominate inputs and outputs of the system). The next largest GHG emissions were from the salmon farming; see Figure 7.

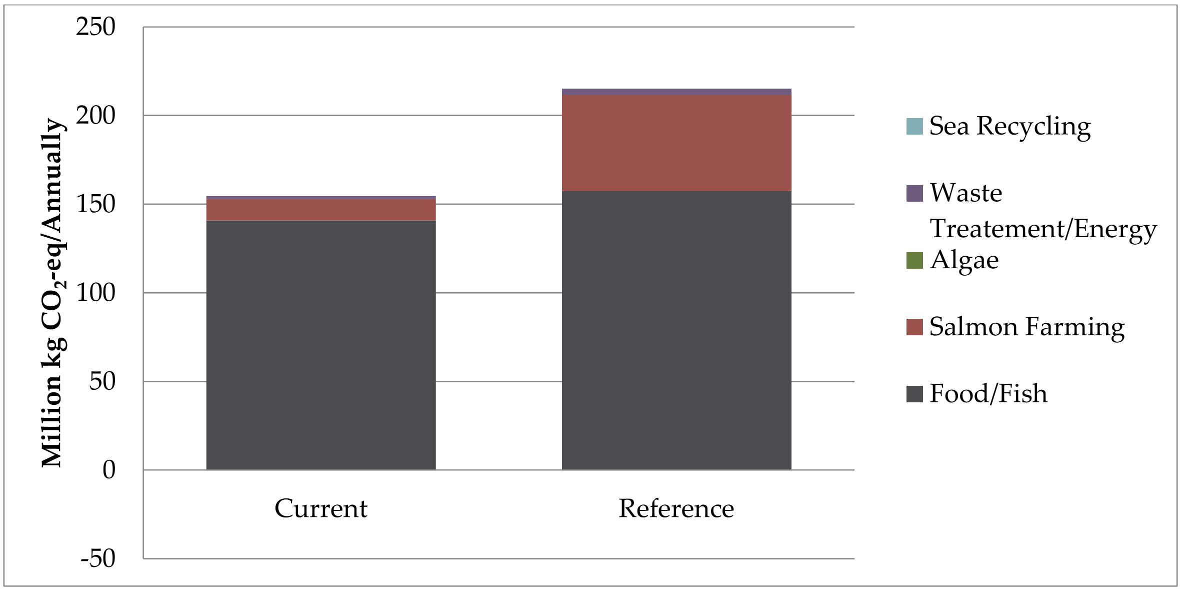

Figure 7: Comparison of the GHG emissions (measured in Million tonnes CO_2-eq annually) between the Functional IS and Reference scenarios.

When reviewing the eutrophication potential, once again the largest potential eutrophication impact reductions stem from the food and the salmon farming clusters. These are dominated by the food industry; see Figure 8.

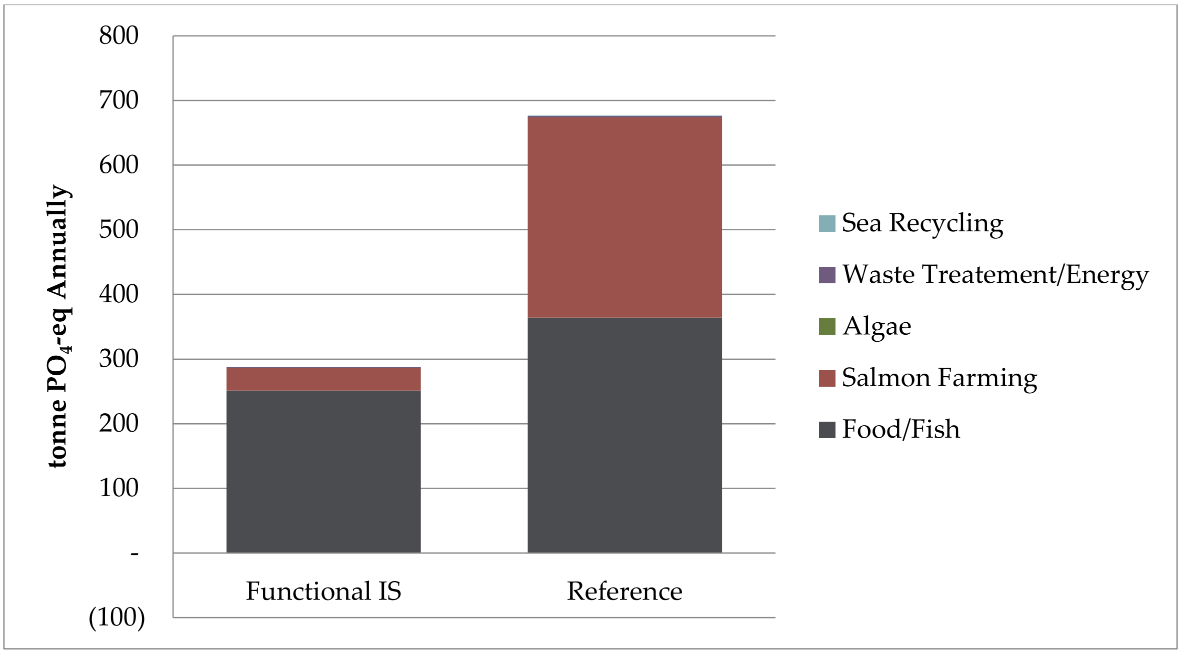

Figure 8: Comparison of the eutrophication impacts (measured in tonnes PO4-eq annually) between the Functional IS and Reference scenarios.

3.2 Symbiosis Benefits for Companies

Figure 9 below, outlines the impacts produced per company when comparing the Functional IS and Reference scenarios and the relative contribution to the overall impacts of each scenario. **Error! Reference source not found.** also illustrates that all companies within the IS network benefit from the exchanges in the network.

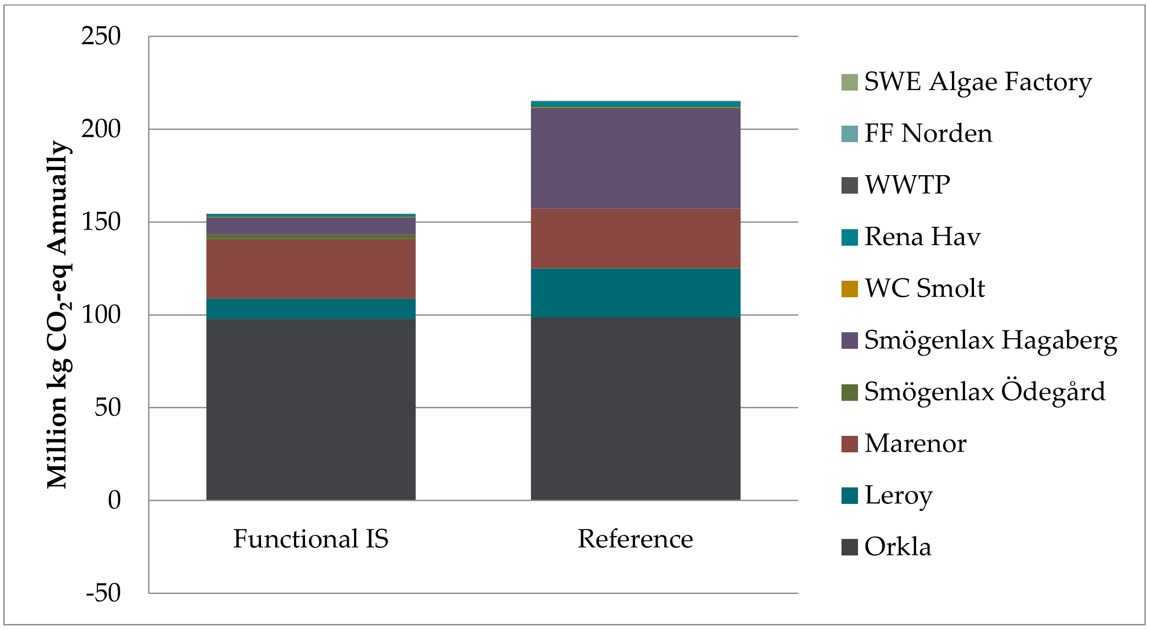

Figure 9: GHG emissions for different firms in the IS network, comparing the Functional IS and Reference scenarios (measured in Million kg CO2-eq annually)

As shown previously, the largest impacts from the system stem from the food/fish producers, i.e. Orkla, Leroy and Marenor. In the modelled system, Leroy has can be shown to have reduced impacts due in part to the reduction of conventional salmon inputs, i.e. by using salmon produced from Smögenlax. The other producers do not significantly reduce their impacts, due in large part to the significant impacts of the input fish; thus no large offsets from reduced transport despite significant impact reductions. The company with the largest impact reductions, when comparing the Functional IS and Reference scenario is the salmon production at Smögenlax Hagaberg. This is due primarily to the replacement of conventional salmon production. However, this assumption is also tested in a sensitivity analysis in subsequent text.

Similar to GHG emissions reviewed above, the largest reductions in potential eutrophication impacts come from reducing the production of conventional salmon; see Figure 10. This is apparent for both the Smögenlax and Leroy firms, where the conventional salmon is replaced by land-based salmon farming. Large reductions are also apparent for the food/fish producers, Orkla, Leroy and Marenor, due in large part to the reduction of direct emissions of wastewater to the sea.

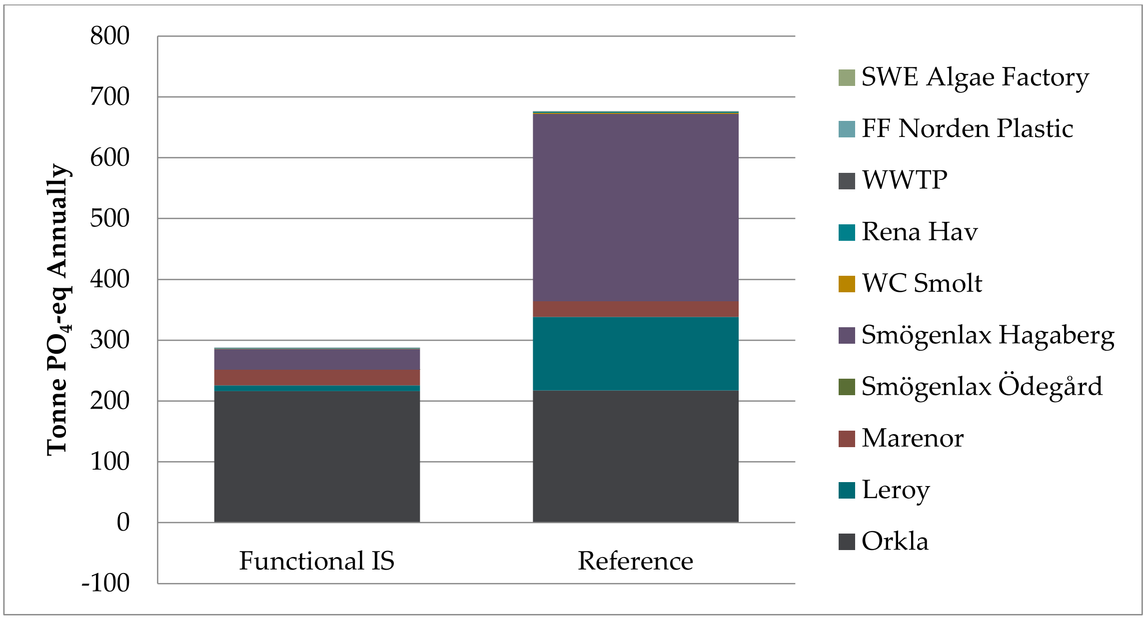

Figure 10: Eutrophication impacts for different firms in the IS network, comparing the Functional IS and Reference scenarios (measured in Tonnes PO4-eq annually)

3.3 Transportation

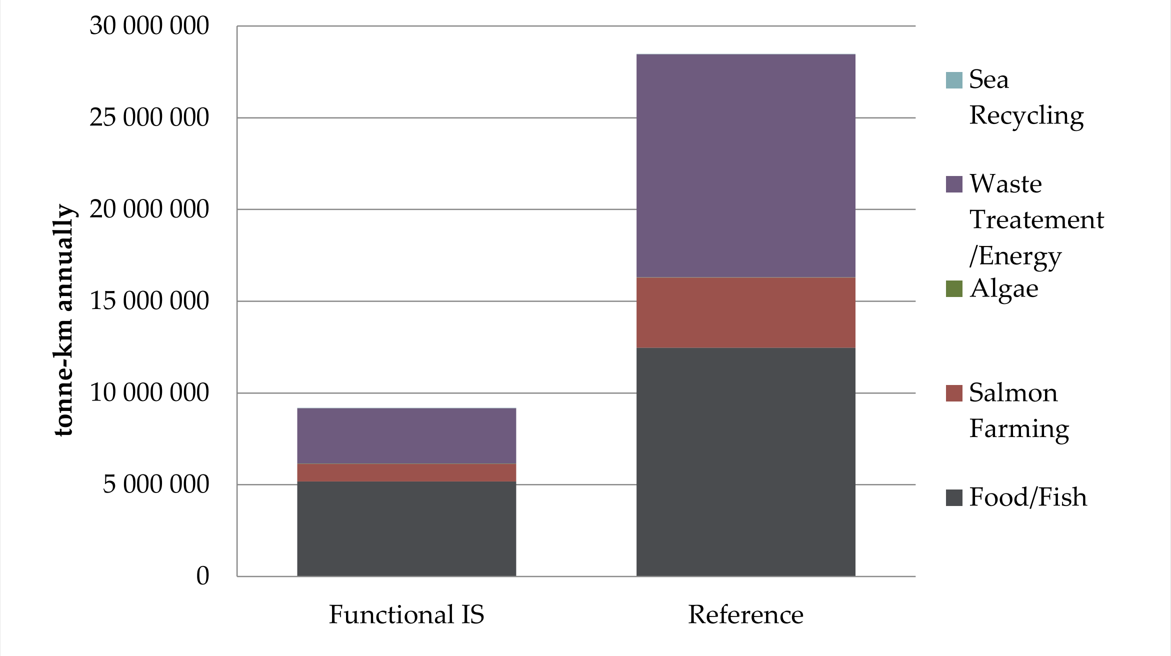

Figure 11: Transportation distances in the compared scenarios (measured in tonne-km annually)

As seen in Figure 11, large reductions in transportation are apparent for the food industry, the salmon farming cluster, biogas and WWTP plants. The largest reductions are seen for the fish processing industry; due primarily to the avoidance of extensive transportation of fish wastes to biogas plants outside of the network. Thereafter, the biogas plant can also significantly reduce the transportation of digestate and other substrates through the co-location (and agreements) with the fish processing industry and agricultural actors in the area. The salmon farming cluster may also significantly reduce transportation through the use of the fish wastes within the symbiotic network.

3.4 Sensitivity to Choice of Reference Scenario

In order to review the choice of reference system, the sensitivity to the biogas plant was tested labelled ‘Reference 2.’ In this case, it was assumed that a CHP plant was installed to produce an equivalent amount of electricity (main product) and heat. The sensitivity to this choice is shown in Table 7. This choice would have resulted in an increase of roughly 2 million kg CO_2-eq emissions annually and no change of PO_4 equivalent annually. As such, the choice did not significantly affect the impact of the reference system.

Table 7: Review of the overall impacts of the network for different reference system choices. Reference 2-using natural gas CHP instead of biogas production, Reference 3-testing of salmon production data for conventional offshore farmed salmon production.

	Functional IS	Reference	Reference 2	Reference 3
GHG Emissions (million kg CO_2-eq)	154	215	217	185
Eutrophication impacts (tonnes PO_4-eq)	287	676	676	583

There are significant differences in available data for salmon farming. In order to test the assumption this may have on the salmon farming outputs for the reference case, 'Reference 3' tests figures for salmon farming provided by Pelletier et al. (2009). It is apparent that the GHG emissions may be significantly reduced compared to the chosen reference system, nearly halving the potential benefit of the IS network. With this system, a significant reduction in GHG emissions (roughly 30 million kg CO_2-eq annually) are possible. Furthermore, there is a large reduction in eutrophication impacts of roughly 100 tonnes PO_4-eq annually when comparing the reference systems; thus stressing the importance of data choices in the reference system.

3.5 Impacts per Output Product

In this section, the impacts from the output (main products) are compared to comparable data in order to gauge the sensitivity to modelling choices. As there is a large range of fish products produced, and due to the limited availability of comparable data for algae production, only the data available for salmon farming and biogas production were reviewed.

3.5.1 Salmon Farming

Based on the model developed for salmon farming at Smögenlax, the impacts outlined for salmon farming (including smolt production in the cluster) are roughly 1.9 kg CO_2-eq per kg salmon (live weight). The results are slightly higher than a previous assessment from Shavalieva (2016), although they are comparable to data available from a d'Orbcastel et al. (2009) for land based salmon production and Pelletier et al. (2009) for offshore production, with a value of roughly 2 kg CO_2-eq per kg live weight salmon. The results are however slightly lower than findings from Liu et al. (2016) for salmon farming in the US, which outline an impact of roughly 4 kg CO_2-eq per kg salmon (head on and gutted). Despite the differences, the data (for GHG emissions) does not differ by more than 40%. Differences for eutrophication impacts were not compared as these were not available in the aforementioned studies for land based salmon production.

Table 8: Review of the impacts for salmon products

	Impact/kg salmon (live weight)	Impact/ kg salmon (head on and gutted)
GHG Emissions (kg CO_2-eq)	1.86	2.72
Eutrophication impacts (kg PO_4-eq)	0.005	0.08

3.5.2 Biogas

The table below outlines the emissions for the biogas production based on the model developed in this study for the Rena Hav plant. The data is equivalent with typical biogas output values outlined in e.g. Martin et al. (2017), Martin et al. (2011) and Börjesson et al. (2010), with biogas production emissions of roughly 20-30 g CO_2-eq/MJ. Accordingly, the biogas production, according to the Renewable Energy Directive (Commission, 2009) guidelines, equates to a reduction in GHG emissions of roughly 75%. However, as the current system both credits and allocates burdens to the biogas plant for the use of waste material, it may overestimate the impacts. Following e.g. the Renewable Energy Directive guidelines for energy production from renewable sources, may lead to reduced impacts from the biogas plant, due to the fact that the substrates may be classified as wastes; and thus carry zero burden.

Table 9: Review of the impacts for biogas output

Emission	Impact/m^3 biogas	Impact/MJ biogas
GHG Emissions (g CO_2-eq)	770.8	21.9
Eutrophication impacts (g PO_4-eq)	0.68	0.02

4 Discussion

4.1 Benefits of the symbiotic network

The industrial symbiosis network at Sotenäs has the potential to reduce global warming impacts and eutrophication impacts through synergistic exchanges between the firms in the network. Previous studies also find similar results, although many of these assessments focus only on GHG emissions or resource savings (Chertow and Lombardi, 2005; Martin, 2015; Sokka et al., 2011).

In this study, the value of cascading nutrients and wastewater were reviewed; and ultimately the potential eutrophication benefits this may have. Studies as such are rare in the industrial symbiosis literature, and this study thus provides a new addition to studies focusing on the water resource demand. While dissimilar to other industrial symbiosis networks, the benefit of the biogas system in this study concurs with previous studies (see e.g. Martin and Eklund, 2012), where the biogas plant acts as an upcycling tenant to allow for more effective waste treatment of biowastes and nutrient recycling. Martin and Parsapour (2012) also review the potential for valorizing, and subsequently cascading, materials and nutrients through biogas production.

This study suggests that the choice of reference system is important for reviewing the potential impacts and benefits of changes (or development) of the IS network. As aforementioned, these results coincide with the assertions of Martin et al (2015) and Mattila et al. (2012) and van Berkel (2010). In this study, similar to any life cycle assessment study, the data employed for the reference system also played a significant role. Using the data available in Buchspies et al. (2011) has significantly higher emissions compared to that of Pelletier et al. (2009). Consequently, the emissions from the references system using the former dataset led to offshore salmon farming with higher impacts, both with regards to GHG emissions and potential eutrophication impacts; and subsequently larger benefits to the system with such reference system choices. Nonetheless, the environmental benefits from the Sotenäs IS network were still extensive.

4.2 Extending the Environmental Assessments

As the Sotenäs IS network is located a short distance from the sea, it is imperative that the benefits of the network be further reviewed. This includes reviewing other impact categories to assess the implications of the work done by firms in the Sotenäs Symbioscentrum in recycling of different wastes along the coast. This can have important implications for wildlife, and thus biodiversity damage should be further reviewed.

Furthermore, the production of salmon in land-based systems has been shown to reduce eutrophication impacts which is important in a Swedish context (Emmelin and Cherp, 2016; Swedish Environmental Objectives, 2008). Other studies also suggest that conventional salmon farming increases the risk of contamination of bacteria to natural stocks of fish and other impacts to the environment (Buschmann et al., 2009; Naylor et al., 1998; Noakes et al., 2000). Thus, it will be important to further review the reduction of these impacts and pathogens to the environment and natural stocks in the area.

As suggested in Martin and Brandão (2017) and Lazarevic and Martin (2016), it may also be important that local impacts are reviewed in accordance to regional specific impact assessment methods. Coastal areas such as the Sotenäs region coast, with large releases of wastewater from the fish industry, households, etc. may not be assessed with current LCIA methodology for e.g. eutrophication impacts. Again, the biodiversity damage from current emissions (and benefits of cleaning up wastes) may also need to take into account resilience of the system based on current stocks of fish, etc.

As the system will be developed in the future, the assessment would be further improved using full consequential LCA methodology to also show the consequences of the changes in the surrounding systems. This includes using marginal data for any increases (or changes) in current demand for energy and resources (Brandao et al, 2016). Once again, this study has been conducted using partial consequential methodology (i.e. system expansion based on the method of Martin et al. (2015). However, both "upstream" and "downstream" consequences of changes in demand for products, energy, resources etc. due to the development, and expansion, of the network may also be explored; see e.g. the discussions by (Sokka et al., 2011). Despite this suggestion, the current study aimed only to review the environmental impacts and benefits of the symbiosis network compared to a reference state, and not the effects on other systems.

4.3 Future Improvements

The current study was completed using a limited amount of data and information, thus requiring many assumptions and modelling choices. In future assessments, the approach used in this report may be improved by following up on the actual material and energy inputs and outputs from the system in the near future (given the synergies progress) to provide a more representative view of the environmental performance of the industries involved.

Furthermore, while the assessments build upon synergies currently being developed, it may be important to explore further synergies (and even changes) in order to optimize the system. For example, in a Swedish context, it may be interesting to explore the upgrading of the biogas for vehicle fuel once the biogas plant is developed further. The use of algae for different applications, e.g. fish feed, nutritional supplements and substrate may also offer many potential improvements to the system. In addition, the use of algae and other fish wastes (from e.g. the fish/food cluster) could provide many opportunities for developing an alternative fish feed for the salmon farming operation. Heat produced from the biogas plant was also assumed to be used outside of the network. As many of the current firms, and coming additions to the network, require heat for different processes, the extent and potential use of this heat should be explored further.

5 Conclusions

The Sotenäs Industrial Symbiosis Network has the potential to significantly reduce environmental impacts for the production system currently being developed, when compared to conventional processes and a reference system. These include both reductions in greenhouse gas emissions and local impacts, namely eutrophication impacts. The largest improvements are seen for the land based salmon system, which significantly reduces impacts from conventional salmon farming. Thereafter, the benefits created for the fish industry, by handling wastes and wastewater (used in the biogas plant) are also significant. Furthermore, using the approach of Martin et al. (2015), it has been illustrated that all firms within the network benefit from the sharing of resources and energy, thus highlighting the importance of the IS network for improving the performance of the firms involved and the products being produced.

It is also important to note the significance of the nutrient recycling of the network. As the network will have an upcycling tenant, namely the biogas plant, wastewater and residues will be valorized and nutrients captured. This reduces both the use of conventional fertilizers in downstream processes and the release of these nutrients into the neighboring sea. With Sotenäs being a fishing community, the symbiotic network thus improves the use of sea-based resources and reduces the potential impacts to the aquatic and natural environment.

The study has also reviewed the significance of methodological choices. Of utmost importance is the choice of the reference scenario; which can influence the benefits of the system. Nonetheless, even using conventional, and fossil, inputs in the reference systems, the symbiotic network still led to large benefits for both greenhouse gas emissions and eutrophication impacts.

Finally, as the study compares a potential future system with a comparative reference system, and is based on a number of assumptions and data from comparative systems (due to a lack of data) the results should not be used as the actual emissions, or reduction potential, of the system. Once again however, the results provide an indication of the potential reductions in GHG emissions and eutrophication emissions from the symbiotic development of the network.

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Appendix

Appendix 1-Reference System Values

Appendix Table 1: Inputs and Outputs for the Reference System Salmon Farming Cluster

Salmon Farming							
		Flow	**Origin/ Class.**	**Amount**	**Unit**	**Use/ Destination**	**Transp.**
Inputs	Material	Smolt	Input Symbiosis (WC Smolt)	184	Tonne	-	200
		Fish Feed	-	7 140	Tonne	-	100
		Plastic Packaging	-	13	Tonne	-	100
	Energy	Electricity	Energy	2.0	GWh	-	-
Outputs	Material	**Salmon Live Weight (F.U.)**	**Main Product**	**6 500**	**Tonne**	**Market**	**200**
		Fish Wastes (Process)	By-Product	6 010	Tonne		250
		Slam Fesces	By-Product	2 140	Tonne		250
Smolt Production							
		Flow	**Origin/ Class.**	**Amount**	**Unit**	**Use/ Destination**	**Transp.**
Inputs	Material	Roe		0.35	Tonne	-	2 130
		Fodder	Fishing/Agriculture	202	Tonne	-	100
		Water	Groundwater	530	Tonne	-	-
		Plastic	-	2.0	Tonne	-	100
	Energy	Electricity	Energy	2.0	GWh	-	-
		Heat	Energy	-	GWh	-	-
Outputs	Material	**Smolt**	**Main Product**	**184**	**Tonne**	Salmon Farm	**5**
		Biowaste	By-Product	7.0	Tonne	-	250
		Fecal wastes	By-Product	54	Tonne	-	250
		Wastewater	By-Product	530	Tonne	-	-

Appendix Table 2: Inputs and Outputs for the Reference System Food Cluster

Orkla							
		Flow	**Origin/ Class.**	**Amount**	**Unit**	**Use/ Destination**	**Transp.**
Inputs	Material	Herring	Fishing	6 500	Tonne	-	50
		Roe	Fishing	1 300	Tonne	-	50
		Anchovies	Fishing	3 300	Tonne	-	50
		Whitefish	Fishing	1 700	Tonne	-	50
		Mackerel	Fishing	10 200	Tonne	-	50
	Energy	Electricity	Energy	9.0	GWh		-
		Heat	Energy	-	-	-	-
Outputs	Material	**Fish Products (F.U)**	**Main Product**	**10 200**	**Tonne**	**Market**	**200**
		Fish Wastes	By-Product	19 800	Tonne	Biogas Plant	250
		Wastewater	By-Product	115 000	m3	WWTP	-
	Energy	-	-	-	-	-	-
Leroy							
		Flow	**Origin/ Class.**	**Amount**	**Unit**	**Use/ Destination**	**Transp.**
Inputs	Material	Salmon	Fishing	2 400	Tonne	-	50
		Other Fish	Fishing	1 200	Tonne	-	50
		Crustasceans	Fishing	1 200	Tonne	-	50
	Energy	Electricity	Energy	2.0	GWh	-	-
		Heat	Energy	-	-	-	-
Outputs	Material	**Fish Products (F.U.)**	**Main Product**	**1 600**	**Tonne**	**Market**	**200**
		Fish Wastes	By-Product	3 110	Tonne	Biogas Plant	250
		Wastewater	By-Product	115 000	Tonne	WWTP	-
	Energy	-	-	-	-	-	-
Marenor							
		Flow	**Origin/ Class.**	**Amount**	**Unit**	**Use/ Destination**	**Transp.**
Inputs	Material	Cod	Fishing	2 500	Tonne	-	400
		Herring	Fishing	2 500	Tonne	-	50
		Other Fish	Fishing	2 500	Tonne	-	50
	Energy	Electricity	Energy	3	GWh	-	-
		Heat	Energy	-	GWh	-	-
Outputs	Material	**Fish Products (F.U.)**	**Main Product**	**2 550**	**Tonne**	**Market**	**200**
		Biowaste	By-Product	4 950	Tonne	Biogas Plant	250
		Wastewater	By-Product	-	Tonne	WWTP	-
	Energy	-	-	-	-		-

Appendix Table 3: Inputs and Outputs for the Reference System Biogas-Energy Cluster

Biogas-Energy Plant							
		Flow	**Origin/ Class.**	**Amount**	**Unit**	**Use/ Destination**	**Transp.**
Inputs	Material	Biowaste	-	30 800	Tonne	-	200
	Energy	Electricity	Energy	2.1	GWh	-	-
		Heat	Energy	1.3	GWh	-	-
Outputs	Material	Biofertilizer	By-Product	30 000	Tonne	Market	200
		Methane Slip	By-Product	12 400	kg	-	-
	Energy	**Electricity (F.U.)**	**Main Product**	**7.5**	**GWh**	**Market**	**-**
		Heat	By-Product	9.4	GWh	District Heat	-
WWTP							
		Flow	**Origin/ Class.**	**Amount**	**Unit**	**Use/ Destination**	**Transp.**
Inputs	Material	WW Orkla	-	55 000	m^3	-	-
		WW Leroy	-	55 000	m^3		-
	Energy	Electricity	Energy	-	GWh	-	-
Outputs	Material	**Treated Wastewater (F.U.)**	**Main Product**	**110 000**	**m^3**	**-**	**-**
	Energy	-	-	-	GWh		-

Appendix Table 4: Inputs and Outputs for the Reference System Algae Cluster

Algae							
		Flow	**Origin/ Class.**	**Amount**	**Unit**	**Use/Destination**	**Transp.**
Inputs	Material	Process Water	-	240	Tonne	-	-
		Nutrients (N)	-	0.45	Tonne	-	100
		Nutrients (P)	-	0.09	Tonne	-	100
	Energy	Electricity	Energy	0.0037	GWh	-	-
		Heat	Energy	0.0004	GWh	-	-
Outputs	Material	**Silicon (F.U.)**	**Main Product**	**1.1**	**Tonne**	**Market**	**200**
		Biomass	By-Product	7.7	Tonne	Market	200
		Organic Fraction	By-Product	6.6	Tonne	Market	200
		Lipids	By-Product	1.3	Tonne	Market	200
		Wastewater	By-Product	240	m^3	-	-
	Energy	-	-	-	-	-	-

Appendix Table 5: Inputs and Outputs for the Reference System Fishing

FF Norden							
		Flow	**Origin/**	**Amount**	**Unit**	**Use/Destination**	**Transp.**
Inputs	Material	Fishing (Herring/Other)	-	5 000	Tonne	-	200
Outputs	Material	Other Fish	-	2 500	Tonne	Market	5
		Herring	-	2 500	Tonne	Market	5

Appendix 2-Results

Appendix Table 6: Review of GHG emissions for the different scenarios and firms (Measured in kg CO_2-eq)

Firm	Flow	Functional IS	Reference	Reference 2	Reference 3
		(kg CO_2 eq)	*(kg CO_2 eq)*	*(kg CO_2 eq)*	*(kg CO_2 eq)*
Orkla	**Inputs**	9.76E+07	9.76E+07	9.76E+07	9.76E+07
	Outputs	0.00E+00	6.51E+04	6.51E+04	6.51E+04
	Transport	3.35E+05	1.19E+06	1.19E+06	1.19E+06
	Replaced-In	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Replaced-Out	-5.99E+04	-1.19E+05	-1.19E+05	-1.19E+05
Leroy	**Inputs**	*1.07E+07*	2.60E+07	2.60E+07	2.60E+07
	Outputs	*0.00E+00*	6.51E+04	6.51E+04	6.51E+04
	Transport	*5.36E+04*	1.87E+05	1.87E+05	1.87E+05
	Replaced-In	*3.25E+03*	0.00E+00	0.00E+00	0.00E+00
	Replaced-Out	*-2.76E+02*	-5.52E+02	-5.52E+02	-5.52E+02
Marenor	**Inputs**	3.19E+07	3.19E+07	3.19E+07	3.19E+07
	Outputs	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Transport	2.51E+05	4.68E+05	4.68E+05	4.73E+05
	Replaced-In	3.70E+03	0.00E+00	0.00E+00	0.00E+00
	Replaced-Out	-2.76E+02	-5.52E+02	-5.52E+02	-5.52E+02
Rena Hav	**Inputs**	1.18E+05	2.58E+05	0.00E+00	2.58E+05
	Outputs	9.50E+05	9.50E+05	4.53E+06	9.50E+05
	Transport	4.96E+05	2.07E+06	0.00E+00	2.07E+06
	Replaced-In	6.31E+03	0.00E+00	0.00E+00	0.00E+00
	Replaced-Out	-1.19E+05	-1.19E+05	-1.19E+05	-1.19E+05
WWTP	**Inputs**	0.00E+00	6.23E+04	6.23E+04	6.23E+04
	Outputs	1.29E+05	6.23E+04	6.23E+04	6.23E+04
	Transport	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Replaced-In	5.30E-01	0.00E+00	0.00E+00	0.00E+00
	Replaced-Out	-7.34E+00	0.00E+00	0.00E+00	0.00E+00
Smögenlax Odegård	**Inputs**	2.35E+06	0.00E+00	0.00E+00	0.00E+00
	Outputs	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Transport	7.74E+03	0.00E+00	0.00E+00	0.00E+00
	Replaced-In	5.72E-01	0.00E+00	0.00E+00	0.00E+00
	Replaced-Out	-5.53E+02	-2.31E+03	-2.31E+03	-2.31E+03
Smögenlax Hagaberg	**Inputs**	9.30E+06	1.13E+07	1.13E+07	1.13E+07
	Outputs	0.00E+00	4.22E+07	4.22E+07	1.16E+07
	Transport	2.92E+04	5.24E+05	8.72E+05	8.72E+05

	Replaced-In	5.72E-01	0.00E+00	0.00E+00	0.00E+00
	Replaced-Out	-5.53E+02	-1.11E+03	-1.11E+03	-1.11E+03
WC Smolt	**Inputs**	4.14E+05	4.18E+05	4.18E+05	4.18E+05
	Outputs	2.10E+02	5.10E+02	5.10E+02	5.10E+02
	Transport	1.06E+03	2.78E+03	5.36E+03	5.36E+03
	Replaced-In	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Replaced-Out	-5.53E+02	-1.10E+03	-1.10E+03	-1.10E+03
SWE Algae Factory	**Inputs**	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Outputs	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Transport	3.71E+02	5.77E+02	5.68E+02	5.68E+02
	Replaced-In	1.33E-01	0.00E+00	0.00E+00	0.00E+00
	Replaced-Out	-3.49E+03	-3.49E+03	-3.49E+03	-3.49E+03
FF Norden	**Inputs**	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Outputs	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Transport	2.61E+03	4.26E+03	1.71E+05	1.71E+05
	Replaced-In	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Replaced-Out	-7.55E+03	0.00E+00	0.00E+00	0.00E+00
Total kg CO_2-eq		***154 440 603***	***215 136 943***	***216 904 625***	***185 073 154***

Appendix Table 7: Review of eutrophication impacts for the different scenarios and firms (Measured in kg PO_4-eq)

Firm	Flow	Functional IS	Reference	Reference 2	Reference 3
		(kg PO_4-eq)	*(kg PO_4-eq)*	*(kg PO_4-eq)*	*(kg PO_4-eq)*
Orkla	**Inputs**	2.16E+05	2.16E+05	2.16E+05	2.16E+05
	Outputs	0.00E+00	8.19E+00	8.19E+00	8.19E+00
	Transport	2.46E+02	8.39E+02	8.39E+02	8.39E+02
	Replaced-In	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Replaced-Out	-1.73E+01	-4.20E-01	-4.20E-01	-4.20E-01
Leroy	**Inputs**	*9.18E+03*	1.21E+05	1.21E+05	2.86E+04
	Outputs	*0.00E+00*	8.22E+00	8.22E+00	8.22E+00
	Transport	*3.93E+01*	1.32E+02	1.32E+02	1.32E+02
	Replaced-In	*2.45E+01*	0.00E+00	0.00E+00	0.00E+00
	Replaced-Out	*-1.05E-01*	-2.10E-01	-2.10E-01	-2.10E-01
Marenor	**Inputs**	2.54E+04	2.54E+04	2.54E+04	2.54E+04
	Outputs	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Transport	1.84E+02	3.30E+02	3.30E+02	3.33E+02
	Replaced-In	2.39E+00	0.00E+00	0.00E+00	0.00E+00
	Replaced-Out	-1.05E-01	-2.10E-01	-2.10E-01	-2.10E-01
Rena Hav	**Inputs**	2.83E+02	2.33E+02	0.00E+00	2.33E+02
	Outputs	6.40E+02	6.40E+02	1.74E+03	0.00E+00
	Transport	3.64E+02	1.46E+03	0.00E+00	1.46E+03
	Replaced-In	3.72E+01	0.00E+00	0.00E+00	0.00E+00
	Replaced-Out	-3.49E+01	-4.94E-02	-4.94E-02	-4.94E-02
WWTP	**Inputs**	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Outputs	8.86E+00	4.27E+00	4.27E+00	4.27E+00
	Transport	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Replaced-In	9.44E-04	0.00E+00	0.00E+00	0.00E+00
	Replaced-Out	-1.26E-02	0.00E+00	0.00E+00	0.00E+00
Smögenlax Ödegård	**Inputs**	3.03E+02	0.00E+00	0.00E+00	0.00E+00
	Outputs	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Transport	5.68E+00	0.00E+00	0.00E+00	0.00E+00
	Replaced-In	2.48E-03	0.00E+00	0.00E+00	0.00E+00
	Replaced-Out	-2.10E-01	0.00E+00	0.00E+00	0.00E+00
Smögenlax Hagabеrg	**Inputs**	3.42E+04	4.16E+04	4.16E+04	4.16E+04
	Outputs	1.41E+00	2.66E+05	2.66E+05	2.66E+05
	Transport	2.14E+01	3.69E+02	6.13E+02	6.13E+02
	Replaced-In	2.48E-03	0.00E+00	0.00E+00	0.00E+00
	Replaced-Out	-2.10E-01	-4.20E-01	-4.20E-01	-4.20E-01
WC Smolt	**Inputs**	1.79E+02	1.36E+03	1.36E+03	1.36E+03
	Outputs	9.10E-01	1.28E-02	1.28E-02	1.28E-02
	Transport	7.60E-01	2.01E+00	3.83E+00	3.74E+00
	Replaced-In	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Replaced-Out	-2.10E-01	-4.20E-01	-4.20E-01	-4.20E-01
SWE Algae Factory	**Inputs**	0.0E+00	0.0E+00	0.00E+00	0.00E+00
	Outputs	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Transport	2.72E-01	4.06E-01	4.00E-01	4.00E-01
	Replaced-In	2.36E-04	0.00E+00	0.00E+00	0.00E+00
	Replaced-Out	-1.58E+01	-1.58E+01	-1.58E+01	-1.58E+01
FF Norden	**Inputs**	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Outputs	0.00E+00	0.00E+00	0.00E+00	0.00E+00

	Transport	1.91E+00	3.00E+00	1.20E+02	1.20E+02
	Replaced-In	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Replaced-Out	-8.33E+00	0.00E+00	0.00E+00	0.00E+00
TOTAL kg PO_4-eq		***287 378***	***676 069***	***675 836***	***583 216***

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