A CRADLE-TO-GATE LIFE CYCLE ASSESSMENT OF AN INDUSTRY CLUSTER OF FIVE CHEMICAL COMPANIES

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ABSTRACT

This paper presents a cradle-to-gate life cycle assessment of an industry cluster in Sweden, consisting of five chemical companies. The purpose of the study is to quantify the upstream and onsite environmental impacts, and to identify environmental hot spots in the system. The results show that upstream processes account for higher environmental impacts in all environmental impact categories than onsite processes. A few of the incoming streams account for a large proportion of the environmental impacts compared to their share of total incoming weight, and should therefore be the subject of future emission reduction strategies.

INTRODUCTION

The industrial cluster in our study consists of the chemical companies AGA, AkzoNobel, Borealis, INEOS and Perstorp, and is situated in Stenungsund, Sweden. The companies produce a variety of products, such as chemicals, plastics, gases and fuels. They also interact strongly with each other in terms of material exchange: energy integration however is still limited. The heart of the cluster is the Borealis steam cracker plant which supplies the companies with raw materials. The cluster is accounting for ~5 % of Sweden's total fossil fuel usage (mainly feedstock), and is a major emitter of fossil CO_2.

The companies are working towards a common sustainability goal to 2030: that the cluster should be based mainly on biogenic feedstock and renewable energy. In order to evaluate the environmental implications of this and other strategies, assessing the environmental impacts of the current system is crucial for comparing environmental advantages and drawbacks.

Life cycle assessments on industrial clusters remain scarce (Dong et al., 2013; Tian et al., 2013) but the method has previously been successfully applied in such studies (Liu et al., 2011).

METHOD

Our approach is to study the cluster as a unit in the foreground system. The background system consists of those flows going into and coming out from the cluster. The functional unit of the study is the total production of the system within the year 2011.

The assessment is a cradle to gate study, covering all life cycle activities associated with the extraction, handling and processing of raw materials and energy inputs to the cluster, and production processes within the cluster. The manufacturing of production equipment, buildings and other capital goods is not included, in agreement with (Chen et al., 2013) and (Bösch et al., 2007). Transportation of incoming stream to the cluster is not included, but will be included at a later stage. The great amount of incoming raw material streams requires some cut-off, but less than 5 % has been excluded.

The data is site specific for the processes within the cluster, and generic (collected from databases) for the raw materials supplied to the cluster. 80 % of the data was collected from Ecoinvent and Plastics Europe, while 20 % was collected from AkzoNobel's own database. The site specific data are for 2011. For one of the companies, data was not available. Since this company is estimated to have a small share of the total impact of the cluster, and also only to a limited extent will be affected by future changes, the company was still included and data was estimated based on 2010 data and input and output flows from the other companies. The electricity mix is a self-modeled mix for the companies reporting having a specific deal with the energy company, or Nordic mix if electricity was bought from the spot market.

The following environmental impact categories are relevant for the study (EPD®, 2012) and are included: global warming potential (GWP), abiotic depletion (AD) , acidification potential (AP), ozone-depletion potential (ODP), ground level ozone creation potential (POCP) and eutrophication potential (EP). The impact assessment was carried out according to the CML 2001 method.

RESULTS

Table 1 presents the results from the LCA in absolute value for the different impact categories and in percentage distribution for inflows to the industry cluster and on site impacts.

Table 1 Results from characterization and relative contribution per subsystem.

Category	*Unit*	*Total value*	*Upstream (%)*	*Onsite (%)*
GWP	kg $CO_{2\ eq}$	$2.36*10^9$	60 %	40 %
AD	kg Sb_{eq}	$4.06*10^7$	100 %	N/A
AP	kg $SO_{2\ eq}$	$1.09*10^7$	96 %	4 %
ODP	kg R-11 $_{eq}$	475	100 %	0 %
POCP	kg $C_2H_{4\ eq}$	$2.16*10^6$	58 %	42 %

EP	kg $PO_4^{-3}{}_{eq}$	$3{,}08*10^6$	97 %	3 %

A recent carbon footprint study on an industrial park shows similar results with regards to distribution of greenhouse gases, with ~55 % upstream and ~45 % onsite (Dong, et al., 2013). Onsite greenhouse gas emissions of the Stenungsund cluster correspond to 1.5 % of the total 61.4 mill ton emissions of greenhouse gases in Sweden in 2011 (Naturvårdsverket, 2013).

GWP and POCP are the environmental impact categories with the largest onsite shares (40 % and 42 % respectively), indicating that combustion of fuels in the cluster play a significant role. Apart from that, production of the incoming streams has the largest environmental impact contribution. Table 2 demonstrates the contribution of those streams with the highest contribution, in comparison with their relative share of the weight of the total of incoming flows.

Table 2 Contribution to emission categories from those materials and energy inflows to the cluster with the largest environmental impact contribution, relative to their share of the weight of total incoming flows.

Inflows to the cluster	*Share of upstream flow (in %)*	*Share of total emissions (in %)*					
		GWP	*AD*	*AP*	*ODP*	*POCP*	*EP*
Ethane, propane and butane	40.5	24	57	53	93	38	57
Naphtha	13.1	5	17	6	0	4	2
Natural gas	5.1	3	7	1	0	>1	>1
Rape oil	4.8	6	1	19	>1	>1	22
Ethylene	4.6	6	8	4	0	3	1
Vinyl chloride	2.4	3	2	1	>1	>1	>1
Ammonia	1.3	3	1	>1	0	>1	>1
Bio-ethanol	0.5	1	>1	2	>1	>1	4

DISCUSSION

Conducting a cradle-to-gate LCA of a chemical industry cluster has been proven feasible. The way industrial clusters are constructed provides both advantages and challenges when conducting an LCA. An advantage is that interactions between the companies in terms of material exchange makes it possible to complement missing data and ensure data quality. A challenge is the complexity of the system, with numerous inputs and outputs. Conducting a cradle-to-grave study would have added further value for future strategy assessments, but it would be extremely time-consuming, as the fate of the multitude of products is difficult to map. The main uncertainties in the study relate to the data on upstream production processes, since the data are from databases, and do not necessarily reflect actual production processes.

Indicating that upstream processes have a higher environmental impact that onsite processes adds a useful aspect, as it becomes clearer what future strategies should concentrate on. The same applies to the division of environmental impact contribution of the inflows to the cluster. Ethane, propane and butane make up 40.5 % of the weight of inflows, and contribute heavily to all environmental impact categories (24 % - 93 %).

CONCLUSIONS

A cradle-to-gate life cycle assessment was conducted for a chemical industry cluster. Upstream processes account for a larger share of all the environmental impact categories than onsite emissions. Global warming potential and ground level ozone creation potential are the environmental impact categories with the largest onsite shares; indicating that the processes resulting in the associated emissions are system hot spots. The fossil raw materials ethane, propane and butane account for a great proportion of all the environmental impact categories, and should therefore also be the target of future environmental strategies. The LCA will be used as a reference scenario in future studies where the environmental implications of switching to biogenic feedstock and extending process integration will be evaluated.

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