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Environmental Performance Indicators of Canned Sweet Corn Industry

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Abstract

The environmental problem is the global issue which many countries around the world pay attention to and realize its impacts on the earth. Thailand is one of the countries paying attention to the environment. Solving the environmental problems requires assessment with the purpose of consumption reduction, which helps directly decrease the impacts on the environment. Therefore, the objective of this research is to study how to determine proper environmental performance indicators (EPIs) in the agricultural industry based on a case study of canned sweet corn. Life cycle assessment (LCA) methodology is used to evaluate the selected impacts, consider percent contribution to each environmental impact, as well as assess sensitivity analysis. Global warming, water, acidification and eutrophication are also those 4 impact categories. In this study, functional unit is a 12-oz can of sweet corn and a scope of the study starting from cultivation until production is defined from cradle to factory gate. The study shows that production process of 1 canned sweet corn releases 333 gCO_2eq, 0.422 m^3 of water, 1.73 gSO_2eq and 0.02 gPeq. to the environment and proper environmental performance indicators for this industry are the amount of nitrogen (N) and phosphorus (P) fertilizer, yield, weight of can, quantity of biomass fuel for high-pressure steam production, quantity of wastewater and BOD (Biochemical Oxygen Demand) and the electricity consumption for the production process.

Keywords: Environmental performance indicator, Global warming, Life cycle assessment, Sweet corn.

Introduction

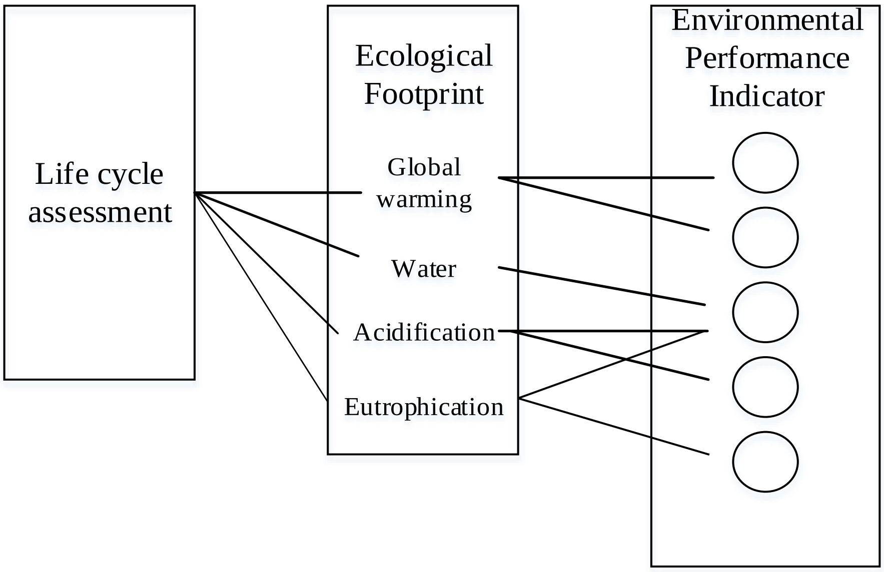
Sweet corn, or by its scientific name *Saccharata* ,is one of the most important economic plants of Thailand. Thailand produced 365,000 tons of sweet corn in 2013, 167,000 tons of sweet corn was exported in 2013 and its exports increased to 200,444 tons in 2014 valued at 206 million USD (Thai Food Processors' Association, 2015). Thailand's agricultural land only for the industrial process of sweet corn was measured at 40,000 ha. Canned sweet corn also has become one of the important products of Thailand. It was found that Thailand's sweet corn industry drastically grew in 2011 and it became the No.1 of the worlds' canned sweet corn exporter (Thai Food Processors' Association, 2014).

According to many environmental problems and higher awareness on environmental issues from the food industry, impacts on the environment from food production or concerns are studied, for instance, tuna (Hospido et al., 2006), tomatoes and canned beans (Tobler et al., 2011), dairy products (Sonesson and Berlin, 2003), canned sardines (Almeida et al., 2015) and canned tomatoes (Marletto and Sillig, 2014). This study consequently focuses on the environmental footprint of canned food processing assessment by using canned sweet corn as case study. The purpose is to define environmental performance indicators (EPIs) of the canned sweet corn production process (starting from raw materials procurement to production or known as cradle to gate of factory) in order to indicate internal efficiencies as a basis for improving the environmental impacts of the company. The assessment's results are defined as baselines. With these baselines, the company makes a decision and sets future targets aiming at environmental impacts reduction. Significantly, environmental footprint assessment requires LCA, a crucial tool used in assessing impacts on environments of food production, however; LCA methodology is complicated, time consuming and moreover the LCA result is complex and could be difficult to understand. Therefore, considering the perspective of personnel in an organization with limited LCA knowledge, EPIs approach can be developed to make them more easily understandable. In addition, previous researches concentrating on the relationship between EPIs and LCA such as Doublet and Jungbluth (2011) studied and applied key environmental performance indicators (KEPIs) for simplified LCA in food supply chains using meat and dairy, fruit juice and aquaculture salmon as case studies. Hermann et al., (2007) proposed an integration method between EPIs and LCA in a case study of the pulp industry.

Methodology

The purpose of this research is to study the environmental footprint assessment of canned food processing in order to identify the proper EPIs using Life Cycle Assessment approach, the key tool of environmental assessment. The industry can utilize EPIs, an internal efficiencies indicator, as a basis for improving environmental impacts of company. EPIs categories which are selected in the study are such global warming impact, water, acidification impact and eutrophication impact; nevertheless, if a full Life Cycle Assessment is needed in this study, many difficulties, for instance the lack of data have contributed to LCA being time-consuming and expensive to perform (Crawford, 2011) and the researcher's knowledge, proficiency and databases of industry are also required, and make the industry especially medium- and small scale industry difficult to operate smoothly. In conclusion, the conceptual idea of the study presents that the environmental performance indicators decrease of manufacturers could reduce impacts on environment in the production process shown as Figure 1.

Figure 1. *Conceptual Idea to Simulate the EPIs*



Environmental Performance Indicator (EPIs)

In the past, there were many questions about decision criteria for production efficiency since the assessment might not thorough enough. Therefore, accurate indicators of "EPIs" are created and utilized in assessment later. EPIs are quantitative measures and evaluate environmental burdens on a business' environmental performance. That environmental problem needs to be solved in order to obtain information that helps decision making regarding these activities (Japan Ministry of the Environment, 2003). The results from EPIs can be compared both in internal and external organizations (Epstein and Roy, 2001). Commonly used EPIs are energy consumption from fuel use or electricity consumption, GHG emissions, waste generated ,water used, hazardous materials, etc (Torres et al., 2012). EPIs setting ought to be concerned with objectives and indicators, for example objectives to reduce the GHGs release from the production processes and indicators to measure quantity of reducing GHGs from the production processes (Segnestam, 1999). In addition, EPIs can be divided into direct EPIs and indirect EPIs. Direct EPIs is quantity of resource utilization such as raw materials usage or waste release; wastewater or air pollution, produced by the manufacturing process. Indirect EPIs is quantity of resource utilization or waste release from either the upstream or downstream supply chain.

An advantage of EPIs is that EPIs should quantify environmental impacts of products over the life cycle and inform consumers about it in order to support sustainable consumption (Doublet and Jungbluth, 2011). However, EPIs is not fixed, but flexible depending on each organization's objective (Segnestam, 1999).

Environmental Footprint (EF)

The product environmental footprint (PEF) is a multi-criteria measure of the environmental performance of a good service throughout its life cycle, using a life cycle approach (European Commission, 2012).

There are totally 14 impact categories specified in PEF such as climate change, ozone depletion, acidification, eutrophication, etc. As it is complicated and difficult to completely assess all 14 impact categories in medium- and small scale industry following PEF approach, only 4 categories; warming impact, water impact, acidification and eutrophication, related with selected product are selected to focus in the study.

Global Warming Impact

The global warming impact EPI quantifies the major global warming impacts of both direct and indirect GHGs emissions associated with selected product entire its life cycle. Direct GHG emissions include combustion of fossil fuels, nitrous oxide from the use of fertilizer. Indirect GHG emissions include use of electricity and raw materials productions. In order to calculate the global warming impact, the carbon footprint concept was used. The carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product (Wiedmann and Minx, 2007). The global warming potential is used, when determining the climatic impact of a substance. This is a measure of the effect on radiation of a particular quantity of the substance over time relative to that of the same quantity of CO_2 (European Commission, 2006). The global warming potential based on the IPCC Fourth Assessment Report (AR4) (2007) is, for example, used to convert CH_4 and N_2O to CO_2eq; global warming potential (GWP) of 25 and 298 that are used for CH_4 and N_2O, respectively. In conclusion, the results of global warming impact are calculated as the following equation

$$Total\ \ GHG\ emissions = \sum GHGs_{cultivation}^{direct} + \sum GHGs_{cultivation}^{indirect} + \sum GHGs_{production}^{direct} + \sum GHGs_{production}^{indirect}$$

Water

The water footprint is an indicator of human freshwater appropriation, defined as the total freshwater consumed or polluted to product (Hoekstra et al., 2011). The general equation to calculate the water footprint is considered from the green (WF_{green}), the blue (WF_{blue}) and the grey (WF_{grey}) water footprint. It is determined that the green water footprint refers to the rainwater consumed. The blue water footprint refers to the volume of surface and groundwater consumed. The grey water footprint of a product refers to the volume of freshwater that is required to assimilate the load of pollutants based on exiting ambient water quality standards (Mekonnen and Hoekstra, 2011), shown as the following equation

$$WF = WF_{green} + WF_{blue} + WF_{grey}$$

The study mainly focused on 2 water resources, one from cultivation and another from the production process. The production process concerns direct and indirect water footprint. The direct blue water footprint is the direct water use of the production process, for instance, water as a product's component, water for washing machines. On the other hand, the indirect blue water footprint is the use of chemicals often composed of water in the production process (Morera et al., 2015). In the study, the ReCiPe methodology for the green and blue water footprint is chosen to determine the chemicals in the production process. In cultivation, the volume of the plant's water consumption (Evapotranspiration, ET) refers to crop coefficient (K_c) and reference crop evapotranspiration (ET_0) by using the calculation of Penman Montheith method based on the climate information of that local area (IWM, 2011). Therefore, the equation of plant's consumptive use is as follows;

$$ET = K_c \times ET_0$$

ET_{blue} results from the difference between ET and effective rainfall (P_{eff}). If effective rainfall (P_{eff}) is higher than ET, ET_{blue} is equivalent to 0 which means there is much rainwater enough to plant's consumptive use. On the other hand, ET_{green} is calculated from minimum of Evapotranspiration and effective rainfall as following equation;

$$ET_{blue} = \max{(0, ET - P_{eff})}$$
$$ET_{green} = \min{(ET, P_{eff})}$$

Thereafter, crop's water use (CWU) during the period of cultivation is the sum of Evapotranspiration (mm/day) as the shown equation;

$$CWU_{blue,green} = 10 \times \sum_{d=1}^{lgp} ET_{blue,green}$$
$$WF_{blue,green} = \frac{CWU_{blue,green}}{Y}$$

Moreover, an indirect blue water footprint from chemicals production and fuel in cultivation is also considered. For grey water footprint in cultivation, only nitrogen fertilizer is considered (Hoekstra et al, 2011) based on the equation of Mekonnen and Hoekstra (2011).

$$WF_{grey} = \frac{(\alpha \times AR)/(C_{max} - C_{nat})}{Y}$$

which is determined that α is a leaching runoff fraction (assumed 10% for nitrogen fertilizers) (Nyambo and Wakindiki, 2015), AR is the chemical application rate per hectare (kg/ha), C_{max} is the maximum allowable concentration (assumed 5 mg/L followed Royal Irrigation Department), C_{nat} is natural concentration (assumed 0 followed Mekonnen and Hoekstra (2011) and Y is the yield of sweet corn (ton/ha).

Acidification and Eutrophication Impact

Atmosphere deposition of inorganic substances such as sulfates, nitrates and phosphates cause a change in the acidity of the soil (Goedkoop et al., 2013). The major acidifying pollutants are SO_2, NO_x and NH_x (Guinee et al., 2004). Acidification potential (AP) used in this study is ReCiPe methodology (Goedkoop et al., 2009) and units of acidification in ReciPe are kg SO_2. Eutrophication covers all potential impacts of excessively high environmental levels of macronutrients (Guinee et al., 2004). It can be defined as nutrient enrichment of the aquatic environment. The most important of pollutants caused eutrophication are nitrogen and phosphorus, so ReCiPe methodology is properly applied in this study (Goedkoop et al., 2009) and define freshwater eutrophication as an impact group. The freshwater eutrophication follows a sequence of ecological impacts offset by increasing nutrient emissions into freshwater. The unit of freshwater eutrophication in ReCiPe is kg P. Characterization impacts at the midpoint level can be calculated as an equation (Goedkoop et al., 2013). Where m_i is the magnitude of intervention i, Q_{mi} is the characterization factor that connects intervention i with midpoint impact category m, and I_m is the indicator result for midpoint impact category m.

$$I_m = \sum_i Q_{mi} \times m_i$$

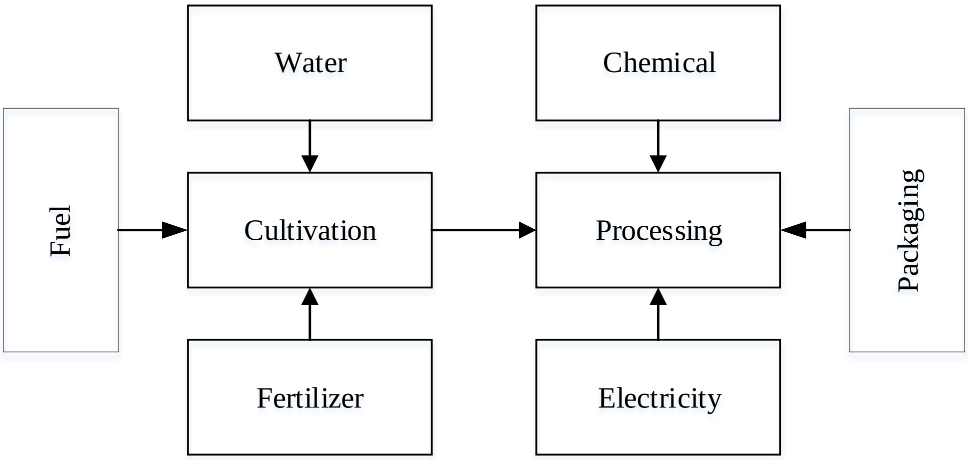
Life Cycle Assessment

Life cycle assessment is a systematic set of procedures or a tool for assessing environmental burdens and potential impacts over the entire life cycle of a product or a service (ISO14040, 2006). Its objective is to identify an environmental hotspot in a life cycle of considered product and benchmark environmental friendliness of products with the same functional unit. Life cycle assessment (LCA) consists of 4 steps which are goal and scope, inventory, impact assessment and interpretation consecutively (ISO14040, 2006). The goal and scope setting is defining the objectives of the study, scope and appropriate functional unit. The life cycle inventory (LCI) is concerned with collecting information and balancing the calculation of all scope-related unit processes. The LCI result is presented in form of inputs and outputs for the whole life cycle. Besides, impacts on the environment are calculated from the inventory results and the classification and characterization of the selected impact categories. Characterization is the inventory results multiplied by the characterization factor for each component. The overall results of selected impacts are equal to the overall results of the characterization in each impact group which harmoniously conforms to defined functional unit.

Goal and Scope

The goal and scope of LCA shall be clearly defined with product details such as the scope of the study as well as functional unit definition. Setting a clear goal and scope can lead you to the effective results which can be applied to any requirements and the user should be designated as well. The objectives of LCA in this study is to assess the global warming impact, water, acidification impact and eutrophication impact and identify the EPI for the canned sweet corn industry. The functional unit is a key element to compare existing products and services. Generally, a functional unit is defined as the product’s function, however, canned sweet corn can, weight 12 oz. (340 g) is a functional unit of this study. The scope of the study is limited to the cradle to gate approach, from cultivating sweet corn, distributing materials to the manufacturing plant until production (Figure 2).

Figure 2. *Simplify System Boundary*



Life Cycle Inventory

Life cycle inventory is a process of data collection or an assessment of resources consumption and the quantities of wastes and emissions related to the entire life cycle of a selected product. As data collection about cultivation from a survey in 2014, a canned sweet corn manufacturer informed that the average product is equivalent to 12,500 kg/ha, 312.5 kg/ha of 15-15-15 fertilizer is added for the first time and 187.5 kg/ha of 46-0-0 fertilizer for the second time. Moreover, chemicals such as 3.75 liters/ha of alachlor and 2.5 liters/ha of paraquat are utilized during the period of soil preparation and plantation by following the Department of Agricultural Extension's guidance for sweet corn growing[1]. After 70 days, sweet corn is harvested and distribute to the processing plant, at a distance of 238 km from the field, by a six-wheeled truck. The whole process of canned sweet corn production consists of the acquisition of raw materials and peeling, classification, canning, steam sterilization and packing. In the processing plant, many minor utilities processes, for instance, soft water production, steam production, wastewater treatment, need chemicals usage such as chlorine, sodium chloride, biomass and coal. To produce a 12 oz-canned sweet corn 1.75 kWh of electric energy per one ton of soft water, 9.42 kWn per one ton of steam, 0.42 kWh per 1 m^3 treated wastewater, 3.04 kg of steam, 0.24 kWh of electricity and 0.22 kg of water are consumed.

Results and Discussion

Impact Assessment

The estimated environmental impact per one canned sweet corn at 12 oz were 333 gCO_2eq, 0.422 m^3 of water, 1.73 gSO_2eq and 0.02 gPeq with respect to the global warming impact, water, acidification and eutrophication, respectively (Table 1). The relative contributions of different life cycle stages to each impact category for one selected functional unit are also shown in Table 1. Table 1 presents 2 kinds of data which are an environmental impact as bold numbers and percent contribution in each process as numbers in parentheses.

[1] Department of Agricultural Extension, Sweet Corn, access at: http://bit.ly/2fuclxi.

Table 1. *Environmental Impacts*

	GWP ($kgCO_2eq$)		Water (m^3)			AD ($kgSO_2$)	EP(kgP)
	Direct emission	**Indirect emission**	WF_{green}	WF_{blue}	WF_{grey}		
Cultivation							
Total	**0.052**	**0.060**	**0.097**	**0.112**	**0.182**	**0.000**	**0.000**
Fertilizer		(99.2)		(0.6)		(93.5)	(76.3)
Chemical		(0.0)		(0.0)		(4.7)	(7.7)
Diesel	(0.2)	(0.8)		(0.0)		(1.8)	(1.0)
Corn	(99.8)		(100)	(99.4)	(100)	(0.0)	(15.1)
Processing							
Total	**0.087**	**0.135**	**0.000**	**0.031**	**0.000**	**0.001**	**0.000**
Ingredient (sugar, salt)		(3.8)		(22.7)		(1.3)	(15.9)
Water		(0.4)		(7.9)		(0.1)	(0.2)
Packaging		(61.2)		(57.8)		(46.0)	(82.2)
Electricity		(21.0)		(0.4)		(2.5)	(0.0)
LPG	(1.1)	(0.1)		(0.0)		(0.1)	(0.0)
Diesel	(1.7)	(0.1)		(0.0)		(0.2)	(0.7)
Steam	(36.0)	(12.7)		(11.2)		(49.3)	(0.9)
Wastewater treatment	(61.2)	(0.7)		(0.0)		(0.1)	(0.0)
Transportation	(0.0)			(0.0)		(0.5)	(0.0)

Global Warming Impact

In the study, the largest portion of the global warming burden is in the processing stage (66%) and the last contributor remains in the cultivation stage (34%). The largest impact on global warming is from the packaging process (25%), the second and the third is production of fertilizer (18%) wastewater treatment (16%).

Considering details of the wastewater treatment, the system causes CH_4 due to anaerobic digestion and the 2-meter depth pond. According to lack of fuel consumption during distributing raw materials to manufacturer, we need to calculate global warming impact values based on distance and type of truck. GHGs emission is a sum total of fuel production and fuel combustion and contribute only a small amount.

Water

Sweet corn manufacturers acquire raw materials on average from 4 provinces, which have different amount of rainfall. Irrigation Water Management Division of Thailand (2015) has summarized the effective rainfall and Evapotranspiration data of sweet corn from each province as shown in Table 2. Therefore, as shown data, green and blue water footprint can be estimated and presented as shown in Table 1.

Table 2. *Effective Rainfall an Evapotranspiration of Sweet Corn in Each Province*

Province	Effective rainfall (mm per month)		Evapotranspiration (mm/crop)
	Dry season	Wet season	
Nakornsawan	23	112	344
Karnchanaburi	20	90	312
Chiangrai	23	76	242
Nakornratchasima	24	97	290

The water footprint from the cultivation stage is 93% of contribution, consisting of 23% green water footprint and 26% blue water footprint from water use by plants. Noticeably, the grey water footprint is up to 43% of the total water footprint. Comparing to water footprint of other kinds of plant, grey water footprint of theirs is similar, only Evapotranspiration and yield are different. For example, the water footprint of field corn is about 1,132 m^3/ton, consisting of a green water footprint 894 m^3/ton and a grey water footprint 237 m^3/day (Sukumlchart et al., 2013). In the production process, production of packaging is the most at 4%, Secondly, salt and sugar ingredient process is less than 2%.

Acidification Impact

The most impact of acidification is from steam equal to 37%. Fuel from palm kernel shell and coal has an impact on the steam production process. Next impact on production of packaging is 34%, which come from can production processes, while packaging has a small impact. And the third, production of fertilizer is 22%, which resulted from 46-0-0 urea fertilizer production.

Eutrophication Impact

Most of the impact of eutrophication comes from the production of fertilizer accounted to 53%. Next, the production of packaging results 25% from paper box production. And P runoff from P_2O_5 fertilizer is 10% of entire impact.

Sensitivity

After analyzing the environmental impacts, the sensitivity analysis was evaluated in order to study which factor changes when the quantity input changes. EPIs is used to track aspects of product that have the greatest environmental impact (Beu, 2009). As a result of the LCIA assessment, the largest contribution is ranked as shown in Table 3.

Table 3. *Ranking of Main Contributions in Each Impact*

Global warming	Water	Acidification	Eutrophication
• Packaging	• Evapotranspiration	• Steam production	• Fertilizer
• Fertilizer	• Fertilizer	• Packaging	• Packaging
• CH_4 from wastewater treatment	• Packaging	• Fertilizer	

From Table 3, some impacts have similar parameters, so the parameters selected for the sensitivity analysis are packaging, fertilizer, CH_4 from wastewater treatment, evapotranspiration and steam production. The sensitivity analysis is a method to perform on the input data of LCA in order to estimate those responsible for the greatest eco-profile uncertainties (Ardente at al., 2005). Therefore, if the base scenario is defined as data from the above mentioned assessment and the selected parameters defined from alternative scenario increases 10% and decreases 10%, Alternative scenario 1 (AL1) is changes of the can weight. Alternative scenario 2 (AL2) is changes of used fertilizer amount. Alternative scenario 3 (AL3) is changes of quantity of methane generate in waste water treatment system. Alternative scenario 4 (AL4) is changes of Evapotranspiration. Alternative scenario 5 (AL5) is changes of quantity of palm kernel, a fuel for steam production. Results from sensitivity analysis are shown in Table 4.

Table 4. *Sensitivity Analysis*

	Percent change			
	Global warming	**Water**	**Acidification**	**Eutrophication**
AL1	±1.62%	±0.36%	±2.31%	±0.02%
AL2	±3.39%	±4.43%	±2.31%	±4.79%
AL3	±1.62%	±0.00%	±0.00%	±0.00%
AL4	±0.00%	±4.90%	±0.00%	±0.00%
AL5	±0.44%	±0.12%	±3.47%	±0.00%

Table 4 shows which amount of fertilizer usage has the biggest impact on environment change. The percentage of change is during 2.31-4.79%. The amount of methane affects only global warming and the percentage of change is 16.2%.

Environmental Performance Indicators

According to this assessment the results on 4 groups; global warming, water, acidification and eutrophication based on principles of life cycle assessment and sensitivity analysis as above mentioned, the key environmental performance indicators can be concluded as in Table 5. A criterion for selecting EPIs is considered based on aims to estimate more than 80% of the environmental impacts. In Table 5, a horizontal data is EPIs and a vertical data is impact category. The mark “X” in a cell presents the EPIs with importance and relevance between impact category and EPIs such as EPIs of N-fertilizers affecting global warming or EPIs of biomass affecting acidification and global warming.

Table 5. *List of EPIs in Each Impact Category*

Impact category	Cultivation			Production				
	N-fertilizer (kg/ha)	P-fertilizer (kg/ha)	Yield (kg/ha)	Can (kg/production)	Biomass (kg/ton steam)	BOD (mg/L)	Wastewater (m3/production)	Electricity (kWh/production)
Global warming	x	x		x	x	x	x	x
Water	x	x	x					
Acidification	x		x	x	x			
Eutrophication	x	x	x	x				

Conclusions

Results from the Environmental Impact Assessment of canned sweet corn are equivalent to 333 gCO_2eq, 0.422 m^3 of water, 1.73 gSO_2eq and 0.02 gPeq with respect to the global warming impact, water impact, acidification and eutrophication, respectively. The appropriate EPIs for the canned sweet corn industry are the amount of N- and P-fertilizer, yield, weight of a can, quantity of biomass in stream production, volumetric flow of wastewater and BOD, and electricity consumption in production process.

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