Improving Company’s Environmental Impacts by Integrating Renewables

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Abstract
The objective of this work was to propose a multi-objective synthesis of a company’s supply-network by integrating renewables in order to achieve an energy self-sufficient supply-network whilst significantly reduce environmental impacts. The model for achieving energy self-sufficiency by integrating renewables into companies’ supply networks (Kiraly et al. 2012) has been extended for the evaluation of environmental impacts, such as carbon, nitrogen, water, and energy footprints. The model was applied to an existing large-scale meat company. For the evaluation of environmental footprints, direct (burdening) and indirect (unburdening) effects (Kravanja 2012) on the environment are considered. The approach enables to identify those alternative energy production technologies that are not only more profitable and environmentally more benign, but exhibit significant unburdening capabilities.

Keywords: environmental impacts, renewables, company’s supply-network, footprints.

1. Introduction
A large part of environmental pollution is caused by process industries, especially those with fossil-based energy sources. With growing concerns over climate change, the understanding of the greenhouse-gas (GHG) emission characteristics of power production from different renewable sources is required (Hondo 2005). Improvements in energy efficiency, and reducing energy waste and costs, whilst significantly decreasing environmental burdens, has become one of the greater challenges for our future. More and more companies have started to utilize accessible alternative energy sources, that are available within nearby regions, to apply them in the most efficient way, such as biomass, and photovoltaics (Graebig et al. 2010). Photovoltaic power plants have become widely used, as the solar energy seems to be completely clean, and without any environmental impact (Stoppato 2008). Life cycle analysis and emissions from photovoltaic panels have been studied on in several research papers (e.g., in Fthenakis et al. 2008), where carbon footprint (Dominguez-Ramos et al. 2010) and reduction of reactive nitrogen (Galloway et al. 2004) have been researched on.

Food industry produces large amounts of different wastes, e.g., organic wastes, animal manure, slurries, etc., that represent severe negative impacts on the environment, and could be converted into green-energy (Čuček et al. 2012a). They can be used as precious renewable sources from which heat, electricity, and other by-products can be produced (Kiraly et al. 2013). As processes converting different types of biomass to
energy, consume large amount of water, a concept of water footprint was applied (Gerbens-Leenes et al. 2007).

2. Problem formulation

2.1 Description of industrial supply-network

Base case

An existing industrial site supply-network of a large-scale poultry company (a detailed description can be find at Kiraly et al. 2013) has been taken into account and upgraded by integrating potential renewable energy sources located within the surrounding region of the company. Company’s baseline includes one biogas plant (BGP-1) producing heat and electricity, within combined heat and power (CHP-1) producing unit. Renewable electricity production is equivalent to 28% of the company’s electricity consumption, the rest is bought from the grid.

Energy from renewable sources

Figure 1 illustrates simplified company’s heat and power integrated industrial supply-network, based on the use of renewables (photovoltaics, animal and organic waste, and waste heat). Full lines represent mass-flows between process plants, the dashed lines the electricity-flows, and the dotted lines the low grade heat energy-flows.

Figure 1. Utilization of renewables within industrial supply-network, after (Kiraly et al. 2013).

The rooftop surfaces, of industrial objects like breeders (BREED 1 – BREED 10), farms (FARM 1 – FARM 3), feedstuff plant (FSP), hatchery (HATCH), meat industry (MI), and rendering plant (REND) located on different locations, are exploited for the electricity production by photovoltaic panels.
Due to excess of the accumulated manure as a side product of poultry industry, additional biogas and cogeneration plants have been proposed at nine alternative locations (BGP-2 to BGP-10 and CHP-2 to CHP-10), see Figure 2.

The majority (80%) of the low-grade heat produced by CHP units is used for the process itself (heating of fermenter within BGP, and processing of untreated water), heating of buildings in the winter, sanitation, and the evaporator. For the rest, district heating of the nearby settlements has been proposed.

2.2 Modelling of regionally integrated company’s supply-network

A Mixed-Integer Linear Programming (MILP) model has been developed for the synthesis of companies’ supply-networks utilizing different types of renewables (solar, biomass, certain types of waste) as sources for the companies’ energy supplies to maximise the self-sufficiency of the company’s energy-supply. The proposed integrated network consists of the harvesting and supply-layer (L1), company’s supply-network-layer (L2), usage-layer (L3), and the transportation between the layers. It accounts for the evaluation of direct, indirect and total environmental impacts (Čuček et al. 2012b), such as carbon, nitrogen, water, and energy footprints. It includes additional features such as possibility of purchasing raw materials needed within the supply network, recycle of produced products within process units, and district’s heating.

2.3 Direct, indirect and total footprints

Due to the proposed replacement of fossil-based energy with renewable one, significant unburdening of the environment was expected. Therefore, indirect unburdening effects had to be considered, besides the usual direct burdening ones, both defining ‘total footprints’.

Direct footprints

Direct footprints present direct burdens on the environment (Čuček et al. 2012b). In the case of energy production, direct burdens consist of all environmental impacts associated with all the stages of energy production from cradle-to-grave: raw materials extraction, their processing, production and usage of renewable energy, including the transportation and distribution flows. Different footprints are evaluated, such as carbon, nitrogen and water footprints:

- **Carbon Footprint:** A ‘carbon footprint’ (CF) is the total amount of CO$_2$ and other greenhouse gases, emitted over the full life cycle of a process or product, expressed in g CO$_2$eq/kWh (UK POST 2006).

- **Nitrogen Footprint:** A ‘nitrogen footprint’ (NF) provides information on how individual and collective action can result in the loss of reactive nitrogen (Nr) to the environment. The NF represents disruption of the natural nitrogen cycle (Leach et al. 2012), and is expressed in g N/kWh.

- **Water Footprint:** A ‘water footprint’ (WF) is defined as the total annual volume of freshwater used to produce the goods and services related to consumption (Gerbens-Leenes et al. 2008), expressed in t water/kWh. The WF consists of three components: green (GNWF), blue (BWF) and gray (GYWF) virtual-water. The GNWF of a product refers to the rainwater that evaporated during the production process. The BWF refers to surface and groundwater that evaporated during the
supply-chain of product. The GYWF of a product is defined as the amount of water needed to dilute pollutants emitted during the production process to water quality standards (Hoekstra et al. 2011).

**Indirect footprints**

Indirect footprints indirectly unburden or benefit the environment, when e.g. fossil-based energy (electricity and heat) is substituted with energy obtained from renewable energy sources, or animal wastes are utilized instead of being deposited.

**Total footprints**

The total footprints represent the sum of direct and indirect effects.

### 3. Results and Discussion

All the proposed rooftop surfaces for photovoltaics and three additional biogas cogeneration plants were selected (BGP-4, BGP-5, and BGP-3), see Figure 2. Note that three additional BGP units were selected out of nine ones at different locations, considering minimization of transportation costs of manure from the breeding facilities (BREED-2 – BREED-10) to BGPs. Two of them were of the same sizes as the one of BGP-1, and the third one approximately of half the capacity, due to the limited availability of manure. Note also that as a result, company’s energy self-sufficiency has not only been achieved, it has been exceeded by 88%.

![Figure 2](image-url)

**Figure 2.** Optimal selection of renewable energy units across the region, after (Kiraly et al. 2013)

Figure 3 presents the increase of relative direct footprints vs. the installation of additional renewable energy producing units. Due to high quantities of CO₂ and N, released during the production of corn, biogas cogeneration units burden the environment much more than photovoltaic panels. Figure 3 clearly shows that almost all the relative direct footprints have been originated by the biogas cogeneration plants. The trend of increasing the relative direct WF curve is much faster than those of CF and NF, because huge amounts of freshwater are needed for the process.

Figure 4 presents relative total/direct footprints versus additional energy-producing units. As can be seen, by adding energy-producing units relative total CF and NF is
lowered. Note that relative total CF becomes negative at added process unit BREED7_PV, and relative total NF at BREED1_PV. Reaching negative values means that the unburdening surpasses burdening of the environment in terms of CF and NF.

On the other hand, the WF is increasing by additional biogas cogeneration plants and starts slightly to decrease by installing photovoltaic panels. As at biogas production process corn silage is needed, the WF of biomass is 70 – 400 times larger than WFs of other primary energy couriers (excluding hydropower) (Gerbens-Leenes et al. 2008).

Figure 3. Relative direct footprints vs. additional energy-producing units

Figure 4. Relative total/direct footprint vs. additional energy producing units
Conclusions

This paper presents the evaluation of environmental impacts, such as carbon, nitrogen, and water footprints, by integrating renewables within a food industry’s supply network. For the evaluation of environmental footprints, total effects on the environment were considered, consisting of direct (burdening) and indirect (unburdening) effects. Future work will be oriented towards evaluating energy/exergy footprints.

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