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Multi-objective synthesis of a company's supply network by accounting for several environmental footprints

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ABSTRACT

This contribution presents the multi-objective synthesis of a company's supply network by integrating renewables (biomass and other waste, and solar energy) and accounting for several environmental footprints. The synthesis is based on a Mixed-Integer Linear Programming (MILP) problem. A previously developed model by the authors for achieving energy self-sufficiency by integrating renewables into companies' supply networks has been extended for the evaluation of environmental impacts, such as energy, carbon, nitrogen, and water footprints. The achievement of an energy self-sufficient supply network has been considered whilst significantly reducing environmental impacts.

The presented model is applied to multinational poultry-meat producing company. Direct (burdening) and indirect (unburdening) effects that form total effects on the environment are considered for the evaluation of environmental footprints. The results showed significant unburdening of the environment in terms of carbon and nitrogen footprints but, however, higher burdening in terms of the water footprint.

Keywords: Multi-objective synthesis; Company's supply network; Renewables; Environmental impacts; Footprints; Total footprints

1. Introduction

Nowadays, industries started planning and designing their activities in a way to minimize negative environmental impacts due to environmental control costs and regulations (Tokos et al., 2013). The investment towards supply chains that exhibit improved economic and/or environmental performances is currently an important research topic (Pinto-Varela et al., 2011). The maximization of the profit is still the main intention of companies, whilst the second objective is becoming the decreasing of environmental burdens. There is, therefore, a need for multi-objective optimization (MOO) (Kiraly et al., 2013a) to make the best decisions from several viewpoints. MOO problems relating to economic, energy, and environmental aspects (Hang et al., 2013) have been investigated by several authors, where they simultaneously considered the profit maximization and the environmental impact minimization (Santibañez-Aguilar et al., 2011) during the optimal planning and site selection (Santibañez-Aguilar et al., 2014).

More and more companies have started to utilize accessible alternative energy sources that are available within nearby

Abbreviations: BGP, biogas plant; CF, carbon footprint; CHP, combined heat and power plant; EF, energy footprint; GAMS, General Algebraic Modelling System; GHG, greenhouse gas; LCA, life-cycle assessment; MILP, mixed-integer linear programming; MOO, multi-objective optimization; NF, nitrogen footprint; PV, photovoltaic; TF, total footprint; TELTRF, total electricity – transportation footprint; THF, total heat footprint; WF, water footprint.

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Nomenclature

Superscripts

d	direct footprint
ind	indirect footprint
L1	harvesting and supply layer
L2	company's collection and processing layer
L3	consumption layer
T	technology
tr	transportation

Sets

FP	set of footprints
I	set for supply zones
J	set for demand locations
N	set for process plants
P	set for products
PS	set for substituted products
T	set for technologies

Indexes

f	index for footprints
i	index for supply zones
j	index for demand locations
n or *nn*	index for process plants
t	index for technologies

Scalars

$c_p^{tr,La,Lb}$	cost coefficient for transporting 1t of material 1 km long, €/(t·km)
EC	company's annual electricity consumption, MWh/y
q_{BGP}^{el}	BGP operating electricity consumption, MWh/y
q_{diesel}^{tr}	diesel fuel consumption, L/(t·km)
U_{diesel}	energy density of diesel fuel, MWh/L

Parameters

c_F^{CHP}	footprint coefficient for BGP, $t_{CO_2,eq}$/MWh, kg_N/MWh, t_{water}/MWh
c_F^{ind}	footprint coefficient for electricity mix, $t_{CO_2,eq}$/MWh, kg_N/MWh, t_{water}/MWh
c_F^{PV}	footprint coefficient for PV, $t_{CO_2,eq}$/MWh, kg_N/MWh, t_{water}/MWh
c_F^{tr}	footprint coefficient for diesel, $t_{CO_2,eq}$/MWh, kg_N/MWh, t_{water}/MWh
$c_p^{tr,La,Lb}$	cost coefficient for transporting 1t of material 1 km long, €/(t km)
D_p	distance between the locations for transporting product *p*, km
$I_{f,p}^{s}$	specific footprint *f* for each raw material and product *p*, kg/t or ha/t
$f_p^{S/P}$	substitution factor between the conventional product S and renewables-based product *P*
$I_{f,p}^{s,tr}$	specific footprint *f* for each raw material and product *p* for transportation, kg/(t·km), kg/(m^3·km), ...
l_p	inverse of the load factor for each raw material and product *p*

Continuous variables

c^{tr}	overall transportation costs, €/y
EF^d	direct energy footprint, MWh/y
EF^{ind}	indirect energy footprint, MWh/y
EF^{tr}	energy consumption related to transportation for energy footprint, MWh/y
EF_n	additional fossil-based energy consumption due to the operation of newly installed green energy-producing units for energy footprint, MWh/y
ELP_n	electricity production of newly installed energy-producing units, MWh/y
F_n	additional fossil-based energy consumption due to the operation of newly installed green energy-producing units for carbon, nitrogen, and water footprint, MWh/y
F^{tr}	energy consumption related to transportation for carbon, nitrogen, and water footprint, MWh/y
HP_n	heat production of newly installed energy-producing units, MWh/y
I_f^d	direct environmental footprint
I_f^{ind}	indirect environmental footprint
I_f^t	total environmental footprint
TEF	total energy footprint, MWh/y
q_p^m	flow-rate of raw material or product *p*, t/y, GJ/y, ...
$q_{n,j,p}^{L2,L3}$	flow-rate of product *p* from plant *n* in layer 2 to demand location *j* in layer 3, MWh/y

Binary variables

$y_{n,t}^{L2,T}$	existence of technology *t* at plant *n*

regions, to apply them in more efficient ways, such as e.g. biomass for biogas production within anaerobic digestion, and photovoltaics (PV) (Graebig et al., 2010). The usage and environmental footprints of fossil-based power generation will need to be reduced especially for mitigating climate change (Eslick and Miller, 2011) and for improving the quality of the environment. Several footprints are introduced for the environmental impacts assessments, such as carbon – CF (Hertwich and Peters, 2009), water – WF (Gerbens-Leenes et al., 2008), nitrogen – NF (Leach et al., 2012) and others. In addition, an attempt has been made over recent years to develop an integrated Footprint approach (Galli et al., 2012).

In this study several environmental impacts are evaluated for utilization of the produced biogas and installed PV-panels for heat and power generation. The generated heat from biogas plants is assumed to replace natural gas-based heat energy, whereas the generated power replaces the marginal power on the grid (Thyø and Wenzel, 2007). As global warming is generally considered as a major environmental threat for this century (Abbott, 2008), a concept of carbon footprint is applied (UK Parliamentary Office of Science and Technology (POST), 2011). However, besides carbon other footprints are also important for being evaluated. Nitrogen pollution is one of the more costly and challenging environmental problems (EPA, 2012) especially due to its non-point sources (Carpenter et al., 1998). Furthermore, processes converting different types of biomass into energy, consume large amounts of water, and therefore water footprint (Gerbens-Leenes et al., 2009) should also be assessed. Finally, energy footprint (EF) needs to be evaluated in order not to spend more fossil-based energy than producing the renewable-based one. All these footprints consider burdening and unburdening effects (Kravanja, 2012) and