CHEMICAL ENGINEERING TRANSACTIONS

VOL. 29, 2012

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at: www.aidic.it/cet

Guest Editors: Petar Sabev Varbanov, Hon Loong Lam, Jiří Jaromír Klemeš

ISBN 978-88-95608-20-4; **ISSN** 1974-9791

DOI: 10.3303/CET1229079

Integration of Renewables for Improving Companies' Energy-Supplies within Regional Supply Networks

Annamaria Kiraly*[a], Bojan Pahor[a], Zdravko Kravanja[b]

[a]Perutnina Ptuj d.d, Potrčeva 10, Ptuj SI-2250, Slovenia
[b]Faculty of Chemistry and Chemical Engineering University of Maribor, Smetanova ulica 17, SI-2000, Maribor, Slovenia
annamaria.kiraly@perutnina.eu

The integration of renewables into companies' energy supplies represents an important challenge that has to be undertaken in order to improve their economic potential and to reduce or even avoid the use of fossil energy sources. Whilst the global energy market is still dominated by fossil fuels as the primary energy source, the intention of more and more companies is to achieve a self-sufficient supply of renewable energy.
The aim of this contribution is to present the integration of renewables within the supply-chain of an existing large-scale meat company. The potential renewable energy sources located within the surrounding region of the company are solar, biomass, certain types of waste, and geothermal energy sources. The surrounding regional network typically comprises agricultural and harvesting (L1), collection and pre-processing (L2), core processing (L3), and usage (L4) layers, and the transportation between these layers. A model for the synthesis of regional supply-networks for the supply of energy and bioproducts, introduced by Čuček et al. (2010) was applied and upgraded in order to i) integrate the company's supply-chain within the regional supply-network, and ii) include, different types of renewables as sources for the company's energy supply. An overall supply-network is proposed that merges the company's supply-chain and the regional supply-network, thus integrating the renewables. At L1, it now comprises the cultivation of food and energy crops, and the harvesting of geothermal and solar energy; at L2, the harvesting of crops and the production of fodder and eggs; and at L3, meat-processing, rendering, anaerobic digestion, and photovoltaic and geothermal power production.

1. Introduction

The majority of industrial companies, as well as agriculture farms, are still dominated by fossil fuels as primary energy sources. Their utility systems are mostly equipped with steam and/or gas turbines, steam boilers, and water heaters (running on electricity or gas). The challenge is to increase the share of renewables within the primary energy mix, that could be met by integrating different types of biomass and photovoltaics (Varbanov and Klemeš, 2010). In addition it is desirable to combine heat and power (CHP) with district energy, thus permitting the cogeneration of electricity and heat (Rezaie and Rosen, 2012). Improving energy efficiency and thus reducing energy waste, on the one hand, and the use of renewable resources, on the other hand, have become two of the more important issues over recent years due to concerns regarding increasing energy costs, and sustainability (Nemet et al., 2012). It is likely to have serious implications for energy consumption, and consequently greenhouse gas emissions, if carbon-based energy sources are not replaced more rapidly by non-carbon or renewable sources of energy, and the energy is not used more efficiently (Perry et al., 2008). On the

Please cite this article as: Kiraly A., Pahor B. and Kravanja Z., (2012), Integration of renewables for improving companies' energy-supplies within regional supply networks, Chemical Engineering Transactions, 29, 469-474

other hand, large amounts of different wastes, e.g. animal manure and slurries, as produced today by the animal breeding sector, as well as the wet organic waste-streams that represent a constant pollution risk with a severe negative impact on the environment (Holm-Nielsen et al., 2009), could be converted into green-energy and thus be used as precious renewable sources.

Process Integration has developed over the years into a credible process-system engineering methodology. One of its important developments has been Total Site Integration (TSI), which has combined the heating and cooling requirements of individual processes, allowing better integration (Varbanov and Klemeš, 2011). Multi objective optimisation of integrated energy systems implies dealing with complex systems in which the synergy between the various components is best exploited (Peleta et al., 2005). Several research papers have dealt with heat integration and energy efficiency issues. For example, Atkins et al. (2010) presented a solar thermal system integrated within an industrial process. Gebremedhin (2012) and Nystedt et al. (2006) presented district heating based on biomass and the use of small CHP plants. Wan Alwi et al. (2012) presented an extention of the pinch analysis concept by using process integration to determine the minimum electricity targets for systems comprised of hybrid renewable energy sources. Liew et al. (2012) presented a site's overall sensitivity to plant maintenance shutdown and production changes, by assessing the sensitivity of a whole site with respect to operational changes, determining the optimum utility generation system's size, assessing the need for backup piping, estimating the amount of external utilities that need to be bought and stored, and assessing the impact of sensitivity changes on a cogeneration system. Mehleri et al. (2012) presented a model for the optimal design of distributed energy generation systems that satisfies the heating and power demands at the level of a small neighbourhood, Muis et al. (2010) developed a model for the optimal planning of electricity generation schemes so that a nation can meet a specified CO_2 emission target, and Fazlollahi et al. (2011) presented a model for the integration of biomass resources within a simultaneous multi-objective and multi-period optimization approach.

2. Problem formulation applied to an industrial case study

The objective of this contribution is to propose a synthesis methodology for the optimal integration of an industrial enterprise's supply-chain within its regional network. This is in order to determine economically-efficient and yet environmentally-benign solutions for the company's self-sufficient generation and supply of heat and electricity from renewable sources. As a result of optimal company-regional integration, it is possible to identify those supply-network alternatives that would increase the competitiveness of the company, and the economic prosperity of the region. The methodology is applied to an existing multinational large-scale meat company. The main idea is to convert large amounts of manure into green-energy by erecting an optimal number of additional biogas plants. Since the source of manure for biogas plants (BGP) is normally spread around the majority of a region, the locations of these plants need to be optimised using a mathematical programming approach. Low-grade heat energy obtained from biogas plants within combined heat and power (CHP) units needs to be optimally integrated within the surrounding farms and breeding facilities, which also carry photovoltaic (PV) panels located on their roof-tops. With these additional renewable energy sources, the aim is to achieve self-sufficiency regarding the company's energy supply, whilst selling their excess electricity to the grid. There is also an opportunity to use the remaining heat energy, e.g. for the district heating of residential dwellings, offices, large building complexes, greenhouses, etc. (Perry et al., 2008).

3. Description of the industrial case-study

The generic optimisation model for company-regional supply networks (Kiraly et al., 2012) was extended for the integration of renewables and applied to a case-study taken from an existing south-east European (SE-EU) large-scale meat company. The simplified industrial supply-network is illustrated in Figure 1, where set *I={i1…i6}* is used for the biomass supply-zones cultivated at different locations, set *N={n_FSP, n_FARM, n_SORT, n_BGP, n_HATCH, n_BREED, n_MI, n_AF_TR, n_REND, n_CHP}* for the feeding-stuff plant (FSP), farms (FARM), farms producing sorted eggs (SORT), biogas plants (BGP), the hatchery (HATCH), breeders (BREED), meat industry (MI), treated and transported meat (AF-TR), rendering plant (REND), a combined heat and power unit (CHP), and set *J={j1…j4}* stands for the demand locations.

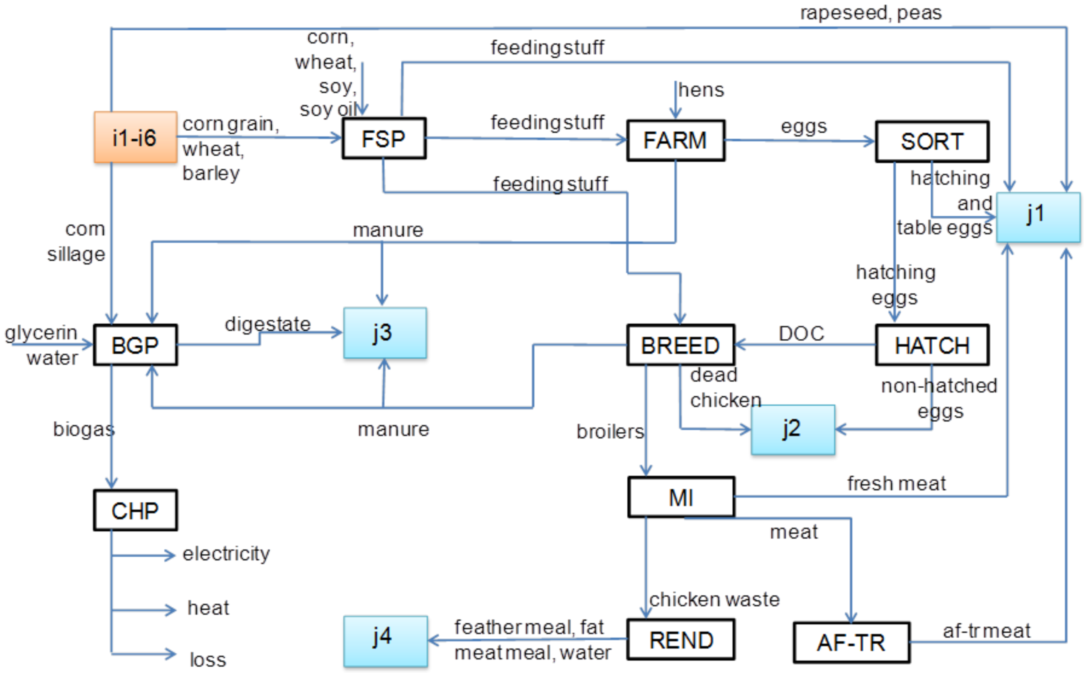

Figure 1. Simplified industrial supply-network (after Kiraly et al. (2012))

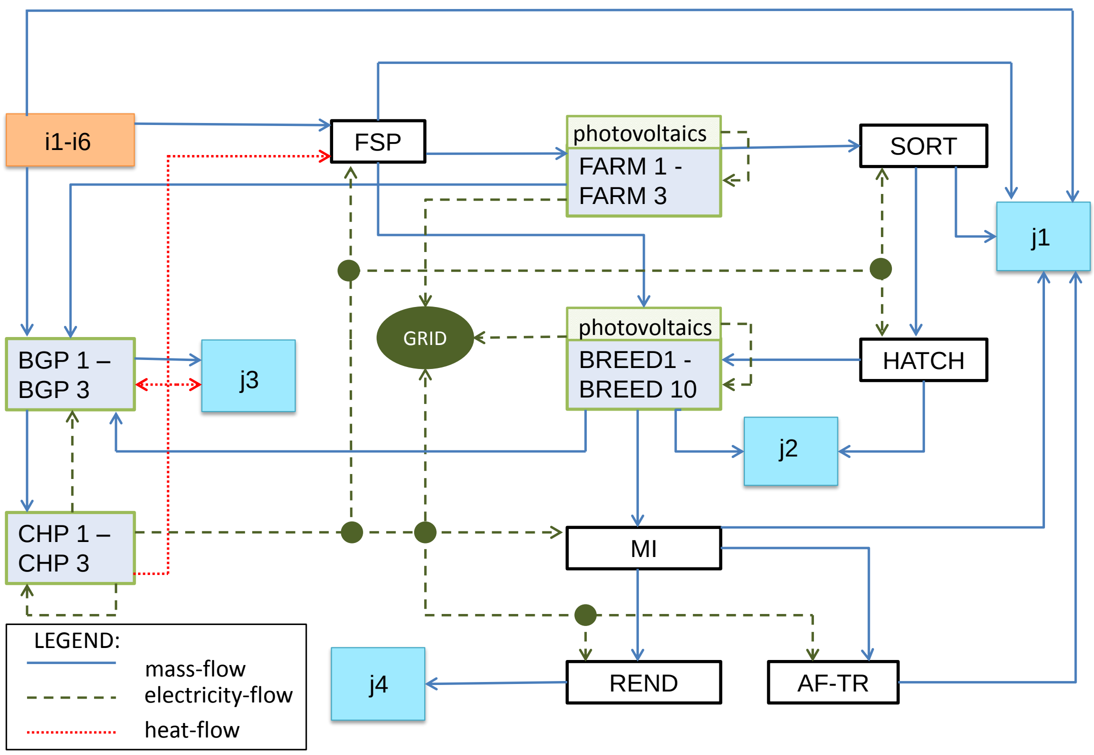

Figure 2. Energy self-sufficient simplified industrial supply-network

Data for inlet waste material and other substrates were collected and calculated, from the company's annual reports as average values. Certain other data were taken from the internal project documentation of the company. Data for economic evaluations were taken from the actual expenditures. A more-detailed description of the industrial case-study can be found in Kiraly et al. (2012).

A heat-and-power-integrated simplified industrial supply-network is illustrated in Figure 2, where the full lines represent the mass-flows between process plants, dashed lines the electricity-flows, and the dotted lines the low-grade heat energy-flows. Location of FARM has been extended to three different locations within the surroundings of BGP 1. BREED has also been extended to ten different locations due to the scattering of breeders across most of the region. Renewables were supplied by the following alternative sources:

1.) PV panels now located on the rooftops of breeding facilities and farms, where they supply the facilities and farms with the needed electricity for their operation.
2.) Two additional BGPs and, consequently, two additional CHP units added to the supply-network chosen from ten possible BGP locations, in order to optimise the transportation costs of the poultry manure from the breeding facilities to BGP 2 and BGP 3. All of the manure produced at FARM 1 – FARM 2 is being used for the biogas production at BGP 1.
3.) Part of the heat produced by the CHP 1 unit, integrated and used at FSP, and the other part used for the operation of the process, specifically for heating the digester unit in BGP 1, heating buildings during the winter time, for the implementation of sanitation, the evaporator, and the processing of untreated water (feed water preheating). Part of the heat produced by CHP 2 and 3 at the selected BGP 2 and BGP 3 is also used for the operation of the processes, and the rest for district heating for the nearby (2km) smaller settlements (demand location *j3*).

The electricity, now produced by three BGPs and PV panels, is used by every process plant of the company, whilst the excess electricity is sent to the grid.

4. Results and discussion

Using the extended generic model and proposed methodology the solutions were obtained for the base case supply-network, for the network's maximal energy self-supply, and for the most profitable network (Table 1).

Table 1: Comparison between base case solutions, maximal energy self-supply solution and the most profitable solution

Scenarios	Relative profit %	Relative electricity generation %	Relative heat generation %	Relative operating costs %	Relative transportation costs %	Energy self-sufficiency %	Electric. self-supply %	Heat self-supply %
Base case	100	100	100	100	100	28	28	23
Max energy self-supply	99.5	510	300	131	119	133	100	75
The most profitable	111	510	300	131	119	133	0	0

Base case: The status quo of the base-case network in Figure 1 was considered first. As this network already includes one BGP plant and one CHP unit, the electricity generated in the base-case represents 28 % of the company's total electricity supply. The rest of the electricity needs to be supplied from the grid. Therefore, the base-case already operates at 28 % energy self-sufficiency. Note that the heat produced at the CHP unit has not yet been integrated within the system. As the base-case provides the reference solution, its relative profit, relative electricity and heat generation, relative operating costs, and relative transportation costs are set at 100 %.

Maximal energy self-supply solution: This solution was obtained under the assumption that the energy produced by the BGSs and PV panels would first be used within the industrial complex and only the surplus sold to the grid, and that the prices for the purchased and produced electricity would be the same (80 €/MWh). The resulted network involves the installation of 220,293 m^2 of PV panels and two additional biogas cogeneration plants. The PV panels produce about 40 % and the three BGPs about 90 % of the company's total electricity demand, so that together 133 % electrical self-sufficiency was achieved, enabling a complete electricity self-supply with a surplus of 33 % being distributed to the grid. Note that energy (electricity plus heat) self-sufficiency is defined here as the ratio between the company's total produced energy from renewable sources and its total energy consumption, and the term self-supply as a ratio of the produced energy that is actually consumed within the company as against the company's total energy consumption. Also note that the heat produced from the two additional BGPs has been under-utilized (75 %), and that district heating of the nearby facilities is proposed. As can be seen in the Table 1, the relative profit of the energy self-supply solution slightly decreased when compared to the base-case solution. This was because in a significant increase of operating (31 %) and transportation (19 %) costs, as a result of collecting large amount of manure from several different locations of breeding facilities.

The most profitable solution: Regarding the most profitable solution, different prices of purchased (80 €/MWh) and produced electricity were considered (260 €/MWh for electricity from PV panels and 140 €/MWh from cogeneration units). Under this scenario, all the produced renewable electricity could thus, in principle, be sold at higher prices to the grid, whilst that needed within the company could be purchased at the lower price. Indeed, according to the resulting solution, all the generated energy from renewable sources should be sold, thus enabling an increase in profit of 11 % when compared to the base case. In the future this increase would probably not be a fully realised case because the prices of electricity for industrial users are expected to increase and subsidies for green-electricity to decrease. Therefore, the prices for green-electricity will not be that different compared to the electricity mix from the grid, unless significant extra taxes occur for the electricity from the grid. Nevertheless, Table 1 shows that by integrating renewable sources into the supply-network, the electricity generation could be increased by more than 5 times (510 %) and the heat generation tripled.

The MINLP optimisations were performed using the General Algebraic Modelling System (GAMS) (Brooke et al. 2005) using a GAMS/DICOPT solver. The model consisted of approximately 1000 continuous variables, 50 binary variables, and 560 constraints, and was solved within a fraction of a second of CPU time on a computer with 2.0 GHz Intel® Core™ i7-2630QM CPU @ 2.00GHz processor.

5. Conclusion

A generic model for the synthesis of a company's supply-network within its regional supply-network was extended for the integration of renewable energy sources, in order to maximise the company's energy self-sufficiency. PV panels and biogas cogeneration units for electricity generation were proposed as the regional and company's renewable energy options, together with heat integration and district heating. This model could be used to optimally-select locations for additional biogas cogeneration units in order to establish an appropriate trade-off between energy generation, heat integration, and transportation costs. From the economical point of view, the overall company's profit could be significantly increased. The aim was to identify alternatives that would increase the competitiveness of the company and achieve its complete energy self-sufficiency. Future work will be oriented towards analysing any environmental impacts from these alternatives.

Acknowledgement

The financial support is gratefully acknowledged from the European Social Fund, the Slovenian Technology Agency - TIA (PhD research fellowship contract No. P-MR-10/89), and the Slovenian Research Agency – ARRS (program P2-0032).

References

Čuček L., Lam H. L., Klemeš J. J., Varbanov P. S., Kravanja Z., 2010, Synthesis of regional networks for the supply of energy and bioproducts, Clean Technologies and Environmental Policy, 12, 635-645.

Kiraly A., Pahor B., Kravanja Z., Integration of a Large-Scale Company within its Regional Supply Network, submitted to 7th Conference on sustainable development of energy, water and environment systems, July 1 - 7, 2012, Ohrid, Republic of Macedonia.

Perry S., Klemeš J., Bulatov I., 2008, Integrating waste and renewable energy to reduce the carbon footprint of locally integrated energy sectors, Energy, 33, 1489-1497.

Varbanov P. S., Klemeš J. J., 2010, Total Sites Integrating Renewables With Extended Heat Transfer and Recovery, Heat Transfer Engineering, 31, 733-741.

Varbanov P. S., Klemeš J. J., 2011, Integration and Management of Renewables into Total Sites with Variable Supply and Demand, Computers and Chemical Engineering, 35, 1815–1826.

Rezaie B., Rosen M. A., 2012, District heating and cooling: Review of technology and potential enhancements, Applied Energy, 93, 2-10.

Nemet A., Čuček L., Varbanov P. S., Klemeš J. J., Kravanja Z., 2012, The Potential of Total Site Process Integration and Optimisation for Energy Saving and Pollution Reduction, 7th Conference on Sustainable Development of Energy, Water and Environment Systems - SDEWES2012, Ohrid, Republic of Macedonia. SDEWES12-0555

Holm-Nielsen J.B., Al Seadi T., Oleskowicz-Popiel P., 2009, The future of anaerobic digestion and biogas utilization, Bioresource Technology, 100, 5478–5484.

Peleta X., Favrata D., Leylandb G., 2005, Multiobjective optimisation of integrated energy systems for remote communities considering economics and CO_2 emissions, International Journal of Thermal Sciences, 44, 1180–1189.

Atkins M. J., Walmsley M. R. W., Morrison A. S., 2010, Integration of solar thermal for improved energy efficiencyin low-temperature-pinch industrial processes, Energy, 35, 1867–1873.

Gebremedhin A., 2012, Introducing District Heating in a Norwegian town – Potential for reduced Local and Global Emissions, Applied Energy, 95, 300-304.

Nystedt A., Shemeikka J., Klobut K., 2006, Case analyses of heat trading between buildings connected by a district heating network, Energy Conversion and Management, 47, 3652–3658.

Wan Alwi S. R., Rozali N. E. M., Abdul-Manan Z., Klemeš J. J., 2012, A process integration targeting method for hybrid power systems, Energy, doi:10.1016/j.energy.2012.01.005.

Liew P. Y., Wan Alwi S. R., Varbanov P. S., Manan Z. A., Klemeš J. J., 2012, A numerical technique for Total Site sensitivity analysis, Applied Thermal Engineering, 40, 397–408.

Mehleri E. D., Sarimveis H., Markatos N. C., Papageorgiou L. G., 2012, A mathematical programming approach for optimal design of distributed energy systems at the neighbourhood level, Energy, doi:10.1016/j.energy.2012.02.009.

Muis Z. A., Hashim H., Manan Z. A., Taha F. M., Douglas P. L., 2010, Optimal planning of renewable energy–integrated electricity generation schemes with CO_2 reduction target, Renewable Energy, 35, 2562–2570.

Fazlollahi S., Maréchal F., 2011, Multi-objective, multi-period optimization of biomass conversion technologies using evolutionary algorithms and mixed integer linear programming (MILP), Applied Thermal Engineering, doi:10.1016/j.applthermaleng.2011.11.035.