View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Institutional Research Information System University of Turin

CHEMICAL ENGINEERING TRANSACTIONS
VOL. 58, 2017
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Remigio Berruto, Pietro Catania, Mariangela Vallone
Copyright © 2017, AIDIC Servizi S.r.l.
ISBN 978-88-95608-52-5; **ISSN** 2283-9216

Web-based tool approach for energy balance estimation designed for multiple-crops production systems

Patrizia Busato[a], Alessandro Sopegno[a], Remigio Berruto*[a]

[a]University of Turin, Faculty of Agriculture, DISAFA Department, Largo Braccini 2, 10095, Grugliasco, Turin, Italy
remigio.berruto@unito.it

Biomass production systems include a number of spread fields located in a range of distances between the storage or processing facilities, multiple-crops rotations, different operational practices and various machinery systems. These aspects differentiate the cost and the energy requirements of the system. For these reasons, assessment tools based on average norms cannot provide an accurate evaluation of a specific production system in terms of cost and energy requirements. This paper is the continuation of a previous work where a web-based tool was presented for the estimation of the cost for the biomass production and transportation of multiple-crop production. In this work, the tool is extended in order to provide in addition the energy balance of the studied systems. The energy input accounting regards the whole supply chain of the biomass, including the crop cultivation, the harvesting and the handling of biomass including the transportation to the processing facilities. The inclusion of operational and agronomic parameters provides an accurate estimation of the energy requirements for a specific system allowing to calculate in detail specific energy inputs/outputs.

1. Introduction

Biomass production systems are complex and include a number of spread fields located in a range of distances between the storage or processing facilities, multiple-crops rotations, different operational practices and various machinery systems. All these aspects contribute to the diversification of energy requirements of the system.

The developed approaches for the assessment of energy balance in crop production are in their majority based on general data or average norms and the overall quality of the input data can vary depending on the technical status of the production and transportation chains (Gissén et al. 2014). Furthermore, there are various production chains where production data are less available (Börjesson and Tufvesson 2011).

Regarding the assessment of the energy requirements for various crops there is an extensive amount of scientific works related, such as vineyards (Kavargiris et al. 2009), peaches (Michos et al. 2012), pears (Liu et al. 2010) and willow (Stolarski et al. 2014), as examples among others. All these works either refer to specific production practices or use average norms for the estimation of the energy inputs of the several field and logistics activities. A change in the production practice, in terms for example of technological diversifications or resource type usage, can lead in significant variations on the estimated output. As for example, as reported in Gissén et al. (2014) for six crops tested, by replacing mineral fertilizer with biogas digestate the energy input in cultivation decreased by on average 34%. In Sopegno et al. (2016), where a computational tool was presented for the estimation of the energy requirements of Miscanthus on individual fields, it was shown that for various field-storage distances the energy requirements resulting to a variation in the energy return on investment (EROI) index between 15.84 up to 23.74, and for different transportation systems a variation between 12.87 and 17.52 for the same travelled distances. In Sørensen et al. (2014), by examining different cultivation practices it was shown that the total energy input in crop production systems compared to the conventional intensive tillage based production system was decreased by 26% when the reduced tillage system was implemented and by 41% for the no-tillage system. Moreover, the values of parameters of the production system can highly affect the energy balance of the production. Slurry used as a fertilizer could also improve the EROI, when distribution is optimized (Busato et al. 2013). From the above, it is evident that any estimation of energy requirements in crop production has been performed individualized and referring to a

single crop with no or limited variations on the production system practices or features. Furthermore as mentioned previously, the results of the existing works can only apply on multiple-crops and multiple-fields systems as average norms.
The work presented here deals with the energy balance assessment of production systems that involves multiple-crops cultivated in multiple-fields. This paper is the continuation of the work presented in Busato and Berruto (2014) where a web-based tool was presented for the estimation of the cost for the biomass production and transportation of multiple-crop production systems with regard to input requirements and internal operational processes. In this work, the tool is extended in order to provide in addition the energy balance of the studied systems. The work regards the adding of data bases for energy coefficients and the generation of new processes for the energy requirements estimations. The presented tool refers to the following stages of the biomass supply chain: crop cultivation, the harvesting and the handling of biomass including the transportation to the processing facilities. Any further processing of the biomass is not included.

1.1 Overall description of the system
The object-oriented language ASP.NET MVC was implemented for building the tool, combined with an SQL Server database used for the generation of the energy requirements estimation models.
The general structure of the tool is presented in Figure 1. The user has to provides a series of input data regarding the fields, crops, in-field and logistics operations, machines, and productions means. Based on these data, a number of various entities such as crop groups, field groups, and production units (a field or a field area linked with a specific crop), are generated by the tool. Then a series of processing models are applied using also a number of embedded databases.
For example, regarding the machinery input, all the inserted inputs are connected with an embedded database that provides all the operation-specific coefficients related to the operational performance of the particular machinery (set-up times, turning times, etc.) and also machinery-specific parameters (repair and maintenance coefficient, average lifetime, etc.) required for the estimation of the direct and indirect energy requirements.
Instead, in the case of the production means, a list is provided by the tool to be selected by the user. The tool determines and provides by the databases the appropriate coefficients for each one of the production means selected by the user.

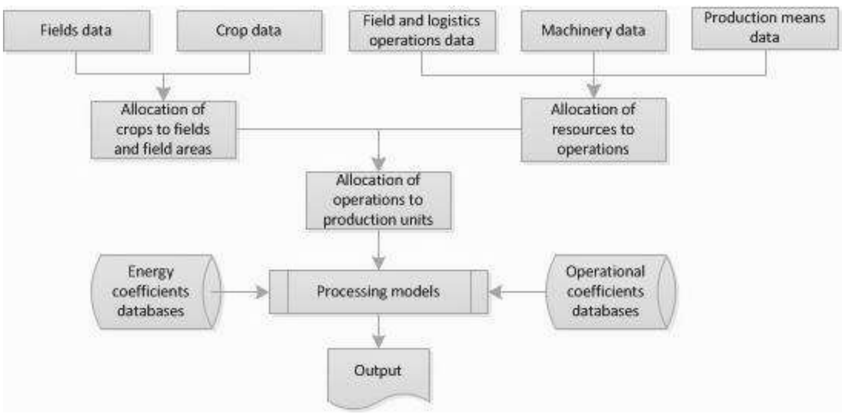

Figure 1: The overall structure of the tool

1.2 Embedded databases
The tool provides to the user a series of lists to select the inputs necessary to design the operational system (type of operations, implemented machinery, etc.) for each production unit. The embedded databases include information for 78 crops in total for which the yield range, the moisture content range, and the energy content of the dry matter are provided to the user as an indication. The embedded databases of the tool regard two types of coefficients, the operations-specifics and the energy-specifics ones. The operations-specific coefficients (Sopegno et al. 2016; Busato and Berruto 2014) are necessary to compute the time requirements for each individual operation including all time elements (e.g. turning time, preparation time in the field, loading and unloading time, etc.) and the fuel consumption requirements in the various parts of a field operation or a logistics operation. The energy coefficients regards the embodied energy per unit mass of the various resources implemented or used in the production system. All energy coefficients have been taken from the related literature (Chamsing et al. 2006; Nassiri and Singh 2009; ASAE 2009; ASAE D497.5. 2009; Hülsbergen et al. 2001; Ozturk et al. 2006; Veiga et al. 2015; Persson et al. 2009; Venturi and Venturi 2003; Nanda et al. 2008).

1.3 Case study description

A case study involving a crop production system of 80 ha that feeds a biogas plant of 200 kW was selected for the demonstration of the tool. The location of the analyzed fields is in Italy, Piedmont region, Venaria Reale at La Bellotta farm. The same production scenario presented also in Busato and Berruto (2014) has been employed here in order to be able to compare the monetary cost and the energy cost contribution of the various operations of three different crops: corn silo, wheat, and rapeseed. Corn silo is cultivated during the summer time period while the other two are winter crops cultivated during the rest of the year.

The crops are allocated to ten (10) geographically distributed fields with different areas. The field operations for each crop are listed in Table 1, while the logistics operations are shown in Table 2.

Table 1: Field operations for the various crops

	Crop					
	Silage maize		Rapeseed		Wheat	
Field operations	ID	Working speed (m s^{-1})	ID	Working speed (m s^{-1})	ID	Working speed (m s^{-1})
Fertilizing	FO1	1.1	FO12, FO15, FO16	1.9	FO21	1.9
Ploughing	FO2	1.5	FO9	1.5	FO15	1.5
Leveling	FO3	1.0			FO18	1.0
Seedbed preparation 1	FO4	1.2	FO10	1.2	FO19	1.5
Seedbed preparation 2	FO6	1.2	FO11	1.2	-	-
Planting/seeding	FO5	1.4	FO13	1.4	FO20	1.5
Pesticide spreading	FO7	1.4	FO14	1.4	FO22	1.4
Row crop operation	FO8	1.4	-	-	-	-
Harvesting	FO23	1.4	FO24	1.6	FO25	1.6
Baling					FO26	1.9

Table 2: Logistics operations for the various crops

	Operation			
Crop	ID	Loading time (min)	Unloading time (min)	Traveling speed (m s^{-1})
Corn Silo	LO1	7.5	3	F1-F3: 6.9 F4-F6: 8.3 F7: 9.5 F8-F10: 10.5
Rapeseed	LO2	92	5	F6: 8.3 F7: 9.5 F8-F10: 10.5
Wheat (grain)	LO3	82	5	F1-F3: 6.9
Wheat (straw)	LO4	24	15	F4-F5: 8.3

The average yield for the various crops was account to: corn silo: 50,000 kg ha^{-1}; rapeseed: 3,900 kg ha^{-1}; wheat grain: 4,350 kg ha^{-1}; and wheat straw: 4,800 kg ha^{-1}.

2. Results

Figure 2, 3 and 4 presents the contribution in terms of the energy input requirements of each operation, both field operations and logistics operations, for each one of the crops within the production system. This contribution regards the energy input from the machinery use and not the embedded energy of the production inputs (e.g. fertilizer) in the case of operations where such an input is involved. The field operations that present the highest contribution (FO1, FO21) are the ones related to organic fertilizer distribution. For these operations the energy requirements was amount to app. 2000 MJ ha^{-1}. This high value of the energy requirements is a result of the high amount of material that has to be transported and applied in the field in the case of organic fertilizing, which amounts, for the examined case, for 56 t ha^{-1} (for both silo corn and wheat crops). Ploughing operations have similar contribution among crops, with a slight increase for the case of

rapeseed as a result of the longer distance between the farm facilities and the fields where rapeseed was allocated.
The energy requirements in logistics operations are influenced by the transport distance, the implemented machinery system, and the amount of the product to be transported from the field to the facilities. The amount of the product is a function of the crop type and the yield. For this reason logistics operation in corn silo (LO1) requires the highest energy among the crops of the production system (2.964 MJ ha^{-1}). For the case of the wheat there are two logistics operations, one for the grain (LO3) and one for the straw (LO4) transportation. The energy requirements for both operations are low because fields are located nearby the facilities and the yield of wheat is below 5 t ha^{-1} for both products.

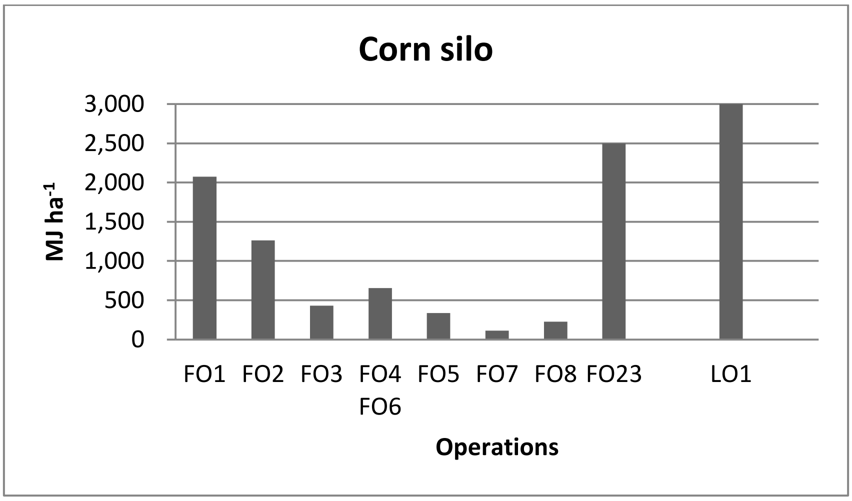

Figure 2: The contribution of the field and logistics operations for the produced corn silo

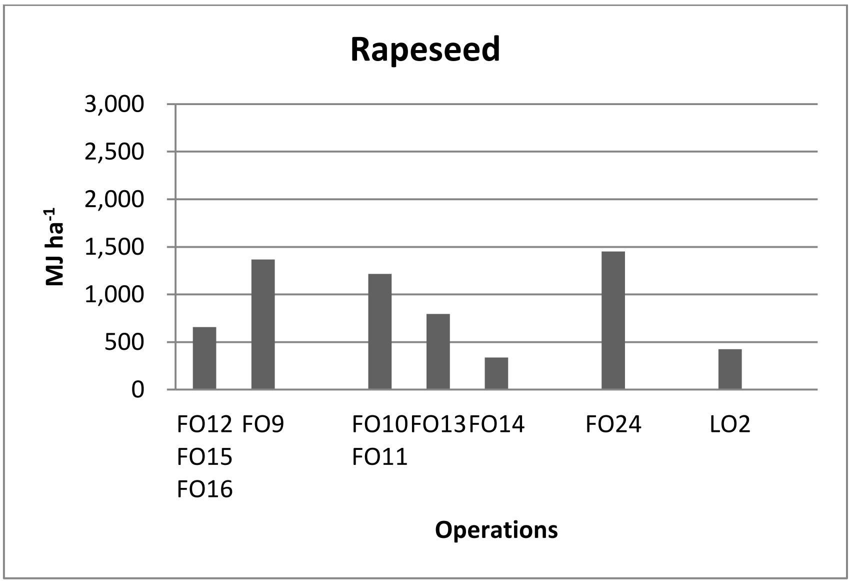

Figure 3: The contribution of the field and logistics operations for the produced rapeseed

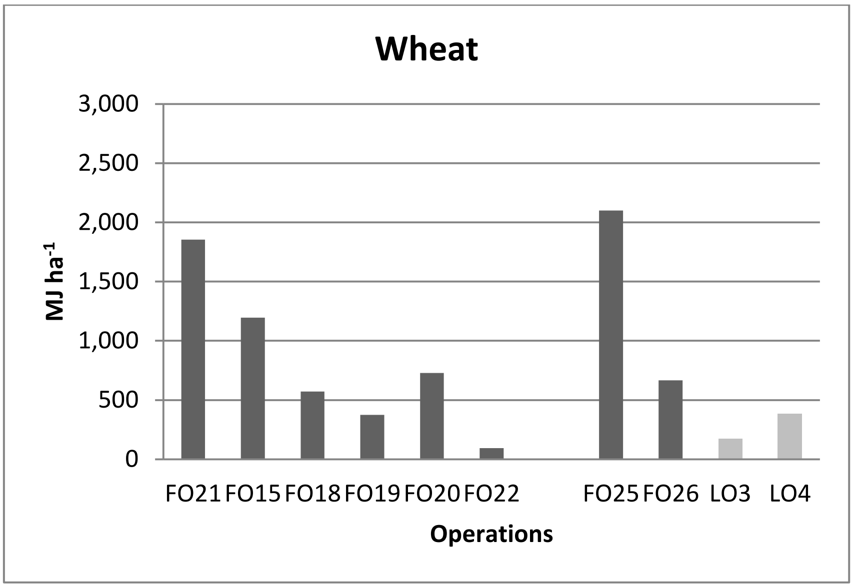

Figure 4: The contribution of the field and logistics operations for the produced wheat

The energy requirements for the production inputs are presented inTable 3. It is interesting to see that fertilizers have a high contribution in the energy input. In contrast, organic fertilizer (digestate) it is considered as a "zero energy" input because is a by-product of the biogas system.

Table 3: Energy requirements for the input resources

	Corn silo		Rapeseed		Wheat	
	Dosage (kg ha^{-1})	Energy (MJ ha^{-1})	Dosage (kg ha^{-1})	Energy (MJ ha^{-1})	Dosage (kg ha^{-1})	Energy (MJ ha^{-1})
Seeds	19	418	7.6	167	240	1080
Digestate – organic fertilizer	50,000	0			56,500	0
Fertilizer Potassium Chloride	-	-	140	784		
Fertilizer Ammonia Nitrate	-	-	176	3,467		
Fertilizer - Urea	100	3,160	130	4,108	-	-
Herbicide	2 x 4	1,837	2	588	-	-

3. Conclusions

A web-based tool for the estimation of the energy balance for the biomass production and transportation of multiple-crop production was presented. The energy input accounting regards the whole supply chain of the biomass including the crop establishment (soil preparation, seeding, planting, etc.) and cultivation (fertilizing, spraying, etc.) of the crops, the harvesting and handling of biomass, and its transportation to the processing or storage facilities. The tool takes into consideration the individual features of each production unit (i.e. a specific field with a specific crop) such as the specific machinery system, soil conditions, travelling distances, and various operational and agronomic parameters. The inclusion of these parameters provides an accurate estimation of the energy requirements for a specific system differentiating the presented tool from other existing tools that are based on average norms.

The tool can be used for the comparison of the performance in terms of energy requirements and balance between various crops, fields, operational practices and systems providing support for decisions on the biomass production system design (e.g. allocation of crops to fields) and operations management (e.g. machinery system selection). However, the accurate values of all parameters is a prerequisite for the production of qualified results by tool. Furthermore, another limitation of the tool is the absence of embedded models that could correlate the yield with the various inputs, e.g. irrigation and fertilizers, as well as the effect of the weather conditions in an area on the yield performance. The above mentioned regards issues for further research.

Acknowledgments

This work was part of the collaborative research project Bio-Energy Farm II. The research leading to these results has received funding from the Intelligent Energy Europe Programme under grant agreement no. IEE/12/683/SI2.675767.

Reference

ASAE, 2009. ASAE EP496.3. Agricultural machinery management. In ASABE, ed. *ASABE STANDARD 2009*. St. Joseph, MI, USA: American Society of Agricultural and Biological Engineers, 354–357.

ASAE D497.5., 2009. Agricultural machinery management data. In ASABE STANDARD 2009, Vol. I. St. Joseph, MI, USA: American Society of Agricultural and Biological Engineers, 360–367.

Börjesson, P. and Tufvesson, L.M., 2011. Agricultural crop-based biofuels – resource efficiency and environmental performance including direct land use changes, Journal of Cleaner Production, 19(2–3), 108–120.

Busato, P. and Berruto, R., 2014. A web-based tool for biomass production systems, Biosystems Engineering, 120 (2006), 102–116.

Busato, P., Sørensen, C.G., Pavlou, D., Bochtis, D.D., Berruto, R. and Orfanou, A., 2013. DSS tool for the implementation and operation of an umbilical system applying organic fertiliser,. Biosystems Engineering, 114 (1), 9–20.

Chamsing, A., Salokhe, V.M. and Singh, G., 2006. Energy Consumption Analysis for Selected Crops in Different Regions of Thailand, Agricultural Engineering International: The CIGR EJournal, VIII(EE 06 013), 1–18.

Gissén, C., Prade, T., Kreuger, E., Nges, I.A., Rosenqvist, H., Svensson, S.-E., Lantz, M., Mattsson, J.E., Börjesson, P. and Björnsson, L., 2014. Comparing energy crops for biogas production – Yields, energy input and costs in cultivation using digestate and mineral fertilisation, Biomass and Bioenergy, 64, 199–210.

Hülsbergen, K.-J., Feil, B., Biermann, S., Rathke, G.-W., Kalk, W.-D. and Diepenbrock, W., 2001. A method of energy balancing in crop production and its application in a long-term fertilizer trial, *A*griculture, Ecosystems & Environment, 86(3), 303–321.

Kavargiris, S.E., Mamolos, A.P., Tsatsarelis, C.A., Nikolaidou, A.E. and Kalburtji, K.L., 2009. Energy resources' utilization in organic and conventional vineyards: Energy flow, greenhouse gas emissions and biofuel production, Biomass and Bioenergy, 33(9), 1239–1250.

Liu, Y., Langer, V., Høgh-Jensen, H. and Egelyng, H., 2010. Energy Use in Organic, Green and Conventional Pear Producing Systems—Cases from China, Journal of Sustainable Agriculture, 34(6), 630–646.

Michos, M.C., Mamolos, A.P., Menexes, G.C., Tsatsarelis, C.A., Tsirakoglou, V.M. and Kalburtji, K.L., 2012. Energy inputs, outputs and greenhouse gas emissions in organic, integrated and conventional peach orchards, Ecological Indicators, 13(1), 22–28.

Nanda, S.S., Mohanty, M., Pradhan, K.C., Mohanty, A.K. and Mishra, M.M., 2008. Production potential, profitability and energy efficient rice based cropping systems for coastal Orissa, Journal of Farming Systems Research & Development, Vol. 14(1), 1–5.

Nassiri, S.M. and Singh, S., 2009. Study on energy use efficiency for paddy crop using data envelopment analysis (DEA) technique, Applied Energy, 86(7–8),1320–1325.

Ozturk, H.H., Ekinci, K. and Barut, Z.B., 2006. Energy analysis of the tillage systems in second crop corn production, Journal of Sustainable Agriculture, 28(3), 25–37.

Persson, T., Paz, J., Hoogenboom, G., Garcia, A.G.Y. and Jones, J.W., 2009. Net energy value of maize ethanol as a response to different climate and soil conditions in the southeastern USA, Biomass & Bioenergy, 33(8), 1055–1064.

Sopegno, A., Rodias, E., Bochtis, D., Busato, P., Berruto, R., Boero, V. and Sørensen, C., 2016. Model for energy analysis of Miscanthus production and transportation, Energies, 9(6).

Sørensen, C.G., Halberg, N., Oudshoorn, F.W., Petersen, B.M. and Dalgaard, R., 2014. Energy inputs and GHG emissions of tillage systems, Biosystems Engineering, 120, 2–14.

Stolarski, M.J., Krzyżaniak, M., Tworkowski, J., Szczukowski, S. and Gołaszewski, J., 2014. Energy intensity and energy ratio in producing willow chips as feedstock for an integrated biorefinery, Biosystems Engineering, 123, 19–28.

Veiga, J.P.S., Romanelli, T.L., Gimenez, L.M., Busato, P. and Milan, M., 2015. Energy embodiment in Brazilian agriculture: an overview of 23 crops, Scientia Agricola, 72(6), 471–477.

Venturi, P. and Venturi, G., 2003. Analysis of energy comparison for crops in European agricultural systems, Biomass and Bioenergy, 25(3), 235–255.