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A web-based tool for biomass production systems

This is a pre print version of the following article:

Original Citation:

Availability:

This version is available <http://hdl.handle.net/2318/149050> since 2016-11-29T16:47:18Z

Published version:

DOI:10.1016/j.biosystemseng.2013.09.002

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29 **1. INTRODUCTION**

30 Biomass production for the generation of bio-energy must adhere to economies of scale requiring
31 a large, arable area dedicated to the supply of “raw material”. This characteristic increases the
32 geographic dispersion of the fields dedicated to biomass production, which increases the need for
33 long-distance transportation. Due to the wide spatial distribution of the fields that constitute
34 biomass production areas, the transportation of biomass has to be carried out through a non-
35 uniform network. In addition, a specific order of different crops is required within the biomass
36 production system to more effectively secure the availability of raw material throughout the year
37 and to provide the raw material for different types of bio-energy production processes.

38 Research has shown that the engagement of farmers in biomass supply chain activities,
39 specifically in the collection and transportation of products [1,2], provides cost-effective solutions
40 for supply chain activities that increase the farmers’ income and reduce the ownership cost of
41 machinery because of increased usage. However, agriculture has not traditionally used formalised
42 planning tools for logistics management, and the decision-making process associated with the
43 planning remains very much implicit and internalised [3-5]. Therefore, easy-to-use tools for
44 different planning levels should be available for farmers and farm managers.

45 A number of models and modelling approaches dedicated to decision-making processes within
46 the biomass supply chain system have been introduced. In [6] a biomass logistics model to
47 simulate the collection, storage, and transport operations for supplying agricultural biomass, was
48 developed which included stochastic aspects such as the influence of weather conditions, the
49 moisture content, and the dry-matter loss of biomass through the supply chain. Taking into
50 account the same stochastic factors, in [7] the changes in quality of potash fertiliser and alfalfa
51 cubes during storage and transport have been modelled. In order to investigate the effect of queue
52 management on the system’s performance, in [8] a discrete simulation model for a country
53 elevator receiving multiple grain streams with a single unloading pit was developed. In [9] a

54 decision-support system was developed by implementing a modelling suite for determining the
55 optimal time for initiating various operations related to the harvesting and treatment of biomass
56 based on biomass moisture content predictions that incorporated the uncertainty of weather
57 conditions. A number of models have been developed for specific crop types. A GIS-based cost-
58 estimation model for the collection and transportation of switch-grass has been developed and
59 described in [10]. A discrete event-simulation model of the harvesting and transportation systems
60 of sugarcane that focused on the amortisation and efficiency of the machinery has been developed
61 in [11]. In [12] a Monte Carlo simulation to estimate the probability distribution of corn-stover
62 feedstock costs was developed using alternative assumptions for key parameters involved in
63 harvesting and transportation.

64 All of the previously mentioned approaches tackle different aspects of the system's complexity
65 (e.g., weather dependency, stochastic demands, etc.) and different functional areas of the biomass
66 supply chain (i.e., production, harvest, storage, and distribution as defined in [13]) that reference
67 single- or multiple-crop systems. Furthermore, different tools provide decision support at
68 different planning levels, such as at the strategic, tactical, and operational levels [14]. The work
69 presented here relates to the production, harvest and out-of-field transport of biomass in multiple-
70 crop production systems and focuses on detailed characteristics of the individual production units.
71 A web-based tool is presented for the estimation of biomass production and transportation costs
72 with regard to input requirements, internal processes, and output.

73 **2. SYSTEM DESCRIPTION**

74 **2.1 OVERVIEW**

75 The overall structure of the web-based decision-support system is illustrated in Fig. 1. The input
76 information is provided by the user in a series of web pages that include appropriate forms (Fig. 2
77 shows a selected input-data web-page). The input parameters are distinguished according to four
78 types: i) descriptive, ii) numerical, iii) selective, and iv) binary. The selective parameters are

79 chosen by the user from provided lists. These parameters are used by the tool for the subsequent
80 selection of various coefficients from databases included in the tool. For the user's convenience, a
81 number of the provided lists have been built by the tool during the input process based on
82 information previously provided by the user. For example, when an operation is allocated to a
83 crop (in the "field-operations" data set), the user can select the crop from the list created by the
84 system because the list includes crops that have been inserted by the user (in the "crops" data set).
85 The underlying models of the system have been developed using the object-oriented language
86 ASP.NET MVC using an SQL Server database. All the computation is performed on the server
87 side by means of a set of functions and storing procedures.

88 **2.2 INPUT**

89 The initial data sets include the general information for the production system under study, the
90 definition of the crops that will be produced and the individual fields included in the production
91 system, and the allocation of crops to field areas (Fig. 3). To produce a user-friendly input, the
92 tool allows users to insert input data in more than one form depending on either personal
93 preferences or the type of available data. For example, in the case of fertiliser application, the
94 dosage for the total area allocated to the crop to which the fertiliser is applied can be defined as
95 either t/ha or as t. Based on data that have been previously provided by the user, the tool assigns
96 the input to the appropriate unit of measurement.

97 *2.2.1 Land and crop data*

98 **2.2.1.1 "User Profile" data set**

99 The information provided in the application's "user profile" data set is limited to username,
100 password, email and language interface. Based on the country selected, the system applies the
101 appropriate databases listed by the country code, such as country-specific coefficients (e.g., range
102 of crop yield per country), energetic coefficients, and currency (e.g., EUR, DKK, USD, PLN,

103 etc.). The user can choose to remain anonymous or share information with other users based on a
104 specific key number assigned to the profiles.

105 **2.2.1.2 “Production system” data set**

106 The information provided by the user in the “production system” data set includes the numerical
107 parameters of interest rates and fuel prices and the selective parameters of the preferred currency.
108 Users can to either allow open access of their registration to other users (shared ← YES) or not
109 allow access (shared ← NO). The selection of the “frozen” binary parameter does not allow
110 changes to parameters and only permits read-only access to prevent accidental changes. However,
111 the user can de-select this feature and make any changes to the input parameters. If a production-
112 system scenario has been selected as shared, it is automatically frozen for all users except the
113 owner.

114 **2.2.1.3 “Field” data set**

115 The information for each individual field of the production system is provided in the “field” input
116 data set. The numerical input parameters provided include the field-area dimensions, the headland
117 width of the field, the distance from the machinery station or farm, and the average speed for the
118 transfer of the machinery to and from the machinery station. The field’s soil texture is classified
119 into one of three classes: fine, medium, or coarse [15]. Based on the soil texture classification, the
120 tool selects from the corresponding database the adjustment parameter used to compute the power
121 requirements and the fuel consumption of the machinery that operates in a specific field.

122 **2.2.1.4 “Crops” data set**

123 In the “crops” data set, the cultivated crops in the production system are iteratively selected by
124 the user from a list provided by the web-tool database.

125 **2.2.1.5 “Crops to fields” data set**

126 In this input-generation step, the allocation of crops to each field is determined. In this data set,
127 the user can combine crops that have been selected by the user in the “crop” data set with the
128 fields of the production system that have also been generated by the user in the “field” data set. A
129 given crop can be allocated to different fields, and conversely, a number of crops can be allocated
130 to one specific field. Each production area of a field in which an individual crop is cultivated will
131 be referred to as a “production unit”. For this reason, the area of a field that is allocated to a
132 specific crop is defined by a numerical parameter. The other numerical parameters that are
133 defined in this data set are the distance between the field and the destination of the crop (e.g.,
134 processing plant) and the year of rotation. The year of rotation applies to perennial crops (e.g.,
135 Miscanthus, meadows, and short-rotation forestry).

136 2.2.2 *Resource data*

137 In the next step, information relative to the resources used in the production system, including
138 manpower, machinery, allocation of manpower to machinery, and productive means (Fig. 3), is
139 provided by the user.

140 2.2.2.1 **“Manpower” data set**

141 In the “manpower” data set, the user assigns a cost to each type of labour used in the production
142 system. The labour types include family, seasonal, and specialised and can be selected from a list
143 provided by the tool.

144 2.2.2.2 **“Tractors” data set**

145 In this data set, the parameters of the available tractors for the production system are uploaded to
146 the web tool. Each tractor is identified by the numerical parameters of purchasing cost, power,
147 and time used for other activities not related to the production system under consideration. The
148 latter information is used in the calculation of the fixed cost of the tractor and takes into account
149 the actual annual use of the tractor. The vehicle type (2-wheel drive, 4-wheel drive, and crawler
150 type) is also defined. The selections within this data set provide the correct coefficients required

151 to compute the fixed and variable costs (e.g., the lifetime of the tractor, repair and maintenance
152 coefficients, insurance cost, settled cost, etc.).

153 **2.2.2.3 “Machinery” data set**

154 In the “machinery” data set, the web tool provides the user with a selection of machines used in
155 the production system. Similar to the tractor data set, the machinery types listed in this data set
156 are connected with a database that provides all the correct coefficients for the calculation of fixed
157 and variable costs and the data related to operational performance (e.g., turning time, loading
158 time, set up times, etc.). Self-propelled machines, including combine harvesters, forage
159 harvesters, self-propelled sprayers and organic liquid fertilisers, committed in the production
160 system (if any) are also defined. A machine is identified by the value of purchasing cost, working
161 width, hourly use for other activities, hopper capacity and type (in the case of input and output
162 material flow operations), and power (in the case of the self-propelled machines). Up to four
163 hopper types can be defined for an individual machine: fertiliser, herbicide, insecticide, and seed
164 or grain for planting or harvesting, respectively. Finally, a labour type is allocated to each
165 machine from the list created in the “labour” data set. In the machinery data set, the tank capacity
166 of equipment devoted to logistics operations is not considered as an input parameter since it
167 depends on the type of transported crop.

168 **2.2.2.4 “Productive means” data set**

169 Each productive mean is identified by the value of the cost. The tool database provides a list of
170 potential productive means. However, the user can add a productive mean if it hasn't been
171 included in the database. In addition, for each of the pre-existing productive means, the tool
172 provides a number of available product names.

173

174

175

176 2.2.3 *Operational data*

177 Operational data refers to information related to field operations and logistics operations and
178 includes the allocation of machinery to these operations and the assignment of these operations to
179 different production units (Fig. 4).

180 **2.2.3.1 “Field operations” data set**

181 For each productive unit, a number of operations are defined. Each operation is characterised by a
182 set of attributes that describes the operation’s allocated “entities”, which include the tractor or
183 self-propelled machine applied in the operation, the implement (machine) to carry out the specific
184 operation, the crop types to which this operation is applied, and the associated production units.
185 These “entities” are provided by the tool in the lists created during previous stages of data
186 insertion. In order to expedite the insertion of the data, when an operation is assigned to a crop,
187 the tool assigns this operation to each production unit of the specific crop by default.

188 The numerical input parameters for each field operation are the operating speed, the working
189 width, the number of repetitions (passes), the skipped area (the distance between what is skipped
190 between two sequential field-work track traversals of the machine where a zero value corresponds
191 to complete area coverage), the number of the labours committed to the operation, and the labour
192 coefficient (the ratio between the total working time of the labour and the working time of the
193 machine). The working width entered in the field operations data set is not necessarily the same
194 as the working width in the machinery data set. The former provides the effective working width.
195 The system, however, provides by default the number of the theoretical working width (pre-
196 selected) that has been stored during the “machinery” data set completion.

197 **2.2.3.2 “Logistics operations” data set**

198 The logistics operations data set consists of three operational tasks: loading/unloading at the field
199 (e.g., loading bales on a trailer and unloading organic fertiliser to the in-field application unit);
200 loading/unloading at a destination point (farm or biomass plant); and transport. A logistics

201 operation is characterised by a set of attributes that includes the type of tractor applied to a
202 specific logistics operation, the machine (transport wagon, loader, etc.) that transports the crop,
203 and the associated production units. The general numerical input parameters are the transport
204 speed, the total quantity to be transported, the load per trip, the loading/unloading time in the
205 field, the loading/unloading time at the destination (farm or plant), the number of the labour types
206 committed to the transport tasks, and the labour coefficient. When the machine does not carry out
207 one or two of the tasks (e.g., the transport task in the case of a loader), the tool does not request
208 any parameter related to these tasks (e.g., the transport speed, load per trip, etc.). The product
209 description refers to the section of crop such as the straw or grain that is transported.

210 *2.2.4 External services and income data*

211 In this step, any relevant information concerning any external service cost (e.g., drying) and
212 product sale is provided to the tool (Fig. 5).

213 **2.2.4.1 “External services” data set**

214 In this data set, the tool provides a list of external services that are allocated to crops. For each
215 service type, a cost is assigned as either a unit cost (€/ha) or a total cost for the crop (€). By
216 default, all the production units of the selected crop are assigned to the service. However, the user
217 can de-select certain production units that are not assigned to the service.

218 **2.2.4.2 “Product sales” data set**

219 Income can be derived from either direct product sales or subsidies. For each type of crop, a
220 number of by-products, such as grain, straw, and crop residues, could be exploited. For each of
221 the main products and by-products, the value of the sale price and the subsidy (if any) per unit are
222 uploaded to the system. When the user defines a production sales data set for a crop, the tool uses
223 this data for all production units of the specific crop by default. However, if more than one level
224 of production exists for different production units of the same crop in the production system (e.g.,

225 rain-fed vs. irrigated fields), each level of production has to be entered as a different production
226 sales data set.

227 **2.3 STORED DATABASES**

228 Embedded in the tool are a number of lists provided to support users when inserting the input data
229 sets. These lists include external service-type expenses, manpower type, product type (e.g., hay,
230 corn grain, corn stover, etc.), productive means (e.g., type of fertiliser, herbicide, fungicide, and
231 insecticide), and tractor and machinery type (e.g., seed bed preparation machinery, ploughing
232 machinery, fertilising machinery, etc.).

233 In order to avoid errors during the input data insertion, the tool includes a number of preventative
234 measures. For example, all numerical inputs have predefined ranges. When the user defines the
235 speed of an operation, the tool uploads from the embedded national database the correct range of
236 operational speeds for the machine selected to carry out that operation. Another preventative
237 measure requires that the measurement units be selected based on category. If the user chooses
238 fertiliser in the “production means” data set, the unit prices are assigned by fertiliser type (e.g., €/t
239 or €/kg for nitrogen-based fertiliser or herbicide, respectively).

240 Finally there are a number of tables providing values of coefficients involved in the estimation of
241 the working time, machinery and tractor costs (specifically for the estimation of the fuel
242 consumption), and repair and maintenance costs. Details on these data sets are given in the
243 following section.

244 **2.4 PROCESSES**

245 *2.4.1 Working times calculations*

246 Initially, a process for the standardisation of the units of measurement is established (PW1) (Fig.
247 7). Establishing this process is essential because various unit options are provided to the user for
248 selection. The tool transforms all of the units into a standard internal unit-measurement system.

249 The first required step is the estimation of the working time of each operation (including field
250 operations and logistics operations) in each production unit (PW9) (Fig. 7). The calculation of the
251 working time in the case of field operations (PW8) includes two types of task times: the effective
252 in-field operation time (PW5), and the non-effective time (PW6) that is the ancillary times for in-
253 field operations that includes times for loading/unloading (in the case of the material handling
254 operations), machinery adjustments, travel from the machinery depot to the production unit, and
255 the non-productive time that is allocated for headland turnings and manoeuvring. The effective
256 time is estimated by calculating the working travel distance (based on the number and length of
257 field-work tracks), the operating speed and the skipped fieldwork track intervals (as provided by
258 the user in the “operations” data set). The estimation of the non-productive time during turnings
259 in a specific field for a specific operation is based on the calculation of the number of turnings,
260 which is a function of the machine’s working width and the field geometry, and corresponds to
261 the specific machine turning time per turning from the embedded tool database. Other embedded
262 tool databases used for the estimation of the field-operations working time include the time for in-
263 field machinery adjustments and the time per loading/unloading tasks for the specific machine
264 type.

265 In the case of the logistics operations (PW7), the operational time includes sub-task times for
266 loading/unloading in the field, the loading/unloading time at the destination (i.e., farm, bioenergy
267 plant, or storage facility), and transport times for both full tanker transport (from the production
268 unit to the material transport destination) and empty tanker transport (from the material transport
269 destination to the production unit). The transport time is a function of the transport distance and
270 speed, the quantity of the product that has to be removed (as provided by the user in the logistics
271 operations data set), and the capacity of the transport unit in terms of the specific product (as
272 provided by the user in the machinery data set). The transport distance depends on the selection
273 by the user of the transported material destination (or origin in the case of material input
274 operations). In the case of logistics operations, there are three cases that depend on the machinery

275 type: when the machine is used solely for the transport task, when the machine is used solely for
276 the loading/unloading task, and when the machine is used in both transport and loading/unloading
277 tasks. For the case of cooperating machinery (primary units and transport units) in material-
278 handling operations (seeding, harvesting, organic fertilising, etc.), both field and logistics
279 operations are performed. In the case of the logistics operations, there are no default data in the
280 database because of the large number of different products that can be carried (e.g., round bales,
281 large rectangular bales, corn silos, wheat grain, organic fertiliser, etc.).

282 2.4.2 *Labour cost*

283 The labour cost for an operation in a production unit is estimated based on the working time of
284 the operation, the assignment of the labour type for the machine carrying out the specific
285 operation, the associated hourly cost, and the labour co-efficient.

286 2.4.3 *Machinery cost*

287 A specific feature of the developed tool is the estimation of the actual annual cost of the
288 machinery, which also includes the hours that the machine is used inside and outside of the
289 production system under study. This means that each time an operation is added, the total annual
290 use of the machine is re-calculated, and consequently, the machine's fixed and variable hourly
291 costs are re-calculated. In order to perform the calculation, the total working time that a given
292 machine is committed to all production units has to be estimated (PM1). Based on the total
293 working time, the annual use of the machine (PM2) and the lifetime of the machine (PM3) is
294 estimated, which allows the tool database to assess the total lifetime in hours of the given
295 machine type.

296 In the next step, the fixed and variable machine costs are estimated. The fixed cost (interest and
297 depreciation cost) is estimated based on the amortisation method given in [15] as a function of the
298 machine lifetime, the annual interest rate, the ownership cost factor for taxes, housing, and
299 insurance, and the salvage value of the machine at the end of its lifetime. The variable costs of the

300 machine refer to the repair and maintenance costs because the other two aspects of the variable
301 cost, the labour and fuel costs, are estimated separately. For the calculation of the accumulated
302 repair and maintenance costs for the machinery used in field and logistics operations, the equation
303 given by Agricultural Machinery Management Data ASAE Standard D496.3 ([16]) has been
304 applied. For ease of use, the tool provides a database of repair and maintenance factors [15].

305 The same steps are also followed for estimating the total variable and fixed costs of the tractors
306 (PM1, PM7, and PM8). For self-propelled machines, only the machine cost is estimated.

307 For the estimation of the fuel consumption, the equation for measuring specific volumetric fuel
308 consumptions given by the Agricultural Machinery Management Data ASAE Standard (ASAE
309 D497.6, 2009) was used. The following data are provided by the tool:

- 310 - The tractive efficiency (built upon ASAE D497, Clause 3, [15]) required for the
311 operation that is needed for the estimation of the equivalent power-take-off (PTO).
- 312 - The rotary power requirement parameters for the estimation of the required power take-
313 off (PTO) for the implement (built upon ASAE D497, Table 2, [15]).
- 314 - The soil texture adjustment parameter (built upon ASABE D497, Table 1, [15]) for the
315 estimation of the implement draft for the specific soil category selected by the user in the
316 field data set.
- 317 - The machine parameters (built upon ASABE D497, Table 1, [15]) for the estimation of
318 the implement draft selected by the user machinery in the machine data set.

319 2.4.4 *Economic balance*

320 Finally, all costs associated with a production unit (machinery cost, productive means cost, and
321 external services cost) are gathered, and for perennial crops, this cost is actualised. The income is
322 also actualised, and the margin for each production unit is estimated.

323

324 2.5 OUTPUT

325 Table 1 lists the output parameters of the tool. In the output of the tool for an individual crop,
326 partial expenses of the production system, which include the operations cost (the summation of
327 all operations carried out for all production units of the specific crop), the service and productive
328 means costs (the summation of all service and productive costs incurred in all production units of
329 the specific crop), and the manpower cost (the summation of all manpower costs associated with
330 production units of the specific crop), are provided. The margin resulting from the subtraction of
331 the cost of total expenses from the total product sales and subsidies is also provided. The system
332 is also able to provide the same output for each individual production unit of a crop, which is very
333 useful for making comparisons of different production strategies for the same crop.

334

335 3. CASE STUDY

336 To demonstrate the tool's utility and capability, a case study of a real production system is
337 demonstrated. The case study refers to a production system of 120 ha that uses 80 ha area for
338 running a 200 kW biogas plant. The production system includes fields scattered at different
339 distances from the farm (Fig. 8; Table 2).

340 The yearly rotation is considered equal for all of the fields because only annual crops are included
341 in the present study. The fields are cultivated with corn silo in summer and are partly cultivated
342 with wheat and rapeseed in winter. In total, 80 ha of corn silo, 19.5 ha of wheat, and 20.5 ha of
343 rapeseed are cultivated in the production system. According to the followed practice, two
344 varieties of corn silo were planted to allow for a longer harvesting period. As can be seen from
345 Table 3, approximately half of the area after harvesting is seeded with a winter crop (wheat or
346 rapeseed).

347 Three tractors are assigned to the production system and used exclusively in the system (i.e., no
348 hours spent for other operations or services to other production systems). The manpower is just

349 family, and no price is stated because the manpower belongs to the farmer's income. It is
350 possible, however, to assume a real manpower cost to estimate the profit for the farm. With the
351 exception of the combine and forage harvester and the baling of the straw, the farmer owns the
352 equipment required to carry out all operations. This machinery is hired as a service, and the
353 corresponding costs are considered external costs. It should be noted that the capacity of the
354 trailers/wagons is stated during the logistics operation because that operation depends on the
355 moisture content of the crop and the material density (e.g., loose vs. pressed material, etc.). Only
356 machines with a tank have a specific capacity because the product to be distributed is known.

357 For each operation, the production means (e.g., fertilising) and the production units of the crop
358 were inserted when needed. Similar to the field operations, the logistics operations are carried out
359 by defining the tractor and equipment used and the loads carried out during each trip. The yield
360 per ha determines the number of trips per field and the working times.

361 **3.1 MODEL RESULTS**

362 As mentioned above, the web tool provides two types of output tables. The first is the average of
363 each individual crop (3 output tables in total) and the second is the output for each individual
364 production unit (10+5+5=20 output tables in total). The average of the corn silo crop is presented
365 in Table 7, and the output for the wheat production unit in field 4 is presented in Table 8. Table 7
366 presents the average result for the corn silo crop from all the production units with this crop as
367 provided by the web tool. Presented for each operation are the day of operation, as provided by
368 the user, the area upon which the specific operation has been applied (in the second bracket), the
369 tractor and machinery used, the type of the manpower and the calculated operational time per ha
370 for labour. Table 9 provides the summarised results for all types of crops and production units.

371 An important aspect to be considered is the variability of the results between the different
372 fields/production units. For the total expenses, the average total cost of corn silo was estimated at
373 28.95 €/t, with a standard deviation of 1.57 and a range of 4.34 €/t; the average total production
374 and transport cost of wheat grain was estimated at 133.89 €/t, with a standard deviation of 5.25

375 and a range of 13.43 €/t; the cost of wheat straw was estimated at 47.82 €/t, with a standard
376 deviation of 1.88 and a range of 4.8 €/t; and the average cost of rapeseed was estimated at 164.49
377 €/t, with a standard deviation of 6.46 and a range of 14.86 €/t. These variations are a result of the
378 operational costs (both for field and transport operations). For corn silo, the variation is translated
379 to 217 €/ha (assuming 50 t/ha yield) and demonstrates the importance of incorporating
380 geographical variability of the production system, which diversifies the transport-operations cost,
381 and field characteristics such as the soil conditions, which diversifies the field-operations cost.
382 The diversification of average-estimated values would be even greater if different cultivation
383 systems (e.g., reduced tillage) were adopted for the same crop in different production units.

384

385 **4. CONCLUSIONS**

386 A web-based tool for simulating the production, harvest, and out-of-field transport of biomass in
387 multiple-crop production systems for feeding bio-energy plants was developed and demonstrated.
388 The detailed consideration of the characteristics of the individual production units with regards to
389 distance from associated facilities, soil conditions, machinery systems, and labour types can
390 provide an accurate assessment of the system under consideration. The tool can also support
391 decisions at different planning levels. By testing alternatives, the tool can support decisions on the
392 strategic level (e.g., number and dimensioning of machines, machine capacity, crop selection, and
393 labour requirements), the tactical level (e.g., fertiliser/chemical application plans, and labour
394 budgets), and the operational level (operations specifications).

395 **5. ACKNOWLEDGMENTS**

396 This work was part of the collaborative research project BioEnergy Farm. The research leading to
397 these results has received funding from the Intelligent Energy Europe Programme under grant
398 agreement no. IEE/09/637 SI2.558213.

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