Simulating the transport performance of online traded biomass

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Abstract

Recently proposed approaches for biomass networks rely on efficient algorithms for automated procurement of offered and requested biomass. Automated procurement for optimal network formation on online biomass exchanges is presumed to be superior to manual search with regard to different objectives. Especially, a great potential is seen in case of many-to-many trade relations for a better exploitation of this scarce resource in cascading processes. For this reason, establishing sustainable inter-connected networks for biomass flows is one goal of automated procurement. Another goal is the optimization of higher-level objectives like minimizing overall transport effort and therefore CO_2 emissions.

Therefore, we have started evaluating the applicability of such approaches to biomass networks. In this paper we describe the general setting of the scrutinized scenarios as well as some first results.

1. Introduction

The use of biomass currently gets an increasing importance: as a substitute for fossil fuels as well as a source of energy and materials for chemical products. This increasing demand for non-food applications competes with the maintenance of crops as the most important feedstock for food and feed. Additionally, biomass is not an inexhaustible commodity, but has to be exploited in a way that different basic needs are fulfilled while the full potential is completely taped. Thus, intelligent management strategies are required for linking producers and consumers with intermediate preprocessing actors so that superior sustainability objectives are achieved. At this point, a need for information technology support arises since complex cross company concerns have to be managed, linked and optimized.

Biomass logistics has to satisfy the needs of a great number of participants in a global optimal way, i.e. for the benefit of all players. The term player here involves more than just the participants of one single chain. Apart from directly involved players (producers, consumers, third-party logistics provider, etc.) stakeholders like municipalities claim their interests, too. Regarding the multiple applicability of biomass, players from competing chains have to be taken into account. As biomass is often waste and raw material at the same time, forward and reverse logistics start mingling. A scarce resource needs for an intelligent control of the material flows from a global point of view.

Compared to other research sectors in the field of biomass, only a few models for optimizing flows for biomass logistics (e.g. Vlachos et al., 2008; de Mol, Jogems, van Beek, & Gigler, 1997) or finding and dimensioning optimal sites (cf. Velazquez-Marti & Annevelink, 2008) have been developed so far. Some models estimate the potential of biomass and/or transport costs (e.g. Suurs, 2002), but do no optimizing. In general, the majority of research in the rapidly growing field of biomass for energy production focuses either on mere technological or on ecological issues. The field of biomass supply chain management and biomass logistics is still rather scarcely scrutinized (Vlachos et al., 2008).

Optimization of biomass flows and network structures is currently mostly reduced to a linear programming problem which can easily be solved with the help of readily available software packages. On the other hand, such a treatment of the problem is only suited for rather static and simplified scenarios. In this way, an optimal supply chain is determined in advance. Environmental considerations seldom play a significant role in such models. Optimizing biomass networks is a task that has to consider multiple objectives at the same time: Every player along the chain wants to have his fair share of benefit (a Pareto optimal situation in itself). Diekema, de Mol, Annevelink, & Elbersen (2005) list six different goals, which can be summarized to maximizing financial and energy profit. Sustainability issues are not addressed in the first place, in contrast to our approach.

The scarce resource land has to be shared and fairly split up between competing use cases. Environmental and socio-economic issues have to be assessed and added to the cost functions. Focusing on static network structures is a major drawback, because such networks are not flexible enough to continuously adapt to changes in conditions or circumstances without having to determine a completely new and different supply network from scratch. Flexibility is a major prerequisite for a robust operation of the network. New and unforeseen upcoming events (including new demands or offers) should be capable of being integrated into existing networks, pushing them towards the new situation in an optimal way. An active biomass network will be a dynamic structure. So, optimality must be defined over time and include considerations about (seasonal as well as strategic and durable) change of structure and flows (quantity, quality and directions). The resilience of a found solution will be another quality criterion. This leads to a far more complicated optimization problem for which new solutions are to be developed.

As a start, we will deal with the aspect of algorithmic support for bringing offers and requests together. Besides the applicability of these algorithms we are interested first and foremost in global, environmental impacts resulting from the trading networks that build-up on the respective procurement approach. As indicator for the environmental impact of different procurement procedures we are currently using the resulting transportation effort, but we are aiming at an integration of respective environmental performance indicators as soon as new integration standards like the one that is currently developed in the OEPI project (www.oepi-project.eu) are available. In addition, different prices that different players have in mind will have to be taken into account, too. In this way, individual benefits will lead to competing objectives that have to be solved in a multi-criteria optimization.

Most conventional internet based systems for the exchange of biomass act as blackboard systems. They commonly allow for posting (mostly free-) text based advertisements without structured annotations of the data entered. Due to the unstructured description of offered goods, the search for suitable advertisements can only be done manually by text based searching. Hence, complex queries, which involve more qualified conditions, cannot be formulated and, due to homonyms, synonyms, and typing mistakes the search returns only a subset of the suitable offers. The same holds true for requests, where the quality of suitable offers depends on the intended purpose, especially on the transformation process, which requires these materials as input.

Manually exploring such an information system of supply and demand advertisements does not guarantee a distinct identification of dependencies and thus no optimal matching between supply and demand, neither with respect to single advertisements nor to the formation of a network of purposive collaboration between users of the system.

As soon as the data of these advertisements is captured in a semantically enriched way, which allows for a computerized understanding and processing, an algorithmic approach for connecting offer and demand becomes possible. Such a capturing and persisting of relevant characteristics, applicability and assessment criteria as meta-descriptions allow for vast possibilities of knowledge discovery and therefore semantic linkage. First of all, matching offers and requests are mapped automatically for an efficiently linked net-

work design. The automated matching of offers and requests uses e.g. material traits, temporal conditions, transportation costs and other available economic, ecologic and social aspects as basis of decision-making. As a second step this local matching has to be extended by a global optimization approach, which allows for having a look at energy efficiency, ecological rucksack and other higher-level optimization objectives. Businesses usually analyze their environmental impacts and material flows in production and logistics by means of isolated systems. By integrating sustainability issues from different isolated systems into a holistic CEMIS (cf. Rapp & Bremer, 2010) impacts may additionally be analyzed from a global point of view.
An appropriate algorithm for automated procurement has to meet different requirements:

- Scalability for large numbers of participants,
- Applicability to different objectives and
- Integration into a procedure for compromise finding between different objectives.

Therefore we are looking for a way of testing and evaluating different optimization algorithms within simulated biomass network scenarios. This paper covers the setup of the currently scrutinized scenarios as well as some results for a first approach to automate biomass procurement. As this research has just started out, in this paper we will limit ourselves to show that there is indeed a positive effect that valuates further research and development.
We will start with a description of the used scenarios and how they are simulated. Afterwards two procurement procedures are outlined in greater detail. Their application to the above mentioned scenarios is presented in the results section. We conclude with an outlook on further work.

2. Scenarios and Simulation

For comparison of different approaches, scenarios with randomly generated sets of offers and requests are used. In a next step each procurement procedure is applied to these scenarios. Because of the stochastic nature, each simulation is rerun multiple times.
As has been said, biomass players are generated randomly. In our scenarios, there is a fifty percent chance for them for being an offerer or a requester respectively. The amount of offered or requested biomass is equally distributed between 200 kilograms and 5 tons. Each player is situated within a region of a given size. So far, we have mainly focused on regional areas of approx. 300 km^2 in size. For setting up the simulation environment, these scenarios are partly toy examples with arbitrary chosen parameters, which will be replaced by real world ones in future. The place where offered biomass is situated, or requested biomass is needed (starting- and endpoint of transport) is randomly generated. Two variants are considered: situations where all players are equally distributed over the area and situations where the players are more or less clustered with a simulated higher density at certain (near built-up areas) places.
As a location for the scrutinized scenarios, a rural region situated south-west of Oldenburg, Germany has been chosen. This region comprises several (depending on the scenario size) municipalities around the small town of Friesoythe, some rather small forests, villages as well as mostly agricultural areas. It is intersected by the Coastal Canal with only a limited number of bridges available. The road transport infrastructure consists mainly of B-roads and few state roads, but without any highway. Railway transport is not considered due to the rather small area size.
Simulation is done by applying each procurement method to a scenario. This results in a matrix that determines the amount of material that has to be carried for each pair of vendor and consumer. From this transport matrix, several performance indicators can be derived for a comparison of different scenarios or different procurement methods. We currently use the following ones:

- Transport performance, the product of transport distance and transported freight volume (mass).
- Aggregated transport distance as a measure for the overall traffic volume that is perceived by not involved people.

- Satisfaction of offers and requests: the ratio of offered/requested amount and actually procured amount as an indicator for the acceptability of the procurement result.

Because of the stochastic nature of the generated scenarios, each simulation is run multiple times.
The simulation has been developed using Java as programming language. A procurement approach for a problem related to the one considered here, using Vogel's approximation (Reinfeld & Vogel, 1958), has formerly been developed for use in recycling networks (Bremer et al., 2007). In order to reuse some components, further development will therefore also be done in Java. Distance for transport is determined in terms of road distance by calculating a shortest route between two biomass players. Routing is done with the help of the OSMNavigation library, which is working on top of OpenStreetMap (http://www.openstreetmap.org). The depiction of maps and calculated routes was realized by using OpenMap^{TM} (http://openmap.bbn.com).

3. Procuring Biomass

With the term procurement, we here refer to the process of bringing offers and requests together. In practice, this means that each request has to find an appropriate offer and vice versa. This task can be achieved in different ways. We will here explore two different procedures for comparison:

- A simulated manual procurement that imitates the traditional approach without any algorithmic support. This approach will serve as reference.
- An automated procurement based on Vogel's approximation proposed in Bremer et al. (2007) for recycling networks.

3.1 Manual Procurement

The manual procurement is currently simulated by a request-driven scenario in which requesters are searching for appropriate and sufficient offers. In this way, a requester is scanning linearly through the list of offers, looking for the first offer that satisfies his request. If none of the offers is sufficient with respect to quantity,, the biggest available offer is taken. Then, the procedure is repeated for the remaining requested amount until the requested amount has been satisfied or no further offer is available. In order to have comparable offers, prices are neglected. In the same way, it is assumed, that the priority of each requester is to find enough input for one's own production processes without paying attention to environmental considerations. This also implies that no attention is paid to the location of an offer and hence to the transport distance. If more requesters are searching, then they are served in random order.

3.2 Vogel's approximation

The algorithm for automated procurement, which is used here for a first comparison with the manual approach, is based on Vogel's approximation. Just some short notes on the algorithm are given here.
Vogel's approximation operates on a cost matrix $C \in M(m \times n, \mathbb{R})$, where m is the number of offers and n the number of requests. An item $c_{ij}; 1 \leq i \leq m, 1 \leq j \leq n$ denotes the costs that arise if offer A_i from the set of biomass offers is matched with request N_j from the set of biomass requests. The costs are determined by a cost function k as $c_{ij} := k(A_i, N_j)$. Function k can be any function that determines the resulting costs based on the information provided by the corresponding offer and request. Function k may reflect transport costs or environmental impact and may be based upon the current location, the distance to be driven or the means of transport.

After solving the transport problem, a matrix $G \in M(m \times n, \mathbb{R})$ is available, where g_{ij} represents the transport volume (exactly the amount procured betweeen offer A_i and request N_j). The available (from A_i) and demanded (by N_j) amount is taken into account as a constraint. Other constraints like restrictions on transport are also possible.
Vogel's approximation aims at reducing matrix C. In each row or column the smallest element (of the respective row or column) is subtracted from each other element in that series (row or column), such that each row and each column contains at least one element equal to 0. In addition, two vectors d_z and d_s are calculated, containing the difference between the two smallest elements for rows (d_z) and columns (d_S). This allows for a rating of the zero elements, because such elements c_{ij}=0 with a large difference to the next higher costs imply higher possible savings at a total cost level.
The approximation requires the following steps:

1. Calculate the differences d_z and d_s.
2. The series R with maximal difference $d \in (d_z \cup d_s)$ is chosen. The smallest element $c_{ij} \in R$ determines the corresponding element g_{ij} that is assigned the maximal possible amount subject to the constraints.
3. A row (offer is completely procured) or column (request is completely satisfied) or both can be marked if the constraints are satisfied. That means they are excluded from the subsequent calculations.
4. As long as a series with more than one non-marked element exists, go to 1.
5. At last the remaining offers are shared between the remaining unsatisfied requests, corresponding ascending c_{ij}.

Vogel’s approximation does not guarantee an optimal solution, but often obtains one for small to medium sized problems, which can be expected here.
The strength of this approach is that constraints might be easily integrated. Originally, this method was intended for use with constraints comprising transport capacities. However, constraints concerning the applicability of the offered biomass can be treated in the same way. For example, nitrogen from animal farm manure must not exceed an application limit of 170 kg/ha (Biberacher et al., 2009).

3.3 Example

Figure 1 shows a comparison of both approaches: manual search on the left hand side, automated procurement on the right. Depicted is – so to speak – a snapshot from the simulation with a single generated scenario after both procurement procedures have been applied. From these resulting networks, transport indicators are derived for scenario evaluation. For each simulation, ample of such scenarios are generated in order to gain statistically firm results.

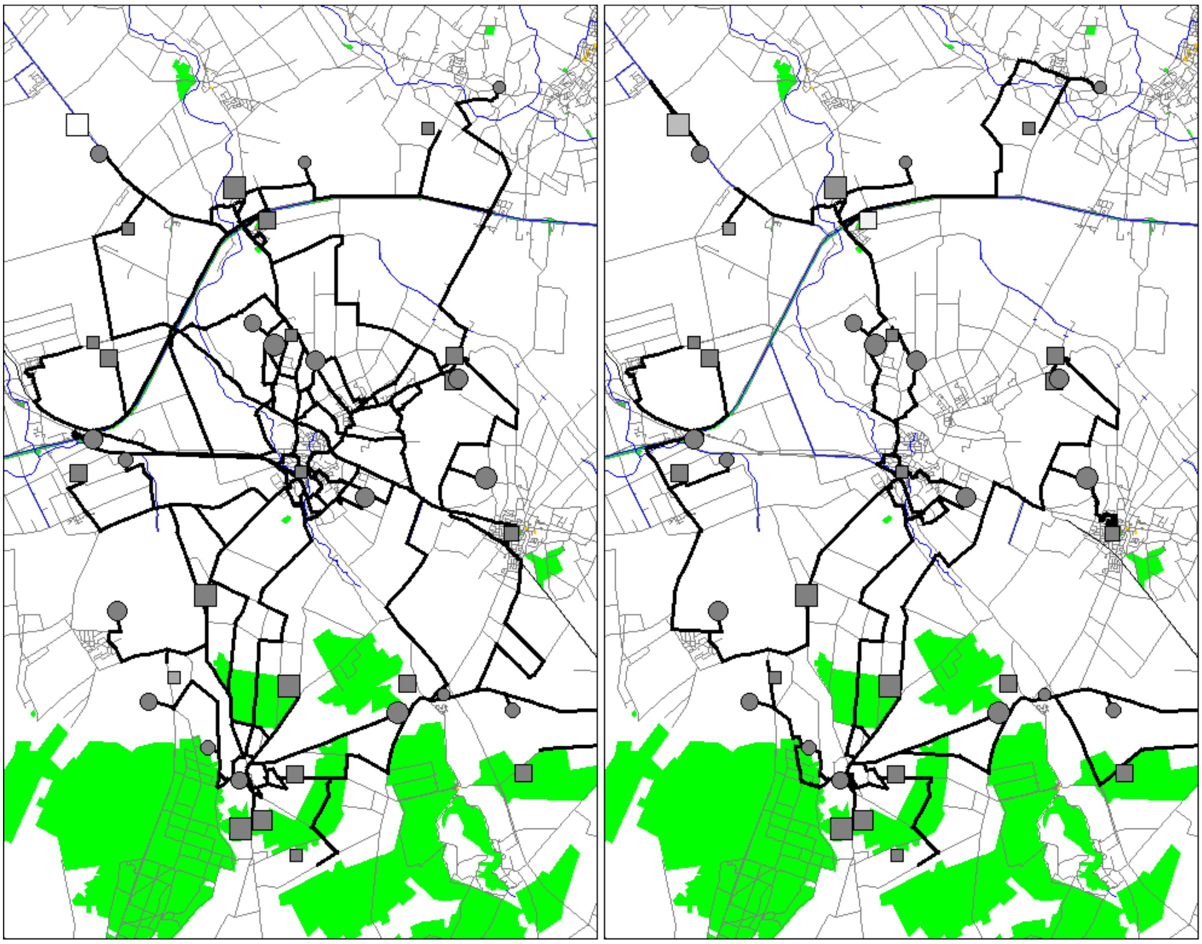

Figure 1: Comparison of transport networks (thick lines) resulting from different procurement strategies: A dense transport structure arising from manual search on the left and a more sparse structure based on automated procurement. Circles depict the location of biomass offers, squares represent requests. The size reflects the amount of biomass; a lighter color denotes a poorer satisfaction. Shaded areas depict forests.

4. Results

In this section some first results are presented. The basic setting of the used scenarios has already been outlined in section 2. Each scenario comprises vendors and consumers with randomly generated amount and locations near Friesoythe.

For the first simulation the number of participants varies from 10 to 100. For each number of participants various runs have been carried out. Within each run both methods of procurement have been applied to the generated set of vendors and consumers. For the resulting transportation networks transportation performance, as an indicator for the procurement quality, has been calculated as:

$$TP = \sum_{i=0}^{n} d_i \cdot m_i \,,$$

for n transports with d_i denoting the distance of the i_{th} transport route and m_i denoting the carried amount. In the case of automated procurement d_i and m_i may be directly taken from matrices C and G.
With the help of this indicator both methods are compared. Figure 2 depicts the differences in transport performance depending on the number of players within the biomass network. The depicted improvement denotes the percentage decrease of transport performance by using the automated procurement. Whereas the overall transport performance rises with growing number of participants, the possible improvement asymptotically approaches an upper bound (in this simulation of approx. 70 percent). The results for the aggregated transport distances are quite similar and have not been depicted.

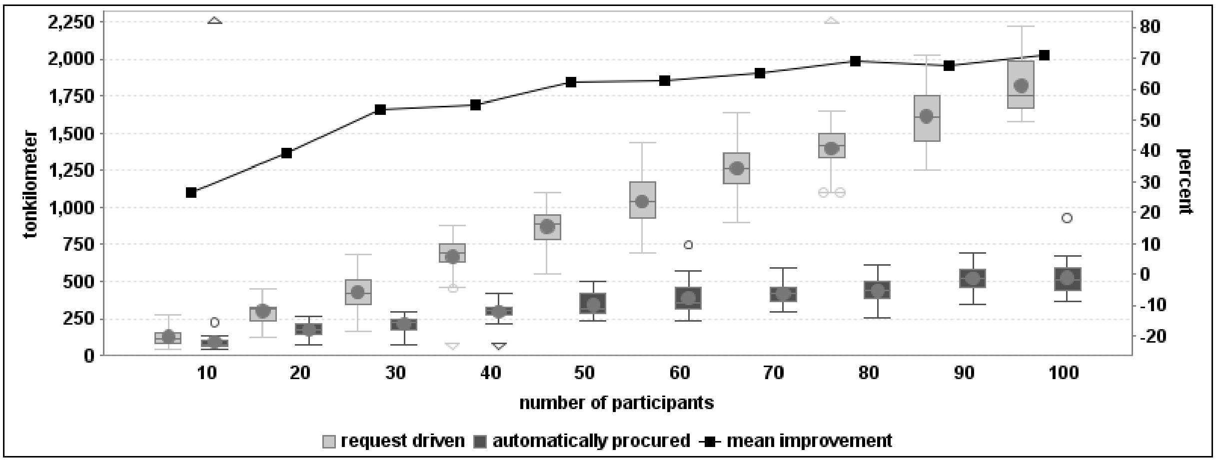

Figure 2: Functional relation of transport performance and number of participants subject to different procurement strategies (left y-axis) as a category box-and-whisker plot. The mean improvement as a function of the participants' number is also depicted (right y-axis).

Figure 3 shows a further result of the previously described simulation. For each procurement procedure the degree of satisfaction has been calculated as the fraction of originally offered (or requested).and actually procured amount of biomass. The plot shows the satisfaction distinguished between offers and requests for each procurement method. As can be seen, automated procurement has only a minor effect on the satisfaction of supply and demand. So, the main result here is that improvements in transport performance are not achieved at the expense of the satisfaction of the participating biomass players. The slightly better improvements for automatically procured offers are caused by the request-driven manual procurement.
In the case of clustered scattering (not depicted here) of the generated biomass locations and consumer locations, automated procurement performs better. This is due to the fact that the here proposed method by exploiting Vogel's approximation naturally prefers intra cluster procurement over inter cluster procurement and the resulting biomass networks are kept as regional as possible. This effect depends on the number of maxima in the spatial distribution and has already been scrutinized for the case of simple beeline distance (Rapp & Bremer, 2010).

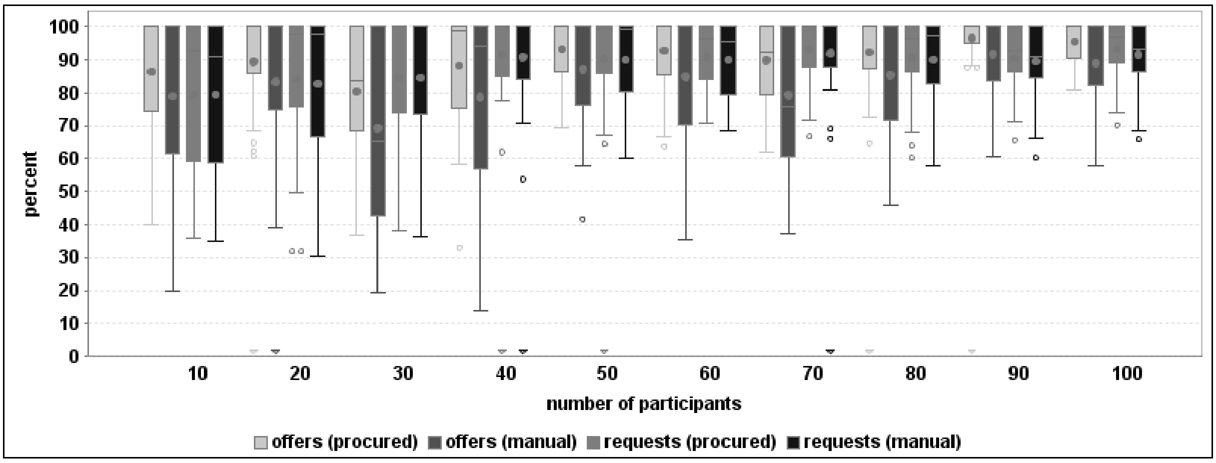

Figure 3: Mean satisfaction of supply and demand subject to different procurement strategies as category box-and-whisker plot. The marginal improvements have not been depicted separately.

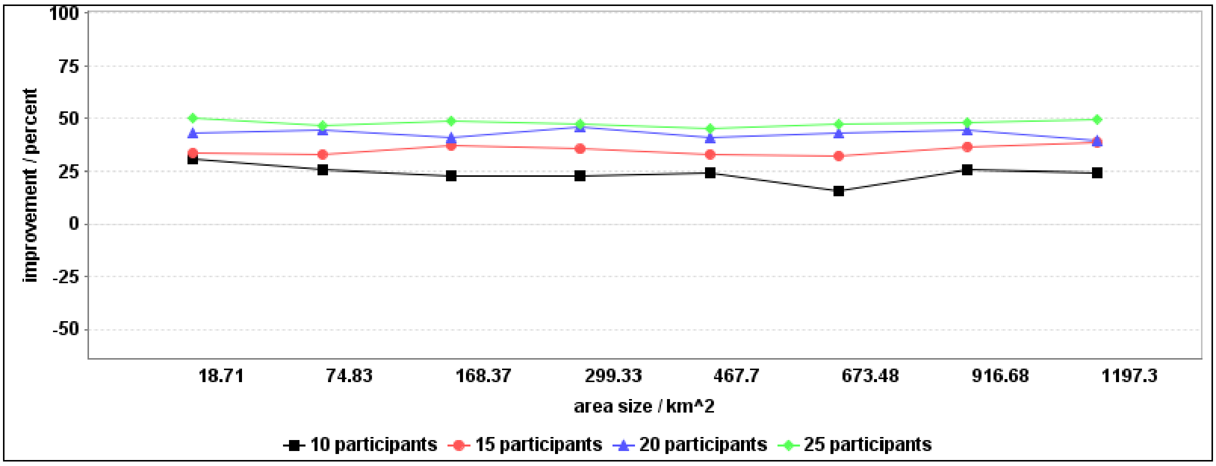

Figure 4: Improvement as a function of area size for different numbers of players.

The next example shows a simulation with varying area size. The remaining settings are as mentioned above. For each of the different area sizes various sets of vendors and requesters have been generated. Procurement is compared in the same way as in Figure 2. Figure 4 shows the functional relations of area size and improvement for different numbers of participants. From this result it can be concluded, that improvement does not depend on the size of the area the participants are scattered.

For these results, so far, different prices have not been considered. Adding compromise finding for different (and opposite) objectives, like in (Bremer et al., 2007), as a precondition for combining different objectives will be one of the next tasks.

5. Conclusion and further work

Berndes, Hoogwijk and van den Broek (2003) have reviewed 17 studies on the contribution of biomass for the future global energy supply. The potential for a steady growth to a considerable proportion is commonly foreseen. However, the predicted achievable amount varies largely. The major drawback of most such studies is a neglect of interlinked dynamic between the growth of the bioenergy sector and other land uses. They mostly ensure a conflict free physical achievability of the stated contributions, by modeling the food and materials sector (if any) exogenously. In this way, the bioenergy sector is defined as not affecting food, feed and chemical needs. Such models do not reveal much insight in possible socio-economic consequences. A holistic perspective is important for a holistic assessment of biomass usage. But, it has to be an integrated view as well, in order to gain sustainable network structures.

It has been shown here, that algorithms for automated procurement indeed can have sufficient positive effects for achieving higher-level optimization objectives. This has been demonstrated using the example of the resulting overall transport effort.

In future, we will further delve into the question for multi-objective optimization within the procurement process as an important precondition for an appropriate acknowledgement of individual needs and preferences. Concurrently the stage for a semantically enriched capture of biomass data in order to make this data accessible for procurement algorithms and – later on – for further applications is set.

6. References

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