Optimal Location and Management of a Biomass Inventory Facility

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Abstract

This paper shows the mathematical formulation of an inventory facility location decision problem. These facilities provide storage for agricultural biomass to be used as fuel at industrial plants. The decision problem bears in mind logistics cost (inventory and transportation), unsupplied penalties and delayed collection costs. Logical constraints, such as maximum storage capacity or maximum monthly available lorries, are taken into account. A real case study has been described in a high biomass collection and demand scenarios analyzing results for different number of inventory facilities.

Keywords: Network flow, Biomass, Logistics.

1. Agricultural Biomass as Surplus Fuel

Biomass may be used as surplus fuel for industrial processes that can use different type of fuels. One type of biomass is the one that comes from agricultural residues and specific energetic crops, as Cynara Cardunculus, Fernandez J. (2006).

This paper describes a mathematical model to locate one or several biomass inventory facilities. These facilities provide optimal biomass management that minimises transportation cost and maximises supply quality at the same time. This biomass comes mainly from agricultural fields, and then it is delivered to industrial plants. These facilities mitigate the natural effect of seasonal biomass harvesting on logistics.

Taking into account industrial processes that require huge amount of energy, this study has been focused on industrial suppliers of building materials -cement, plaster and brick. Their manufacturing plants have furnaces that can burn a wide variety of fuels such as agricultural biomass -straw, wood of pruning, processing residues of olives or grapes and specific energetic crops, Fernandez, J. (2006).

Farmers may diversify their possible incomes growing energetic crops and selling as well agricultural residues as fuels for industrial processes. Due to progressive abandonment of the least productive agricultural fields, there are more opportunities for energetic crops specifically adapted to these fields, Liberali, R. (2002).

One main drawback of using agricultural biomass is the wide spread among biomass collection fields, inventory facilities and industrial plants. Nevertheless, distance is extremely important due to the scarce energy density of agricultural biomass. In this paper the case study area is the Community of Madrid.

2. Facility Location and Biomass Management Modelling

The facility location decisions together with a network flow management are modelled as a mixed integer linear problem, Hillier (2006). This modelling evaluates at the same time adequacy of monthly collection, inventory and transportation decisions.

The objective function minimises, as a whole, transport, storage and lack of delivery costs. Transportation flows may be from agricultural fields to inventory facilities, from inventory facilities to industrial plants, or direct deliveries from agricultural fields to industrial plants, as Figure 1 shows.

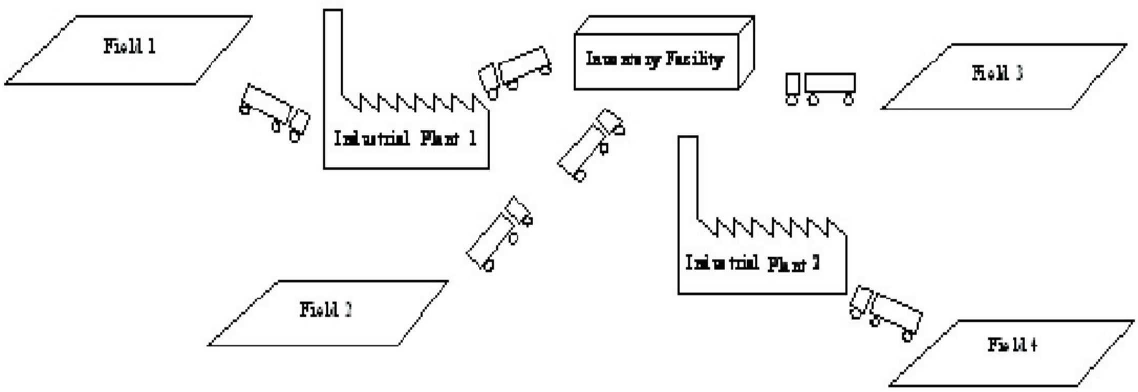

Figure 1. Biomass Logistic Scheme

Agricultural collection forecasting is based on historic data and estimations on energetic crop growing. The modelled time horizon spans over two years where initially inventory facilities are empty. After running the model, the steady state of the process is reached after the first half of the first year. From July of the first year to June of the second year is the makespan whose results are then analyzed.

If it is impossible to collect biomass monthly at fields, part of this biomass is kept for the next month and the rest is ruined or sold for different purposes. Polls and interviews have been made to companies that potentially might demand this type of biomass in order to evaluate different scenarios of possible biomass collection and consumption.

2.1. Mathematical Programming Model

2.1.1 Notation

– *Indices and Sets*

i, j : Location of fields, inventory facilities, industrial plants and transfer nodes

$t(i, j)$: Direct road between *i* and *j* adjacent locations

k : Biomass types [straw, pruning wood, olive and grape residues, energetic crops]

m : Monthly periods [month1_year1,…,month12_year2]

– *Parameters*

Note: Some of these parameters are expressed into articulated lorry capacity due to this logistic unit is very useful for road transportation constraints.

$v_{i,p}$: Highway transportation cost per km (round trip) [€/km]

f_i : Road type transportation cost factor [p.u.]

a : Storage capacity of an inventory facility [MWh]

q : Maximum monthly shippings

z : Maximum number of inventory facilities to be located

g_k : Maximum volume of *k*-biomass in an articulated lorry [m^3/lorry]

cr_k , cs_k : *k*-Biomass monthly delayed collection and storage cost [€/lorry·month]

r_k : *k*-Biomass monthly non collected reduction factor [p.u.]

cc_k : Penalty for non delivered energy [€/MWh]

e_k : *k*-Biomass energy shipped into an articulated lorry [MWh/lorry]

$d_{(i,j)}$: Distance between adjacent locations *i* y *j* [km]

$b_{i,k,m}$: Available *k*-biomass at location *i* during month *m* [lorry]

$v_{i,p}$: Demanded energy at location *i* during month *m* [MWh/month]

– *Variables*

Z_i : Installation decision of an inventory facility at location *i* [binary]

$X_{i,j,k,m}$: *k*-Biomass shippings circulating between locations *i* and *j* during month *m* [lorry]

$S_{i,k,m}$: *k*-Biomass stored at the inventory facility of location *i* at the end of month *m* [lorry]

$G_{i,k,m}$, $E_{i,k,m}$, $F_{i,k,m}$: *k*-Biomass delivered, non collected and undelivered at location *i* for month *m* [lorry]

$S^{+}_{i,k,m}$, $S^{-}_{i,k,m}$: Increment and decrement of *k*-biomass stored in the facility situated at location *i* for month *m* [lorry]

2.1.2 Objective function

The objective function equation with four terms is detailed at equation (1). The first term establishes the transportation cost of articulated lorries taking into account distances and types of roads (multiplying d_l times f_l). Depending on the type of road, f_l changes its per unit value because the transportation cost per km is different too. The second term includes the storage cost computing per month the semisum of stored biomass in inventory facilities at the end of two consecutive months. This semisum is assumed to be equal to the monthly average of stored biomass at agricultural fields or at inventory facilities. The third term is the penalty of non delivered biomass to industrial plants. The last term represents the delayed collecting cost based on the semisum of stored biomass at agricultural fields at the end of two consecutive months.

$$\sum_{l(i,j)k,m} c \cdot f_l \cdot d_{l(i,j)} \cdot X_{i,j,k,m} + \sum_{i,k,m} cs_k \frac{S_{i,k,m}+S_{i,k,m+1}}{2} + \sum_{i,k,m} cc_k \cdot e_k \cdot F_{i,k,m} + \sum_{i,k,m} cr_k \frac{E_{i,k,m}+E_{i,k,m+1}}{2} \qquad (1)$$

This objective function does not take into account the fixed investment of inventory facility installation. This cost is modelled as a fixed amount per year. In addition, the possible number of facilities is less than four, so the post optimality analysis may be easily done separately for scenarios with a different number of inventory facilities.

2.1.3 Constraints

Following mathematical expressions of constraints of this optimization model:

– *k-Biomass balance per location i and month m*

$$\sum_{j\in(i,j)} X_{i,j,k,m} - \sum_{j\in(j,i)} X_{j,i,k,m} + E_{i,k,m} - E_{i,k,m-1} \cdot r_k + S_{i,k,m} - S_{i,k,m-1} = b_{i,k,m} - G_{i,k,m} + F_{i,k,m} \ ; \forall i,k,m \qquad (2)$$

All the terms of the constraint are expressed in lorries. Following its explanation,

- $\sum_{j\in(i,j)} X_{i,j,k,m} - \sum_{j\in(j,i)} X_{j,i,k,m}$ is the net difference between lorries coming into location *i* and leaving out that location for the month *m*.
- $\sum_{j\in(i,j)} X_{i,j,k,m} - \sum_{j\in(j,i)} X_{j,i,k,m}$ is the non collected biomass difference at fields

situated at location *i* between month *m* and the previous one. The non collected biomass is updated per month by a reduction factor due to ruined biomass and sales for other purposes.

- $S_{i,k,m} - S_{i,k,m-1}$ is the increment of stored biomass at the inventory facility at location *i* between month *m* and the previous one.
- $b_{i,k,m} - G_{i,k,m}$ is the net *k*-biomass injection at location *i* during month *m.* This net injection is computed as the difference between available biomass at fields and delivered biomass to industrial plants situated at location *i.*
- $F_{i,k,m}$ is the non delivered biomass to industrial plants situated at location *i*. This non delivered biomass may be caused by lack of biomass at fields, or at inventory facilities or lack of available drivers to ship biomass.

– *Storage capacity at the inventory facility at location i and month m*

$$\sum_k g_k \cdot S_{i,k,m} \leq a \cdot Z_i \;;\forall i,m \tag{3}$$

This constraint limits the volume of stored biomass at the inventory facility. The occupied volume is computed in cubic meters and checked per month. Only if the inventory facility is situated at location *i* (Z_i =1), its inventory volume is limited to the maximum capacity, *a*. By contrast, if Z_i =0 only delayed biomass is allowed at location *i*.

The inventory facility layout is composed by ten adjacent squared areas. Each one has a side length of 100 meters and its building height is 10 meters. Each facility can be used simultaneously by different types of biomass. The usual inventory management consists of storing biomass during summer season and, then, delivering biomass to industrial plants during autumn and winter seasons. So, the maximum inventory capacity is usually reached only during one or two months along the year.

– *Limited number of inventory facilities*

$$\sum_i Z_i \leq nz \tag{4}$$

This constraint limits the number of different inventory facilities located at the study area. This number is set by the analyst and then, the effect of increasing number of facilities is individually computed.

– *Energy supply at location i and month m*

$$\sum_{k} e_{k} \cdot \left(G_{i,k,m} + F_{i,k,m}\right) = v_{i,m} \quad ; \forall i, m \tag{5}$$

This constraint is expressed in MWh. The supplied and non supplied energy are added at the left hand side of the equation and equalled to the demanded energy at location *i* for the month *m*.

– *Increment and decrement at inventory facilities*

$$S_{i,k,m} - S_{i,k,m-1} = S^{+}_{i,k,m} - S^{-}_{i,k,m} \quad ; \forall i, k, m \tag{6}$$

Variations of stored biomass at each inventory facility between two consecutive months are split into increments, $S^{+}_{i,k,m}$, and decrements, $S^{-}_{i,k,m}$.

– *Transportation service limitation per period*

$$\sum_{i,k} \left(G_{i,k,m} + S^{+}_{i,k,m}\right) \leq q \quad ; \forall m \tag{7}$$

The total amount of shippings is limited due to the number of available drivers to cope with monthly biomass collecting and delivering. Monthly shippings are computed as the sum of biomass delivering lorries at industrial plants and the increment of stored *k*-biomass at inventory facilities expressed in lorries.

– *Lack of delivery limitation*

$$\sum_{k} e_{k} \cdot F_{i,k,m} \leq v_{i,m} \quad ; \forall i, m \tag{8}$$

Non delivered biomass can not be higher, expressed in energy, than the demanded energy at every location *i* for each month. So, the energy contained into a *k*-biomass articulated lorry is multiplied by the non delivered *k*-biomass quantity at each location per month. This quantity is less or equal to the total demanded energy at that location.

2.2. Software implementation

This model has been implemented using GAMS programming language, Brooke (2005) and solver package CPLEX 10.0. Each scenario problem has an approximate dimension of 200.000 variables, 140.000 constraints and 1.500.000 non zero elements. Every execution takes 30 minutes to get an integer solution with a 5 % integrality gap to the optimal solution in a Pentium IV 2.34 GHz.

3. Implementation on a real study case

3.1. Scenarios

The study case takes into account 180 locations where are situated 35 agricultural locations, 18 industrial plants and transfer nodes of the road network of Community of Madrid.

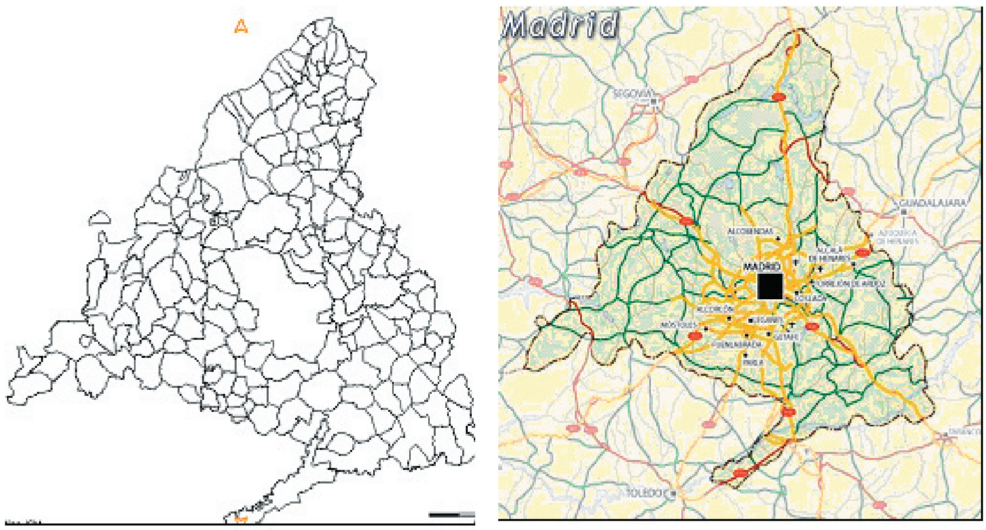

Figure 2. Community of Madrid (locations and road network)

Four biomass collection scenarios based on an historical data base have been combined with four possible biomass consumption scenarios based on prospective consumptions of suppliers of building materials. These scenarios have been solved independently. The model scope is two years. However, the numerical analysis has only taken into account from July of the first year to June of the second year (same as an agricultural year). For each collection-consumption scenario, one, two or three simultaneous inventory locations have been installed depending on the impact of increasing inventory capacity.

The harvest calendar depends on the type of agricultural biomass. For example, straw is packed on June and July. Wood pruning is done mainly on February and March. Olive residues are available on January and grape residues are available on September and October. Energetic crops, such as Cynara Cardunculus, are harvested on July and August. Best collection scenarios are mainly focused on gradual growing of energetic crops.

3.2. Results

At this section, the highest biomass collection and consumption scenario is analyzed for different number of inventory facilities. Figures show the biomass management along the July-June annual horizon computed in percentage values. “Stock” percentages provide the storage level of all the inventory facilities. “Lack” values represent percentages of non supplied monthly consumption. “Delay” values are computed as the ratio of monthly delayed biomass at fields to the annual available biomass.

Limiting to one inventory facility, Figure 3 shows the top level storage at this facility along the summer season (July-October). This unique facility has only enough inventory capacity to cope with half of the annual demand. From January to March the “lack” percentage increases, and finally from April to June no biomass is delivered. During summer season, there is delayed biomass at fields. Collection delay allows to mitigate non supplied biomass because part of it is later delivered directly to the industrial plants and also stored at the inventory facility for future deliveries.

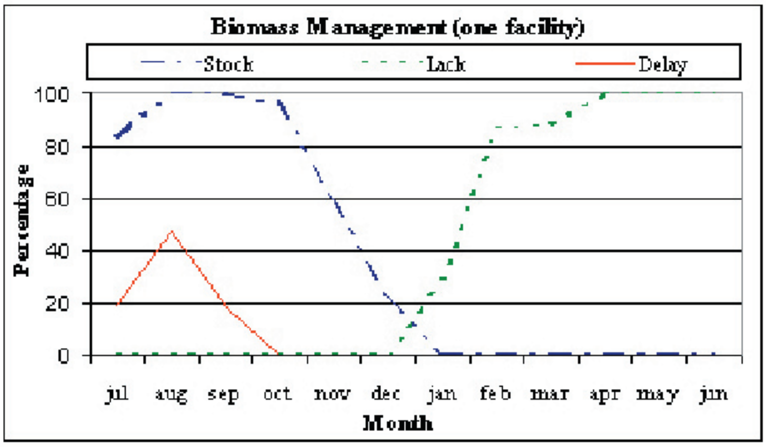

Figure 3. Biomass management with one inventory facility

Limiting to two inventory facilities, Figure 4 shows that the top storage use of inventory facilities is only reached on August and September. During the same period the delayed biomass is lower than with a single facility. In addition, the non supplied industrial demand is substantially diminished. Nevertheless, during one third of the year there is not enough biomass to supply completely the industrial demand, but only from May and June no biomass is delivered.

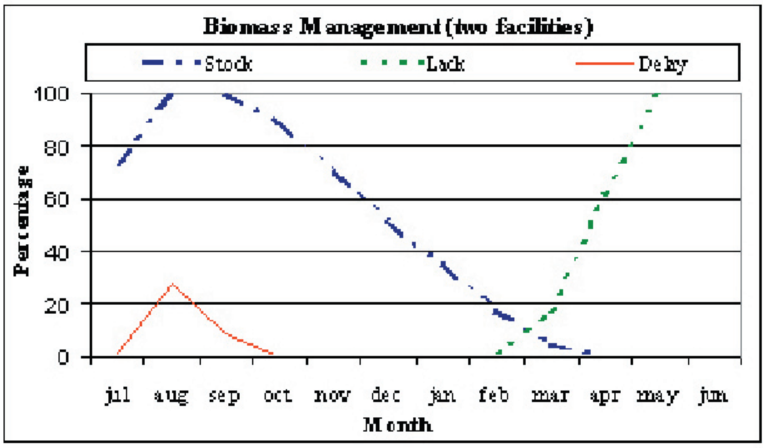

Figure 4. Biomass management with two inventory facilities

Finally, Figure 5 shows the biomass management with three inventory facilities. The resulting inventory overcapacity removes completely delayed biomass because the remaining biomass is stored at inventory facilities instead of staying at fields. In that case, non delivered biomass is partial on May and June.

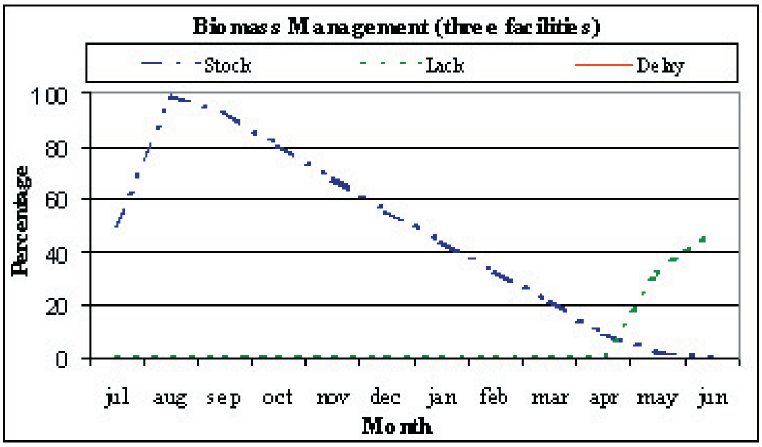

Figure 5. Biomass management with three inventory facilities

Location decisions with different number of facilities are depicted at Figure 6. The south, southwest and southeast of the Community of Madrid are areas where agricultural fields and industrial suppliers of building materials are mostly located.

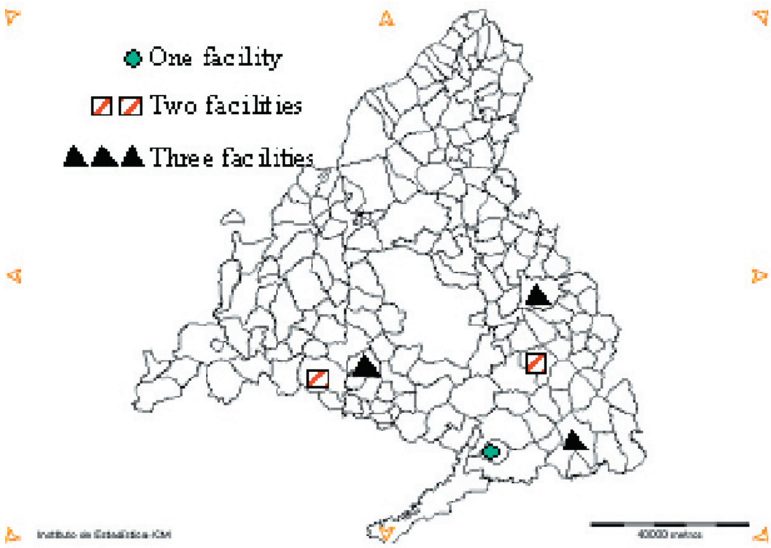

Figure 6. Locations of inventory facilities

Figure 7 shows the evolution of transportation variable cost for one, two or three inventory facilities. Three vertical bars, measured in thousands of euros, are displayed at each month representing the number of facilities located at the area. On July and August the transportation cost is high due to the combination of direct deliveries from fields to industrial plants and inventory facilities. On September the transportation cost is low due to few deliveries to inventory facilities and they are mainly direct deliveries from nearby fields to industrial plants.

After the summer season the transportation cost is due mainly to deliveries from inventory facilities to industrial plants. So, on October the transportation cost is higher than on September because most deliveries come from facilities that on average, are not so close to the industrial plants as agricultural fields. As more facilities are available, lower transportation cost, as Figure 7 shows on October, November and December.

After December the transportation cost diminishes with one inventory facility decision due to the unsupplied demand. So, the transportation cost diminishes with two and three inventory facilities after February and April respectively.

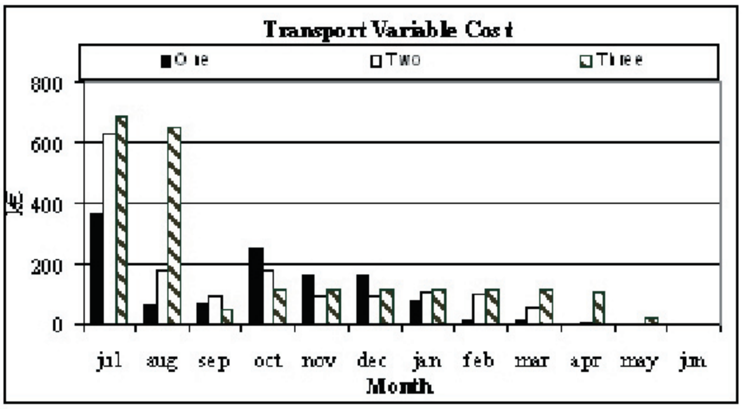

Figure 7. Monthly variable transportation cost

4. Conclusions

This paper has shown in detail the mathematical transportation model to address the location decision of biomass inventory facilities. These facilities improve biomass collection and industrial delivery management. Several scenarios of a realistic study case have been computed and one of them has been analyzed in detail.

A future extension of this research is the formulation of the stochastic nature of each collection and consumption scenarios with a certain probability distribution. Additionally, a monthly installation fixed cost of each inventory facility can be included in the objective function to determine the optimal number of facilities and their location.

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References

Liberali, R. (2002). Directorate-General for Research. European Commission. Renewable Energy Technologies. Long term reseach in the 6th Framework Programme. 2002-2006. http://ec.europa.eu/research/energy/pdf/synopses_res_en.pdf.

Fernández, J. (2006). Los cultivos energéticos en España y las tendencias de su desarrollo. I Intenational Congress of Bioenergy, Valladolid.

Hillier, F.S.; Lieberman, G.J. (2006). Introducción a la Investigación de Operaciones. McGraw-Hill.

Brooke, A.; Kendrick, D.; Meeraus, A.; R. Raman. (2005). GAMS: A Users Guide. GAMS Development Corporation.