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Sustainable Management of Energy Wood Chips Sector: Case Study of the Regional Park "Caps et Marais d'Opale"

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Abstract

We propose in this paper a two-phase methodology to design a supply chain network for managing the energy wood chips sector. Firstly, a GIS based spatial analysis is made to estimate all the data (offer, demand, potential locations for warehouse) of the network. Then an optimization phase takes place to solve the location-allocation problem in order to minimize economic cost indicator and CO2 emissions. The methodology has been applied for the case study of the regional park "Caps et Marais d'Opale" using three different strategic scenarios of development. A comparison is made in order to evaluate each selected sustainable criteria.

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Keywords: Energy wood; GIS; optimization; location and allocation problem

1. Introduction

"Parcs naturels régionaux" (PNR) in France are large populated areas which are recognized for the distinctiveness of their natural, cultural and rural heritage, and which have elected to protect and develop this heritage through sustainable development.

The Nord-Pas-de-Calais region is one of the most populated part of Europe situated in the north of France close to the Belgium border. This region also has three regional natural parks (PNR) that have been preserved from the demographic development. These parks cover over 25% of the region and they are named PNR Avesnois in the

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South-East, PNR Caps-et-Marais-d'Opale (PNR CMO, i.e. our case study) in the North-West and PNR Scarpe-Escaut in the East middle part of this region.

Hedgerows and woodlands are very present in these PNR compare to other places in the region that are fully dedicated to cities or crop production. This wood resource can be view as an alternative and renewable energy for private customers and municipalities especially for those who have to heat medium sized building (small industries, farm buildings, castles, town halls…). Such buildings can benefit from a renewable fuel heating using either woodchips or wood pellets. The advantage of woodchips is the direct cost whereas the advantage of wood pellets is the controlled fuel value. Woodchips have been traditionally used as solid fuel for heating or in energy plants to generate electric power from renewable energy. The use of woodchips in automated heating systems is based on a robust technology.

In this study, we only consider the development of woodchips produced by the regular cutting of hedgerows for heating systems. We also focus on the PNR-CMO which is composed of 152 municipalities spread on over 130.000 hectares (figure 1). The question asked by the PNR-CMO managers was to help them in developing the woodchips sector in a sustainable way or in other words to motivate farmers to enhance their hedgerows resources by encouraging small communities and individuals to shift their heating systems for this renewable energy.

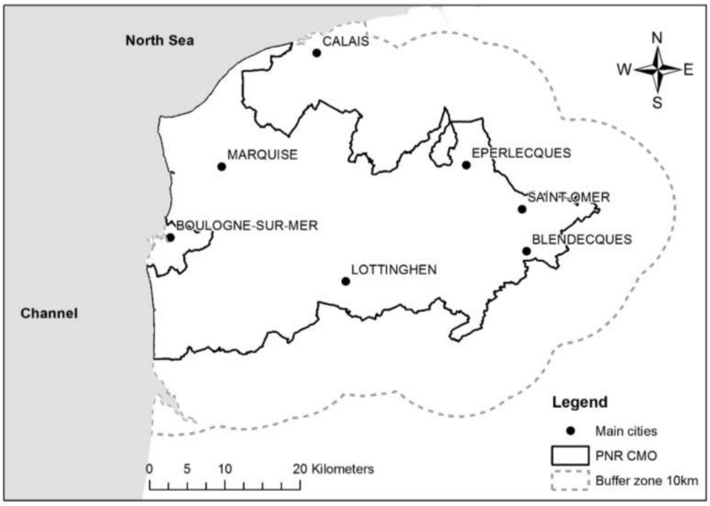

Figure 1: Location of the case study including a 10 km buffer zone for calculations (data: PNR CMO, 2015; BDTopo® IGN, 2013).

To answer the territorial aspect of this problem, a spatial analysis has been performed in order to define the location of potential storage facilities at a strategic level (i.e. the PNR territorial level). This location issue should answer the question of creating a new renewable energy network including the natural resource (i.e. the hedgerow), the transportation network (road are only considered regarding to the spatial clustering of resources and customers) and potential customers (private or public). This has led us to build a Geographical Information System (GIS) database to apply a spatial analysis methodology to provide the PNR CMO managers and various stakeholders with a multi criteria spatial decision tool. Then in a second step, there was a need to choose between different scenarios in order to fine tune the final best location according to the transportation cost that represent the major issue in the business building of such a renewable energy system.

The paper is organized as follows. In the next section, the generic methodology is presented then a focus on the PNR-CMO is made. A GIS spatial analysis used to provide data for the supply network design is described in the third and fourth section. Lastly, final conclusions are drawn in the last section.

2. Geographical information gathering

Firstly, we can notice that we are at a strategic decision level. No other studies (marketing one) have been made on the PNR-CMO to investigate the potential of the wood energy of this area. The role of managers of the PNR-CMO is to promote this new renewable energy to farmers and small collectivities. So no statistical data from sales or forecasting from marketing surveys are available at the starting point of this project. To overcome these uncertainties, we use a spatial analysis coupled with an optimization network design (see chapter 4 of this paper) to provide optimal solutions for three main strategies of wood energy management. The objective is to give several alternatives to decision makers (politic ones, entrepreneurship ones) to focus on geographical zones where the potential of demand or offer are the most promising ones. This kind of hybrid method has already been used with success to design a supply chain network for recycling waterways sediments (Bouzembrak Y. et al., 2010; Bouzembrak Y. et al., 2013; Masson E. et al., 2013).

The goal of this study is also to provide with a generic methodology for the development of the energy wood chips sector which can be replicated in all regional parks which want to exploit and develop this renewable energy on their own territory.

In this study, we decomposed the problem in a sequence of two main phases. The first phase is concerned by providing the data or estimated data for the next step. To do that a spatial analysis of the area has been performed using GIS tools (ArcGIS® and Spatial Analyst®) applied to a GIS dataset gathering 45 primary layers. This large GIS database was collected to provide decision makers (including PNR CMO managers) with a list of potential criteria that could help them in finding storage facilities locations according to their own territorial decision ruleset. This database gathers national and regional data sources covering different environmental thematics:

- land uses (data source: SIGALE, 2009 modified by PNR CMO),
- environmental perimeters (data source DREAL, 2015),
- roads (data source: BDTopo® IGN 2012),
- forest (data source IFN, 2012),
- hedgerows (data source: SIGALE 2009),
- buildings (data source: BDTopo® IGN 2012).

One of the first steps was to extract three types of potential clients from the building layer:

- private buildings,
- public buildings,
- farm buildings.

Private buildings could be big houses or small industrial facilities. Public buildings could be town halls and other municipality buildings. Farm building is a self-evident type of building. This classification has been performed using the attribute data of the building layer from the BDTopo® IGN 2012. Moreover, a selection on potential clients for each building types has been performed using an approximated building volume calculation in which each building surface was multiplied by each building maximum height. All buildings between 2000 and 10000 cu.m have been finally selected for the three building types on this volume threshold basis. This threshold value has been provided to us by PNR CMO managers according to their own view point on potential building targets considering that smaller building will not fit regarding to the cost of the heating system and that higher volume buildings will not be relevant considering the cost benefit analysis of using another heating solution. The location of existing woodchip warehouses in the buffer zone area (figure 1) was finally the last layer to be created. This dataset has served as a spatial knowledge base for scenario building according to PNR CMO manager's viewpoints).

3. Spatial analysis

Spatial Decision Support System (SDSS) are increasingly recognized within the DSS research community (Jankowski P., 1995; Malczewski J., 2004, 2006; ReVelle C.S., Eiselt H.A., 2005; Murray A.T. 2010), because of their broad applicability across a range of fields including, *inter alia*, planning, impact assessment, and environmental management (Basnet B.B. et al., 2001; Changa N.B. et al. 2008; Guiqina W. et al., 2009; Zhang F. et al., 2011; Salze P. et al., 2011; Gorsevski P.V. et al., 2012; Gbanie S.P. et al., 2013; Carter B., Rinner C., 2014).

Specific applications have been developed and combine DSS and Geographical Information System (GIS) to create solutions using weighted sum methodology (Malczewski J., 2004, ReVelle C.S., Eiselt H.A., 2005, Salze P. et al., 2011). The validity and utility of these techniques are now well established in several fields (Malczewski J., 2004). This operational decision making tool forms a methodology that integrates a multi-stakeholders decision rule set, processing GIS layers and weighted sum calculations.

In our case study the spatial analysis has been performed using AcGIS® 10.3 and its extension Spatial Analyst® in order to:

- Calculate a spatial constraint for each layer (figure 2),
- Combine constraints according to PNR CMO viewpoints,
- Calculate a final scenario mapping a range of constraints between 0 and 1 (figure 3),
- To refine the result in a data grid of 2.5 x 2.5km for the logistical analysis.

The spatial constraint can be attractive (figure 2A) or repellent (figure 2B) according to any stakeholder decision ruleset. If a stakeholder is a woodchip warehouse manager, he might find attractive to locate potential clients and hedgerow resources at a minimal distance from his facility. On the opposite way, PNR CMO managers who want a more sustainable development might want to open new warehouses in order to minimize the transport cost between the hedgerow resource and potential clients. In this case the minimum distance to an existing warehouse is a high spatial constraint because it is not reducing significantly the transportation cost and the associated environmental impact to deliver distant customers. One sees that a GIS layer can be considered on opposite values (i.e. attractive or repellent) depending on the decision goals and on the decision makers.

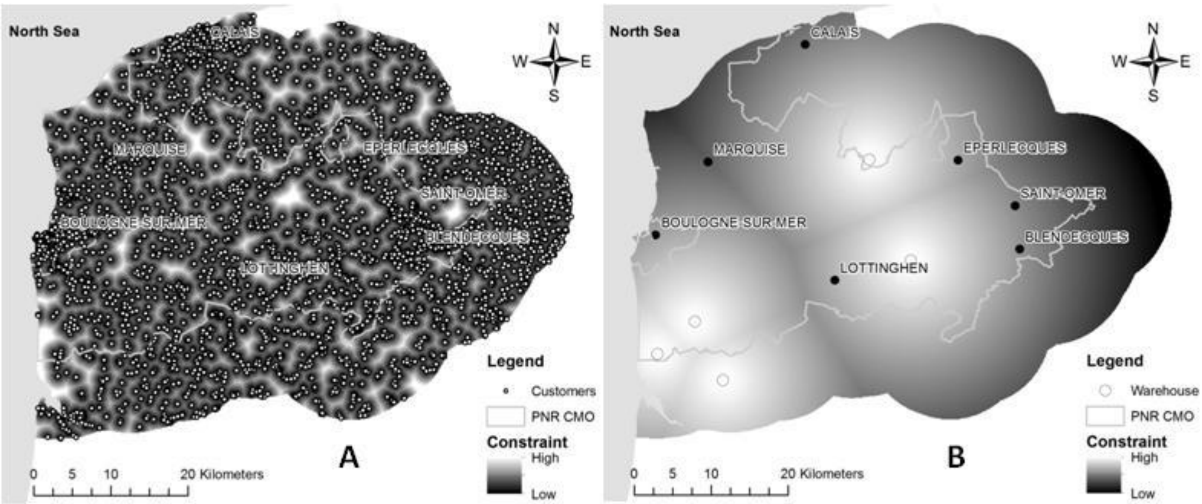

Figure 2: Map A displays an attractive constraint. The closer distance to the customer the lowest is the constraint. Map B displays a repellent constraint. The closer distance to a warehouse the highest is the constraint (Data: PNR CMO, 2015; BDTopo® IGN, 2013).

All the attractive and repellent constraints calculated under GIS are providing the decision maker with multi-criteria spatial data that can be combined according to any decision ruleset. By doing this the GIS is computing a spatial decision scenario involving a simple set of constraints (figure 3) or a complex one including weighs to give priority to the main spatial constraints within a multiple dataset. In the spatial analysis phase the calculation used a 1ha cell size firstly because it's an appropriate surface unit for warehouse building and secondly because many potential customer buildings are very close in space within the case study's area.

During the spatial analysis phase, different scenarios have been calculated using a weighted sum methodology with normalized constraints layers. Then the results of these scenarios have been merge into a larger grid dataset (i.e. 2.5 x 2.5 km) in order to reduce the amount of data (i.e. 423 cells) analyzed in the logistic phase of this research. Five final grids have been computed as a result of the GIS data collection and the spatial analysis in which each grid cell gives:

- the potential woodchip production according to hedgerow cumulative length in each cell of the PNR CMO including its 10km buffer zone,
- the potential customer needs according the number of customer in each cell of the PNR CMO including its 10km buffer zone,
- the ten best cell locations within the PNR CMO territory for a centralized scenario,
- the five best locations within the PNR CMO territory in each of the three zones for a sectorized scenario,
- the hundred best locations within the PNR CMO territory for a scattered scenario.

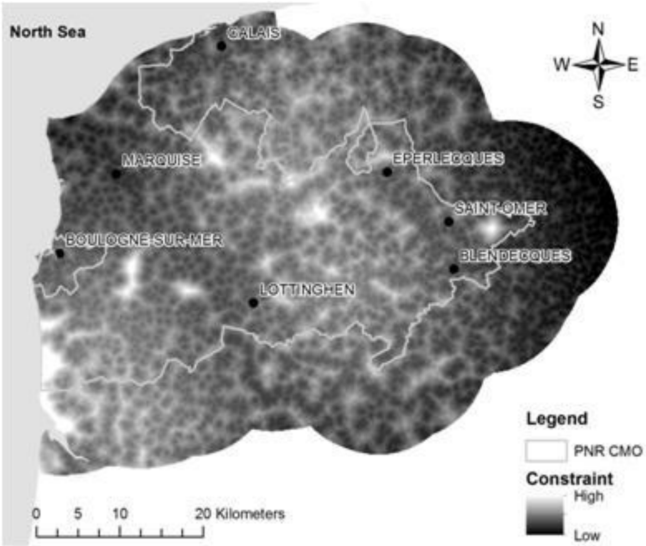

Figure 3: Scenario combining three spatial constraints (including constraints from figure 2A and 2B) without weighting. Customers and hedgerow are attractive and woodchip warehouses are repellent (Data: PNR CMO, 2015; BDTopo® IGN, 2013).

4. Design the optimal logistics network

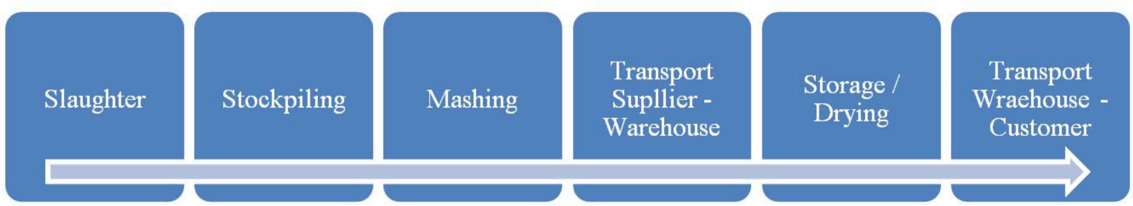

Figure 4: Business process of energy wood chips.

As shown on the figure 4 (above), the production of wood chips requires several operations:

- the cutting phase (slaughter and stockpiling operations) with produces the branches for the chipping phase. This phase is generally made *in situ*,
- the process of making wood chips is called wood chipping and is done with a wood chipper. This phase is again made *in situ*,
- once the chips are produced, they are transported by agricultural tippers from the land to a storage warehouse,
- during at least 6 months, chips are stored for drying before to be sold. Usually, the quantity which is stored corresponds to the annual consummation because the quality of the wood chips is decreasing after one storage year,

- after the drying operation chips can be distributed to customers using dump trucks or farm tractors depending the distance to travel.

As we are in a strategic decision, two sub problems have to be solved. The first one is how many storage warehouses do we need to satisfy the annual customer demands and where are they located in the area? The second problem is how wood suppliers and customer demands are served once the locations of warehouse have been chosen.

These two well-known problems are very hard optimization problems to solve (Hesse Owen, Daskin, 1998). Researchers of the optimization community have developed a number of mathematical programming models to represent a wide range of facility location problems. Unfortunately, these models can be extremely difficult to solve to optimality (most problems are classified as NP-hard) when the problem instance is large (Meloa, Nickelb, Saldanha-da-Gamad, 2009). We chose amixedinteger linear programming to model the problem and Cplex solver has been used to get optimal solution for each scenario we defined before. In order to make this study, a 6-step approach has been defined (figure 5):

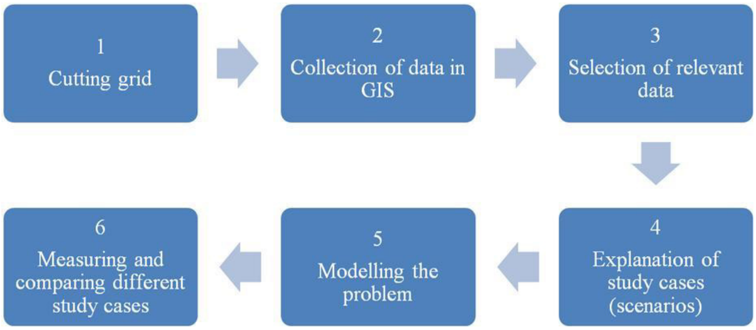

Figure 5: Different steps of the optimize phase.

4.1. Selection of relevant data

May be it is the most critical point of this study. Recall that we are in a strategic design of a new network supply for the energy wood chips sector. All data provided by the GIS analysis must be filtered and sorted in order to supply the mathematical models. Three kinds of data are needed by these models.

About wood resources (suppliers layer): approximately 21 000 wood chips tons potentially available each year. To start the project, a strategic target was set: 5000 T. A priority selection of the most productive areas has been made.

About chips requests (customers layer): a total of 81 000 tons of demand per year (estimate based on the building's volume to heat). At a strategic level, only 10% of the estimate is taken in each area. Finally, we take account of only 8100 T, which is more realistic. To start the project, a strategic target was set: 5000 T. Priority selection of the higher needs areas.

Potential locations for storage wood chips (warehouses layer): a hard constraint is that potential locations for building warehouses must be inside the park's territory.

To feed the different scenarios, different numbers of potential locations identified among the best (in phase 1 of the project) were determined to limit the combinatorial problem to be solved by the solver. These limitations were set to the following limits:

- 10 potential warehouse's locations selected for the central scenario. As this scenario contains only one warehouse, the number of potential warehouses didn't need to be very high,
- 15 potential warehouse locations selected for sectored scenario. In this scenario, the park is divided into 3 main sectors. Each sector then has 5 potential warehouses. The purpose of this scenario is to find the best potential warehouse localization for each sector,

- 100 potential warehouse locations selected for the scattered scenario. This scenario provides the use of existing farm buildings or new ones.

4.2. Explanation of the different scenarios

For the centralized scenario (figure 6A), the idea was to build a central warehouse with high storage capacity (10.000 T) that would supply all customers within the park or close to. Long distances are favored using existing highways or main roads.

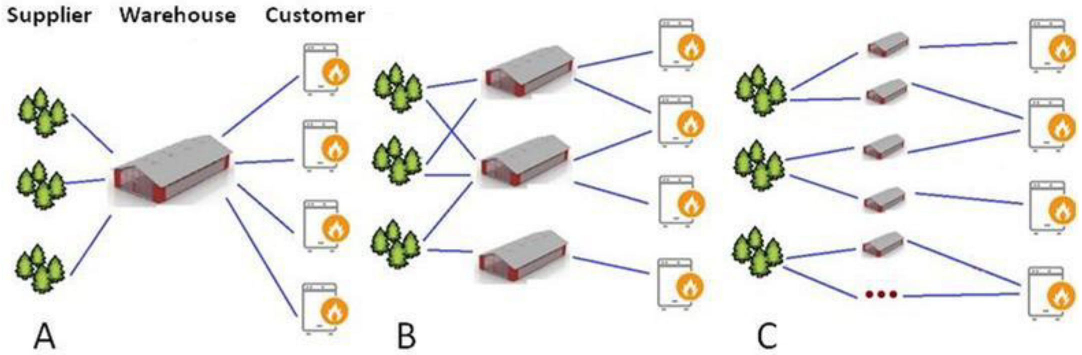

Figure 6: Scenarios tested in this research. A is centralized B is clustered and C is scattered

For a clustered scenario (figure 6B), separating the park in 3 main sectors has been proposed by the team project. The idea was to establish one single medium warehouse in each sector. Medium distance transportations are needed in this case using secondary road network.

For the scattered scenario (figure 6C), a multitude of small farm buildings of limited capacity (200 T) have been advanced. The use of storage in a farmer's shed was also envisaged.

4.3. Modeling of the problem

To model this problem, a 3-layer network which included three actors was designed: suppliers, warehouse(s) and customers (Wei, 2015). The model is based on one objective function and some hard constraints which are described in the next part.

Objective function: at strategic design level, only the transportation costs and infrastructures costs can vary depending on the scenario the decision maker want to choose. Upon reflection, we realized that the distance had a direct influence on transport costs and CO2 emissions. So we decide to focus in a first step on the distance optimization. The objective function we want to minimize is equal to the produce of the total traveled distance (in kilometer) per the total volume of transported goods (in ton).

Once we got the solutions by the solver, we evaluate in a second step all the related costs and the CO2 emissions for each scenario.

Constraints to be respected:

- customer satisfaction, we suppose that the supplier's offer is enough in each scenario,
- limited capacity of a warehouse and flow conservation are checked (total input flows = total output flows),
- supplier's ability, each predefined zones has a limited provider capacity,
- the number of warehouses, which is limited in the centralized and sectored scenarios and unlimited in the scattered scenario.

Decision variables: we have two kinds of decision variables. Location variables are binary ones, they indicate that the corresponding zone has to open a storage warehouse. Flow variables are real ones and represent the quantity of wood chips to transport from one actor to another actor of the supply network.

4.4. Running the models

Once data and mathematical models are built, we can run these ones and we obtained the following solutions for each scenario. Location and related costs of the objective function are only discussed in this part, other aspects (total costs, gas emissions) are detailed in the next step.

For the centralized scenario, zone number 203 was selected as the best among 10 potential locations. As expected, this zone is situated in the center of the park and close to highway in order to optimize the total traveled distance (figure 7). Using the previous objective function, the cost of the solution is 238.000tkm.

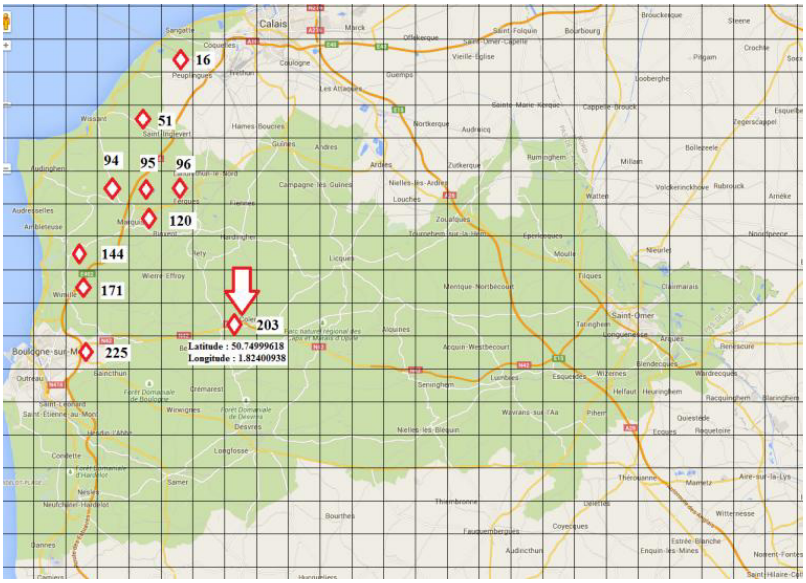

Figure 7: Warehouse location for a centralized scenario.

For the sectored scenario, zones number 203, 216, 226 were selected by the solver as the best ones among 15 potential locations. Selected locations are not in the center of each sector because some suppliers/customers of an identified sector can make business with a closest warehouse than the one they belong to.

Table 1 shows the repartition of flows between the different sectors. For the sector 3 near Saint-Omer (see figure 1 for location), we remark that about 80% of the offer is provided by other sectors because the sector is poor in woodland. On the other side, sector 3 must provide a lot of customers (no customer came from other sectors). The cost of the objective function is 160.700 Tkm which is smaller than the centralized scenario one.

Table 1: Repartition Offer/Demand - Clustered scenario.

Warehouse	Offer (T)	Demand (T)
Sector 1	53% of the offer come from Sector 2	16% of the demand come from Sector 2
Sector 2	10% of the offer come from Sector 1	7% of the demand come from Sector 1
Sector 3	79% of the offer come from other sectors (18% from Sector 1 and 61% from Sector 2)	No demand from other sector

Finally, for the scattered scenario, 38 zones were selected by the solver as the best ones among 100 potential locations. The capacity of each shed is around 200 T in this scenario. Short transportation distances and small storage capacities are related to this scenario, so a lot of sheds need to be opened to satisfy the wood demand. The solution cost is 77.800 Tkm. We can conclude that scattered scenario is the most efficient one in term of the traveled distance per transported Ton.

4.5. Measuring and comparing different scenarios

After getting the solution for all scenarios, we are able to compare them in term of costs or CO2 emissions. For the transportation cost we take an average cost of 0,6€/Tkm for all scenarios. Concerning infrastructure cost, we consider a range of costs from 300 €/m² to 500 €/m² for building a new warehouse in the scenario 1 and 2. For the scenario 3, we consider a range of costs from 130 €/m² to 150 €/m² for building a new shed and a range of costs from 25 €/m² to 50 €/m² for fitting an existing shed at farmer's house.

Table 2 reports the different costs per year: transportation costs which include upstream transport and downstream transport, infrastructure costs including the return on investment over 20 years and other evaluated (fixed) costs using data from table 3. Scattered scenario has a global cost which is the cheapest one.

Regarding CO2 emissions, again the third scenario is the one which provides the least emissions whatever the version we consider (using or not existing shed in the farm). Note that in this scenario the farmer can take both the roles of supplier, distributor and customer in the supply network. We are in local economy development in which the proximity of each stakeholder is very decisive means to the efficiency of the system.

Table 2: Focus on scenario's costs and CO2 emissions.

Scenario	CO2 emission	Transport cost	Infrastructure cost	Other costs	Global cost
Centralized	200 T	142 800 €	37 500 €/year to 62 500 €/year	405 000 € to 435 000 €	585 300 € to 610 300 €
Clustured	132 T	96 420€	37 500 €/year to 62 500 €/year	405 000 € to 435 000 €	538 920 € to 563 920 €
Scattered (new warehouses built)	64 T	46 680€	12 675 €/year to 14 625 €/year	324 000 € to 348 000 €	383 355 € to 385 305 €
Scattered (actual warehouse adapted)	64 T	46 680€	9500 €/year to 19 000 €/year	324 000 € to 348 000 €	380 180 € to 389 680 €

Table 3: Focus on other costs.

Other costs	Slaughter	Stockpiling	Mashing	Storage	Treatment
€/T	26 to 30	10	28 to 30	12	5

4. Conclusions

Wood energy is a promising renewable energy of the future because its low costs and its low CO2 gas emission. However, the development of this energy involves equipment with a ROI between 10 and 20 years.

In this paper we proposed a two-phase methodology to optimize the development of the energy wood chips sector in a region of France. The main challenge of such strategic study is the lack of consolidated data about the estimation of the quantity of wood resource we can consider as available. At the other end of the supply chain, we have no information about the future need of customers.

The methodology we proposed is a generic one and can be replicated in other similar regions of any country. The goal of this research is to provide the decision maker with a set of scenarios including a comparative assessment of several key indicators (economic, social and environmental).

The first phase mainly consists to estimate the demand (customers) and the offer (wood suppliers) of the considered region, and to locate what are the most promising locations to build storage/distribution warehouses taking into account several geographic criteria. To do that a spatial analysis with the help of GIS is necessary.

The second phase gives the best (optimal) warehouse locations among all potential locations provided by the phase 1 in order to satisfy the demand and respect the offer. A mixed linear program model has been defined and a solver is used to obtain a solution for each selected scenario. Finaly the eco-environmental assessment revealed that the scattered scenario was the best solution at a strategic level of decision making.

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