OPTIMAL LOCATION OF NEW FORESTS IN A SUBURBAN AREA

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Abstract

This paper looks for the optimal location of new forests in a suburban area under area constraints. The GIS-based methodology takes into account timber, hunting, carbon sequestration, non-use and recreation benefits and opportunity costs of converting agricultural land, as well as planting and management costs of the new forest. The recreation benefits of new forest sites are estimated using function transfer techniques. We show that the net social benefit of new forest combinations respecting the area constraints may differ up to a factor 21. The substitution effect between forests, both new and existing, turned out to be the dominant factor in the benefit estimation.

Keywords: Benefit transfer, travel cost analysis, cost-benefit analysis, forest recreation, Geographical Information Systems (GIS)

JEL-classification: Q23, Q24, Q26, R14

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1. Introduction

The United Kingdom, Ireland, Flanders (Belgium), the Netherlands all have a low forest cover (+/- 10% of the total area). In suburban regions, very little forest is present. Many regions have set aside budgets for afforestation projects. These projects will take place on former agricultural land. In this paper we develop and apply a methodology for the optimal location of new forest sites in suburban areas.

PEARCE (1994) is one of the classic references for a cost benefit analysis of a forestation project. As main costs he lists the costs of planting, maintaining the forest and the opportunity costs of lost agricultural output. The main benefits are carbon sequestration, hunting, other recreation and ecological values. The last years two types of benefits have received more attention: the carbon sequestration potential and the recreation benefits.

The carbon sequestration value of a new forest is an important issue in the climate change negotiations (STAVINS, 1999) but it is unlikely to be a decisive element for afforestation in suburban areas (GARCIA QUIJANO *et al.,* 2004). Particularly in more urbanized areas, the recreation value of a new forest is likely to be much more important. One of the main issues in the estimation of the recreation value is whether benefit measures of other areas can be used to assess the recreation value of new or ‘no-data’ sites (ROSENBERGER and LOOMIS, 2000). Although benefit transfer is usually considered to be a second-best strategy due to high variation of spatial and temporal characteristics of each forest recreation site, when assessing potential afforestation projects, it is a good strategy, especially compared with techniques that don’t take into account recreation values at all.

In this paper we develop a methodology to select a combination of forest sites that maximizes net social benefits taking into account restrictions on the total surface/size of new forest land. We use GIS technology to estimate for each site the major cost elements including lost agricultural output and to estimate the recreational value. Special emphasis is placed on the recreational value of a potential site as this raises two issues. First, the recreation benefits of a base site estimated via the travel cost method need to be transferred to all potential sites. Second, the recreation benefit of each potential site depends on the existing sites and on the other sites that are in the selection. We show that the same ‘amount’ of afforestation (i.e. the same total surface divided into multiple sites at varying locations) creates a wide range of potential net social benefits due to the role of a varying set of recreation substitutes.

Compared to the existing literature (BATEMAN *et al*. (1998))[1], our paper improves the methodology by working with realistically feasible sites rather than grid sites, by including the complex recreation substitution effects between potential sites and by including all costs and benefits of afforestation bringing the analysis closer to a real cost benefit analysis.

In section two we outline the methodology, in section 3 we present the case study area and the main data sources. The estimation of the recreation values is the object of section 4. Section 5 presents the results. Section 6 concludes and contains suggestions for further work.

2. Methodology

In this paper we develop a continuous maximization model to determine the combination of forest sites that maximizes net social benefits subject to a maximal area restriction for the whole combination. The main challenge is to take into account substitution and complementarity effects, due to the geographical interdependence of the different forest sites. This two-way geographical interdependence causes strong non-linearity and non-convexity of the optimization problem. For this reason we use a discrete and heuristic optimization procedure in the empirical application. We solve the problem in a static context: we assume that all sites are afforested simultaneously and immediately and that there is no uncertainty.

2.1. Formulation

2.1.1. General

There are I potential forest sites $(i \in I = \{1, 2, ..., I\})$ that can be afforested to an extent x_i $(0 \le x_i \le 1)$. Each potential forest site has a number of characteristics y_{ji} $\left(j \in J = \{\text{location, soil, size, present agricultural production, manure deposition limit, etc.}\}\right)$ that influence costs and benefits of afforestation. A combination of potential forest sites is a subset Z of I $\left(Z \subset I\right)$. We assume all sites are afforested at the same point in time $(t = 0)$ but costs and benefits occur at different points in time $(t = 0, 1, ..., T)$, where T is sufficiently large to avoid end of horizon effects.

[1] The methodology for the estimation of the recreational value of potential new forests has been developped by Lovett *et al*. (1997), Bateman *et al*. (1998), Bateman *et al*. (1999) and Brainard *et al*. (1999). Their analysis has shown that using GIS in benefit transfer increases efficiency and consistency (Brainard *et al*., 1999).

Social costs and social benefits are defined as follows:

B_i: social benefit of afforesting site i; this is a vector presenting all annual benefits for site i

C_i: social cost of afforesting site i; this is a vector presenting all annual costs for site i

The discount factor is defined as follows:

$$d_t = \frac{1}{(1+r)^t} \tag{1}$$

where r is the discount rate.

2.1.2. Social cost

Social cost of afforestation of one site i

The total social cost is the sum of the different types of afforestation costs $k \ (k \in K = \{1, 2, ..., K\})$. In practice these costs include planting, management and the opportunity cost of converting agricultural land. Costs are supposed to be geographically additive. This means that the cost of afforestation of site i is independent of what happens to other sites. In addition we assume constant marginal costs. c_{it}^k is the cost of type k in period t to afforest site i.

$$C_i = \sum_{t=0}^{T} d_t \sum_{k=1}^{K} c_{it}^k x_i \qquad for\ \forall i \in I; k \in K \tag{2}$$

Social cost of afforestation of a subset of sites Z

We assume additivity in afforestation costs. The total discounted cost of subset Z is

$$C_Z = \sum_{t=0}^{T} d_t \sum_{i \in Z} \sum_{k=1}^{K} c_{it}^k x_i \quad for\ \forall i \in Z; k \in K$$
$$or \tag{3}$$
$$C_Z = \sum_{i \in Z} C_i$$

2.1.3. Social benefit

Social benefit of afforestation of one site i

The total social benefit is the sum of the different types of benefits of afforestation $l \ (l \in L = \{1, 2, ..., L\})$. These benefits include direct and indirect use values (recreation, hunting, timber sales, carbon sequestration and other ecological values) and non-use values. If we assume marginal benefits per site are constant, we have:

$$B_i = \sum_{t=0}^{T} d_t \sum_{l=1}^{L} b_{it}{}^l x_i \qquad for\, \forall\, i \in I; l \in L \tag{4}$$

Social benefit of afforestation of a subset of sites Z

We distinguish between geographically additive types of benefits $l \in A\,(A \subset L)$ and geographically non-additive types of benefits $\left(l \in L \setminus A\right)$. For additive benefits ($l \in A$), , we assume that the benefit of afforestation of site i has no influence on the benefit of afforestation of site –i (e.g. timber sales, hunting and carbon sequestration). There is no geographical interdependence. Therefore, the benefit of afforestation of the subset of sites Z equals the sum of the benefits of afforestation of each of the sites belonging to combination Z:

$$B_Z = \sum_{t=0}^{T} d_t \sum_{i \in Z} \sum_{l \in A} b_{it}{}^l x_i \quad for\, \forall\, i \in Z; l \in A$$
$$or \tag{5}$$
$$B_Z = \sum_{i \in Z} B_i$$

But for some types of benefits (e.g. recreation) the value of afforesting one site influences the recreational value of all other sites. These benefits are said to be non-additive $\left(l \in L \setminus A\right)$. This means that the recreation benefit of site i becomes a function of the afforestation of all other sites. For recreation, the following is true:

$$B_Z^{rec} \le \sum_{i \in Z} B_i^{rec} \tag{6}$$

The recreation value of site i decreases if other afforested sites can be found in its neighbourhood. Each time forest visitors intend to visit a forest, they will have to choose one, when their choice set expands, the probability that they will visit one forest in particular will decrease. The lower the number of visits to one particular forest, the lower the recreational value of that forest. For potential forest visitors all forests in their surroundings are substitutes.

For most ecological values, such as biodiversity, the opposite is true: the proximity of other forests may have a positive influence on the ecological value of one particular forest or, in other words, forests within the same geographical region are considered to be complements and parts of an ecological network:

$$B_Z^{bio} \ge \sum_{i \in Z} B_i^{bio} \tag{7}$$

2.2. Maximization problem

We want to select the subset Z of forest sites i that maximizes net social benefits taking into account a maximal area constraint (a). The proportion of afforestation of a site (x_i) is in the formal model a continuous choice variable (b). This problem can be formulated as follows:

$$\underset{x_i}{Max}\left[\sum_{i=1}^{I}\sum_{l\in A}\left[B_i^l - C_i\right]x_i + \sum_{i=1}^{I}\sum_{l\in L\setminus A}\left[B_i^l\left(x_1,...,x_I\right)x_i\right]\right]$$
$$s.t. \quad (a) \quad \sum_i S_i * x_i \leq S^{MAX} \qquad (8)$$
$$(b) \quad 0 \leq x_i \leq 1$$

The complementarity and substitution effects between sites have made this a complex optimization problem. In the application we therefore distinguish five subsequent steps to be taken:

1. Selection of combinations of potential forest sites that meet the maximal area restriction;
2. Calculation of all costs and benefits of the additive type for each potential site;
3. Calculation of recreation benefits for each forest site in each combination selected in 1;
4. Calculation of net social benefit per hectare for each potential forest site in each combination and for the combination as a whole (i.e. the sum of 2 and 3 divided by the total area); and
5. Ranking of combinations selected in (1) based on the net social benefit per hectare of the combination.

We experienced many data problems to estimate the ecological value functions linking the benefits of one site to that of the other sites. In this paper we therefore consider the ecological functions as additive functions. The only non-additive type of benefit considered is recreation.

3. Data

3.1. Description of the study area and selection of potential new forest sites and combinations

The province of East Flanders has the second lowest forest index of all five Flemish provinces. Total forest area in East Flanders amounts to about 17000 ha. This leads to a forest index of 5.6%, half of the average index for Flanders as a whole. Agriculture takes up more than 155000 ha (51.2% of total area). The province counts approximately 1.33 million inhabitants with high population concentrations in cities like Gent, Aalst and Sint-Niklaas. Apart from these urban areas, the large parts of the province have a suburban character. All existing accessible forest complexes are situated in open space areas at relatively large distance from major population centres.

In order to limit the number of potential forest sites, we started from a previous expert study (Mens en Ruimte, 1996). This study indicated 56185 ha of potential forest land in the province. Next, we excluded the road network, valuable ecotopes, legally protected areas[2], built-on areas, existing forests, infrastructure, industry and residential areas. This leaves 35190 ha for potential afforestation projects, the so-called "net desired forest structure".

Furthermore, (non)suitability for agricultural production and ecological arguments like the proximity of existing forests reduced the total potential forest area even more.

Finally we end with 14565 ha potential forest land in the whole province of East Flanders which was divided into 113 sites with a minimal area of 20 ha each (see figure 1). We subdivide the province into 4 regions each with a different character with respect to the degree of urbanisation and availability of forest land.

In this paper we present possible locations of new forest sites in one suburban part of the province: Vlaamse Ardennen. As it is an objective of the policy maker to have at least 2500 ha new forest land area in East Flanders, proportionally 670 (665-675) ha are to be allocated to the region of the Vlaamse Ardennen. Twenty-nine potential forest sites were (pre)selected in this area (see figure 1, orange forest sites). This gave us more than 62000 possible combinations of four to eight forest sites each[3].

[2] Habitats Directive 92/43/EEC and Birds Directive 79/409/EEC.

[3] We limited the analysis to combinations of four to eight forest sites as the area restriction of 665-675 ha can only be fulfilled by at least four sites.

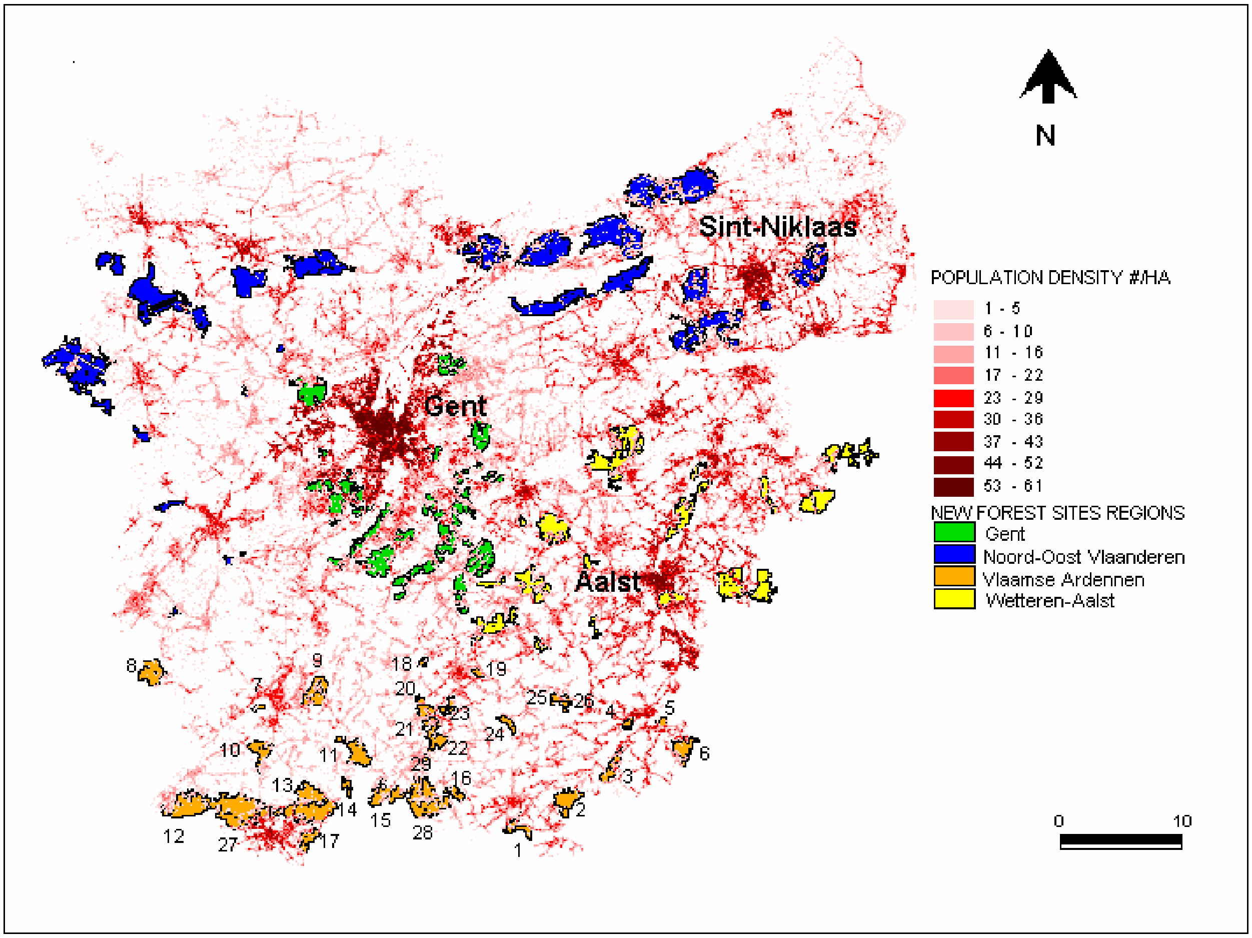

Figure 1: Map of the province of East Flanders: population density, the 4 different regions with their potential forest sites

3.2. Overview of costs and benefits

Table 1 represents the mean annual values[4] of all costs and benefits included in the analysis. They are calculated for each potential forest site for each possible combination of forest sites that meets the area constraints.

[4] We are aware that the list of costs and benefits is incomplete. Several ecological function values such as biodiversity, watershed protection, microclimate, air pollution, water pollution (Pearce, 1994) have not been taken into account due to data constraints and the focus of this paper (i.e. using Travel Cost Analysis with varying substitute set).

Table 1: Costs and benefits of afforestation with their mean annual value per hectare (annuities – in EURO/ha for the year 2000)

COSTS (€ $ha^{-1}year^{-1}$)		BENEFITS (€ $ha^{-1}year^{-1}$)	
Planting and management	38.60	Timber sales	28.50
Opportunity costs		Hunting permits	15
(1) loss of agricultural production	-714 - -362	Carbon sequestration	25
		Non-use	3680
(2) loss of manure deposition	457-590	Recreation	av. 3000
(3) lost recreational and non-use values in agricultural environment	229.81		

Most costs and benefits, such as planting and management costs, timber, hunting, carbon sequestration and non-use values, are fixed amounts per hectare of forest. They are independent both of the precise location of the potential forest site itself and of the location of its substitutes or of important population centres. Opportunity costs on the other hand differ according to the characteristics of the soil. This also applies both to the loss of agricultural production and the loss of manure deposition. We assume, however, a fixed amount for the lost recreation and non-use values of the agricultural land.

Recreation is then the only benefit category that is assumed to be both dependent on the location of the forest and the location of its substitutes, which can be both existing and other new forests. The same forest will therefore have a different recreation value depending on the respective combination.

3.2.1. Costs

Planting and management costs are calculated for a multifunctional mixed oak-ash forest where wood production is combined with high ecological and recreational values, characterized by long rotations (200 years). The forest is managed with a thinning frequency of 10 years and regenerated with a group selection system (GARCIA QUIJANO *et al.*, 2004). Annual planting and management costs per hectare accrue to 38.60 €.

Forest planting and management costs are very modest compared to opportunity costs. As all new forests will be planted on current agricultural land, the loss of agricultural production, potential manure deposition and recreation and non-use values of agriculture must be taken into account.

The agricultural sector in East Flanders produces a wide mix of agricultural products (various crops along cattle for dairy and meat production). Due to high subsidization of the sector by the EU, the calculation of the correct opportunity cost is quite complicated. Agricultural yields of the past five years (1995-1999) are multiplied by world prices to get the correct opportunity cost[5]. This way, crop rotation is implicitly taken into account. For grassland we assume that one hectare of land is grazed by 2 heads of cattle. Each is assumed to produce 6000 l of milk and 200 kg meat per year.

Costs per hectare cultivated land include implicit wages for the farmer, wages paid to third parties, machinery depreciation, maintenance, purchased and self-produced feed, seeds, pesticides, fertilizers, capital costs, etc. These costs differ with respect to soil and crop type (CENTRUM VOOR LANDBOUWECONOMIE, 2000).

The cost of the agricultural production loss is actually negative. This means that once agricultural subsidies are eliminated, the value of agricultural output is smaller than the cost of inputs (labour, capital, etc.) used.

A second opportunity cost is the cost of the manure surplus. In Flanders there is an excessive production of manure from pig farms. Use of the soil for agricultural production allows – limited - deposition of this manure on the agricultural land. Manuring norms have become more stringent over the last decades. Norms for nitrogen and phosphate differ per parcel of land in function of soil type, as well as protection laws for area and ground water and type of crop.

When agricultural land is afforested, more manure will have to be processed at a cost in stead of being spread on agricultural land. In Flanders, manure processing costs approx. 12.5 € per tonne.

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[5] NIS (2000a) (NIS (National Institute of Statistics) (2000a), Landbouwstatistieken, Landbouw- en Tuinbouwtelling op 15 mei 1999.);

FAO (2000a) (http://faostat.fao.org/faostat/form?collection=Crops.Primary&Domain=ProducerPrices&servlet=1&hasbulk=&version=ext&language=EN, last checked November 2004.);

FAO (2000b), (http://faostat.fao.org/faostat/form?collection=Livestock.Primary&Domain=ProducerPrices&servlet=1&hasbulk=&version=ext&language=EN, last checked November 2004.)

Finally, recreation and non-use values of the agricultural land will be lost[6]. For data on these types of values, very few sources are available. A Swedish contingent valuation study from 1992 (DRAKE, 1992) studies open and varied agrarian landscapes finds a value of 229.81 € per hectare[7].

3.2.2. Benefits

On the benefit side we see that non-tangible benefits like non-use values are far more important than the benefits that are directly perceptible and create direct income for the forest owner (e.g. through the sale of timber and hunting permits).

Timber values include the revenues of wood from thinnings and final harvesting for a multifunctional mixed oak-ash forest with a 200 year rotation. Price per m^3 of wood depends on age, average circumference and yield and were obtained from the Service Center for Forestry. Growth predictions are based on the Wiedemann tables (WIEDEMANN and SCHOBER, 1957). Timber yield amounts to 28.50 € per hectare per year (annuity).

Revenue from hunting permits is more stable than revenue from timber sales and less dependent from external factors (DIENSTENCENTRUM VOOR BOSBOUW, 2000). We assume only small game hunting will take place at the new forest sites. Annual hunting values per hectare are estimated at 15 €.

Carbon sequestration includes sequestration in above- and below-ground biomass, detritus and soil as well as sequestration in harvested wood. GARCIA QUIJANO *et al.* (2004) found long term figures of 2 to 2.75 tonne C per hectare per year plus a more uncertain below-ground storage of 0.2 tonne C per hectare per year on average. We assume a 2.5 C per hectare per year storage valued at 10 € per tonne (CIEMAT, 1999).

Non-use values include a bequest value and an existence value. The bequest value is. the benefit accruing to any individual from the knowledge that others might benefit from the forest in the future. Whereas the existence value is the benefit accruing to any individual from the mere existence of that forest area (MITCHELL and CARSON, 1989). Monetary valuation is based on the Contingent Valuation Method (CVM).

Data for Flanders are available from the "Heverleebos-Meerdaalwoud" study (MOONS *et al.*, 2000), the only valuation study for forests in Flanders. A CVM-survey was conducted and

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[6] Lost recreation and non-use values of agricultural land will be replaced and exceeded by recreation and non-use values of the new forests.

[7] Annuity, Euro 2000.

approx. 800 families in Flanders were asked about their willingness to pay for transformation of a Military Domain adjacent to Heverleebos-Meerdaalwoud into a closed access forest reserve. Respondents were asked if they would be willing to pay a single, non-recurring amount using the double bounded dichotomous choice method (CARSON *et al*., 1986). The median once-only willingness-to-pay of households that had never visited the Heverleebos-Meerdaalwoud forest complex for the proposed project was 76.15 € in 1999. Extrapolation gives an annuity of 3680 € per hectare.

Due to the complexity of calculating recreational values, we deal with this in a separate section.

4. The recreational value of potential new forest sites in the presence of a varying set of substitutes

As there are no data available for the potential forest sites, we use the benefit transfer technique that 'transfers' the monetary value of one site to another (DESVOUSGES *et al.*, 1992). ROSENBERGER and LOOMIS (2000) distinguish two broad approaches to benefit transfer: value transfers and function transfers. Value transfers include single point benefit estimates or average point benefit estimates. Function transfers imply the transfer/adaptation of either a benefit/demand function or a meta-regression analysis from several sites.

Transferring a pure benefit estimate leads to inaccurate results as the value of one particular site or visit to that site depends on the characteristics of both the site itself and its visitors. Although several authors have tried to refine the value transfer method by relating these benefit estimates of a site with its characteristics, LOOMIS (1992) has shown that more accurate results can be obtained by transferring a *recreation demand function* that was estimated for one or more base site(s). Therefore we choose to apply the function transfer method.

To automate the transfer of a recreation demand function, we highly depend on GIS techniques to determine the value of the variables in the demand function. BATEMAN *et al.* (1999) have shown that using GIS techniques to calculate travel time and costs and to define origin zones for the zonal TCM increase significantly the validity/consistency of transfers of a recreation demand function.

4.1. Base site analysis: Meerdaalwoud-Heverleebos complex

The Meerdaalwoud-Heverleebos complex (1890 ha in total) is the only forest in Flanders for which an economic valuation study has been conducted. This forest complex is situated in the province of Vlaams-Brabant, 10 km south of Leuven, a university city approx. 25 km east of Brussels, the capital of Belgium.

In the original study (MOONS *et al*., 2000), the recreational value of the site was determined using an individual travel cost model. We have repeated the analysis with a zonal travel cost model as only a zonal TCM can be transferred to different potential forest sites. To predict the potential number of visitors at a new forest site one needs data on visitor rates (i.e. the percentage of households in a specific region that visits a forest) and how they relate to travel cost and travel time, socio-demographic data etc. for the base site. This requires a zonal TCM although we do acknowledge that, for original or base site studies, the individual TCM is the preferred method (LOOMIS and WALSH, 1997).

The *zonal travel cost model* gives us a recreation demand function that predicts visit rates. We present the recreation demand function as follows:

$$Visit\,rate = f\left[price, socio-dem, substitutes, site\,characteristics, X\right]$$

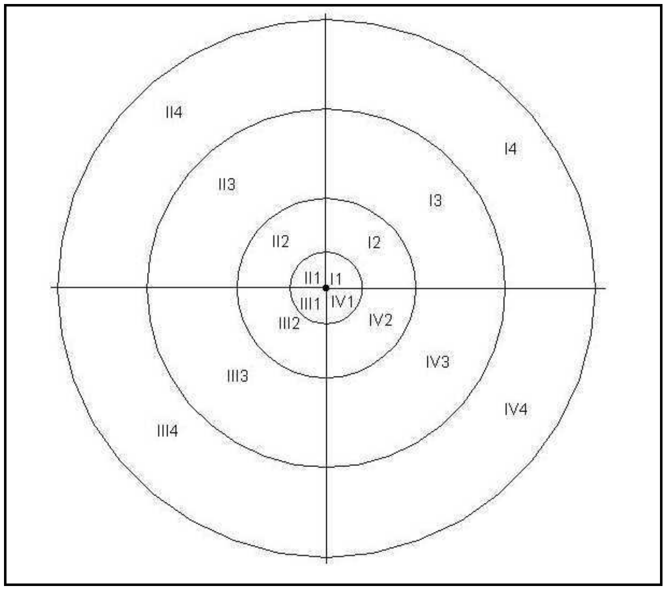
$$\begin{aligned} with: \quad & Visit\,rate = \frac{total\,visits}{total\,visitors}\, x\, \frac{total\,visitors}{total\,population} \\ & price = cost\ per\,visit\,(monetary\,and\,time\,travel\,costs) \\ & socio-dem = age, gender, occupation, available\,leisure\,time, ... \\ & substitutes = availability\,and\,quality\,of\ other\,recreation\,sites \qquad (9) \\ & site\,characteristics = natural\,and\,management\,characteristics \\ & \qquad (proportion\,deciduous-coniferous, \\ & \qquad length\,of\ accessible\,paths, ...) \\ & X = other\,variables\,influencing\,visit\ frequency \end{aligned}$$

As variation in site/location characteristics and socio-demographic characteristics in Flanders is very limited, we feel that using the MW-HB complex as base site is justified.

4.1.1. Definition of origin zones

By means of GIS we can locate the gravity centre of the MW-HB forest complex. This is considered to be correspondent to the crossing of a line from east to west and a line from north to south. This way we get four quadrants. Around the gravity centre we draw four concentric circles at 2, 5, 10 and 15 km[8]. In total we get 16 origin zones for which we want to predict visit rates (figure 2).

[8] The original valuation study has shown that 75% of the visitors of the forest complex live at a distance of max. 15 km of the forest complex (Moons *et al*., 2000).



I, II, III and IV indicate the four quadrants: 1, 2, 3 and 4 indicate the concentric distance zones. E.g. origin zone I1 is the zone in the north east quadrant at a distance of less than 2 km of the gravity point of the forest site.

Figure 2: 16 origin zones for a potential forest site

4.1.2. Visit rates

In 1998 and 1999 two types of surveys were conducted regarding the economic valuation of the MW-HB forest complex. An on-site recreation survey of visitors (1100 persons) provided data for the construction of an individual travel cost model to estimate recreation demand and consumer surplus of a forest visit. Another survey included person-to-person interviews (800 households) across the whole Flemish region. These interviews provide data for a CVM study that leads to an estimate of the non-use value of the forest complex. The CVM-survey also provides information on the recreation behaviour of the respondents with regard to the MW-HB forest complex. The survey provided useful data on visit frequency for each of the origin zones that are less prone to truncation and endogenous stratification problems (MOONS, 1999). Therefore we prefer this off-site survey over the data from the on-site recreation survey.

4.1.3. Travel costs

As travel costs are the most important variables in any recreation demand function based on the TCM, calculation of these costs needs to be as accurate as possible. GIS provides detailed information on both travel distance and travel time.

Travel costs include both monetary and time costs. Monetary costs are the product of distance travelled and a fixed cost per km (fuel costs, insurance, …). Time costs are the product of time travelled and the value of time savings in transportation. For the exact figures see MOONS *et al.* (2000).

For each origin zone we calculate a weighted average of travel costs per transport mode (car, bus, bike and on foot). Survey data are available on the proportion of different transport modes used for the trip to the forest.

4.1.4. Socio-demographic factors

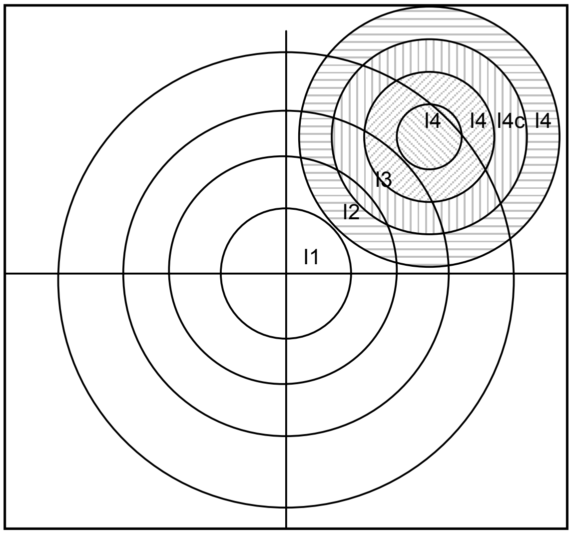
Data on population, age, education, activity are provided available on a detailed geographical level (1 ha or 100m*100m)[9] (source: NIS, 2000b). We aggregate these data for each of the 16 origin zones. The following variables are constructed:

- Age: -19; 20-34; 35-54 and 55+
- Education: primary school, lower secondary school, higher secondary school, higher education (except university), university
- Activity: Student –18, Student +18, unemployed, employed, retired

4.1.5. Substitutes

GIS maps provide data (location, total area, etc.) of nearby forests. For all visitors we include all possible forests other than the MW-HB forest complex. The starting point is the gravity centre of each origin zone. Again we construct four concentric zones of 0-2, 2-5, 5-10 and 10-15 km around the centre of each origin zone. This gives us 4x16 (64) different substitute zones for which the total area of forest land (both publicly and privately owned) is determined. This is shown on figure 3.

[9] NIS (2000b) (NIS (National Institute of Statistics) (2000b), Werkelijke bevolking per gemeente op 1 januari 2000)



The shaded areas are the 4 concentric substitute zones for origin zone I4. Substitute zones were constructed for each origin zone, defined through quadrants and concentric zones around the gravity point of the forest site (as explained in section 4.1.1. and shown of figure 2).

Figure 3: Substitute zones a, b, c and d for one origin zone

We use one aggregate index for the available substitutes. The diminishing importance of substitutes at further distances is taken into account by dividing - for each origin zone - the total substitutes area within a substitute zone by the weighted average of the travel time to the site (weighted by transport mode). Next, the results for each of the substitute zones of one origin zone were summed to obtain one substitution index for each origin zone (in ha per minute travel time).

4.1.6. Estimation of visit rates and total yearly visits: the recreation demand function for the base site

Several zonal travel cost functions – or recreation demand functions based on the TC method) have been estimated. Visit rates are explained by travel cost and time (separate variables or combined variable), socio-demographic variables and a substitution index[10].

The following demand equation gives the best results[11]:

$$Visit\,rate = \underset{(4.206)}{250.595} - \underset{(-2.056)}{3.426}\,travelcost - \underset{(-1.876)}{0.024}\,popden - \underset{(-2.344)}{1.156}\,subindex - \underset{(-2.946)}{774.205}\,prop55^{plus}$$

[10] We do not control for site characteristics. We assume all potential new forest sites have approx. the same characteristics – apart from size/area – than the MW-HB forest complex.

[11] T-statistics between brackets; R^2-adj: 0.76.

with:

- Visit rate = average number of yearly visits per visitor*participation rate (visitors/total population) per origin zone
- Travel cost = cost of a displacement to HB-MW (two-way) (weighted average per origin zone)
- Popden = population density (inhabitants per km²) per origin zone
- Subindex = substitution index per origin zone
- $Prop55^{plus}$ = proportion of people older than 55 per origin zone

The variables have the signs that could be expected based on the travel cost literature and economic theory. Increasing travel costs decreased visit rates; the higher the availability of substitutes the lower the visit rates to MW-HB; the higher the proportion of older people (55 years or older), the lower the visit rates.

The negative sign of population density might seem strange if we think of population density as a measure of the degree of urbanisation of a region. In this reasoning, we would expect city dwellers to be more frequent forest visitors than people living in the countryside. However, the negative sign may be explained by the fact that we do not account for other substitute leisure activities than forest visits and it is common knowledge that city dwellers have a wider range of possible leisure activities (cinema, shopping, musea, concerts, …) (BATEMAN *et al*., 1998).

Based on this recreation demand regression, the predicted average number of yearly visits to MW-HB is 12.51, whereas the actual average is 11.01 (on-site recreation survey). Non-parametric tests show there is no significant difference between actual and predicted numbers of visits per zone.

4.1.7. Consumer surplus estimates

Consumer surplus is first estimated for a single visitor in a single origin zone. On average, the yearly consumer surplus was 40.22 € per capita.

Based on consumer surplus estimates on the one hand and predicted visits to the MW-HB forest complex on the other hand, the total recreational value of the forest complex amounts to 2720000 € or 1440 € per hectare per year.

4.2. Analysis for potential new forest sites: benefit transfer of the recreation demand function

For each of the 29 potential new forest sites in the Vlaamse Ardennen we calculate total recreational values per hectare per year by transferring the recreation demand function estimated for the MW-HB forest complex.

We define origin zones around each forest as described in section 4.1.1. for the base site. We aggregate detailed NIS-data on socio-demographics for each origin zone using GIS.

For each forest we calculate a substitution index as described in section 4.1.5. However, not only existing forests act as substitutes for the potential new forest site. As the afforestation goal consists consists of creating 670 ha new forest land (for the region Vlaamse Ardennen) that can only be attained by creating several separate forest sites. For each potential forest site we compute the substitution indexes for each combination the potential forest site belongs to.

Transferring the demand equation to each of the potential forest sites gives us a prediction of the number of yearly visits to the site, consumer surplus per visit and total recreational value of each forest site, taking into account the substitution effect for each combination.

As the base site and potential forest sites differ quite substantially in size, we need to correct for this area difference. Preferably we could add a 'size' variable in the demand equation. But as there are no data available in Belgium on number of visitors to forests of different sizes, we use on-site experience from foresters to make an ex-post correction. Apparently forests smaller than 20 ha attract few to no visitors. The marginal change in visitor numbers for forests larger than 300 ha when enlarged with one hectare seems to be negligible. Therefore, we linearly correct predicted zonal visit numbers through size-corrected participation rates, with the participation rates for MW-HB (1890 ha) as an upper limit for all forest sites of at least 300 ha.

5. Results and discussion

The final step in our analysis is to rank all possible combinations of potential forest sites according to their net social benefit estimate per hectare. This NSB (net social benefit) is presented by the following equation:

$$NSB_{z}^{\text{lim/full}} = \frac{\sum_{i \in Z} B_i - C_i}{\sum_{i \in Z} surface_i} \qquad (10)$$

Two net social benefits were calculated:

- NSB^{lim} : without recreation (LIMITED ANALYSIS);

- NSB^{full} : with recreation (FULL ANALYSIS).

In the first case, NSB^{lim} of one potential forest site is independent of the combination it belongs to. The net social benefit is unique and variation between forests is solely due to variation in opportunity costs (agricultural production and manure deposition) **a**s all other costs (planting and management, loss of recreation an non-use value of converted agricultural land) and benefits (timber, hunting, carbon sequestration and non-use value) are taken fixed per hectare and are the same for all forests.

In the second case, NSB^{full} of one forest is dependent on the combination of potential new forest sites it belongs to, due to the variation in the set of substitutes that determines the recreational value of a forest recreation site. Now geographical location is very important – both for the location of forest sites with regard to other forests and for the location of forest sites with regard to population centres.

The results are presented in table 2 and table 3. Table 2 gives the numbers of the forests areas that are in the 10 'best' combinations according to the limited, table 3 shows the results for the full analysis. Between brackets we added net $NSB^{full/lim}$ of the forest site.

Figure 1 shows the location of each of the 29 forest sites. Appendix A gives an overview of the size and all the cost and benefit categories except recreation.

Table 2: The 10 best combinations in the limited analysis: forest number and NSB^{lim}

C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**
5 (5127)	5 (5127)	5 (5127)	5 (5127)	5 (5127)	5 (5127)	5 (5127)	3 (3745)	5 (5127)	5 (5127)
9 (3814)	20 (4992)	10 (3737)	11 (4118)	9 (3814)	9 (3814)	16 (4034)	5 (5127)	15 (3661)	9 (3814)
20 (4992)	21 (3680)	20 (4992)	15 (3661)	10 (3737)	11 (4118)	20 (4992)	11 (4118)	20 (4992)	11 (4118)
28 (3849)	28 (3849)	26 (4115)	20 (4992)	16 (4034)	20 (4992)	23 (3464)	15 (3661)	25 (3821)	16 (4034)
	29 (4303)	28 (3849)	25 (3821))	20 (4992)	23 (3464)	28 (3849)	20 (4992)	28 (3849)	20 (4992)
			26 (4115)	26 (4115)	29 (4303)	29 (4303)	26 (4115)		25 (3821)
			29 (4303)	29 (4303)					26 (4115)

Forest numbers correspond to the numbers on Figure 1. NSB^{lim} between brackets.

Table 3: The 10 best combinations in the full analysis: forest numbers and NSB^{full}

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
9 (5804) 12 (3445) 14 (11044) 22 (6141)	9 (5579) 12 (3342) 21 (6839) 26 (11189)	5 (18055) 9 (5059) 12 (3689) 22 (6000)	9 (5667) 12 (3374) 22 (6162) 24 (8875)	9 (5647) 12 (3341) 16 (9924) 21 (6580)	3 (6667) 9 (5067) 12 (3714) 26 (11261)	6 (5524) 9 (5217) 12 (3677) 20 (21164) 25 (6593)	6 (5754) 9 (5139) 12 (3675) 16 (9306)	7 (19925) 9 (5029) 12 (3657) 14 (9533) 21 (4546)	9 (5628) 12 (3465) 14 (10873) 17 (6054) 20 (10117)

Forest numbers correspond to the numbers on Figure 1. NSB^{full} between brackets.

Although results were not clear at first sight, according to the Wilcoxon Signed Ranks test for differences (Berenson *et al.*, 2002), adding recreation values didn't make a significant difference. Ranking all possible combinations from highest to lowest net social benefits shows that the highest NSB^{full} (best combination) is more than 21 times higher than the lowest NSB^{full} (worst combination) per hectare. This is clearly shown on figure 4, which shows net social benefits per hectare ranked from high to low for every tenth combination (out of the approx. 62000 possible combinations).

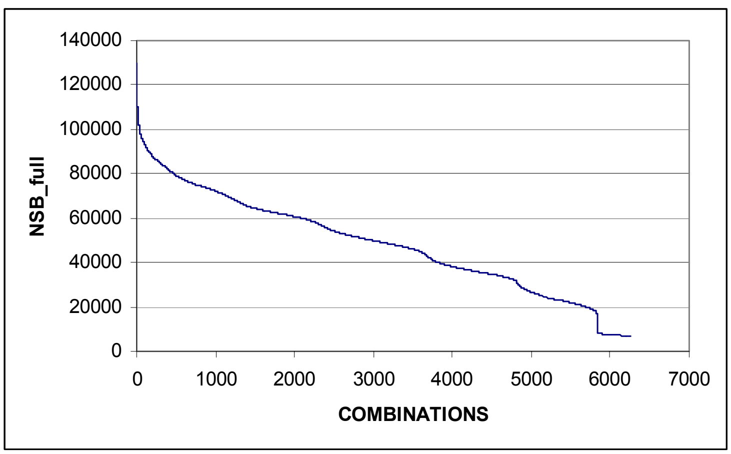


Figure 4: Distribution of NSB^{full} from highest to lowest for each 10^{th} combination

Concentrating on the results of the full analysis (with recreation) figure 5 shows the importance of the substitution effect in estimating the recreational value of a potential forest area. In other words, geographical location of a forest relative to major population centres and to other forests matters a lot. The wider the choice of forests a person can visit, the fewer the number of visits to one particular forest, the lower the recreational value of the forest and the lower the net social benefit per hectare. Figure 5 shows that the NSB^{full} of one particular potential forest site differs substantially for the different combinations the site belongs to. On average, the difference between the NSB^{full} for one particular forest when we look at the 1st, 1001th, …, 9001th combination is 22%.

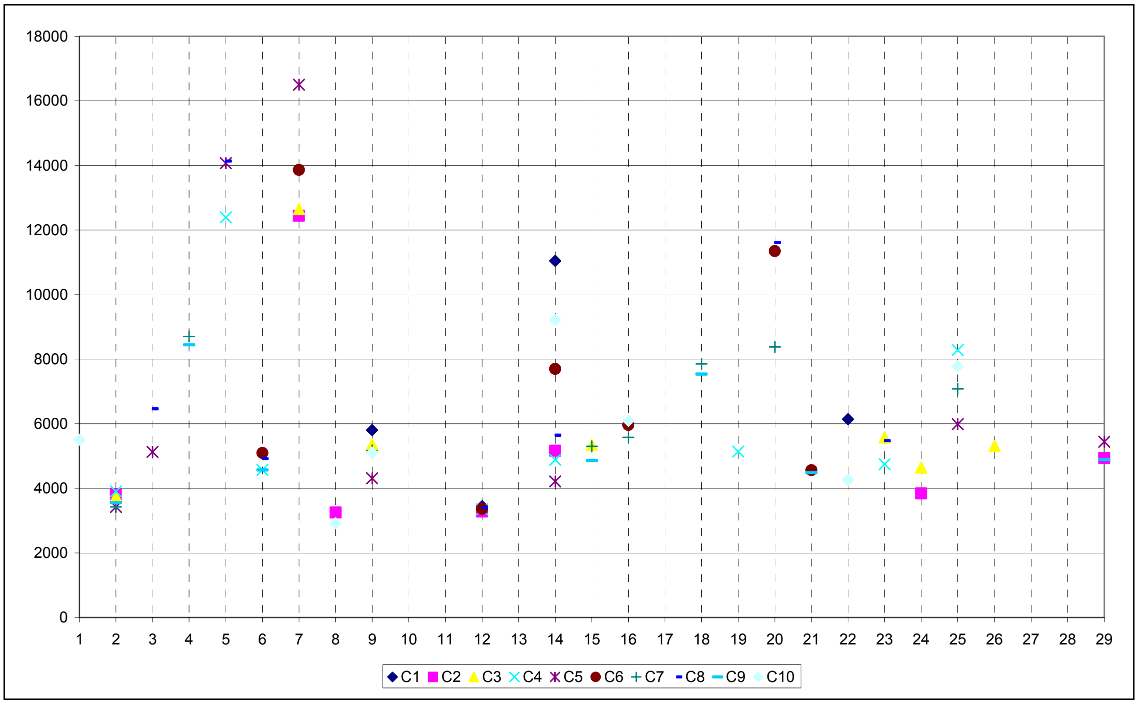


Figure 5: NSB per site in the 1st, 1001th, …9001th best combinations (FULL ANALYSIS – with recreation value)

From our findings we can conclude that substitution effects play a major role in the recreational value of forest sites 'an sich' and combinations of forest sites as a whole.

This finding is of great importance for the afforestation policy of suburban regions. Afforestation of a certain area of agricultural land at different locations leads to high variations in the net social benefits per hectare of afforestation. In other words, the same EURO spent on afforestation can create different net benefits.

6. Conclusions

In this paper we have shown how GIS-based cost-benefit analysis can be used as a decision support mechanism for afforestation projects. We focused on the role of a varying set of substitutes as the surface restriction set by the afforestation policy of the government can only be met by creating multiple new forests out of the set of all potential new forest sites.

Moreover, we found that taking into account recreational values significantly changes the net social benefit of afforestation projects. The best combination of forest sites has a net social benefit many times higher than the worst combination. This is another way of showing the importance of substitution effects in recreation values.

There are several limitations of the current methodology that need to be addressed in the future. We discuss here four issues. First, we made a once and for all analysis where all projects were decided and started at one point of time. So the optimal timing problem still needs to be solved and this may become a very complex issue once one allows visitors to relocate endogenously. In this case, the benefit of a forest site increases if it can attract recreation lovers to its neighbourhood. A second issue is the decentralisation of the afforestation decisions: do we need public forests or can private forests do the job at lower costs and what is the appropriate level of decision making: regions or countries. A third problem that we want to mention is the importance of site attributes in the travel cost analysis. Due to lack of data (only one base site study was available in Flanders), we were unable to test for variation in site characteristics. The major problem here is the difference in size between the base site and the different potential forest sites for which visitor numbers were predicted. For other characteristics (such as proportion of deciduous trees, type of paths, …) we know that variation within the Flemish region is limited anyway. A fourth problem is the estimation of ecological benefits where non monetary indicators are in general available but their monetarisation remains difficult.

Appendix A: overview of size, costs and benefits (except recreation) for each of the 29 potential forest sites in the Vlaamse ardennen

SITE NUMBER	SIZE	BENEFITS EURO 2000				COSTS EURO 2000			NSB_{LIM}
		TIMBER	HUNTING	CARBON	NONUSE	PLANTING AND MANAGEMENT	MANURE	AGRICULTURE	
1	**70**	1995	1050	1750	257600	2702	21170	-126858	365381
2	**91**	2594	1365	2275	334880	3513	44571	-219785	512814
3	**125**	3563	1875	3125	460000	4825	45191	-248098	666645
4	**31**	884	465	775	114080	1197	7871	-36793	143929
5	**40**	1140	600	1000	147200	1544	18518	-75189	205067
6	**118**	3363	1770	2950	434240	4555	41411	-208847	605204
7	**24**	684	360	600	88320	926	248	-1113	89903
8	**100**	2850	1500	2500	368000	3860	27467	-199599	543123
9	**221**	6299	3315	5525	813280	8531	80305	-366382	1105965
10	**159**	4532	2385	3975	585120	6137	58850	-287377	818401
11	**229**	6527	3435	5725	842720	8839	103049	-509535	1256052
12	**267**	7610	4005	6675	982560	10306	109990	-366405	1246958
13	**525**	14963	7875	13125	1932000	20265	209445	-889978	2628231
14	**43**	1226	645	1075	158240	1660	17353	-79096	221270
15	**185**	5273	2775	4625	680800	7141	79078	-359239	966492
16	**65**	1853	975	1625	239200	2509	26326	-136118	350935
17	**112**	3192	1680	2800	412160	4323	25322	-74673	464860
18	**23**	656	345	575	84640	888	11812	-51157	124672
19	**31**	884	465	775	114080	1197	7152	-45189	153044
20	**30**	855	450	750	110400	1158	11354	-59797	159740
21	**120**	3420	1800	3000	441600	4632	47385	-213107	610910
22	**139**	3962	2085	3475	511520	5365	58788	-283956	740845
23	**51**	1454	765	1275	187680	1969	20067	-101065	270203
24	**44**	1254	660	1100	161920	1698	16411	-75564	222389
25	**29**	827	435	725	106720	1119	9693	-74036	171930
26	**58**	1653	870	1450	213440	2239	21121	-102216	296269
27	**669**	19067	10035	16725	2461920	25823	267663	-1182520	3396780
28	**383**	10916	5745	9575	1409440	14784	143654	-601079	1878317
29	**100**	2850	1500	2500	368000	3860	43195	-210126	537921

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