Chapter 10
Interactive Spatial Decision Support for Agroforestry Management

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10.1 Introduction

Forests are important ecosystems that are able to support productive functions (e.g. supply of wood products and non-timber forest products) and protective functions such as climate regulation, air pollution filtering, regulation of water resources, conservation of biodiversity and protection from wind erosion, coastal erosion and avalanches (FAO 2005). In the last decade, around 13 million ha of forest have been ruined or converted to other uses each year, compared to 16 million ha per year in the 1990s (FAO 2010). Despite this decrease, deforestation rates are still alarmingly high. Therefore, there is a need to globally improve the management of forest resources, and particularly to take into account additional forest values (such as biodiversity and social functions) towards long-term sustainable management (Varma et al. 2000).

Paletto et al. (2013) define Sustainable Forest Management (SFM) as a dynamic concept with the main purpose of maintaining and enhancing the economic, social and environmental value of forests, for the benefit of present and future generations. Agroforestry is regarded as a promising approach for sustainable forest management (Schoeneberger and Ruark 2003). Agroforestry systems are practiced in

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tropical and temperate regions and include traditional and modern land-use systems in which trees are managed together with crops for multiple benefits. These systems allow communities to produce food, contributing to food and nutritional security, and to achieve productive and resilient cropping environments. Moreover, they can provide a range of forest products, including fuel-wood and non-timber products, increase biodiversity, protect water resources and reduce soil erosion. On a large scale, agroforestry systems can also prevent the occurrence of extreme weather events, such as floods and drought (FAO 2013).

However, agroforestry projects present very complex and interdependent economic, technical, political and social challenges, with its sustainability ultimately depending on the extent to which a well-coordinated land management strategy is designed and implemented (Sampson 1998). Decision support systems (DSS) have been an important tool in forest management since the early 1980s (Reynolds 2005). Segura et al. (2014) suggest that the future development of DSS for forest management should place stronger emphasis on economic models integrating the value of environmental services and collaborative decision making of multiple decision makers and stakeholders. In addition, decision support and management should be augmented with spatially explicit analysis as the costs and opportunities for different solutions have intrinsic geographic variability. A dynamic approach to land-use planning is needed to evaluate the long-term effects of present management decisions (Mönkkönen et al. 2014; Varma et al. 2000).

Spatially explicit systems for forest management have been developed in the past, but mainly based on individual tree growth (Phillips et al. 2003) or forest succession (Gustafson et al. 2000; He and Mladenoff 1999), not taking into account economic parameters. Van der Hilst et al. (2010) studied the potential, spatial distribution and economic performance of regional biomass chains, using attainable yields for biophysical suitability. Kosonen et al. (1997) studied the financial, economic and environmental profitability of reforestation of Imperata grasslands in Indonesia, a monoculture in a similar area to the case study of this paper. Furthermore, soil erosion and biodiversity indices were also developed for different vegetation covers, where the slope and the richness of bird and tree species were the principal components considered.

From a financial perspective, Hinssen and Rukmantara (1996) built a cost Comparison Model for budgeting of reforestation projects. While Chertov et al. (2005) used geo-visualization of forest simulation modelling on a case study of carbon sequestration and biodiversity. Wang et al. (2010) presents an integrated assessment framework and a spatial decision support system as a tool to support forestry development with consideration of carbon sequestration.

Vierikko et al. (2008) studied the interrelationships between ecological, social and economic sustainability at the regional scale, analysing their trade-offs. Segura et al. (2014) compared different decision support systems (DSS) for forest management and concluded that the majority of DSS do not include environmental and social values, focusing mainly on market economic values.

Stakeholders are generally uninformed of the benefits of agroforestry and the factors that determine the adoption of agroforestry practices (FAO 2013). The lack of awareness of the consequences and benefits of agroforestry projects may lead to unsustainable forest management. Therefore the tool presented can provide the needed awareness of the outcomes for different innovative agroforestry solutions including the complicated small scale permaculture approaches.

Despite the recent progress, a DSS for agroforestry management that is able to combine spatially explicit information with non-spatial factors and perform integrative assessments of the economic, social and environmental aspects has not been developed so far. In this work, we propose an interactive system that makes use of advanced visualization and analysis of spatially and temporally related data that attempts to inform and support decision making in the field of agroforestry management. It is intended to be useful for planners, stakeholders and managers in order for them to understand consequences of their spatial plans. The system was developed as an implementation of the emerging concept of geodesign (Steinitz 2012; Ervin 2011). In geodesign, proposed landscape changes are directly evaluated against impact models previously defined, so the design ideas and solutions can be iteratively and collaboratively created by different stakeholders and domain experts (Dias et al. 2013). The plans are continuously evaluated against multiple objectives and continuously evolved to develop fitter (less impact) and more robust (more benefits) solutions.

The goal of this chapter is to present a spatially explicit DSS fully integrating the economic, environmental and social dimensions of agroforestry systems streamlined by the geodesign framework. The system demonstrated in this chapter provides:

- An approach to identifying the most beneficial locations for agroforestry projects based on the biophysical properties and evaluate its economic, social and environmental impact;
- A simulation environment that enables evaluation via a simple dashboard and with the opportunity to perform straight forward sensitivity analysis for key parameters;
- A tool to inform prospective investors of the potential and opportunities for integrated forest management;
- A 3D interactive geographic visualization of the economic, social and environmental outcomes to facilitate direct understanding, also by non-experts.

10.2 Material and Methods

10.2.1 Methodology

The system is intended to be a spatially explicit integrative assessment tool for agroforestry projects. It allows the comparison of the economic, social and environmental performance of different management options, by combining spatial data on biophysical features, population, infrastructure and transportation networks with data on economic and technical factors. It also functions as an exploratory tool, being deployed in an interactive environment that enables sensitivity analyses of system performance for the main key factors (e.g. cost of production factors, market prices of commodities) and different spatial options (designs) in forest plantations. The conceptual model behind the spatially explicit cost benefit analysis is illustrated in Fig. 10.1.

The system aims to determine the local performance of agroforestry recipes, defined as a mix of crops that are sequentially cultivated in a certain area. Different recipes have different environmental requirements, timing and economic values in terms of field operations, field inputs, commodities, labour needs and costs. The considered recipes are defined according to the opportunities and constraints set by the biophysical features of specific regions. Examples of recipes are given on the case study description (Sect. 10.3).

The performance of each recipe depends to a large extent on the local biophysical suitability, which affects the attainable yield/productivity per year for different species, which in turn is determined by the combination of local biophysical parameters such as soil, altitude, temperature, precipitation and slope. Suitability and recipes are assessed by local expert knowledge and map analysis, combining different biophysical layers and parameters. Recipes are specially selected to enhance synergies between different crops and other spillover effects such as avoiding soil erosion, protecting watersheds and providing regular jobs and other products.

The produced commodities entail spatially explicit field operations costs and inputs including labour force, planting, maintenance, harvesting and tapping, which are integrated in the total costs of the system. Commodities are dependent on the area suitability and yields per year, hectare and recipe. Commodities include timber and crops (such as cassava and pineapple), as well as by-products (such as broom, roof covers and furniture). Conversion efficiency factors are used to determine the final products, depending on the type of mechanism applied for the transformation. The user is able to introduce and change the commodities produced as needed.

Besides the revenues derived from selling the commodities in the markets and the production costs, there are also highly variable costs that have to be considered, such as transportation and storage. Transportation is one of the economic factors with more expression as access to the production sites is often difficult. Transportation costs are calculated on a combination of geographic data of the roads, ports and markets, simulating the price depending on the distance to transport the commodities via advanced network analysis. This network analysis takes into account the type of roads and fuel costs.

Field operations are defined in terms of the number of each operation per year, per recipe and per unit area. The field operations initially taken into account in the system are land clearing (suppression and removal of existing trees and weeds), seeding and planting, maintenance (e.g. weeding), harvesting and tapping.

The field inputs are the inputs needed for each field operation, such as labour force, fuel consumption, number of seeds and fertilizer per hectare and recipe. These were the initial inputs considered, but the system can support more complexity as needed during the project. Additional field inputs or operations can be added for different progress or scenarios.

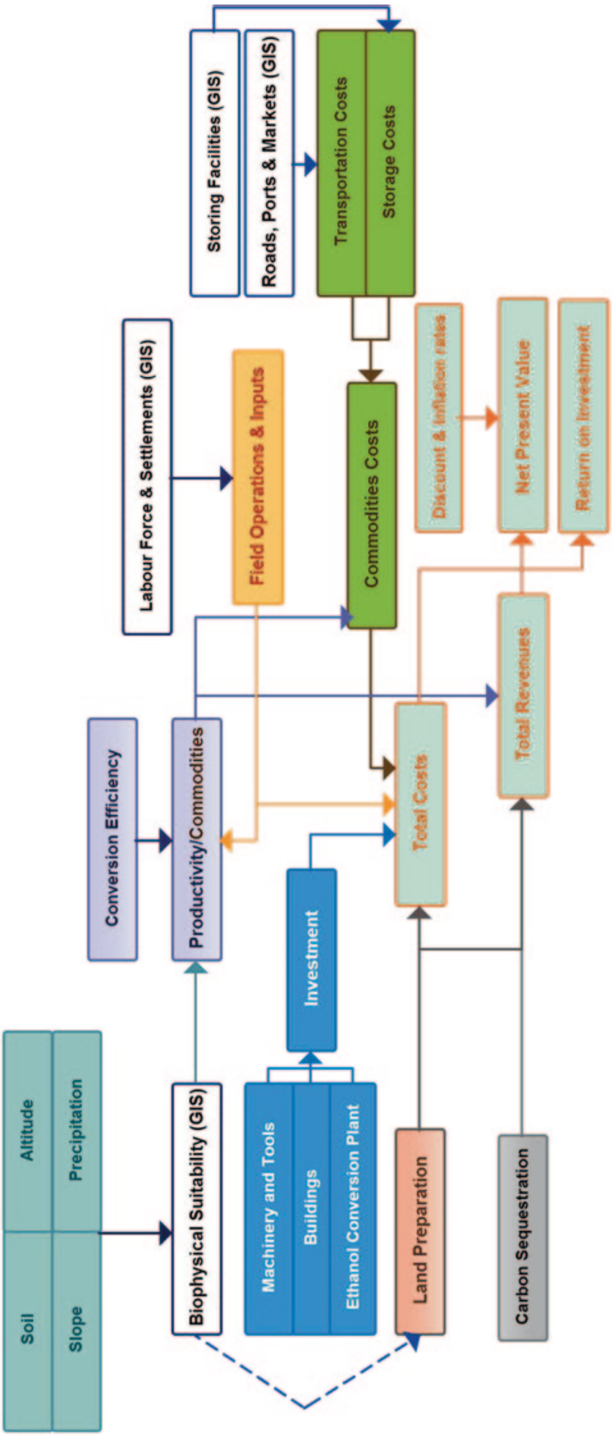

Fig. 10.1 Spatial distribution and economic performance of an agroforestry project

In a first phase approach, all field inputs are combined to give a final value ($/ha) for each field operation described. The total cost of field operations per recipe is calculated by the multiplication of each field operation input with the according number of field operations. Depending on the biophysical suitability of the area and the recipe to apply, a land preparation might also be required in order to reforest it. This land preparation, might include land clearance which is translated into a cost and revenue, as some materials can be sold. Since labour force is required for the realization of the project, it is important to take into account the location of the settlements to choose the most suitable location. The labour force will be determined by the hours of work needed for certain recipe and unit area. Therefore, the recipes can also be chosen or modified to match the amount of labour available or job opportunities needed. Labour has two important perspectives, as a financial cost for the system but also as a social output via the increase of employment rate and welfare improvement.

Economic Aspect

The economic performance is determined by the Net Present Value (NPV) and return on investment (ROI), calculated based on the investment, total costs and revenues. The NPV and ROI are essential economic key factors for investors' decision. Specification of the investment needed for the project is also considered, being determined by the required number of units and costs of machinery, tools, buildings and conversion plants units (e.g. sawmill).

The total costs include field operations, investment and commodities costs (transportation and storage). The total revenues represent the sum of the cash inflow of the entire project, such as cash inflow from commodities, land clearance, as well as carbon emission permits. Both total cost and total cash inflow, are calculated per year, as management decisions are made yearly in the specific case study.

To assess the long-term benefits of different recipes and therefore different land use practices, we calculate the NPV per hectare using the following equation:

$$\mathrm{NPV} = \sum_{t=1}^{N} \frac{\text{Cash Flow}}{(1+i)^t} - \text{Investment}(\$ \ / \ \text{ha}) \tag{10.1}$$

where NPV is the net present value cumulated to year n; i is the discount rate (%); NPV = Net Present Value of recipe per ha ($/ha); Cash flow = Revenues − Costs ($/ha), t = annuity period (y), *N* = lifetime of the project.

The discount rate, can also take into account inflation and depreciation rate. The annuity time period considered was 20 years, which is in line with an agroforestry project lifetime. When comparing investments, the one with the highest NPV, assuming the same discount rate, is considered the most desirable on the economic perspective.

ROI is the internal annual rate of return of an investment. It is the compound interest rate that equates the present value of future incomes with the present value of future costs.

$$\text{ROI}=\frac{\text{Total Revenues}-\text{Total Costs}}{\text{Total Costs}} \tag{10.2}$$

Environmental and Social Aspect

So far the system is intended as a "quick scan", easy to use and understandable, therefore instead of complex indices (composite indicators), we represent the social performance by the number of jobs created and the environmental performance by the amount of carbon sequestration (CO_2e tons), per recipe.

Carbon sequestration (CS) of the recipe accessed by the following equation:

$$\text{CS}_{\text{recipe}} = \sum\nolimits_{j=1}^{t} n_{T_j} \times \text{Sequestration}_{\text{T}_\text{j}}\,(\text{CO}_2\text{e}) \tag{10.3}$$

n_{T_j}—number of trees of a specific tree species; Tj—specific tree species; $\text{Sequestration}_{T_j}$—tonnes of carbon stored of a specific tree species; t—number of different tree species of the recipe.

Afforestation and reforestation are included in trading schemes for carbon sequestration offsets, and therefore through credits generates revenue (Eq. 3) (Saundry 2009).

$$\text{CS}_{\text{revenues}} = \sum\nolimits_{i=1}^{x} \text{CS}_{\text{recipe}} \times \text{Ccredits}_{\text{price}}\,(\$) \tag{10.4}$$

$\text{Ccredits}_{\text{price}}$—$CO_2$ emission permits market prices; x—number of recipes on the agroforestry project.

However, the system is prepared to receive data from more complex indices, such as biodiversity or soil erosion for environmental performance. Kosonen et al. (1997) developed soil erosion and biodiversity indices for different vegetation covers for a case study on South Kalimantan, where the slope and the richness of bird and tree species were the principal components considered, respectively.

10.2.2 Implementation

Microsoft Excel™ was chosen as implementation environment for the modelling system, due to its flexibility to add and edit different parameters or values, integrating all the system parameters in different spreadsheets. Each parameter has a sheet, in order to ease comprehension and changes for the final user. A dashboard was created to gather the essential controls for the end-user where different parameter values can be simulated.

Reforestation and agroforestry investments can be complex due to the uncertain future conditions. Therefore investors are often sceptical about investing on agroforestry projects. To address this problem an interactive tool with a sensitivity analysis was built so that different parameters could be simulated. For example, price fluctuations can be analysed and simulated in order to evaluate its impact.

The simulation of different parameters through interactive sliders can be instantly visualized spatially in an interactive 3D geographic visualization interface. In this interface, combining geographic location (latitude, longitude) and outcomes data, the user can navigate on the map, helping the comprehension of the different locations benefits.

This way it is possible to simulate spatial and non-spatial variations in a geodesign framework that can help better informed decisions, while exploring different possible scenarios. Besides that, this implementation provides an easy and flexible environment to become aware of the sensitivity to different parameters, allowing a combination of different alternatives and scenarios that wouldn't be possible in a hard copy consulting report.

10.3 Case Study

The methodology is generic and can be applied anywhere in the globe. A model application has been recently developed for a specific study area in Indonesia. Indonesia has the third largest area of tropical forest in the world, 68 % of its landmass, and its impressive biodiversity is contained in those forests. Wood manufacturing paper and printing industry is also an economically significant sector, 3–4 % of the country GDP (Josef et al. 2009). According to 1998 data, almost 24 % of 69.4 million ha under logging concessions were degraded (Kartodihardjo and Supriono 2000).

The study area is located in East Kalimantan, Indonesia, where a local company manages a forest concession of around 200,000 ha. The concession aims to implement a sustainable forestry management strategy, profitable but also fostering development in local communities and promoting the conservation of the surrounding environment. This way, economic, human development and environmental goals can be jointly pursued.

Sustainable use of the forest relies upon a multi-crop reforestation scheme, in which different trees species and crops benefit together from mutual synergies, being therefore more efficient than monoculture schemes for environmental goals (Gamfeldt et al. 2013). Species vary in their nutrients, sunlight and soil moisture requirements to establish and grow successfully (Stringer 2001). Integrating many different species in one unit of land with different spacing, with optimal sunlight utilization through a succession of species will also reduce losses of nutrients. It relies on an integration of growing cycles with different lengths in one total longer rotation of the system. The total success of an ecosystem depends on how the complex processes are adapted to local conditions, and the evaluation of the recipes by a local expert. Everything depends upon competition driven utilization of light and nutrients, as well as strategies in the process of succession during development of a locally stable ecosystem. Matching site-species is a necessity to promote growth and maintain long-term sustainability (Chokkalingam et al. 2006).

In order to maximize the productivity, a recipe has specific timing and biophysical conditions. The following recipe is an example for a wet tropical climate condition on terrain with less than 30 % slopes, well-draining soil, reasonable good access from roads and with enough local labour and local needs for food and energy.

- Start: Land preparation, Planting, Fertilizing
  - Clearing planting spots, digging planting holes, mobilizing compost;
  - Transporting plants to field, planting trees (nitrogen fixer and sugar palms) and cassava mixed;
- Year 1: Harvest and Maintenance, new Planting
  - Harvest of the cassava for food, animal feed and production of ethanol;
  - Maintenance of the planted trees;
  - Planting of banana in between the trees;
- Year 2: Harvest and Maintenance
  - Harvest of the bananas;
  - Maintenance of the trees;
- Year 3: Harvesting and Maintenance
  - Fuel wood from thinning;
  - Harvest of palm fibres;
  - Last maintenance of trees;
- Year 4–6: Harvest of palm fibres and Fuel Wood removal
  - Regular harvesting of palm fibres;
  - In year 6 removal of the remaining fuel wood;
- Year 7–9: Start tapping of sugar palms
- Year 10: Harvesting of sugar palms
  - Last tapping of sugar palms;
  - Harvest of sugar palm fruits and sugar palm wood;
- Restarting the Recipe.

One of the species in the case study is the sugar palm (*Arenga pinnata*). Besides yielding sugar, this palm also provides a great number of other products and benefits to its users, such as bioethanol from the sugar palm juice, after fermentation and distillation. It has a positive contribution to small households (e.g. opportunities for additional sources of income, clean fuel for cooking, transport, electricity, etc.) and requires little maintenance (Mogea et al. 1991; van de Staaij et al. 2011). The bioethanol produced from the sugar palm can then be used to replace gasoline in motorcycles, small vehicles, small machines and generators, and can also be used as cooking fuel in special burners (Smits 2010). A mixed production system can therefore provide food security, energy, regulate water, support biodiversity, sequester more carbon, as well as create jobs year-round, because each culture has its harvesting period.

10.4 Results

10.4.1 Interactive System

A sensitivity analysis is an important tool as an investor or manager can easily see the impact of parameters prices fluctuations on the project.

The goal was to produce an easy to use system, incorporated with sliders that can control different field operational costs. An excel sheet was created for each parameter, example of the field operations sheet on Fig. 10.2, which represents the number of each field operations per year, recipe and hectare.

The system is prepared to easily analyse or edit each recipe, whereas each column represents a year on the 20-year project lifetime considered and the user can change the number of each field operation per year and observe the impact on economic aspects. For example, when labour becomes a limiting factor at a certain moment in time (e.g. because a new industry nearby offers higher paid jobs) the absence of maintenance can directly be translated in terms of income and less carbon sequestered.

Commodities (Fig. 10.3) are organized in a list where the user can input the quantity (tons or m^3) produced per year and price ($) of the crops and raw materials, final products or by-products. Options to control the price through sensitivity analysis sliders is also provided on the dashboard.

A dashboard has been developed (Fig. 10.4) where the user is able to see the content of the recipe, the map suitability of the recipe, as well as the possibility to change the field operations and commodity value prices and instantly see the impact in terms of Total Revenues, Total Costs, Net Present Value and Return on Investment.

The objective of the sensitivity analysis sliders is to explore the critical factors of the agroforestry project. In the present case study, tapping and transports are the most critical ones. The user can also decide the area of cultivation to be calculated, having an instant result of that change on the dashboard. For other changes, for instance, when a disease wipes out certain seedling planting stock in the nursery, other recipes can be chosen to make up for the loss. This might mean planting fewer recipes but larger areas of each of them.

The distance map (Fig. 10.5) is a first approach for the decision algorithm that will give the most suitable locations depending on the roads and settlements available. In the Fig. 10.5, the settlements are represented as dots, and the colours depending on the distance and roads available to the settlements. Green surfaces are the closest areas to the villages and red the most distant and inaccessible. For labour intensive recipes, it is more suitable to be close to the labour force.

This type of network analysis can also be applied to determine the best cost-effective way to transport the commodities to the markets and ports.

As the project consists of a large geographical area with heterogeneous characteristics, visualization can help to support planning and management. Each geographical unit has unique geographical coordinates, it is then possible to combine the model outputs and visualize them in an interactive 3D geographic visualization. In this way, the user can see which areas and recipes are more profitable (Fig. 10.6) or the ones that have a higher carbon sequestration or higher employment.

Field operations per year for each crop

☐ **Recipe A** ☑ **Recipe B**

☐ Recipe C ☐ Recipe D

Number of field operations per year	Recipe B (years)																				
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Land Clearing/Site preparation	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Seeding/Planting (nr)																					
Planting (seedlings and nursery incl.)	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
Maintenance (eg. weeding)																					
Maintenance	0	1	1	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0
Harvest (nr)																					
Harvesting	0	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	0	0	0	0
Tapping	0	0	0	0	0	0	0	360	360	360	360	0	0	0	0	0	0	360	360	360	360
Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Fig. 10.2 Field operations tab, recipe B example. (N.B: Fictional data due to company confidentially)

List of commodities produced each year per ha & Market Prices

☐ Recipe A ☑ RecipeB
☐ Recipe C ☐ RecipeD

	Recipe B (years)																				
Crops & Raw materials (ton)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Lifetime
Sugar Palm Juice (m3)	0	0	0	0	0	0	612	612	612	612	612	612	612	612	612	612	612	612	612	612	8568
Cassava	0	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	152
Albicia	0	0	0	0	0	0	0	0	0	0	8	8	8	8	8	8	8	8	8	8	80
Agathis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
pineapple	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acacia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
beans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
corn	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
papaya	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
banana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
cacao	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood (m3)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Final Products																					
ethanol (m3)	0	0	0	0	0	0	48,96	48,96	48,96	48,96	48,96	48,96	48,96	48,96	48,96	48,96	48,96	48,96	48,96	48,96	685,440
other (fill if applicable)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
By-products (units)																					
roof cover	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
handy craft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
floorings	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
furniture	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
other (fill if applicable)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Fig. 10.3 Commodities tab, recipe B example. (N.B: Fictional data due to company confidentially)

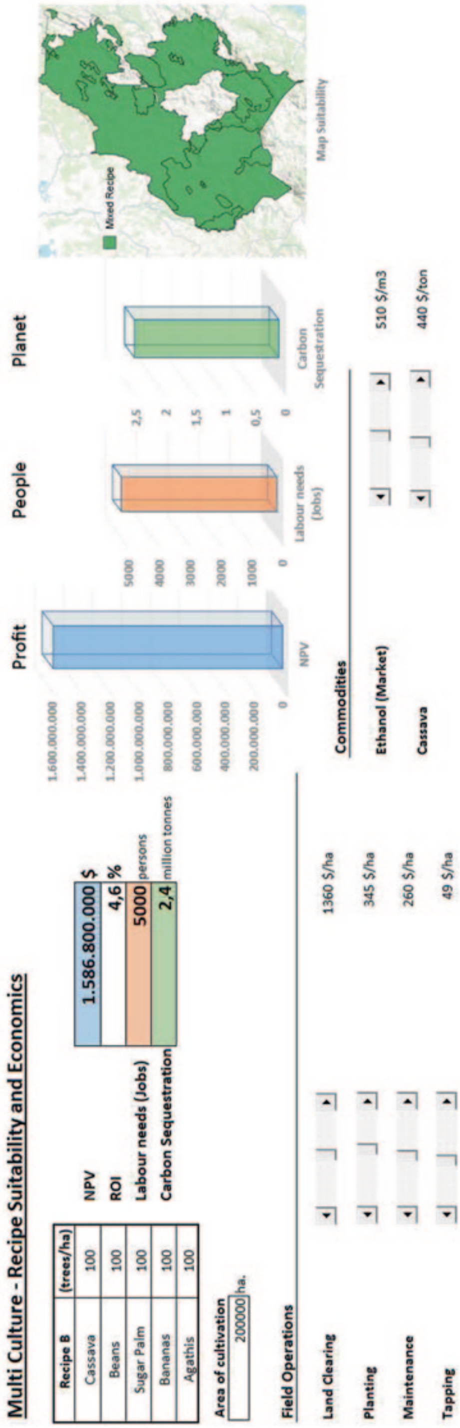

Fig. 10.4 Multi-culture - Suitability and Economics dashboard

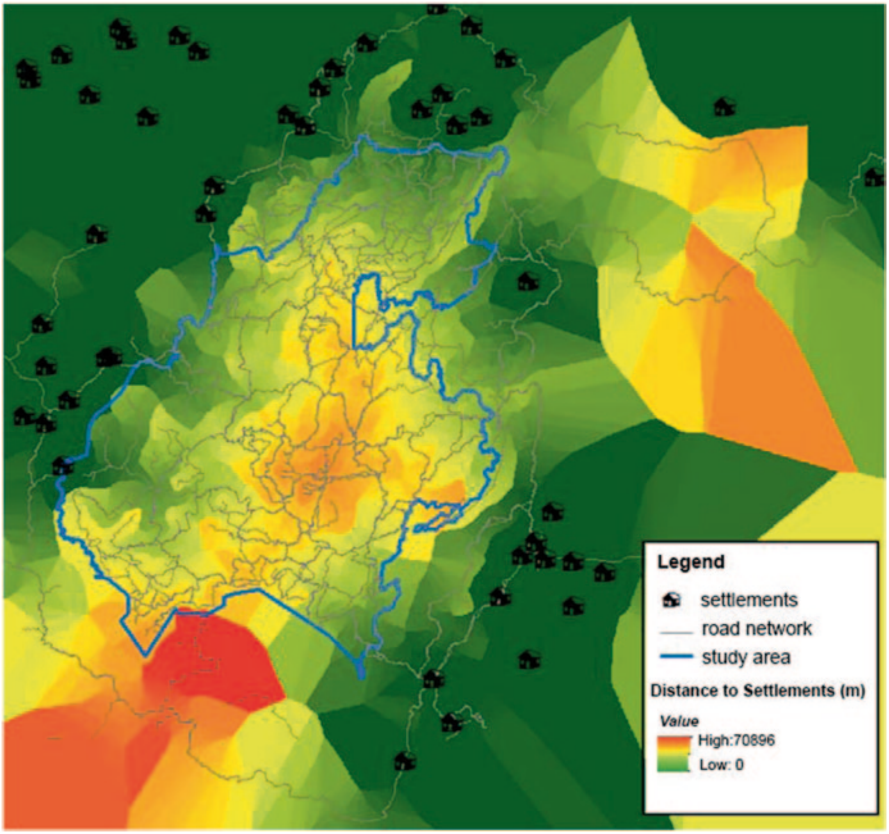

Fig. 10.5 Distance to every point based on settlements and roads available

An agroforestry project can have lifetimes from 15 to 30 years usually, which is a long-term investment, therefore it's important to show geographically, through time how the project will develop and when the economic investment pays off (Fig. 10.7).

The interactive geo-visualization was developed using Microsoft™ Power Map Preview. Each column on the 3D graph, is geographically positioned via the latitude, longitude and represents the value (cash inflow, jobs or carbon sequestration). The user can click on the desirable column and to access additional specific information, such as the exact value.

10.4.2 System Application

The proposed system is hereby exemplified with a hypothetical[1] case study in Indonesia. A system application was developed to assess and compare the economic, en-

[1] Due to company confidentiality the data presented is fictional.

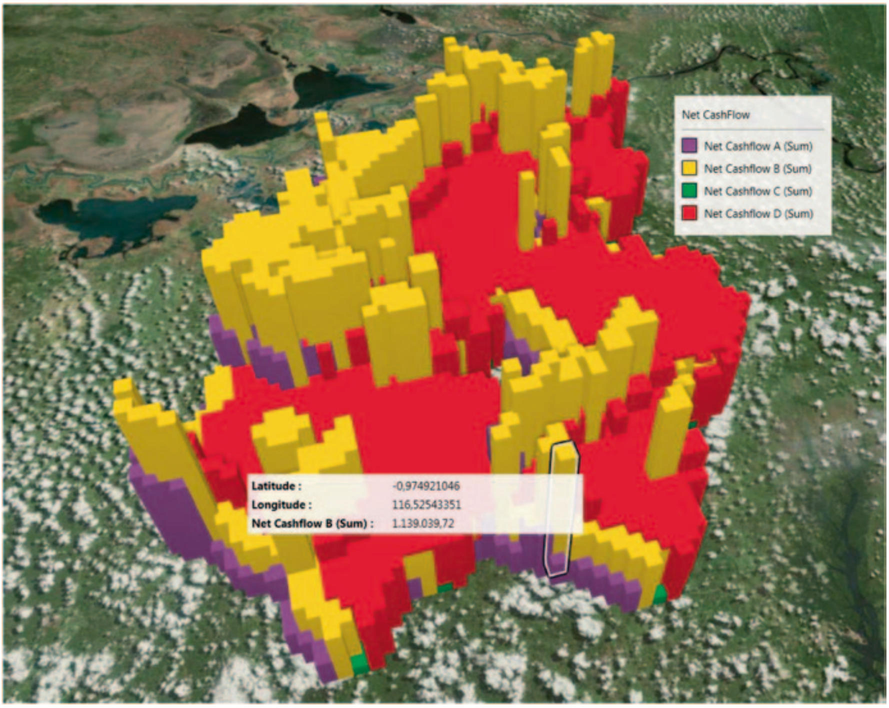

Fig. 10.6 Interactive geo-visualization of the net cashflow per recipe

vironmental and social impact of three different possible agroforestry approaches: a recipe of a monoculture scheme of timber production, a mixed recipe and a mixed design approach with different recipes for all the area.

As different recipes have different biophysical suitability, it's important to maximize the use of the area depending on the suitability for each recipe. In the mixed recipes approach (Fig. 10.7), 5 different recipes were implemented for the entire area, according to their best suitability.

Analysing the three plantation schemes (Fig. 10.8 and Table 10.1), we can evaluate the result of the different implementations and see which is more profitable or which provides more jobs or carbon sequestration.

The sliders on the recipes dashboards (Fig. 10.4) give the possibility of an interactive sensitivity analysis of each commodity. A sensitivity analysis of the timber price is illustrated in Fig. 10.9. It provides important information on the variation of the overall economic performance of the system due to volatility of market prices. In the present example, we can see that the plantation scheme with the five mixed recipes is less vulnerable to fluctuation of timber prices. Furthermore, NPV remains positive even if timber market prices are much lower than initially assumed. Therefore, it can be concluded that financial risks are distributed over different crops in this plantation scheme. On the other hand, monoculture schemes appear to be much more vulnerable to sudden changes in commodity prices.

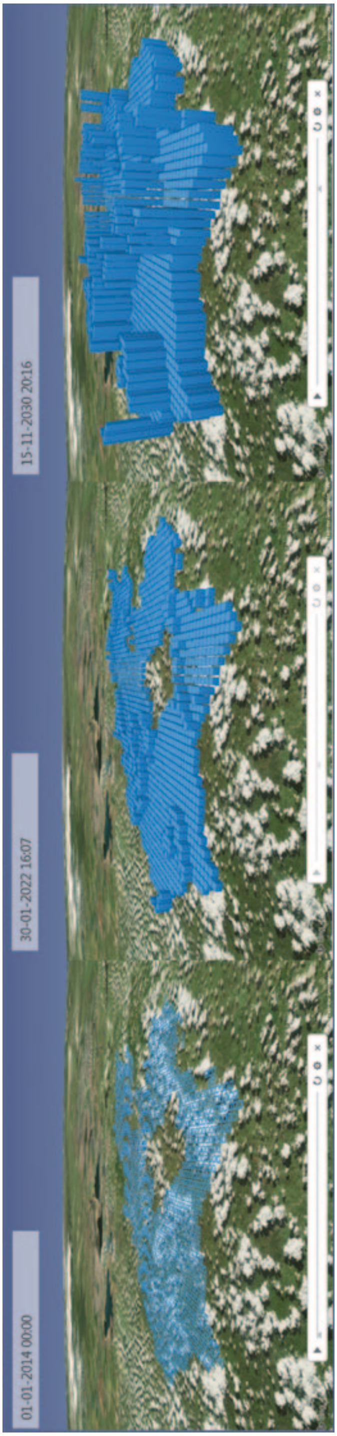

Fig. 10.7 Interactive geo-visualization of the net cashflow per recipe, through time

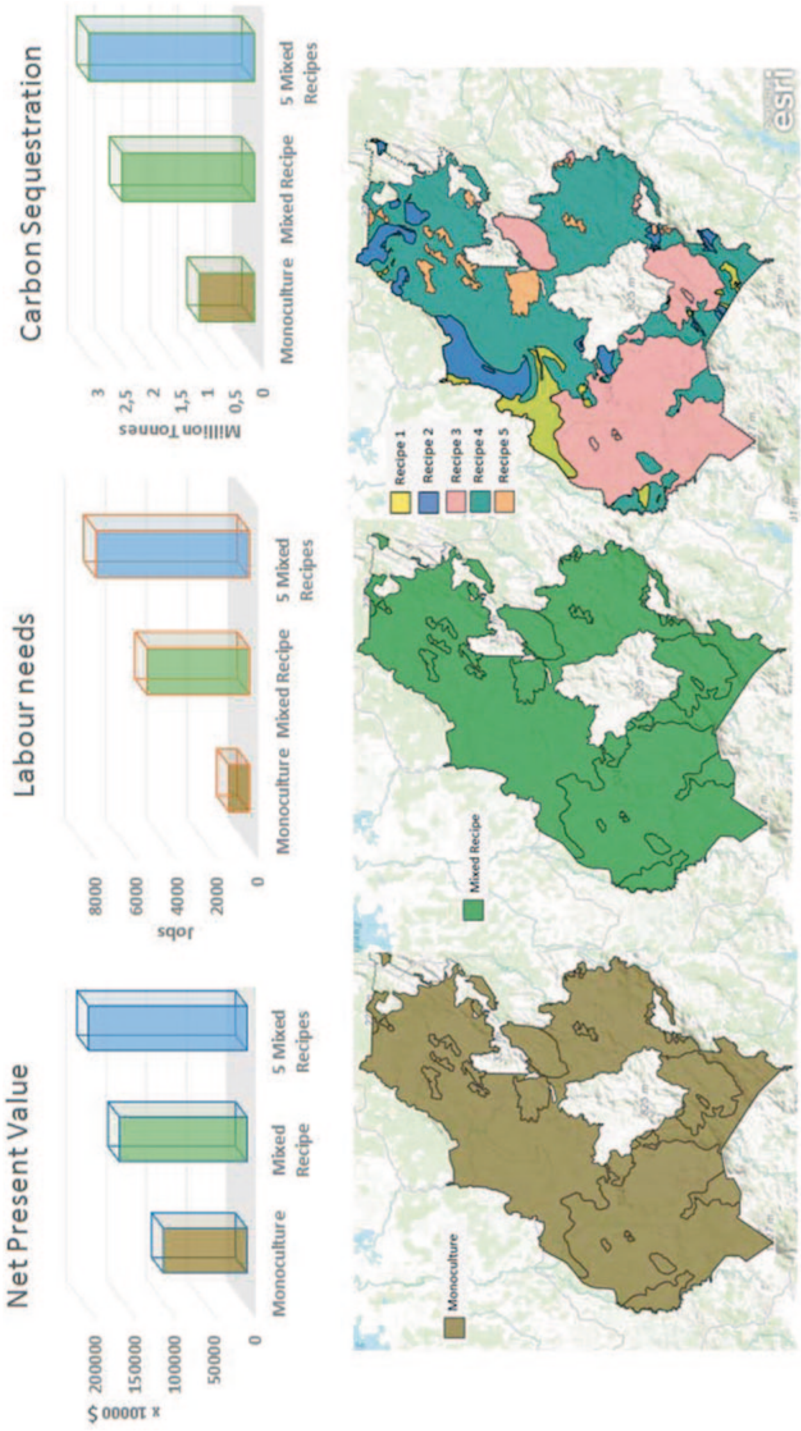

Fig. 10.8 Recipes' perfomance

Table 10.1 Recipes' performance. (N.B: Fictional data due to company confidentially)

	Monoculture	Mixed recipe	Five mixed recipes
Net present value ($)	1,042,300,000	1,586,800,000	1,972,200,000
ROI (%)	2.5	4.6	6.1
Labour needs (Jobs)	1000	5000	7500
Carbon Sequestration (Million tonnes)	1.1	2.4	3.0

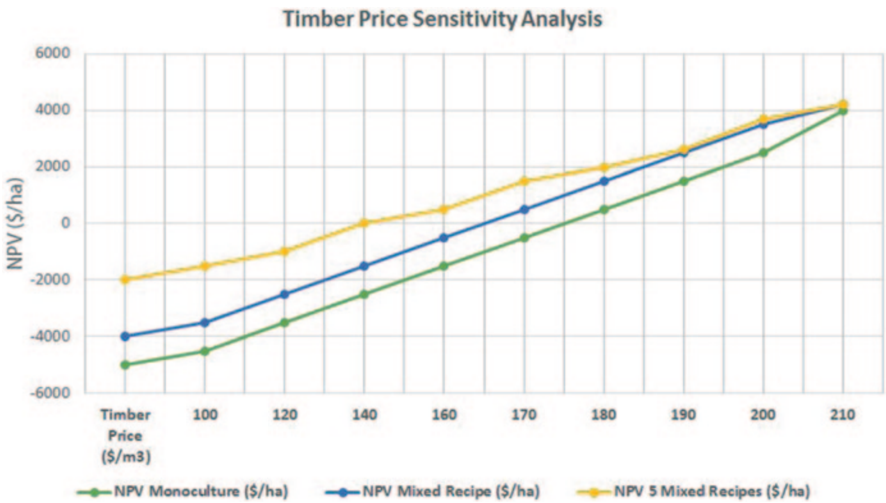

Fig. 10.9 Timber price sensitivity analysis example. (N.B: Fictional data due to company confidentially)

10.5 Conclusions

This paper describes the methodological framework of a spatially explicit decision support system being developed for sustainable forest management, integrating economic, social and environmental performance.

The system could also be used as a tool to analyse beforehand the performance of agroforestry projects, taking into account regional-specific environmental challenges in terms of climate change and soil and forest degradation.

Reforestation projects can benefit and gain efficiency through decision support systems that help to evaluate the feasibility and the overall security of the project. The geographical visualization is also an important decision and communication tool, especially in large area projects with spatial variability of biophysical conditions.

From an economic point of view, a higher NPV is generally desired, but other non-economic factors also need to be taken into account when determining project feasibility such as the carbon sequestration and number of jobs created. This system can provide insights and explore possible win–win solutions for reforestation projects between local residents, the environment and the economy while enhancing transparency and fairness.

This system, integrating spatial and non-spatial information for a better decision, has enormous potential for geodesign in agroforestry projects as provides powerful information of the most beneficial location for a sustainable forest management. Moreover, it can inform stakeholders providing them a tool to better understand the impacts of the project and its exact location.

The use of suitability maps allowed assessing expected productivity and the economic performance of growing different agro-forestry commodities. An underlying assumption of this approach is that the maps are static and maximum production yields are always attained. Negative impact from short-term events (e.g. heat waves or excess of rainfall) and long-term dynamic processes (changes in climate conditions or soil erosion) are not explicitly incorporated in the current model. Therefore, the tool may over-optimize the real capacity for delivering commodities and, as a result, the determined economic performance can actually be lower than what is being determined by the model. Nevertheless, the present model is able to provide an indication on what could be attained under optimal biophysical circumstances, as well as exploring the sensitivity to changing conditions. In addition, it should be noted that environmental spatial externalities (e.g. resulting from the movement of materials such as water, soil, plants, pests and contaminants) and factors related to economies of scale (e.g. clustering of production systems) were not explicitly taken into account. Our system is nevertheless able to inform the main areas where the production of different commodities could become economically attractive and thus provide an indication for decision-makers on the areas where positive externalities and increasing returns to scale are worth being explored while minimizing ecological risks.

Future developments on the system will emphasize user friendliness and spatial design capabilities on the interactive map, powering it up as a geodesign tool. In addition, the development and incorporation of more complex indices for the social and environmental performance should be pursued, as well as methods to estimate the benefits resulting from economies of scale.

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