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Title: An Optimization Model to Allocate Forestry Incentives Funds in Teak Plantations of the Southern-Coastal Region of Guatemala.

Abstract approved:

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John Sessions

Guatemala is internationally recognized as a country suitable to invest in the forestry industry. The first Guatemalan Forest Incentive Program – PINFOR- was implemented in 1996 to foster local forestry through cost-sharing. However, it lacks both formal land use planning processes and mechanisms to assess economic potential of projects, so it is questionable whether funds have been invested efficiently. Subsidies as a means to stimulate productive activities have been the subject of criticism and controversy, even though they have been effectively applied in other Latin American forestry sectors. Effects of subsidies and the landowner response to assistance have been relevant topics in international research. Little work however is encountered regarding project-level public funding allocation criteria. In the 1970s, Murphy (1976a; 1976b) and Gregersen *et al*. (1979) developed rational criteria to allocate public funding among projects which combined economic assessments, investment financial need estimation, program budget limitations, ranking-based selections and linear programming. These works provide the basis to develop a pilot, regional-scaled study in the Southern-Coastal region of Guatemala reported here. This study proposes a multi-period mixed integer linear programming model to allocate public funding from the PINFOR program among 101 simulated teak projects within a 15 year future planning horizon. Simulation is performed with

stochastic assignment of project size, locally representative silviculture, timber production and land market features, and geographically located through spatial analysis. Economic analysis of project financial performance yields optimal rotation ages of 9 to 14 years at social and private discount rates between 8% and 14%. The model formulation provides an optimal solution to the 15-year funding allocation problem faced by PINFOR that maximizes long-term contribution of projects to social benefits. Model requirements include compliance with program budget limitations and non-economic requirements of forest cover and future employment. Within the pool of projects simulated, between 38 and 88 are evaluated as socially profitable depending on the discounting scenario and the rotation regime, but only between 18 and 46 meet the condition of socially profitable – privately unprofitable. Optimal allocation assigns about 1,200 hectares to future enrollment in the PINFOR program. Financial requirement is estimated as strongly variable and ranges between $0 and $2,603 per hectare. The optimal overall social benefit from the simulated project base ranges between $3.3 and $5.6 million of net present value with a strong allocation of the most socially profitable projects within the first four years. Present value of the subsidy allocation is estimated as of $90,700 for the lower discounting scenario to $306,300 for the higher discounting scenario, and allocation strongly favors the single rotation regime within the region. One of most interesting outcomes of the study is that the optimization model and the Gregersen *et al*. methodology allocate funding similarly even while they are methodologically different; the general rule is that projects highly socially profitable and requiring little financial assistance are preferred for an earlier allocation.

An Optimization Model to Allocate Forestry Incentives Funds in Teak Plantations of the Southern-Coastal Region of Guatemala

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Ricardo Pavez, Author

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1 Introduction

Since the 1990s, Guatemala, the country with the largest economy in Central America, has faced the challenge of the development of its forestry resources. It is internationally recognized as a country suitable to invest in the forest business. Within 1990s, the first Guatemalan Forest Incentive Program – PINFOR (as its acronym in Spanish language) - was designed and implemented to foster local forestry through cost-sharing. Since then, remarkable progress has been made in establishing and managing forests in the country.

Fifteen years have passed since the PINFOR implementation occurred and the first National Forest Policy was created. In 2016 the program will complete its first twenty years of being the main instrument to promote the establishment and sustainable management of the national forests in Guatemala. However, criticism of the program's performance has arisen because the PINFOR program lacks mechanisms to assess the economic potential of projects applying for assistance under the PINFOR program. Public funds invested in forestry projects enrolled in the program currently total about US$185 million (SIFGUA, 2013), but it is questionable whether these funds have being invested in a profitable way. Unfortunately, no data are available to make an *ex post* economic analysis of the public investment at either national or regional scale.

Because of this, some questions seem important to include at this point:

- How can the administrators of the PINFOR program make good decisions about the allocation of the public funds administrated by the program?
- How can decision making be assessed in light of an accurate long-term planning process that guarantees maximization of the public investment's return?

PINFOR is a cost sharing-based assistance program. In this sense, it has several common elements with public cost-sharing implemented in the 1970s in the United States aimed to increase timber production from non-industrial private forests. Similar questions relevant to programs' performance can be stated regarding the funding allocation decision making. Gregersen *et al.* (1979) in the context with the 1974's Forest Incentive Program (FIP) performance in Minnesota stated "what economic criteria are relevant in determining who gets a subsidy?" and in addition, "if the program budget is limited, how should individual program investments be prioritized in order to maximize the social benefits?" (Gregersen *et al.*, 1979).

In the United States, a variety of evaluations of effectiveness and efficiency of forestry cost-sharing programs have been made. Further, specific planning tools that employ economic assessment of forest projects should be designed and implemented in order to determine the allocation of public funds in a profitable way. In this context, the following research developed the formulation of a multi-period optimization model to support long-term decision making about the allocation of funds administered by the PINFOR program in Guatemala.

Given that this is the first Guatemalan study regarding public funding allocation to develop forestry, the study was focused in just one region: the Southern-Coastal region of Guatemala (identified as Region 9 according to the national forest regions classification) and one specie: Teak (which has become one of the top two forest crops established throughout the country in the PINFOR program framework). To the extent that the whole program's data are available to perform a similar analysis in all the regions and species, the model could be extended to provide national-scaled results. In the meantime, the present study is pilot study directed toward establishing the basis for future work regarding economic analysis of afforestation projects involved in forest incentive programs, national-scaled forest planning process and decision making support in the allocation of public funding oriented to forestry development.

1.1 Guatemalan Forestry

According to a forest coverage study carried out in 2010, Guatemalan forests cover 3.7 million hectares (about 9.1 million acres) of the country. Forests represent about 34% of the total national area (INAB *et al.*, 2012). Agriculture, cattle ranching, hunting, silviculture and fishing are among the top four productive activities contributing to the country's gross domestic product (BANGUAT, 2013).

Successive governments in Guatemala have actively supported forestry development since the 1970s. They have created and implemented governmental forestry and forestry-related institutions charged with the administration of the country's natural resources as well as the incentives programs intended to foster forestry activities throughout the country (INAB, 2000). The National Institute of Forests - INAB (as its acronym in Spanish language) – is the current government institution charged with the administration of the PINFOR program.

The PINFOR program is the second forest incentive program developed in Guatemala. Its target audiences are local forestland owners or tenants to be granted direct government funding[1]. Thanks to this program, forest plantations have remarkably increased within the last fifteen year period. According to the national statistics of forests, between 1998 and 2012 approximately 112,300 hectares (about 278,000 acres) of forests plantations were established in the country. They correspond to nearly 4,900 afforestation projects (SIFGUA, 2013). It is interesting to notice that more than a hundred different tree species have been declared as relevant in the program. Consequently incentives have been allocated to promote the establishment of all of those species[2].

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[1] Between 1975 and 1996 a forestry incentives program based on tax benefits was created and implemented in Guatemala for the first time. This program was directed toward companies and people as an alternative option to invest their income tax liabilities in forestry activities. The benefit allowed individuals and companies to deduct up to 50% of the tax payment. This program was called PINFIS - Programa de Incentivos Fiscales -

[2] Personal communication with Mario Salazar, Director of Forest Development in the INAB

1.2 Guatemalan National Forest Policy

As of 1996, afforestation and natural forest conservation were declared a national priority by implementing the Decree N°101-96 National Forest Law. Guatemala's forestry development and sustainable forest management were also directed toward this forest policy. Private forest investment as a mean of economic and social development was also declared as a critical driver for country development due to the potential employment generation and increase in timber production (Congreso de la República de Guatemala, 1996).

The PINFOR program is required by law to benefit private forestland owners, municipalities that own forestland properties, and lawfully authorized communities or associations occupying municipal properties. One percent of the Annual National Ordinary Income Budget is given to the INAB to administer the program among the PINFOR program beneficiaries. Delivery of the incentives program is performed in coordination with the Guatemala's Ministry of Public Finances (Congreso de la República de Guatemala, 1996).

Regarding the governmental incentives of interest of this study, which are subsidies directly addressed to the landowner or tenant to invest in forestry by carrying out forest plantation establishment, some of the articles in the law establish the following (Congreso de la República de Guatemala, 1996)[3]:

- Objectives of the Law, section b) Promote afforestation in areas currently lacking forest coverage in order to provide the country with the forest products it requires (Article N° 1);

- Objectives of the Law, section d) Support, promote and facilitate public and private forestry investment in order to increase production, trading,

[3] Texts are interpretative translations of actual articles which are in Spanish language

diversification, industrialization and conservation of forest resources (Article N° 1);

- Incentives. The State will provide subsidies according to this law and in coordination between the INAB and the Ministry of Public Finances. Subsidies will be provided to landowners including municipalities and lawful tenants occupying municipality properties that develop afforestation projects in areas lacking forests or natural forest management. Plantations established through forest incentives programs are defined as voluntarily planted forests (Article N° 71).

- Annual Budget for the Forest Incentive Program. The State will assign one percent of the Nation's Annual Ordinary Income Budget to the INAB to providing forest subsidies (Article N° 72).

- Duration of the Incentives Program. The State will provide subsidies addressed to plantation establishment and maintenance and natural forest management for a period of 20 years following passage of the law. Subsidies will be provided to forestland owners or tenants according to a forest management and/or afforestation plan presented and approved by the INAB (see Article N° 74 for details about the Afforestation or Forest Management Plans) (Article N° 73).

- Afforestation or Forest Management Plan Submittal. To become a forest subsidy program beneficiary, an Afforestation or Forest Management Plan must be submitted by the landowner and approved by the INAB. Submittal should include the property's forestland qualification. The INAB will deliver a resolution within thirty days since the plan is submitted (Article N° 74).

- Subsidies Payment Delivery. Subsidies will be paid to the landowner or tenant by the Ministry of Public Finances at the moment in which the INAB validates the plantation as they have been properly established according to the guidelines declared in the Afforestation or Forest Management Plan. The

INAB will deliver a certificate of approval to the landowner or tenant (to be presented to the Ministry) within thirty days since the request is made (Article N° 75).

- Minimum Land Area. The minimum forest project area to receive a subsidy is two hectares. It must be entirely in the same municipality (Article N° 76).

- Subsidies Program Overhead. The Ministry of Public Finances will assign nine percent of the subsidies delivered to the INAB as overhead for the program institutional administration (Article N° 77).

- Costs. Per-region and per-specie unit costs associated to commonly used activities of both afforestation (establishment and maintenance) and natural forest management will be determined by the INAB's Board of Directors in yearly basis (Article N° 78).

- Subsidies within the Plantation Maintenance Stage. Subsidies in afforestation projects will be delivered within a five year period as maximum to cover maintenance activities cost. This must be clarified and authorized through the Afforestation Plan approval process (Article N° 79).

- Species and Regions of the Program. The INAB's Board of Directors will determine forest species and regions where the subsidies program applies. High-productivity species and regions will be taken into consideration regarding their contribution to national priorities established in context with environmental, energy or productive requirements (Article N° 80).

- Apportionment of Subsidies. The INAB will apportion the annual national forest subsidies budget in the following proportions: eighty percent available for afforestation and plantation maintenance, and twenty percent available for natural forest management (Article N° 81).

- Loan Guarantee from the Program. The INAB will provide small landowners that borrow funds to banks to invest in forestry activities with a loan guarantee that endorses the funding request (see Article N° 83 for details about small landowners-oriented resolutions of the law) (Article N° 82).

- Size-based Subsidies Delivery to Projects. The INAB will deliver up to fifty percent of the subsidies program's annual budget among small landowners that submit forest projects of less than fifteen hectares. The remaining budget will be assigned to forest projects larger than fifteen hectares. No one will be granted more than one percent of the program's total annual budget (Article N° 83).

Criteria to assign funding to projects are established by the INAB in a case-by-case basis, but forestry law indicates such aspects as tree species, regions and priorities regarding productive, energy-based or environmental needs are aspects that could also be considered for the application approval (Congreso de la República de Guatemala, 1996). However, it is not stated in legislation that economic or financial assessment of the projects are required as part of the application and approval process.

Amounts involved in the PINFOR cost-sharing assistance are shown in the Table 1.1. According to the regulations and the sectorial statistical data, every project that involves establishment and maintenance of forest commercial plantations has been granted about US$1,800-1,900 per hectare (about US$730-770 per acre) delivered in partial payments during the first six years of the project's cycle (Congreso de la República de Guatemala, 1996).

Table 1.1. Subsidy payments declared by law addressed to afforestation projects (values in local currency "Quetzals", exchange rate at January 2014 equal to Q7.8/US$) (BANGUAT, 2013; INAB, 2013)

Area	2-5 hectares		>5 hectares	
Period	Quetzals/hectare	US$/hectare	Quetzals/hectare	US$/hectare
0	6,000	769.23	5,600	717.95
1	2,550	326.92	2,380	305.13
2	2,250	288.46	2,100	269.23
3	1,650	211.54	1,540	197.44
4	1,500	192.31	1,400	179.49
5	1,050	134.62	980	125.64
Total	**15,000**	**1,923.08**	**14,000**	**1,794.88**

The total public investment performed through the program is shown in the Table 1.2. As mentioned before, the total amount to date spent during the entire program period accounts about Q1.4 billion (about US$185 million).

Table 1.2. Total public investment through the PINFOR program in afforestation projects throughout the country (values in local currency "Quetzals", exchange rate at January 2014 equal to Q7.8/US$) (BANGUAT, 2013; SIFGUA, 2013)

Year	Quetzals/hectare	US$/hectare
1998	5,054,939	648,069
1999	23,856,042	3,058,467
2000	43,258,444	5,545,954
2001	59,332,965	7,606,790
2002	84,629,304	10,849,911
2003	88,406,158	11,334,129
2004	95,877,682	12,231,559
2005	102,626,227	13,157,209
2006	126,033,414	16,158,130
2007	140,180,407	17,971,847
2008	153,645,485	19,698,139
2009	153,350,005	19,660,257
2010	145,513,517	18,655,579
2011	114,578,618	14,689,566
2012	110,209,401	14,129,410
Total	**1,446,552,608**	**185,395,016**

1.3 Teak Plantations of Region 9 in PINFOR

Teak (*Tectona grandis* L.f.) occupies the second highest position among the most planted trees under the program with about 17,300 hectares (about 42,700 acres) established throughout the country. Sixteen percent of the country's teak plantations are located in Region 9. They have been established since 1998 and total about 2,800 hectares (6,900 acres) planted (SIFGUA, 2013). Figure 1 and Figure 2 show the establishment dynamic of teak in Region 9 and in the country and the proportion of those in the entire country.

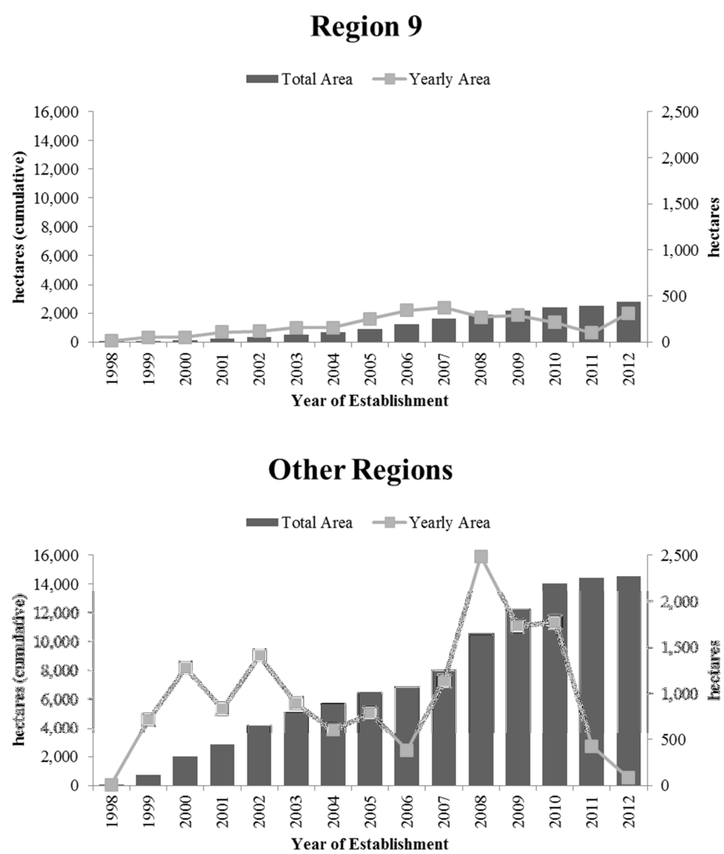

Figure 1. Comparative graphs of the establishment dynamic of teak in Guatemala within the PINFOR program framework (SIFGUA, 2013)

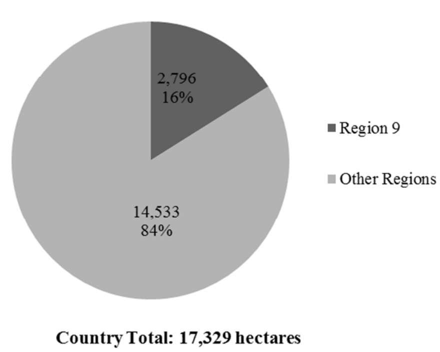

Figure 2. Proportion of teak plantations established within Region 9 and in Guatemala (SIFGUA, 2013)

The age distribution of teak plantations ranges between one and fifteen years-old with a relatively equal proportion of area in each age class. The one, four, and eight year-old age classes are most represented (base year 2013). Figure 3 shows the age distribution in relation to the area planted within Region 9.

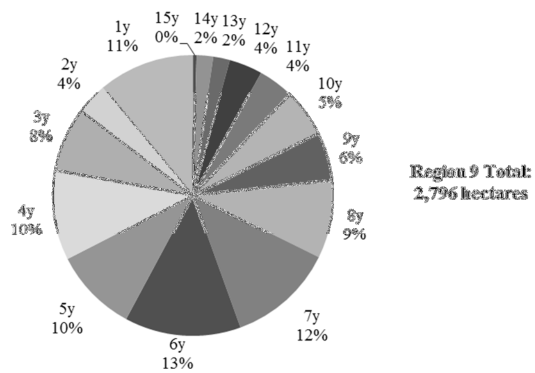

Figure 3. Distribution of age classes among teak projects within Region 9 (SIFGUA, 2013)

About 96 percent of the teak plantation projects within the region are owned by individual private landowners and companies. The average project size is 17.6 hectares (about 43.5 acres) with a strong concentration of projects in the less-than-20-hectares category. Figures 4 and 5 show the ownership distribution in Region 9's teak plantation projects and the project size distribution found within Region 9 established through the PINFOR program.

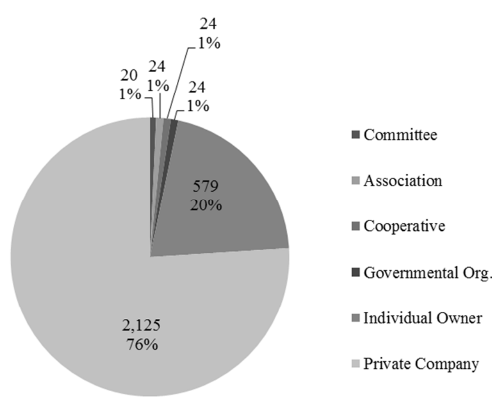

Figure 4. Teak plantation projects ownership distribution within Region 9 (SIFGUA, 2013)

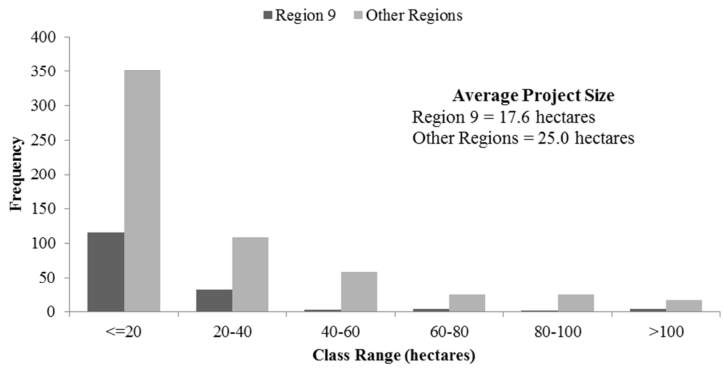

Figure 5. Frequency distribution of teak projects by size class in Region 9 and in other country regions (SIFGUA, 2013)

The entire area planted with teak in Region 9 was established through the PINFOR since 1998. Each project's current status in the program differs to one other as funding could have been completed or not. Figure 6 shows the current status of the Teak projects established throughout Region 9.

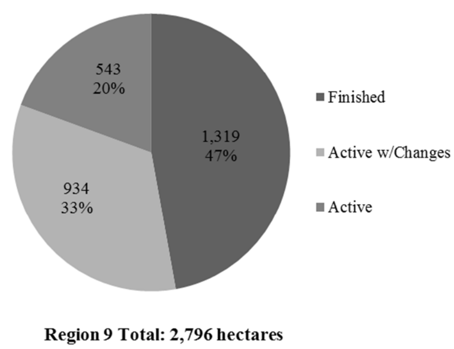

Figure 6. Enrollment status of teak plantations of Region 9 in the PINFOR program to 2013 (SIFGUA, 2013)

Teak plantation projects are becoming an important forestry business in Guatemala as well as in Latin American countries due to the increasing presence of Asian traders that look for roundwood supply in the region. Because of this, successful investments in commercial plantations of teakwood have taken place in Guatemala since 2009 (Pavez, 2012). Unofficial sources indicate that a couple cases are associated to United States' TIMOs (Timber Investment Management

Organizations) that account for joint investment of up to US$60 million. One of them is present in the Southern-Coastal region.

1.4 Region 9's Capabilities for Forestry Development

Guatemala has favorable biophysical and political conditions to grow trees. As well as some other countries in Central and South America, Guatemala is internationally recognized as a good country to invest in forestry (Pavez, 2012). Region 9, also called the Southern-Coastal region of Guatemala, is located along the Pacific South-West of the country. This region includes three Departments (Escuintla, Suchitepequez and Retalhuleu) that jointly total about 860 thousand hectares (about 2.1 million acres). The region is an important cluster of agriculture, livestock and forestry activity as well as one of the most productive areas of Guatemala in this fields. It also has two important ports that facilitate international trading: Puerto San Jose and Puerto Quetzal. Figure 7 shows both the location of the country in Central America and the location of Region 9 within Guatemala.

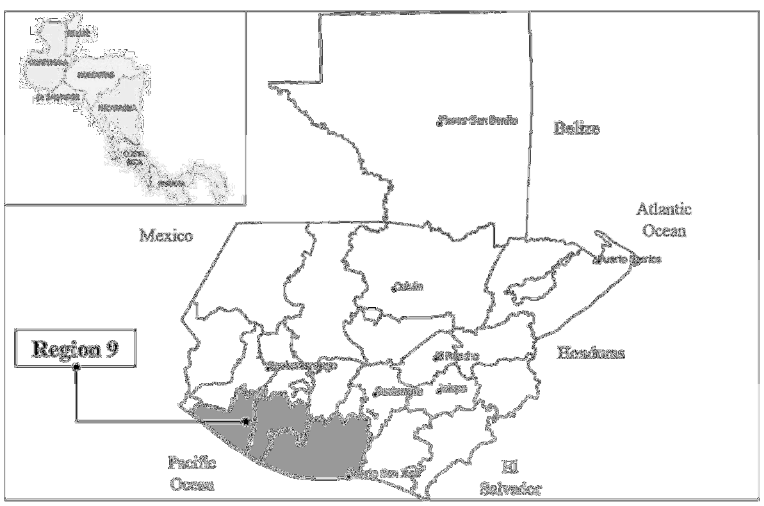

Figure 7. Map of Guatemala and location of Region 9 in Guatemala

The main productive activities in the region are agricultural. Up to 60 percent of the regional area is used with crops as grains and cereal, sugar cane and grasslands. The regional terrain is mostly flat which favors agricultural activities. Soils are of good quality, probably the best ones in the country, because they originated by volcanic activity and fluvial sediments in the past (Alvarado, 2007). Table 1.3 and Table 1.4 show the most important geographic and agricultural features of the region.

Table 1.3. Topographic features of Region 9 (adapted from Alvarado, 2007 and IGN, 2014)

Type	Hectares
Coastal flatlands	681,180
Recent volcanic hill slopes	84,227
High lands	94,442
Total	**859,850**

Table 1.4. Current land use in Region 9 (adapted from Alvarado, 2007; MAGA, 2011; MAGA, 2013;SIFGUA 2013 and INAB-CONAP-UVG-URL, 2012)

Type	Hectares	Proportion
Sugar Cane	259,019	30%
Grassland	129,034	15%
Grains and Cereals	119,302	14%
Rubber Tree	67,424	8%
Natural Forest	62,106	7%
Fruits and Vegetables	45,742	5%
Oil Palm	27,500	3%
Coffee	26,920	3%
Scrubs	24,372	3%
Non-productive Land	19,205	2%
Forest Plantations	11,412	1%
Urban	6,597	1%
Subtotal	**798,633**	**93%**
Available for new forest plantations	61,217	7%
Total	**859,850**	**100%**

According to IGN (2014), land distribution by agricultural use categories defined by USDA Soil Fertility Capability Classification (FCC) is shown in Table 1.5. Figure 8 shows regional features of interest in regard of both the regional land use and the analysis of potential future teak projects presented in this study.

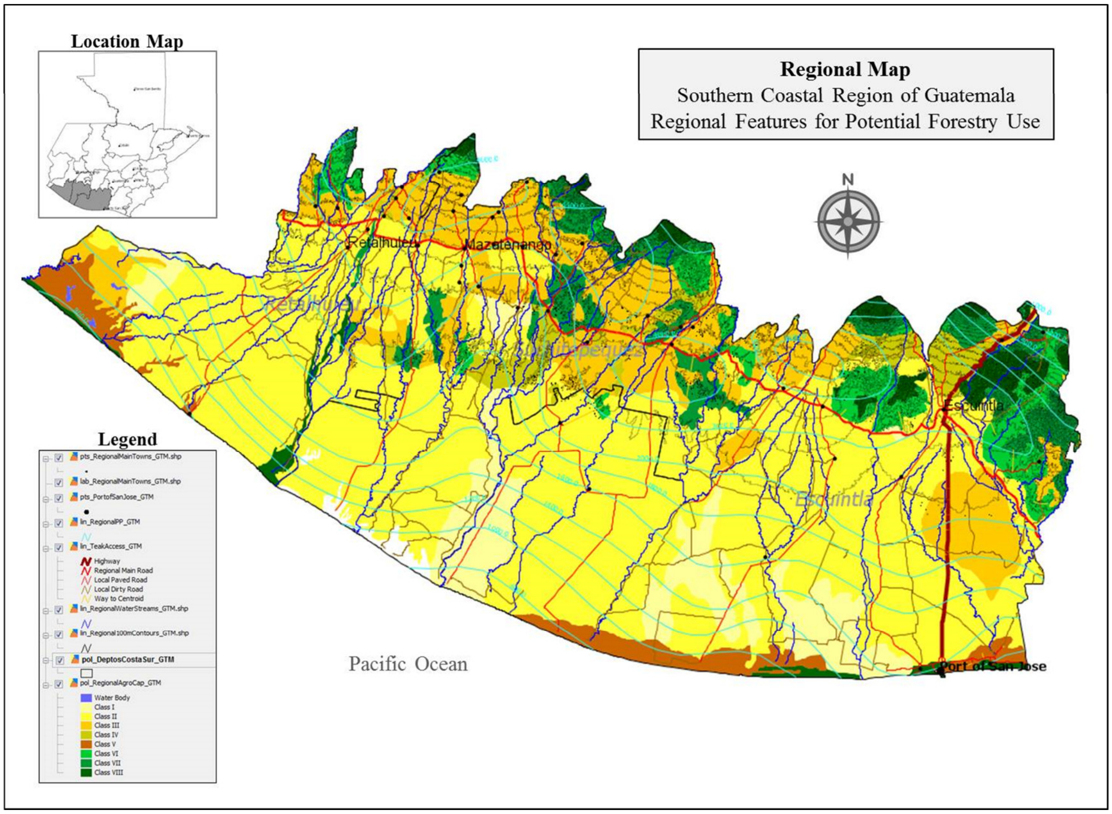

Figure 8. Map of regional features of the Southern-Coastal region of Guatemala in regard to its potential for forestry use (adapted from IGN 2014).

Table 1.5. Region 9's agricultural soil use classification (adapted from IGN 2014)

Class	Hectares	Regional Proportion	Available Area[4]	Site Class
I	68,466	8%		
II	476,731	55%		
III	136,351	16%	35,221	S1
IV	28,045	3%	7,244	S2
V	33,848	4%	8,743	S2
VI	38,744	5%	10,008	S3
VII	51,883	6%		
VIII	25,362	3%		
Water	420	0.05%		
Total	**859,850**	**100%**	**61,217**	

Information shows that the land available for new teak projects is located in the range of soils of class III to class VI. The estimated proportion that is associated with forest site classes is as follows: 35,221 hectares (86,996 acres) are of higher site quality; 15,987 hectares (39,488 acres) are of intermediate site quality; and 10,008

[4] Area estimated as currently available for new teak plantation projects. The spatial analysis of this area in the region is presented in Section 4.11 'Spatial Analysis of Potential Areas for Teak of Region 9'

hectares (24,720 acres) are of lower site quality. A complete description of forest growth projection according to the corresponding site quality classes is provided in Chapter 4.7 ‘Timber Growth Modeling in Teak Plantations of Region 9’.

1.5 Scope of the Research

The geographical scope of the research is limited to Region 9. Only the Departments of Escuintla, Suchitepéquez and Retalhuleu are considered as part of the regional scope. Although this is a pilot study, it is expected that this study will provide a basis for future research in this matter.

Information and data to perform the analysis was requested from key Guatemalan forest investors and Region 9 representatives of government institution. This allowed the research to reflect local forestry reality around marketable teak plantation projects in a realistic way. Data were requested from as many available sources throughout the region as possible; however some private companies were not able to provide the study with information and some others requested their names to be kept confidential due to security concerns.

This study focuses exclusively in marketable teak plantation projects and the potential of Region 9 for the development of this type of forest crop. No other species currently planted as forest commercial plantations were considered as part of this work.

A multi-period optimization model was developed to determine the optimal allocation of funding addressed to teak projects within Region 9. A 15-year planning horizon was established as appropriate for this purpose and the year 2014 was defined as the starting period for the model. The rationale for this is based on the period from which most of the information of the specie was collected (past 15 years of PINFOR program).

1.6 Organization of the Thesis

Guatemala's most relevant forestry features, the local forest policy framework, the status of teak plantations in the PINFOR framework and the potential of Region 9 for forestry development were described in the introductory chapter.

Chapter 2 introduces international research in the general context of the land use planning process in developing countries. It also provides an overview of subsidy programs worldwide, relevant issues that have captured the attention of researchers regarding their effectiveness, traits that encourage and justify their implementation and their role as instruments to promote forest investment. Some of the most important forest incentive programs in the United States and the world are also mentioned and briefly described in this chapter.

The role of subsidies as a way to promote forestry development and investment among nonindustrial forest private owners is reviewed in depth by citing research on the economic analysis of their effectiveness. Cited studies include work performed since the 1970s. Special attention is paid to international research that analyzes funding allocation mechanisms provided by forest assistance or incentive programs. In this regard, the studies carried out by Gregersen *et al.* (1979) and Murphy (1976a; 1976b) are particularly relevant as they provide an economic basis to support the formulation of the multi-period optimization model of this study. Optimization techniques commonly employed to assist forest investment and funding allocation are also described as part of the literature review in this chapter.

Chapter 3 presents the problem statement. In this chapter a match is made between the most frequent issues in world research on the allocation of funding and Guatemala's challenge of delivering the PINFOR program funds in an adequate way among teak plantation projects. Adequacy is basically defined as profitability from a social and economic standpoint in the context of the study. Furthermore, a brief review of the application process to the PINFOR funding program is presented to identify gaps that the PINFOR process has and that justify the implementation of improved mechanisms of forest investment analysis for public funding.

Chapter 4 presents methodological procedures. Details are provided about data collection stage, the sources consulted, the characterization of the most important silvicultural and site features of teak plantations established within Region 9, the growth projection and timber yield associated to projects currently established, the most common production features found in Guatemalan forestry operations, teakwood market characteristics relevant for the study and land market considerations.

As part of the research foundation, Gregersen *et al.*'s work performed in 1979 in Minnesota is fully described. Its role as an economic basis for the formulation of the multi-period optimization model is noted; citations of the Gregersen *et al.*'s work in international research are also mentioned to provide background. International literature about economic and financial analysis of forest private and public investment is employed as complementary information that corroborates the use of the Gregersen *et al.*'s methodology.

The adaptation of Gregersen *et al.* methodology to the Guatemalan subsidies allocation problem is treated in depth in this chapter. The economic analysis of potential teak projects in the region is performed using stylized teak management and timber production prescriptions and representative discount rates to estimate optimal rotation age and the economic role of the land in each case. For this purpose, the simulation of a future spatial scenario of potential teak projects was performed which was geographically located through a complete spatial analysis within the region. Finally, the economic performance of the potential projects identified as potential contributors to social benefits is calculated to determine the contribution of each to the optimization model's objective function. Bounds of the problem are also included in this part of the methodology.

Chapter 5 shows the complete procedure employed to develop the multi-period optimization model aimed to solve the Guatemala's subsidies allocation problem in teak plantation projects in Region 9. A brief description of the justification for the use of mathematical programming techniques in solving this type of problem and a comprehensive translation of the components of the local problem to both interpretative text and mathematical language are also provided. The mathematical formulation of the optimization model (activity and availability levels, decision variables, objective function, technological coefficients and resources constraints) are provided in this chapter.

Chapter 6 presents the solution of the problem according to the particular inputs included in the formulation. The LP system, LP method employed, features of the mathematical run and full description of the optimal solution outcomes are aspects included in this chapter. A key for an adequate interpretation of the mathematical outcome is provided. This includes a schematic description of the prescriptions, management conditions, the optimal allocation of land and subsidies, and the economic performance indicators that become the main descriptors of the optimal solution found. The review of compliance of the particular optimal solution found in regard of the constraints established for the problem is also developed. Finally, the outcome of the dual problem that supports in part the sensitivity analysis of the results is presented.

Chapter 7 presents a comprehensive discussion of the results considering three main aspects of the optimal solution: general assumptions employed in the formulation of the economic analysis and optimization methodology, analysis of influence of the technical and economic variables and values employed in the economic assessment stage, and finally sensitivity analysis from both dual problem and relaxed problem outcomes.

Finally, Chapter 8 provides the reader with overall conclusions from the results in regard of the problem statement, hypothesis and study objectives, and recommendations for future research in this matter. Chapter 9 and Chapter 10 show the academic reference list and the Appendices that gather all the complementary information employed in the study.

2 Literature Review

2.1 Land-Use Planning and the Developing Countries Forestry Framework

According to Hyman (1984), the land use planning problem in tropical countries arises from the challenge of matching land development activities with site capabilities. Hyman concluded from his research that, although suitable planning techniques are available, they have not been used to their full potential in tropical countries because of insufficient appreciation by decision makers, limited availability of data, scarcity of planning expertise, cost issues and domination of decision-making by special interest groups. Although the Hyman's research dates from 1984, the problems identified remain valid up-to-date in Guatemala in regard of the natural resources long-term planning. High deforestation rates caused by the uncontrolled land use change to agriculture or livestock grazing could be considered as a proof of the lack of formal land use planning processes.

In the course of seeking the match between land development and capabilities, Hyman mentioned four components for a land-use planning process: (1) biophysical assessment, (2) financial and economic analysis, (3) social assessment, and (4) monitoring and evaluation. Since a financial and economic analysis is a relevant part of the planning process, the economic assessment of plantation projects applying to the PINFOR program takes on great relevance as an instrument to drive adequate decision in the allocation of public resources. The problem is that the economic analysis stage in the funding allocation's decision making process in the PINFOR program framework simply does not exist[5].

Existing techniques in land use planning can improved by encouraging the provision of adequate databases and time framework, stakeholders' participation, communicational processes, an interdisciplinary approach and improved monitoring

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[5] This fact was discussed with Edgar B. Martinez, Administrator of the PINFOR program in the INAB, and Mario Salazar, Director of the Forest Development Department in the INAB, both in personal communication. Both agreed on the fact.

and evaluation (Hyman, 1984). In this sense, the first step in developing countries is simply the recognition of land-use planning techniques and their potential to improve national resource allocation. This study seeks to meet this basic, fundamental objective.

Planners and managers can use land management models to help choose programs of action (Osteen and Chappelle, 1982), and models based on mathematical programming appear as suitable options to undertake the resources allocation problem. Zadnik (2006) cited a variety of forest management models and related work that have been developed in the world research to support forest and land-use planning and decision making including: linear and non-linear programming, dynamic programming, goal programming, multi-criteria decision making and multi-objective forest management models.

2.2 Forest Subsidies: An Overview

Criticism has been made of the role of subsidies as a political way to promote productive activities. Econometric analysis has shown that government forest subsidies in some countries have had adverse effect on economic performance of the forestry sector (Aoyagi and Managi, 2004). In the United States, some critics consider that government programs should be oriented toward improving markets before subsidizing management practices (Osteen and Chappelle, 1982). Mehmood and Zhang (2002) stated that irrespective of the rationales or justifications for incentive programs, political pressure on the forest industry makes subsidies possible, and a healthy state economy makes them a reality.

Peters and Fisher (2004) explain that there are two main justifications for the incentives: the first one is that incentives will lead to business investment and thus new jobs, and the second one is that economic growth increases public revenues. According to Ubeda (1991), mechanisms of forest promotion undertaken by governments are justified (1) when forest activity competes with other shorter term investment alternatives (at the same return level), and (2) when it is simultaneously required to promote self-supply of forest products in order to replace imports. Promotion can be implemented in the form of credits, tax benefits and/or subsidies (Ubeda, 1991).

In the same context, and according to other authors, arguments that justify the application of economic incentives to foster forestry can be listed as follows (McGaughey and Gregersen 1988, Beattie 1995, Southgate 1995):

- To change the ‘anti-forest’ attitude commonly encountered among farmers and farm workers who have traditionally considered forests as a barrier for agricultural activity;
- To increase profitability of investments with relatively low economic yield, but involving positive externalities (social and environmental);
- To reduce risk and uncertainty in the gestation of forest projects;
- To reduce the financial impact of negative cash balance within first stages of forest projects implementation;
- To accelerate formation of critical mass for timber supply and to build a competitive forest industry;
- To speed up the initial development of plantations with social or industrial purposes.

Most of the literature is strongly focused in analyzing forest incentive programs as a mean to motivate forestry investment. Efforts have been made to analyze the effects of the programs in terms of economic effectiveness and efficiency in reaching this goal. Interestingly, not just one direction in the conclusions has been drawn from the research. A couple questions whose answers have been intensively sought are: how much should be provided and in what form? (Skok and Gregersen, 1975). Becvarova (2006) also reports that the selection of allocation criteria (i.e. the suitability of subsidies) and the efficiency of subsidies related to the determination of transfer forms/instruments and their economic cost are the two major problems in regard of defining an adequate subsidies program. In this sense, looking for the best way of promotion that returns the highest benefits to the nation because of the public investment in forestry becomes the critical objective. The ultimate result of this is making the sector grow (Ubeda, 1991).

Reasons to implement direct economic incentives to foster forestry are heterogeneous and they are often based on the local forestry history and policies (Keipi, 1998). Justifications for public expenditure in forestry can be summarized as follows (Skok and Gregersen, 1975): increase wood supply, keep prices from rising rapidly, increase participation of nonindustrial private owners in the nation's supply, increasing public investment efficiency by allocating the funds to nonindustrial private forest owners, and bring forth social benefits (and cost) by getting public expenditure involved in this kind of activity.

It is easily realizable that additionality is a key concept in the analysis, so evaluating the 'with-without' scenarios has been the most used approach to estimate actual program contribution. However, uncertainty, pessimism and controversy have been common reactions, particularly about those programs involving public cost-sharing, although some of them have demonstrated to have positive results in the evaluations (Harou, 1985).

In an economic context, incentive program types can be classified in two main types: direct and indirect incentives. Direct ones influence directly the values of inputs and outputs of a landowner project, while indirect ones don't necessarily impact landowners' actions directly. The latter ones may or may not influence an individual's investment decision and profits (Skok and Gregersen, 1975; Gregersen *et al.*, 1979). Forest subsidies may take the form of a proportional share, a lump-sum allocation and tied technical assistance, a transfer of public rights in land or infrastructure to private parties, or a shift of public to private rights by reduction of taxes on timber or forestland (Romm *et al.*, 1987).

2.3 Forest Subsidy Programs in the World

Direct economic incentives in forestry applied by subsidizing management costs are common in countries with suitable conditions to grow trees (Keipi, 1998). Examples of public incentives provided by law for specific purposes are able to be found in the United States and elsewhere. In the United States, a total of 18 states have such programs, and state cost-sharing programs are public assistance usually in the form of direct subsidy payments (Mehmood and Zhang, 2002). Table 2.1 shows a list of the principal 1970's public incentives programs for private forestry that took place in the United States (Skok and Gregersen, 1975; Gregersen *et al.*, 1979).

In the 1970s, the Virginia's Reforestation of Timberland Program and the Seed-Tree Law were programs oriented to pine stands in which cost-share incentives were assigned to increase forestland areas dedicated to pine timber growing (Flick and Horton, 1981). The 1973's Forest Incentive Program (FIP) was a response to its predecessors which were mostly oriented to objectives others than cost-effective production of timber (e.g. soil and water conservation) (Mills and Cain, 1976). It was addressed to increase production of timber among landowners holding between 10 and 500 acres[6] and yielding at least 50 cubic feet of timber per acre per year (Harou, 1985, Romm *et al.*, 1987). This program was the first in incorporating efficiency indicators as part of the applicant's evaluation (Skok and Gregersen, 1975; Mills and Cain, 1976). The Pacific Northwest Regional Commission also provided funding to supplement Federal cost-sharing in Washington, Oregon, and Idaho (Greene, 1977). The Mississippi Forest Resources Development Act program of 1974 offered both planting and timber stand improvement practices on nonindustrial private, state, and municipal lands. It was financed by a special fund which includes the privilege tax on

[6] The lower bound of ten acres is constrained to be contiguous tracts of land.

timber and timber products (Greene, 1977). The 1980's California Forest Improvement Program CFIP was addressed to the more productive management of forestland for different purposes (Romm *et al.*, 1987).

Table 2.1. Principal 1970s' public incentives programs for private forestry in the United States (Gregersen *et al.*, 1979)

Type	Examples
Direct fiscal (exemption, remission, or deferred payment of taxes)	1. Capital gains treatment for timber 2. Yield taxes 3. Modified property tax laws 4. Tax exemptions and rebate laws
Direct non-fiscal (subsidization of inputs through low-cost credit, outright subsidies, etc.)	1. Forestry Incentives Program (FIP) 2. Rural Environmental Assistance Program, practices A-7 and 8-10 (formerly ACP) 3. FHA loans (and other subsidized loans) 4. Low cost seedlings
Indirect (government research, training, technical assistance, and extension, marketing information, etc.)	1. Funding of extension foresters, Cooperative Forest Management (CFM) program 2. U.S. Forest Service, state, and university applied research programs 3. Funding of production and marketing cooperatives 4. Public cooperative forest protection programs such as Clarke-McNary Act and Forest Pest Control Act of 1947

In the form of cost-sharing, the United States governmental programs carried up to 75 percent of the initial establishment cost; the remainder is on the landowner. Between 1964 and 1979 in ten states of the United States, it was observed that the total government share in forest investment was 73 percent against 23 percent of private capital (De Steiguer, 1982).

In the form of assistance, examples as the Rural Forestry Assistance service in Georgia are found among the incentives programs in the Unites States. Cubbage *et al.* (1985) developed one of the first studies aimed to quantitatively evaluate the benefits of the assistance, if any. An economic 'with-without' approach was used. According to Ovaskainen *et al.* (2006), personal assistance has a potentially important role in encouraging the use of public subsidy and in triggering effects on the decision whether to invest.

Japan implemented a forest subsidy program in which NIPF landowners must report the stand conditions and the silvicultural treatments applied. The information collected is integrated in local government GIS (Nakajima *et al.*, 2011). The program differs among the nation's prefectures; as example, the Hokkaido Prefectural government subsidizes thinning activities providing about 70 percent of cost-sharing, but the forest cannot be subsidized if it received subsidy within the last five years (Nakajima *et al*., 2011).

In Finland, public intervention in non-industrial private forestry dates since the 1920s. Initially with legislation, as of 1928 funding for selected forestry activities was implemented. Increase of forest industry investments, subsequently the increase in commercial tree felling and the operations mechanization, were the basis for the new forest policy (Linden and Leppänen, 2003). Forest planning is an activity also publicly subsidized in Finland (Ovaskainen *et al.*, 2006).

Several Latin American countries have developed incentive programs to stimulate forestry. In Uruguay, expansion of forest plantation establishment occurred since the 1990s. This took place thanks to a policy framework that fostered forest investment through bank loans addressed to forest plantation establishment, direct subsidies and tax benefits (Bussoni and Cabris, 2006). In Chile, the implementation of the 1974 Decree 701 of forest cost-sharing to stimulate forestry activities, which currently covers between 75 and 90 percent of the establishment and maintenance plantation expenses, yielded about US$2 billion per year after twenty years of program operation with an initial public investment of US$162 million (Toledo, 2010). In Brazil, a tax benefit-based forest incentive program was created in the 1960s (FAO, 2010) which operated until 1984 and allowed the country to increase the establishment of forest plantations; up to 3.5 million hectares were established while the program existed. Currently, Brazil no longer has government incentive programs as forestry became a profitable productive activity thanks to the impulse given by the program (Toledo, 2010). In Argentina, the "Ley 25080 de Inversiones para Bosques Cultivados" (Law 25,080 of Investments for Cultivated Forests) was created in 1999 to promote the expansion of plantations around strategic consumption clusters. It includes tax benefits and non-refundable financial support for afforestation; in projects larger than a hundred hectares an environmental impact analysis is required (Toledo, 2010). In Costa Rica, subsidized, state-supported credits and bonds are provided to promote the establishment of forest plantations. Funds are delivered by the FONAFIFO through several trusts administrated by the institution (Toledo, 2010). In Colombia, a Certificate of Forest Incentive (CIF as its acronym in Spanish language) was created in 1999 to promote afforestation through cost sharing of 50 to75 percent of the total net establishment cost depending on species established (native or introduced). Maintenance cost is also subsidized over the first five years of the plantation lifetime (Toledo, 2010). In Panama, the "Ley 24 de Incentivo a la Reforestación en la República de Panamá" (Law 24 of Incentive for the Reforestation in the Republic of Panama), whose main objectives are to promote afforestation in all its forms and to promote forest industry development and research, was approved in 1993 for a 30 year period. Among its principal benefits are tax benefits and exemption in related investments and trading (Toledo, 2010).

2.4 Economic Analysis of the Effect of Subsidies on Forest Investment

Mechanisms of forest promotion can be classified according to what they economically affect: income or cost (variable and/or fixed). Regardless of the form they adopt, the effect obtained is a benefit increase that stimulates forest producers to increase forested areas or new investments to enter the business (Ubeda, 1991).

In the context of the effects of a nation's forestry policy oriented to stimulate forestry investment, it is important to distinguish between an economic analysis within a given policy environment (which is actually the framework of this study) and economic analysis of the effects of the policies creating the environment (Contreras and Gregersen, 1982). It is important to drive conclusions to the right direction in order to avoid misunderstanding in the goals sought.

In this regard, international research journals widely report studies related to the creation of econometric models to estimate the effects of different amounts of subsidy by using scenario-based approaches (Bolkesjo and Baardsen, 2002; Kurttila *et al.*, 2006; Gottschalk *et al.*, 2007; Lewis and Plantinga, 2007; cited by Nakajima *et al.*, 2011b). Research performed on the effects of implementing forestry subsidy systems in timber production, carbon stock and its consequences in harvesting strategies (thinnings and clear-cuts) have been conducted as well (Nakajima *et al.*, 2011a). Nonetheless, few can be found that estimate subsidy amounts or regional, long-term allocation of funds. This is a relevant justification for the development of research related to evaluating *ex ante* economic and financial criteria for the allocation of public funding in forestry.

Theoretical analysis could be considered as a starting point of the evaluation of subsidies in forestry; taxes in a variety of forms are also included in the analysis as their effect is economically analogous to that of subsidies. Terraux (1989) reported a model to evaluate the introduction of taxes and subsidies in the economic assessment of forest plantations in France. Qualitative as well as quantitative results were provided. The methodology was more focused on analyzing the effect of changing from one tax system to another in the optimal rotation period, the interest on the investment and the wooded area. The subsidy effect was theoretically analyzed in terms of its influence in the rotation period length. Conclusions were driven towards confirming the effect of these economic instruments in the forestry investment features (Terraux, 1989).

Subsides can be economically considered as transfers not related to the flow of goods and services (Becvarova, 2006). In agriculture, it is recognized that subsidies could trigger ‘deforming effects’ depending on the subsidy form and type. A deforming effect can be basically defined as the interference in market conditions and the deformation in market signals. Five types are possible to identify according to their deforming effect (Becvarova, 1992, 2006): targeted transfers, proportional subsidies to primary factors, output/input subsidies, and subsidization of market prices.

Examination of the effect of forest incentive programs among nonindustrial forestland owners has been an issue since they exist as an instrument to promote forest activities. Economic analyses (e.g. benefit-cost analysis and investment analysis) are the most used approaches in the research worldwide. Interestingly, the final aim is to approach answers to a simple question: would a landowner have invested to undertake forestry activities for which an incentive program provides cost-sharing if that program did not exist? (Harou, 1985).

From the investor's point of view, forest investment analysis simulation provides the decision maker with powerful tools to answer this question; Bussoni and Cabris (2006) reported positive results in a forest plantation return evaluation in Uruguay even removing the subsidy from the analysis. The influencing factor in the impact of having subsidies or not was the poorer product assortment obtained from plantations established in lower quality sites (Bussoni and Cabris, 2006). Araújo *et al.* (2010) reported not only improved financial performance in subsidized charcoal and timber production projects in Brazil but also less sensitivity to prices change in the investment risk analysis.

Recent studies have verified that the existence of a subsidy program is a critical factor determining the landowners' behavior in forest management (Koskela *et al.*, 2005; cited by Nakajima *et al.*, 2011).

Studies in the United States have modeled the effect of coexisting federal and state forestry cost-share programs on nonindustrial private forestland owners that employ the same financial means and have the same public objective (i.e., to increase private investment in the productivity of nonindustrial forestland) (Romm *et al.*, 1987). Evaluations of the 1974 FIP program showed that the performance of the program was favorable since its first year of operation (Mills and Cain, 1976).

It is recognized that the expected effect of subsidy programs aimed to promote forestry investment among small landowners is (sometimes adversely) influenced by their typical characteristics as nonindustrial private forest owners. This makes it harder to predict participation in such programs. Zivnuska (1975) cited by Gregersen *et al.*, (1979) provides a list of those adverse features that match with the reality of small forest landowners in Guatemala:

- Properties are too small for efficient forestry operations;
- Tenure is too short to give continuity to long-term investments inputs;
- Older owners not interested in long-term returns or in personal participation in the often heavy work of forestry operations;
- Low income farmers without means to invest in forestry;
- High income owners with expectations put on short term investment benefits and not willing to be property resident as to supervise the investment;
- Accidental nature of the ownership thus unwillingness to incur the costs of learning about management possibilities;
- Lower rates of return of forestry investments compared to the interest rates of owner's mortgages or personal debts;

In addition, many of the NIPF lands don't have the physical/biological potentials that would make investment attractive from a social point of view, even with their owners wanting to perform this type of activities (Gregersen *et al.*, 1979).

By assuming that nonindustrial forest landowners possess different resources and opportunities[7], thus their responses to a given subsidy policy would be expected to differ as well, Romm *et al.* (1987) determined that selectivity, diversity and combination of different cost-share policies determine the effect of them, specifically regarding the probability of investment among different groups in forestry activities (Romm *et al.*, 1987).

In theoretical terms, it can be stated that if there is divergence between public and private costs and benefits, then an incentive payment or subsidy might change the private individual's actions and induce him to move toward a socially desirable result (Gregersen *et al.*, 1979). Nonetheless, several studies' conclusions about investor's behavior indicated that forest investment decisions don't fully rely on the benefits attributable to the cost-sharing programs (Gregersen *et al.*, 1979; Flick and Horton, 1981). Actually, cost-share payments might be considered as a source of capital substitution in private investment more than an impulse to increase the forest investment (De Steiguer, 1982; Linden and Leppänen, 2003). Nonetheless cost-share programs do induce investment anyway (De Steiguer, 1982).

Predicting investor behavior is not an easy task. Instead, assumptions about this behavior are usually stated a priori and from the assumptions, economic analysis is applied. De Steiguer (1982), who attempted to model the investor reforestation behavior in ten U.S.'s states by using data from 1964-1979 where cost-share payments were part of an econometric model, concluded about the difficulty of approaching models for personal saving and investment. However, it was demonstrated that the government cost-share programs had induced the amount of private investment that they were designed to induce.

Flick and Horton (1981), who assessed the cost-efficiency of the Virginia's forest cost-share program, suggest that the effect of an incentive program can be measured in terms of the real change that the program promotes and assuming that the

[7] And that they are used in an economically rational way

change wouldn't happen without the program. In forest incentive programs aimed to increase timber supply, real changes are defined as those that increase the total wealth of society. The Virginia program happened to be efficient; but costs depend on records and benefit estimations depend on a number of assumptions (Flick and Horton, 1981).

The use of benefit-cost analysis must consider the definition of the program cost as well (as assumed that the program's benefits are those defined as the real change in the society's wealth). Flick and Horton (1981) defined this cost through the real cost of the program which is the value of resources foregone due to investing in the forestry program. The total cost components can be classified in three items: landowner's share, incentive share and program-operating cost (Flick and Horton, 1981).

Harou (1985) evaluated the FIP program in Massachusetts by using a benefit-cost (B/C) ratio and a 'with-without' analysis; he demonstrated the program's efficiency (B/C ratio greater than one) at 4 percent and 6.625 percent discount rate. It was also concluded that the forest management decisions are crucial in the program's performance. As well Flick and Horton's work, Harou (1985) distinguished private and federal direct costs (cost-share on the landowner and subsidy payments respectively), and program delivery cost (those related to the administration of the program).

Mills and Cain (1978) employed two types of benefit-cost ratios for a nationwide evaluation of the FIP program. They defined the indicators 'program effectiveness' (PE) and 'social efficiency' (SE) as part of the economic assessment; in the first one, the programs benefits were related to the program's costs (direct and delivery), and in the second one the same benefits were related to total costs by adding those that would not have occurred without the program. Gregersen *et al.* (1979) employed the same economic indicators to assess the program's effectiveness and efficiency in Minnesota.

2.5 Allocation of Subsidies

In general, subsidies and taxes and the way to allocate them have impact on the optimal forestry project's income, the value of wood production and on silvicultural parameters like the rotation period (Terraux, 1989). According to this, determining subsidies allocation in a forestry project takes on relevance in the assessment of forest investment.

Allocations of the 1973 FIP funds among states and among state counties were guided at the beginning by proportionality of nonindustrial forestland, and later by trends in past expenditures (Plumb 1985, cited by Romm *et al.*, 1987). Among counties, funds were redistributed in the case of deficit or excess after completing one-year in the program and, virtually, no landowner proposal appeared to have been refused for lack of funds (Romm *et al.*, 1987). When approved, a county committee ranked the proposals on their merits and allocated funds accordingly (Romm *et al.*, 1987).

Allocations of the 1980 CFIP funds depended on timber sale receipts from State Forests and were addressed to owners who had committed their land to forestry for at least ten years. Requests substantially exceeded the funds available. The subsidy could be used for afforestation, stand improvement, fish and wildlife habitat improvement, erosion control or to cover costs of a land management plan (Romm *et al.*, 1987). The State Forester had final approval. Funds were allocated to the approved projects on a first-come first-served basis (Romm *et al.*, 1987).

Becvarova (2006) examined the performance of the SGFFF (Support and Guarantee for Farmers and Forestry) as the main capital-related instrument in the Czech Republic's agriculture. Although the program was critical in the agricultural sector development between 1994 and 2004, the allocation of loans and subsidies truly did not depend on the quality of land conditions, reacting to economic criteria instead. Evaluation of an agricultural company's economic status as a loan borrower was the main criteria to allocate the funds.

In the study reported by Nakajima *et al.* (2011b), an algorithm that employs the stand area, the forest owner's address, the distance to the nearest road, the site slope and the stand's historical record of silviculture is used to determine thinning areas under the Japan's forest subsidy program. Information is processed in a GIS for spatial analysis. However, the only criteria employed to allocate the funds is that the stand's silvicultural record doesn't report allocation of program's funds within the last five years. The algorithm is capable of simulating different subsidy systems[8], so simulation can help predict cost-effectiveness of the different programs for expanding thinned stand areas (Nakajima *et al.*, 2011b). A similar study was performed by simulating the applicability of different subsidy systems in harvesting strategies (clear-cutting area) and estimations of carbon stocks in Japan (Nakajima *et al.*, 2011a). Similar conclusions to the first work cited were obtained; however, nothing is reported regarding an economic criterion and/or the use of a model to determine the allocation of subsidies among particular projects.

Shigematsu and Sato (2012) reported the examination of Norway's private forest subsidies system reestablishment of 2007[9] in which the provision of public funds was redirected from the municipality-level to the county-level regarding the budget addressed to forest production activities (road construction and cable yarding). The objective of the reestablishment was to encourage prevention of environmental degradation among production activities. The examination provides an interesting analysis and suggestions about promoting subsidies in the use of domestic wood stock under sustainability, but nothing is detailed about the allocation-related methodology employed among individual landowners applying to the funds.

[8] The Japan's forest subsidy system is different between one prefecture and another.

[9] The Norwegian forestry subsidies program addressed to private forest owners existed since 1994 in the form of municipal administration. Because of prevalence of conservation purpose over production purpose in European countries, the program was terminated in 2003.

Rankings and "first-come first-served" basis have been used as selection criteria to allocate public investment funds. Murphy (1976a) developed the first approach of a way to allocate the cost-sharing 1973 FIP program into potential forest activities based on economic criteria by using parametric linear programming. The question he wanted to answer was: how can restricted public funds be directed to those areas where they will produce the greatest return? Cases of land-use conversion from low-quality stands to higher productivity forests were analyzed. By using a procedure where conversion classes were determined according to site, size and regeneration/plantation conditions as well as yield and market projections, areas with different potential productivity and economic performance were ranked according to a LP-based procedure. The methodology was tested by changing some conditions and adding resource constraints to the problem (Murphy, 1976a).

According to Murphy's methodology, no matter how much funding is available, the best allocation is always made by employing the parametric LP and the ranking criterion (Murphy, 1976a). This conclusion is relevant as it would allow a decision maker to allocate public funding in a rational, well-supported way regardless of the budget assigned for the purpose.

In 1979, Gregersen *et al.* proposed a methodology to analyze the effectiveness and efficiency of cost-share subsidy programs aimed to increase timber production and, from it, provide insights for allocating and controlling the use of these funds. Specific guidelines and criteria for the allocation of funds to landowners under the program were some of the main results of the study (Gregersen *et al.*, 1979).

Gregersen *et al.* developed a model to help answer questions about of the effectiveness and efficiency of the 1970 forest subsidy programs in Minnesota. The principal of those in regard to this research are summarized here: "what economic criteria are relevant in determining who gets a subsidy, and if the program budget is limited, how should the individual program investments be ranked in order to maximize the present value of net social benefits?" (Gregersen *et al.*, 1979). In our case, instead of the ranking criteria, a LP-based multi-period optimization model is employed as selection criteria. More details are provided in the Chapter 4.

Within Gregersen *et al.*'s work results, it was found that 24 out of 159 landowners (equivalent to 140 acres of red pine plantations owned by cost share funding recipients in Minnesota) were reported as having projects socially profitable but privately unprofitable. This divergence in the profitability analysis under public and private interest framework, according to Gregersen *et al.*, justifies the delivery of a subsidy (Gregersen *et al.*, 1979).

When the budget is limited, the ranking-based subsidy allocation criterion is the commonly used technique to allocate funds to projects. In the case of evaluating single projects, Gregersen *et al.*'s work proposes the use of the ratio calculated between the project's social benefit and the investment deficit estimated as the divergence between social and private project's profitability to allocate the funds (which would equal the theoretical subsidy amount to be granted). Only 14 out of the 24 "socially profitable but privately unprofitable" projects in Minnesota should have been granted with funding assuming the limited budget restriction of the program at that time (Gregersen *et al.*, 1979).

2.6 Optimization Techniques in Forestry Investment and Subsidies Allocation Analysis

Linear programming, mixed integer programming, binary integer programming and heuristics are among the most commonly used mathematical programming techniques in forestry planning. These tools have been extensively used to solve problems related to transportation and harvest spatial scheduling. They have been also used in economics to solve fund allocation, portfolio managing, trust and appraisal problems (Sessions, 2013).

Mathematical programming using optimization techniques can be useful for analyzing effectiveness and efficiency in the allocation of public resources into productive activities that take place over several periods. Dynamic programming (DP), recursive linear programming (RLP) and multi-period linear programming (MPLP) are reported as methodologies suitable to solve this type of problems (Ubeda, 1991).

According to Barnard and Nix (1984), DP is one of the most versatile techniques as it is suitable to analyze processes in the form of deterministic or stochastic, discrete or continuous and linear or not. Because of this, there is not a unique mathematical model to formulate and solve a DP problem. According to Irwin (1968), RLP is just able to employ one period; if it is necessary to formulate and solve a multi-period allocation problem, the model must be run several times with modifications in each phase. Yaron and Horowitz (1972) called this 'sequential programming' and justified it in the sense as it is better to run several small problems instead of solving a big one at once.

The major problem in using these two techniques when a forest economic cycle is evaluated is that they usually present sustained cash outflows at the beginning and cash inflows at the end. This uneven revenue condition provokes activities at the beginning to be eliminated because the methodology would not recognize the deferred revenues at the end. MPLP resolves this situation as it provides a mathematical methodology to simultaneously solve several periods at the same time (Ubeda, 1991).

Murphy's (1976a; 1976b) methodology to allocate funding employs the combined criteria of ranking with linear programming. When the economic performance of all the potential cases is assessed, it is possible to make a priority list depending on the funding level. The list, which finally becomes the ranking, is obtained by applying LP that maximizes return (expressed as net present value of a perpetual series of rotations) at a fixed budget, which is initially set as low as possible in accordance with the smallest project's financial need. The parametric part takes place when the budget level is increased time by time allowing other projects enter the optimal solution. Finally, the entering order becomes the priority list of projects in which the funds should be allocated to maximize the economic indicator previously established (Murphy, 1976b).

Previous to Murphy's work, some other authors had already reported analysis in which LP was used to assess forestry investments. Teeguarden and Von Sperber (1968) demonstrated that LP was superior in scheduling a reforestation program of Douglas-fir in Western Oregon when compared to capital budgeting and the use of professional judgment in the decision making. Net present value of the projected program was employed as an economic indicator for the comparison. The research illustrated the advantages of LP in analyzing complex problems involving multiple resource constraints (Teeguaden and Von Sperber, 1968). Buongiorno and Teeguarden (1978) showed similar conclusions when simulating management regimes and approaching optimum allocation of management resources by using LP. They also briefly provide the applicability of the model to forestry investments in developing countries. Weingartner (1963) cited by Murphy (1976b) applied mathematical programming to capital-budgeting including allocation of a fixed sum.

Osteen and Chappelle (1982) reported the use of a LP-based model that selects practices needed to meet projected demands of timber production and wildlife while minimizing discounted costs of harvesting timber, stand improvement and transportation.

Shadow pricing as a methodology to appraise investment has also been used in evaluating economic performance of forestry projects. The methodology has been more developed for industrial investments and agricultural projects, and since the 1980s has been adopted in forestry as a cost and benefit measurement technique (Harou, 1984).

In a perfectly competitive economy, shadow and market price would be equivalent, as the shadow price represents the real opportunity cost of one unit of a resource (in terms of the units of the objective function). By incorporating real economic values for inputs and outputs in a forestry management project (i.e., the best estimations of the opportunity cost for inputs, the willingness to pay for outputs, and a real, lower social discount rate) and making a profitability calculation in the similar way as for a financial analysis, the economic evaluation assesses the project in a societal context. Only if the economic appraisal is favorable then the allocation of the society's resources (e.g., a subsidy) to the landowner is recommendable (Harou, 1984).

This double analysis of the program performance (financial and economic) permits it to show that the project might need a subsidy in order to, for example, undertake more intensive management and that the management intensification is in the society's benefit. Policy makers making decisions about public investment should require a broader analysis including a societal perspective like that described above, so the use of shadow prices makes sense if the analysis is to be meaningful (Harou, 1984).

Ubeda (1991) cited work performed in the twentieth century in context with the use of multi-period linear programming in allocation of resources, investment and financial analysis. Examples include the work of Earl Swanson (1955), and Loftsgard and Heady (1959) in agricultural planning; Irwin-Baker (1962) in multi-period financial analysis; Martin (1966-67) and Judez-Asencio (1975)' in investment analysis and company growth; Dean and Benedictis (1964)'and Mainie *et al.* (1975) in fruit production and its relation to public loans; and Arnoud (1975) in vineyards. In her work, Ubeda compared the performance of three different forest promotion mechanisms (plus the "without promotion" scenario) in the optimal investment combination of forest activities. Comparison was made in terms of public benefit, which was quantified through the economic result obtained by the government due to the taxes accrued among the different promotion scenarios (Ubeda, 1991).

Some work has been performed in the analysis of policy instruments to promote resource sustainability by using mathematical programming. Dolisca *et al.* (2009) reported a study performed in Haiti to evaluate various policy instruments to persuade farm households to adopt conservation measures by employing mathematical linear programming models. Agricultural subsidies tied to environmental conservation appeared as the most suitable mechanism for the sustainable use of resources.

Non-linear optimization is also reported in the subsidies allocation literature. Friis Bach (1999) developed a multi-period non-linear model that analyzes stock, yield and cost from timber production in Ghana to evaluate different policy options to promote low-impact logging through the use of economic incentives. A numerical solution was reached which provided the evaluation and comparison of two promotion options: direct area-dependent subsidies (defined as fixed subsidies per hectare regardless of the production size) and higher prices (defined as fixed, exogenous price subsidies per unit of production).

Linden and Leppänen (2003) reported the effects of public cost-sharing on private forest investment with a simple cost-sharing optimization model in Finland. Three different forest investment classes (private investments with no public support; private, individual investments with public support; and private, collective investments with public support) were evaluated. Complementary and substitution effects among investment categories were modeled.

Zadnik (2006) developed a study in Slovenia in which decisions on investment, silvicultural and harvesting activities are considered as part of the forest management problem that guarantees sustainability, profit maximization and public acceptance of the decisions. Zadnik used a fuzzy, dynamic and multi-objective model for optimal forest management to determine the sequence of decisions that jointly maximizes economic, ecological and social objectives.

After reviewing the above literature, it can be concluded that significant efforts have been done in the direction of evaluating effectiveness and efficiency of subsidies in their role of forestry promotion, most of the research focused in a macroeconomic framework and in places where incentive programs to promote forestry have been in place for some time. However little work has been performed in evaluating particular cases where the determination of an adequate (i.e. optimal) funding schedule is required. Developing countries lack research in this area. Many authors allude to the political context in which the decision making process on subsidies allocation usually takes place. This is an unavoidable fact indeed. Nonetheless, there is still a need to develop methodologies that provide political decision makers the basis to objectively and rationally support the decisions in public funding analysis. This is the problem statement's starting point.

To provide a rational methodology, Gregersen *et al.* (1979)'s work and a multi-period mixed integer linear programming (MILP) model were employed and combined in order to set such methodology to support the future allocation of PINFOR funds in Guatemala.

3 Problem Statement

As in several countries where evaluation of forest subsidy programs have been performed, positive effects resulting from the implementation of the PINFOR program in Guatemalan forestry are not totally clear. Monterroso and Sales (2010) and Monterroso (2011) evaluated the performance of the 1996 Guatemala's National Forest Policy which declared the PINFOR program as the most important instrument to foster local forestry. Some of the conclusions of the study pointed out that the increase of the afforested area in the country and the sectorial employment creation were the only goals effectively met after fifteen years of program (Monterroso, 2011). Curiously, none of them involved economic/financial indicators or effectiveness analysis of the public investment.

A political debate is currently taking place in Guatemala similar to what happened in the United States during the debate about the FIP funding program between Congress and the Office of Management and Budget in the 1970s (Gregersen *et al.*, 1979). This is a good opportunity to contribute a methodology for determining total public incentive funding to forestry, determining regional allocation of these incentive funds and evaluating the effectiveness of the program over time. An interesting aspect derived from the 1974 FIP analysis is that evaluations were required by law and immediately carried out within the first year of operation of the program (Mills and Cain, 1978). Economic and financial assessment of the program was a critical component of the evaluation process. This is the missing link in the Guatemalan forest policy and its instruments to promote development within local forestry (at least for those that have invested in the activity).

By using methodologies based on social-economic assessment of projects to allocate public funds that are expected to provide benefits to the society effectively and efficiently, funding criteria within a certain local forestry policy would no longer rely on political rhetoric and vague impressions. In this regard, a wise statement from Gregesen *et al.* research is: “there is particular no reason to accept incentive programs based on the simple dictum that the more trees planted the better" (Gregersen *et al.*, 1979). Ubeda (1991) also states that governments should base decisions making about forest promotion policy implementation on thorough technical and economic studies about efficiency of the resources allocation. Unfortunately, as said, few studies have been performed in this regard[10].

The United States' FIP program can be compared with the Guatemalan forest incentive program PINFOR. Among a variety of goals, the law stipulates that funds should be directed to those areas where they can produce the greatest returns, but few criteria existed to guide decision makers in the task of allocating the funds in the right way (Murphy, 1976a). In context with the Guatemalan Forest Policy and the 1996 National Forest Law, and according to the funding allocation process carried out by the INAB's Forest Development Department, no forest project is left unfunded if all the application requirements are met by the landowner[11].

The application requirements for a landowner to enroll in the PINFOR program mainly focus in meeting the following (INAB, 2010):

- An Application Form is completed and filed.
- A Study of Land Use Capacity (ECUT as its acronym in Spanish language) has been completed.
- A Forest Management Plan (FMP) has been developed.
- A Certification of the Land Ownership is available.

[10] Statement confirmed through personal communications hold with Jeff Kline, Research Forester of the USDA Forest Service, PNW Research Station, and Darius Adams, Emeritus Professor of OSU College of Forestry.

[11] Information obtained thanks to a personal communication hold with Edgar B. Martínez, Administrator of the PINFOR Program in the INAB.

- The legal status of the landowner is audited (personal, business society, tributary registration, commerce license and/or social groups with legal status).

- An affidavit of beneficiary designation (in the case of title holder's death) is available.

A plantation project's FMP must consider planning, execution, follow-up and evaluation activities that will be carried out to establish the project on a specific tract of land and along certain time line. Clear objectives have to be set in the plan (INAB, 2010). Following the documents submittal, two types of auditing are performed: technical (in which technicians of the INAB's regional offices check mostly aspects like establishment and maintenance activities compliance and land use status) and legal (in which staff of the INAB's headquarters check the legal documents submitted in the application). The auditing should take no longer than 30 days to deliver the program acceptance notice if all the requirements are met.

Nothing is mentioned in the regulations about performing a project's economic assessment, an evaluation of financial feasibility or a projection of expected returns. A typical plantation FMP, which is prepared by a forest technician formally registered in the INAB's forest professionals database, includes sections related to property and landowner's general information, project objective[12], justification for the use of the species chosen, general characteristics of the species, species' market general features[13], seed source, plantation method proposed, justification for the site preparation proposed[14], plantation sketch, protection program, silvicultural activities' timetable and forest technician's information. Nothing is included about silvicultural

[12] Apparently the statement of the project objectives is a task delegated to the technician in charge rather than being a project owner task.

[13] Although general world market information is cited in this section, local market opportunities or prices trend are usually not explicitly mentioned. It is commonly found in FMPs that they have been written by the same technician and with exactly the same paragraphs taken from literature review of the specie.

[14] This is mainly focused in justifying the removal of vegetation that is unable to be used commercially.

cost, projected revenues due to timber sales, discount rates, market research, single- or multiple-rotation condition, opportunity cost of land, or other project economic characteristics.

Consequently, the FMP revision and approval process lacks a review of economic aspects that allow the INAB to determine the economic feasibility of an individual project or as part of the whole program, and thus to allocate the funds in a profitable way or in context with programs' goals. The lack of this revision reflects the lack of strategic planning in the allocation and annual apportionment of the funds provided by the Ministry of Public Finance. Actually, the 1996 National Forest Law declares its intent to further the public interest through ensuring forestry development and sustainable forest management with the PINFOR program and INAB's supervision. However, little is encountered in the procedures of the policy that really guarantees forestry development and sustainability of the sectorial activity.

Fortunately, the existence of sectorial data about forest growth, land use, timber production and market features of Guatemalan teak, makes it possible to formulate an alternative methodology for the delivery of the program. In simple words, the analysis of the PINFOR program as a mean of public investment can be addressed as a typical forest investment problem. Maximization of return, land availability and allocation, long-term horizon, variety of silvicultural and production regimes, budget limitation, financial projection, discount rate, and social (i.e. sustained employment generation) and environmental (e.g. non-decreasing planted area) constraints are typical elements to consider in the formulation of a strategic plan for the allocation of funding in the PINFOR program framework. Mathematical programming provides the tool that gathers all these elements in the search of an optimal solution. Use of this framework suggests an alternative way to deliver the PINFOR funding and that, at the same time, guarantee the compliance of that stated by law about Guatemalan forestry development.

In this sense, the main objective of this work was to develop an optimization model based on multi-period linear programming that serves as a long-term funding allocation model. It manages all elements in order to formulate a rational, objective methodology based on the maximization of return to provide an optimal solution to the allocation problem of the PINFOR program's funds for teak plantation projects in Region 9 of Guatemala. Specific objectives also sought were: (1) perform an economic assessment of different forest management and production regimes commonly found in commercial teak plantations of Region 9 established through the program; (2) incorporate social and environmental requirements in the model formulation that complement the economic standpoint of the analysis in compliance with the sustainable forest management stated by law; and (3) provide an optimal solution to the funding allocation problem regarding the particular spatial scenario of simulated projects and inputs employed through the study as proof of effectiveness of the methodology.

4 Methodology

The methodology applied to this research work is based on three main stages: (1) simulation of Region 9 teak projects to be theoretically enrolled in the PINFOR program in the near future, (2) economic and financial assessment of the simulated teak projects of Region 9 that provides a basis for the determination of indicators and decision criteria to include in the model, and (3) model formulation that includes those indicators and criteria as part of the model structure. Next chapters describe in brief the basic elements of the economic analysis of forest investment as well as the methodology employed by Gregersen *et al.* in 1979 that provides the foundations of the funding allocation criteria included in the model. A brief review of the literature that cited the Gregersen *et al.* work is made. After that, the adaptation of the Gregersen *et al.*'s economic model and allocation criteria to this particular case and the whole process performed to gather all the information about the Guatemalan forestry needed to input the model formulation is described in detail.

4.1 Economic and Financial Analysis of Forest Public Investment

In forestry investment decisions, it is important to select the correct economic model (Teeguarden and Von Sperber, 1968). The statement applies as well to subsidies for cost-sharing as they are part of the investment's economic and financial assessment, especially when public funds are involved.

Financial analysis of a project estimates profitability from the investor's point of view. By financially assessing inputs and outputs[15] in a scheduled cash flow, indicators like net present value, internal rate of return and benefit-cost ratio can be obtained (Harou, 1985). Other approaches to evaluate investor's return may be employed by approaching the Faustmann's land expected value (*LEV*) or the annual forest rent (Klemperer, 1996; Bussoni and Cabris, 2006; Wagner, 2012). Economic analysis of a project, by contrast, estimates profitability from a societal point of view.

[15] By using their corresponding market prices

Shadow prices replace market prices, transfers are not considered and a social discount rate is included as part of the assessment (FAO, 1979; Harou, 1981; Harou, 1984; cited by Harou, 1985). The same indicators can be obtained as well.

Shadow prices represent the resources' true opportunity cost to society. Transfers are omitted because benefits exchange is not considered. The social discount rate should adopt a different value from the private one (Harou, 1985).

Basically, a forest project can be evaluated from these two points of view, and the investment decisions' course could diverge accordingly. But if they provide similar responses regarding an investment decision, it can be stated that both the private and the public's point of view are in the same direction.

According to Gregersen *et al.* (1979), a direct incentive or subsidy can make a rational investor move toward a socially desirable course of actions if there is a divergence between the public and the private interests in the investment. The assumption is that such an incentive payment should be just sufficient to accomplish the objective; if it is greater, the grant would be inefficient, and if it is less, the objective will not be accomplished and the program would be ineffective (Gregersen *et al.*, 1979).

4.2 Economic Model and Subsidy Allocation Criteria: Gregersen *et al.*'s Model[16]

The FIP program in the United States was intended to substitute for the REAP program in terms of forestry incentives related to increasing timber supply beginning in 1974. The Gregersen *et al.*'s work focused on evaluating the *ex post* performance of the REAP program to provide insights for an *ex ante* evaluation of the FIP's allocation and control of funds. According to this, the study aimed to solve (or at least

[16] Model and criteria taken from the research work performed by H. Gregersen, T. Houghtaling and A. Rubinstein in 1979 in a case study in Minnesota. See the section 'Literature Cited' for the complete reference.

to provide a solution approach to) a problem foreseen in a time of changes regarding the programs' allocation of the subsidies.

The condition of "socially profitable but privately unprofitable" of a forest plantation project can be determined according the Gregersen *et al.* (1979) methodology. The basic economic model for doing this is described as follows:

A rational investor wanting to invest in forestry should consider the relationship between five different rates to make the investment: the rate of value increase of the land (r_l), the rate of return of the forestry activities being considered (r_f)[17], the composite rate of return of both mentioned before (r_r), the social rate of return (r_s, which is defined by the way society discounts[18]), and the alternative rate of return (r_a), which should be equal to the highest rate among: (1) the rate of return from allocating the land to another use (if any), (2) the rate of return obtained by selling the land and investing the money received plus the money he would spend on the practice, or (3) the rate of interest of borrowing money to buy land and/or carry out the project (if such borrowing actually would have taken place).

According to this, private profitability of the plantation project at optimal rotation age can be estimated as both the net present value of the forestry activities alone (NPV_f) and the total net present value of the investment by including costs and returns of the land (NPV_r). The investment decision rule would be as follows: if both indicators are greater than or equal to zero, there is no financial reason to not make the investment. But if either of them (or both) are less than zero, then there is an "investment deficit" (*ID*), defined as the absolute value of the more negative of the two. In the case that neither of them is negative, the *ID* is zero. The principal assumption to employ this basic economic model is that a plantation project investment with *ID* zero would be made without receiving financial aid and one other

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[17] Excluding the costs and returns of holding the land

[18] Selection of a social discount rate for the study is treated in the Chapter 4.13.2 'Private and Social Discount Rates'

with *ID* greater that zero would not be made without receiving financial aid at least equal to *ID*, i.e. a subsidy[19].

By assuming that each plantation project applying to funding could be assessed in order to determine its NPV_f, NVP_r and (virtually) *ID*, Gregersen *et al.* proposes an *ex ante* criterion for the subsidy allocation to those accounting for *ID*>0: a ranking of participant projects should be made to define a "funding order" which maximizes the net present social value (NPV_s) of the program. A single project's NPV_s is calculated by discounting all project benefits for the participant to the present using r_s as the relevant discount rate; the same is made for all costs (including the opportunity cost for land and operational expenditure), and the difference between the discounted benefits and costs is the net present social value of the program[20]. All those projects identified as having NPV_s greater than or equal to zero enter the selection next stage. Next, the financial aid quantity needed to make the investment of interest is determined by estimating the *ID* from the corresponding assessment of the project's NPV_f and NPV_r. Those projects having NPV_s greater than or equal to zero and *ID* greater than zero are selected to be considered for the grant. They, thus, enter the selection final stage.

As a budget is often found in public assistance programs, an additional criterion must be defined to select those projects (accounting for an investment deficit) that maximize the net present social value of the program. The ranking system proposed by Gregersen *et al.* employs the ratio NPV_s to *ID* as a measure of the social return per dollar of program budget. The limited program budget should then be allocated to projects with the highest NPV_s/ID ratio in the funding order until the budget becomes exhausted. This program beneficiaries group represents the best

[19] Harou (1985) stated the same idea: if NPV_r is positive, the landowner would not need financial aid to undertake the forestry activities. So the extra timber produced by managing the woodlot would not be a result of the program.
[20] The economic methodology of making a financial analysis of the investment to determine its need of subsidy and making after an economic analysis by using a social discount rate and by including the administrative cost of the program is supported by Harou (1985).

solution as it maximizes the economic contribution of the funding provided through the forest subsidies program.

In the Gregersen *et al.*'s analysis, the critical inputs to generate the data and the assumptions underlying the analysis consider subjects as local aspects of site conditions, expected plantation yields (at the rotation age that maximizes NPV_f), an adequate alternative rate of return (r_a) in each case, expected stumpage prices, present value of stumpage receipts, and cost associated with private land, hand and machine planting, private seedling, site preparation and land taxes.

Schematically, the economic assessment of single projects and the selection/allocation criteria proposed by Gregersen *et al.* to allocate funds into several plantation projects applying to the program can be explained according to the scheme shown in the Figure 9.

In the figure, the index i represents any single project applying to the funding program, NPV_{si} represents the net present social value of the project i, NPV_{fi} represents the net present private value of the forest management activities employed in the project i, NPV_{ri} represents the total net present value of the project i, ID_i represents the investment deficit of the project i as defined previously, and R_i represents the public investment social return ratio due to the project i. The latter represents the criterion to assess the project priority metric in Gregersen *et al.* work: the higher the ratio the greater the chance to be selected in a preferential position for the allocation of funding.

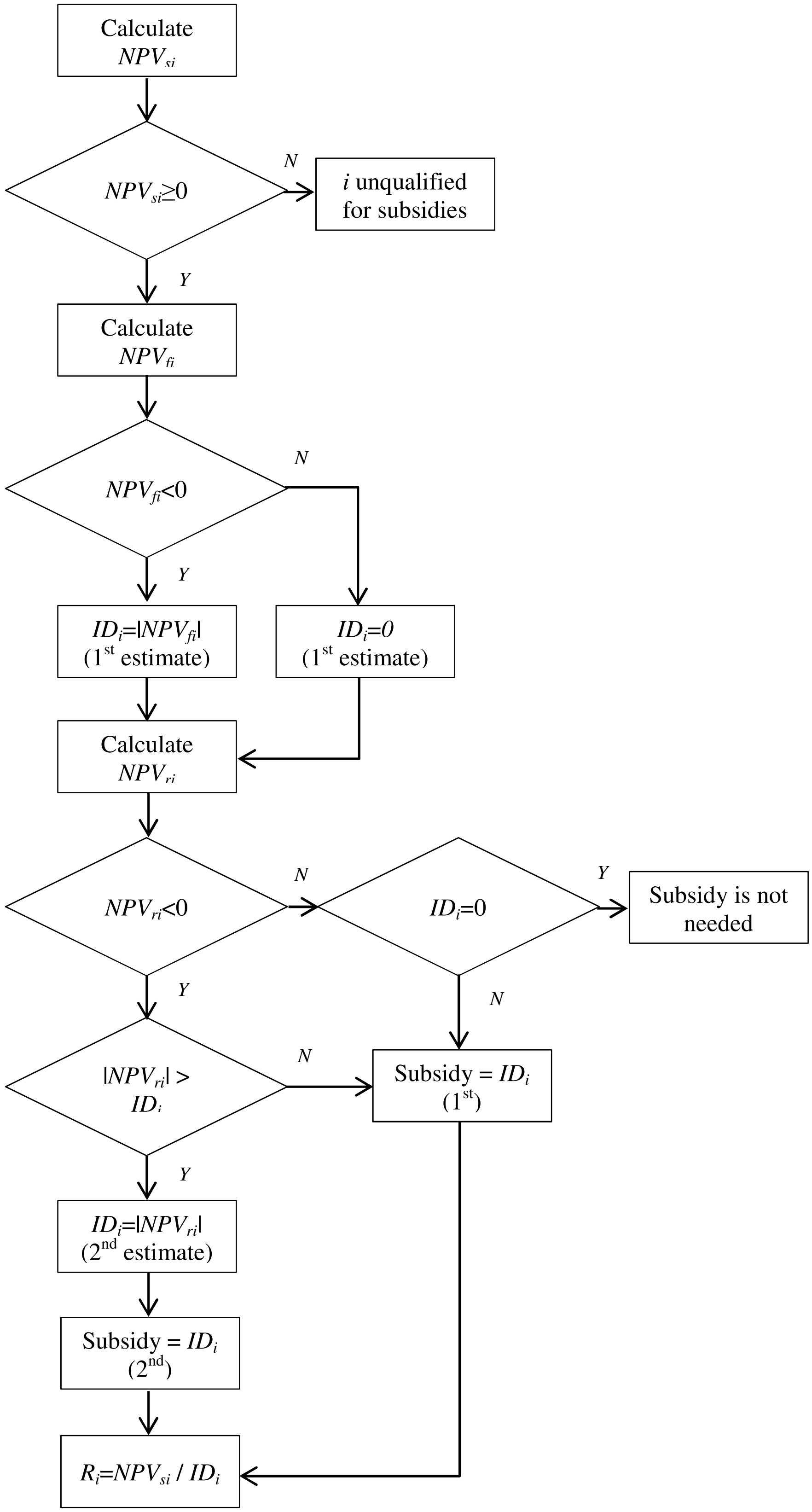

Figure 9. Flow diagram of Gregersen *et al.*'s methodology to assess the selection/allocation of funding into projects (source: adapted from Gregersen *et al.* 1979)

According to the assumptions that: (1) ID_i represents the financial need to induce the investment that project *i* represents, (2) the whole budget to be apportioned among projects applying to the subsidy program is limited, and (3) the goal of the fund allocation is to maximize the overall return of the program, then the R_i of the projects serves as the metric to rank the projects and allocate the funds into them according to a R_i-based order, from the highest to the lowest, until the total budget is exhausted.

4.3 Gregersen *et al.*'s Model in Previous Research

Several studies have cited the Gregersen *et al.*'s study related to the evaluation of effectiveness and efficiency of the 1970s forest subsidies program in Minnesota. However, few of them actually take the *ex ante* economic approach and the subsidies allocation criteria proposed by Gregersen *et al.* as basis for future work for allocation of subsidies in a public forest investment framework.

Flick and Horton (1981) cited some of Gregersen *et al.*'s conclusions in reference to the fact that the forest investment decision doesn't fully rely on benefits attributable to a cost-sharing program. De Steiguer (1982) cited the Gregersen *et al.*'s work as one of the studies that examined the so-called "capital substitution problem" in regard with the cost-sharing programs, indicating that there are inconclusive results about the overall net impact of these type of programs. Harou (1984) and Harou (1985) cited the Gregersen *et al.* work as one of the few studies that employed shadow pricing and benefit-cost ratio as methodologies to approach an economic assessment of forestry projects on a systematic basis. Cubbage *et al.* (1985) cited Gregersen *et al.*'s work in relation to other studies that evaluated programs for public and private returns.

Gregersen and Walker (1985) conducted a follow-up study of the Gregersen *et al.* earlier study of 1979 in Minnesota after ten years of FIP cost-sharing among the state's forest landowners. The follow-up study was based on the comparison between the answers provided by the landowners in the 1972 survey with the 1982 follow-up survey applied over the same objective group in the context with the later study. The most important conclusions of the follow-up study pointed out the lack of follow-up instruments to monitor the investment from the public assistance, the positive results in the ownership continuity, and the positive results about the willingness to follow-up the investment detected among larger properties enrolled in the program. Nothing was found regarding the economic model and the subsidies allocation criteria within the study.

Straka (2011a) and Straka (2011b) cited Gregersen *et al.*'s work as part of a long list of literature that evaluate effectiveness of cost-sharing programs, response of landowners to cost-sharing and the role of state programs in stressing cost effective timber production among nonindustrial private forest landowners.

4.4 Adaptation of Gregersen *et al.*'s Model to the Current Study

In the context of this research work where teak plantation projects within the Guatemala's Southern-Coastal region are analyzed using an *ex ante* economic approach, similar assumptions and criteria are employed to assess the allocation of funding. In general terms, Gregersen *et al.*'s economic model is adapted to formulate a multi-period mixed integer linear programming-based (MILP) model that basically replaces the ranking-based methodology to select suitable projects and allocate them into the funding program.

Methodologically, adaptation of Gregersen *et al.*'s model to the Guatemala's PINFOR problem ultimately relies in the replacement of the ranking-based static criterion to allocate funds among alternative projects using an *ex post* economic approach with a MILP-based model that solves the allocation of funds among a variety of alternative projects within a long-term planning horizon using an *ex ante* economic approach. MILP offers certain features that make possible the optimal allocation of resources in a multi-period framework by defining the activities duration, the planning horizon length and an appropriate discount rate to make each period comparable (Ubeda, 1991).

Gregersen *et al.* stated that the methodology (the economic model and the subsidy allocation criteria) should be applicable in Minnesota as well as in other areas to guide cost-share allocations under forest incentive programs. Guatemala's forest reality fits this statement as all the necessary elements to input the analysis are identifiable and quantifiable.

An interesting conclusion from Gregersen *et al.*'s work is "the model needs to be converted to an operational model for use in *ex ante* evaluation of cost-share subsidy allocations". An adaptation of the model is performed in this study by using a different type of information base without making major changes in the conceptual framework of the "investment deficit" as a metric of financial aid. Local project information of potential forest projects is desirable for an adequate *ex ante* approach. In this context, the study develops an information base obtained from local research aimed at teak growers who have been granted funds from the PINFOR program within Region 9. This information base is representative of the majority of the potential teak plantation management and production opportunities in the region and serves as input for the *ex ante* economic assessment of any potential teak plantation project able to be developed in the future.

Regarding the inputs and outputs of Gregersen *et al.*'s model, all the variables necessary to perform the *ex ante* economic assessment (i.e. NPV_f, NPV_r, NPV_s and ID estimations) of any potential teak plantation projects within the region are found in the information base of the study. Similarly, the subsidies allocation criterion is defined from the information base and the economic assessment's outputs that represent local conditions. In the context of the recommendations given by Gregersen *et al.*, it is relevant to have a structured, local information framework of productivity, cost and market features as well as good comprehension of the *ex ante* economic assessment that serves to the decision making process faced by the policy makers in Guatemala. By having these elements, the allocation of public funds addressed to promote future teak-based projects in the region is performed under economically rational criteria, even if the information base provides averages, "guesstimates" or rough data in the first approach (Gregersen *et al.*, 1979).

Additionally, some features of relevance in current Guatemalan forestry are included as part of the information base and in the model formulation. They introduce a brief spatial analysis throughout Region 9 regarding potential projects to be theoretically enrolled in the PINFOR program and some sustainable forest management principles regarding social and environmental impacts expected to happen by promoting forestry development in the country. These sustainable forest management principles are not explicitly present in Gregersen *et al.*'s model. However, positive social and environmental impacts linked to the development of forest activities and the increase of production, trading, diversification, industrialization and conservation of forest resources in Guatemala are desirable results mentioned in the 1996 National Forest Law (Congreso de la República de Guatemala, 1996).

Finally, the *ex ante* economic assessment and the subsidy allocation criteria are stages of a methodology applied over "virtually unknown" teak projects. They were modeled by performing a project simulation through stochastic assignment of project size, management and production regime, and land market category. This methodological statement forms the basis to define "projects to be theoretically enrolled in the program year-by-year in the near future" as the decision variable of the funds allocation problem in the multi-period MILP-based model formulation. Thus a spatial scenario of simulated teak projects was especially created for the study. Different activity levels of the decision variable are associated with the simulated, alternative teak plantation projects of the Southern-Coastal region of Guatemala[21]. This is an important adaptation from Gregersen *et al.*'s model which employs an *ex*

[21] See Chapter 5.2 'Model Formulation' for the details in the decision variable definition.

post economic approach that considers real projects as subjects of analysis in the calculation of the total amount of subsidy needed and for the allocation process into the ranking system. The study in Guatemala considered different "potential projects" as subject of analysis evaluated by using the *ex ante* economic approach. It accounts for the optimal allocation of these potential projects in the subsidy program year-by-year in a 15-year planning period. Thus, in some sense, the Guatemalan allocation model provides information a priori about the potential scale of area to theoretically enroll in the program annually in the near future.

4.5 Data Collection

A variety of local sources were used to obtain the information necessary for the development of the study. Information categories associated to teak plantations within Region 9 are:

- Regional land market features (categories and purchase prices related).
- Forest inventory databases registered since 2003.
- Regional silvicultural management description.
- Timber production features.
- Teak log market features (assortment and sale prices).
- Operational costs.
- Regional spatial features through GIS data.

Administrative and non-operational costs were not considered as part of the study. Reasons for adopting this assumption were: (1) given the broad diversity of project ownership conditions found in teak plantations regionally, it was not easy to obtain a homogeneous structure in the information about administrative and overhead costs in the projects visited; (2) the economic assessment and the optimization model formulation were both based on the share of contribution before administrative and overhead costs from the forest activities; (3) teak plantations within Region 9 are mostly owned by private companies whose core business is not forestry, so the administrative burden is usually distributed in the whole business.

Information sources about teak plantation projects in the region were:

- INAB: National Institute of Forests of Guatemala. Specific information was provided by representatives of the following institutional units:
    - Department of Forest Incentives Program Management
    - Department of Forest Inventory and Growth Monitoring
    - Department of Forest Development
    - Region 9 regional office

- IGN: Guatemalan National Geographic Institute. A variety of GIS shapefiles containing regional spatial data were provided by this governmental institution. Among the information provided it was possible to encounter agricultural capacity of soils, regional altitude database, water bodies, streams and watersheds, local precipitation and temperature, regional road network, SIGAP's[22] protected areas, and towns, cities and ports. This information facilitated the spatial analysis of the regional forest investment strategy.

- Pilones de Antigua: a local company dedicated to the production and trade of forest seedlings; they own about 300 hectares (740 acres) of teak plantations. Most of the plantations they own have been established with genetically improved clones of teak from Costa Rica.

[22] SIGAP: Guatemalan system of protected areas

- Ingenio Magdalena: a company dedicated to the production of sugar cane in the region; it also owns one of the most important sugar mills in the country. This company owns about 1,000 hectares (2,470 acres) of teak plantations.

- Company X: generic name given in the context of the study to a private company that would not permit its name to be used as part of the data sources. This company manages about 850 hectares (2,100 acres) of teak plantations in the Southern-Coastal region of Guatemala for a foreign timber investment organization. They have had an interesting experience harvesting and producing teak logs and trading them in log markets of India.

- Small landowners of the region thanks to the collaboration of the regional office of INAB. The study accounted for data from three small nonindustrial private landowners that own about 100 hectares in total (250 acres). They employ common, traditional practices of forestry widely used in teak plantation management in the country.

4.6 Silvicultural Management of Teak Plantations in Region 9

According to information of silvicultural management provided by the sources, six different management regimes applied in teak plantations were identified in Region 9. These management regimes include activities of site preparation, plantation establishment and maintenance, plantation management (pruning and thinning), forest protection and inventory, and institutional supervision[23]. Activities schedule and per-hectare costs were also determined. Appendix 1 shows the six management regimes in detail.

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[23] These activities consider technical auditing, follow-up and counseling provided by a registered forest technician, which are required by law in the PINFOR program's regulations framework.

The stylized present value of the silvicultural cost (*PVC*) was obtained by modeling a financial projection of 20 years[24] of silvicultural investment for each management regime. Figure 10 and Figure 11 show per-hectare *PVC* for the six regimes and the average proportion of the silvicultural investment along the 20-year turnover for the six regimes, respectively[25]. This calculation served for the purpose of defining silvicultural management cost categories that serve in the economic and financial assessment of simulated teak projects.

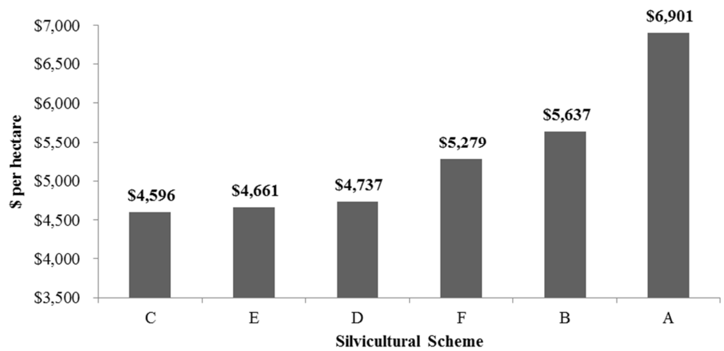

Figure 10. Present value of silvicultural cost of six teak plantation management regimes in Region 9 according to a common 20 year projection for each.

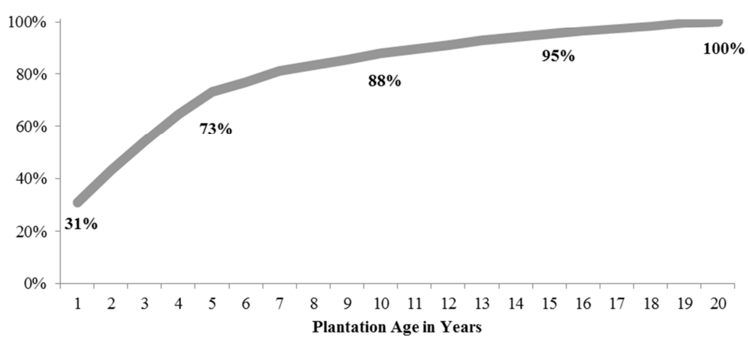

Figure 11. Average proportion of the investment in silviculture applied in teak plantations in Region 9 with a 20 year rotation (*PVC*-based percentage)

[24] A 20 year rotation is commonly found among teak growers, regardless what the optimal financial rotation is. Performing the estimation of the optimal financial rotation of commercial plantations in Guatemala is not a common practice.

[25] A 10 percent discount rate was used for the calculations in each case. See section 4.13.2 'Private and Social Discount Rates' for details on the discount rates definition.

By exploring the maximum and minimum values obtained from the financial projection and rounding to the nearest hundred, the range [US$4,500-7,000] was established as representative of a typical 20-year discounted silvicultural cost in Region 9. Three silvicultural cost classes (SCC_1, SCC_2 and SCC_3) and their respective class values were derived from the range. Figure 12 shows the class ranges.

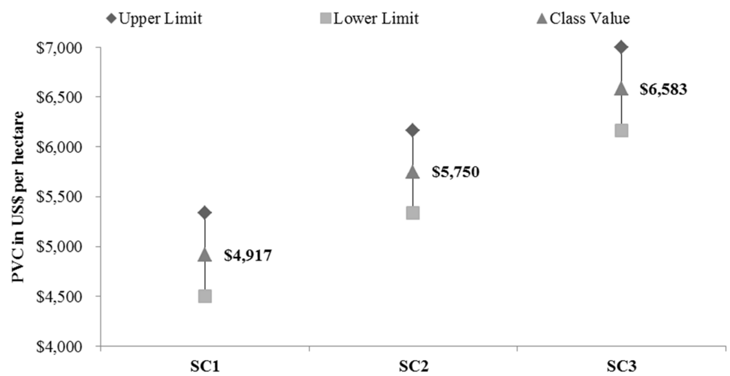

Figure 12. *PVC*-based silvicultural cost classes (*SCC*) and class values for teak plantation management regimes in Region 9

Similarly, the labor force required in each of the six management regimes was estimated. The employment generation capacity (*EGC*) was defined as the indicator that modeled the labor force required along the 20-year projection previously used. The *EGC* was estimated through the total per-hectare work-days necessary to be employed to carry out all the silvicultural activities described along a 20-year rotation period of the plantation. The results are shown in the Figure 13 and Figure 14. Appendix 1 shows the distribution of employment in each of the six management regimes.

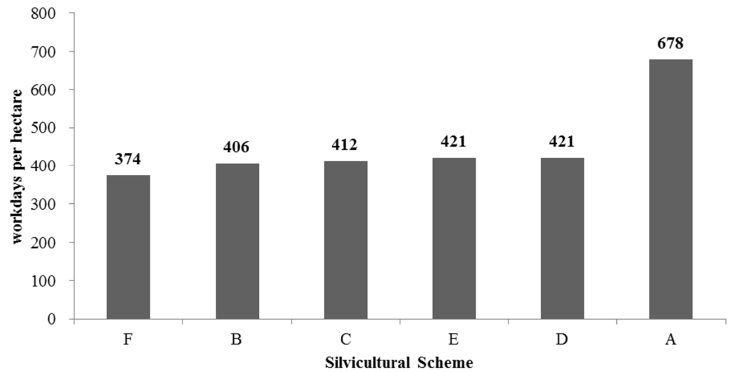

Figure 13. Employment generation capacity of six teak plantation management regimes in Region 9 according to a common 20-year rotation for each

Figure 14. Annual average distribution of silvicultural employment in teak plantations in Region 9 along the 20 year rotation (*EGC*-based annual percentage)

In order to associate class values of *EGC* with the silvicultural cost classes previously defined, the EGCs of all the regimes belonging to the same cost class were averaged. This way the regimes C, D, E and F were associated with the silvicultural cost class SCC_1 and provided a class value for *EGC* of 407 total work-days per hectare, regime B was associated with SCC_2 and provided a class value for *EGC* of 406 total work-days per hectare, and finally regime A was associated with the SCC_3 and provided a class value for *EGC* of 678 total work-days per hectare.

4.7 Timber Growth Modeling in Teak Plantations of Region 9

Since PINFOR began, INAB has developed a forest growth monitoring program. Thanks to the data generated through the program, there is a valuable collection of inventory data to perform inventory analysis and growth projections. The information generated in teak plantations was provided by INAB for the study. Furthermore, some of the private companies that collaborated with the research also provided their own inventory databases of teak plantations which were added to the INAB database in order to improve the data sample.

By performing a non-linear regression analysis in which the non-linear equation of Chapman-Richards was fitted to the data, it was possible to make the projection of timber growth of teak wood as a function of the plantation age. A database of 188 plots including 354 average estimations of DBH, total height, dominant height, plantation density and per-hectare timber volume was used. Some sample plots were monitored with a single measurement (just one year), but others happened to be monitored continuously over a 9 year-period, so it was possible to develop an age-based projection.

The analysis was performed by segregating the data according to three different site classes identified in the database (S_1, S_2 and S_3). This allowed the research to account for growth trends in different site qualities where teak plantations of Region 9 have been planted. Predictions of timber production per hectare for the three site classes were also derived from the analysis. *RStudio*© and a code especially created for this non-linear regression analysis was employed. The timber yield table generated for regional teak is shown in Table 4.1. The statistical analysis results are shown in the Appendix 2.

Table 4.1. Per-site class timber yield table for teak plantations of Region 9 of Guatemala (values expressed in solid cubic meters over-bark per hectare)

Age	Site Class 1	Site Class 2	Site Class 3
1	2	1	1
2	14	10	6
3	38	25	17
4	69	46	31
5	104	69	47
6	140	93	63
7	175	116	78
8	207	137	92
9	235	156	105
10	259	172	116
11	281	186	125
12	298	198	133
13	313	207	140
14	325	216	145
15	336	222	150
16	344	228	154
17	351	232	157
18	356	236	159
19	361	239	161
20	364	241	163

4.8 Timber Production Features in Teak Plantations of Guatemala

Given the lack of maturity of teak plantations in the region, none of them have been clear-cut yet so there is no significant information from harvesting experience in Region 9. Little data is even available from intermediate cuts (Pavez, 2012). However harvesting experience taken from the Atlantic Coastal region of Guatemala and from the Pacific Coastal region of Costa Rica in clear-cut of thirteen year-old plantations was considered for the study[26] to provide it with general operational configurations in local timber production.

Harvesting operations in Guatemala used to be manual (labor force-based in all stages) and little experience from mechanized operations can be found. Within the Southern-Coastal region, small-sized logs and firewood collection from thinnings employing human power are among the most commonly used activities in context with teakwood production. Nonetheless, some companies are beginning to implement

[26] The author provided the research with information about harvesting operations accounted along his professional experience in Guatemala and in the Central American region as consultant in timber production planning.

mechanized harvesting operations in teak and in other planted species. Skidding and loading operations are timber production activities in which the use of agricultural tractors with adapted devices for forest production are often found, but their use is limited to flat or rolling hills. Very little production planning is found among forest producers, so formal cost structures are not easily identifiable.

The production cost structure for teak used in the study was built through the use of the system PACE2HILL (Pavez, 2013), an Excel©-based program especially designed to estimate timber production cost by considering operational features as machinery characteristics (ownership-, operating- and labor-related aspects), basic spacing features (skidding distance and landing setting), timber yield, unit cost of landing and road construction, operating times, machine capacities/yields and transport distances. Appendix 3 shows PACE2HILL modules with example calculations. The cost structure assumes the following:

- Roads and landings: A standard of US$15,000 per kilometer was assumed as unit cost of road network construction for local harvesting. A standard of US$500 per unit was assumed as unit cost for landing construction. Landing and road spacing were assumed of 400 meters and 400 meters respectively. It is important to mention that landings are usually not planned; instead a centralized landing located near to the property gate (locally called “bacadía”) is commonly implemented for log classification and loading.

- Felling and skidding: Manual felling (whose cost calculation was determined by employing a Stilh© MS261 chainsaw type) and agricultural tractors with external winches (whose cost calculation was determined by employing a Massey Ferguson© 5470 with winch Fransgaard© types) attached for logging are included as part of this cost item. Machines indicated are common equipment in teak logging operations. Appendix 3 shows example calculations of unit cost for these equipment considering specific cycle times and yields.

- Loading operation and transport: An in-field loading operation in 20-feet containers for teak logs exportation[27] was considered with representative loading cycle time and yields (a Massey Ferguson© 5470 tractor and a Farmi© log loader were considered in the loading configuration). Transport was assumed as a container hauling operation addressed from the harvesting operation to the port in which adequate cycle times and yield were defined (a Kenworth T800 truck for heavy hauling was considered in the machine cost calculations). Velocities were determined according to the road quality categories described in the IGN's regional road network shapefiles. Transport distances were independently defined according to the location of the simulated projects (see section 4.11 'Spatial Analysis of Potential Areas for Teak in Region 9' for the details on the simulation of future teak project within the region). Appendix 4 shows in detail the transport unit cost calculations basis according to the spatial analysis included in the study.

- Port logistics and exports: it includes all the in-port container handling and export paperwork which is commonly performed by export agencies. Export cost estimation based on the per-container unit cost for this service (about US$89) and the 20-feet container load capacity for 2 meter long teak logs (about 15 solid cubic meter over-bark).

Production cost associated with the operational configuration described is shown in Table 4.2. Very few companies are able to implement a production operation that includes all the stages, but it is assumed that an improved production strategy could be adopted in the future in the region.

According to the information provided by the sources, thinning activities in the region are scheduled according to three different regimes (TR_1, TR_2 and TR_3).

[27] In Guatemala, almost hundred percent of the teakwood traded in the form of logs is exported in containers which have to be loaded either in field (where topography allows it) or in a yard near to the port.

Schedule and timber yields of the three regimes in the three site classes previously identified are shown in Table 4.3.

According to the information supplied from some local sources and based on a previous study of product assortment from teak plantations as a function of the tree size performed by the author in teak trees planted in the Caribbean Region of Colombia (Pavez, 2011)[28], Table 4.4 shows the product assortment expected to be obtained from teak plantations in different development stages. The product ID shows the identification of the market (sawn or fuel wood) attached to numbers representing the perimeter (or girth) range from which sales prices can be differentiated.

Table 4.2. Teakwood production structure and costs associated with moderate mechanization and timber production yield in Guatemala (values expressed in $US per solid cubic meter over-bark of timber produced)

Activity	Production Activity[29]	Unit Cost ($/cubic meter) Site Class S_1	Site Class S_2	Site Class S_3
Production[30]	TR_1	$21.11-31.92	$26.02-35.58	$31.55-40.88
	TR_2	$20.94-38.91	$29.96-44.99	$40.61-56.11
	TR_3	$12.88-38.81	$17.03-44.99	$22.97-56.11
Transport[31]			$9.48-52.46	
Export			$5.90	

[28] Consultancy provided by the author to an important forest group of Medellin, Colombia in 2011 where the commercial characterization of the Teak plantations owned by the company was performed as part of the professional service.
[29] TRs represent thinning regimes. See Table 4.3 for details. Final cut was estimate according to the particular financial optimal rotation in each simulated project and according to two rotation assumptions: under single and multiple rotation regimes. See details in section 4.13.3 'Financial Optimal Rotation Age Analysis'.
[30] It includes roads, landings and harvesting operations.
[31] Transport cost depends on the one-way distance between the production area (which was determined through the spatial analysis described in the section 'Spatial Analysis of Potential Areas for Teak in Region 9') and the ports San Jose and Quetzal. Values show the range within the region in which distances vary between 6.5 and 181 kilometers.

Table 4.3. Schedule and timber yield in intermediate cuts (thinnings) in teak plantations of Region 9 (values are expressed according to: age in years, volume in solid cubic meters over-bark per hectare).

Thinning Regime	Intermediate Cut	Age	Volume to Extract per Site Class		
			S_1	S_2	S_3
TR_1	1st	7	53	35	23
	2nd	10	88	58	39
	3rd	-	-	-	-
TR_2	1st	5	26	17	12
	2nd	7	30	20	13
	3rd	9	20	13	9
TR_3	1st	5	26	17	12
	2nd	10	50	33	22
	3rd	15	66	43	29

Table 4.4. Product assortment (volume-based percentage) in teak plantations according to trees size (DBH-based metric, values expressed in centimeters in the DBH class ranges and in the product ID classification)

Product ID	DBH Class Range							
	<10	**10-14**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**	**>39**
Fuel0035	100%	48%	18%	13%	11%	8%	7%	11%
Fuel3642		42%	27%	5%	1%	1%	1%	
Saw4352		10%	38%	20%	7%	2%	4%	1%
Saw5368			17%	45%	29%	7%	5%	3%
Saw6980				16%	35%	23%	21%	6%
Saw8196				1%	17%	39%	35%	22%
Saw97++						21%	27%	57%

By identifying the DBH class range in a certain production stage (thinning or clear-cut) it is possible to define the product assortment associated with the corresponding production process. Each production stage could be economically valued as a function of the product assortment and the corresponding sales price level. Based on this, several rotation age-based clear-cut regimes were evaluated by including income and cost items to determine the financial optimal rotation age in each case. The calculation of the optimal rotation age for each case is presented further.

The labor force required for each production operation was also estimated. Similar to the labor force requirement analysis performed in silvicultural regimes, the employment generation capacity (*EGC*) of timber production operations was estimated through the total per-hectare work-days necessary to carry out the production activities. The results are shown in the Figure 15 and Figure 16.

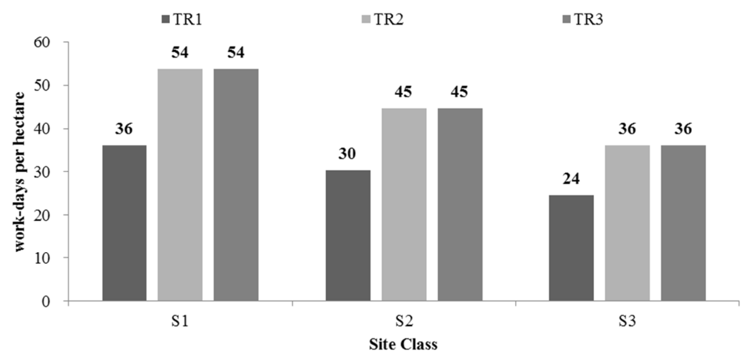

Figure 15. Employment generated by thinning operations in Guatemalan teak plantations per site class (values expressed in work-days per hectare)

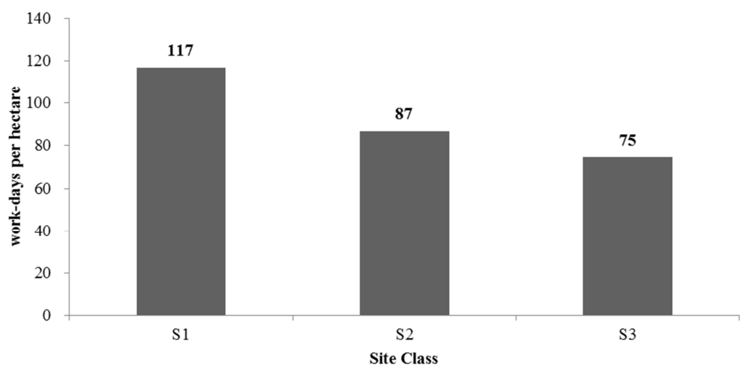

Figure 16. Employment generated by clear-cut operations in Guatemalan teak plantations per site class at optimal rotation age[32] (values expressed in work-days per hectare)

4.9 Teakwood Market Features in Guatemala

In the regional Teakwood market, logs are measured and valued according to their middle-length perimeter or girth (*G*). The general rule is: the greater the size of the log the higher the market price. Thanks to the information provided by the sources related to local market features of Guatemalan teakwood, it was possible to create a FOB price table based on the product assortment considered in the study and the

[32] Details of the calculation of the optimal rotation age are provided in the Chapter 4.13.3 'Financial Optimal Rotation Age Analysis'.

history of trading around local teakwood with foreign buyers between 2007 and 2010. It was not possible to get information about sales prices updated to 2013 as it seems there was not significant teakwood traded between 2011 and 2013. It is important to mention that most of the teak logs sold to foreign buyers within the last five years in Guatemala probably came from thinning operations and from informal, non-permanent supply sources.

Table 4.5 shows the FOB sales prices used in the economic analysis of different forest management prescription to formulate the optimization model.

Table 4.5. Prices employed in the economic and financial analysis of forest management and production prescriptions for teak plantations in Region 9 (values expressed according to: girth in centimeters and prices in $US per solid cubic meter over bark)

Product ID	Girth Class Value	Mean FOB Price (period 2007-2010)
Fuel0035	18	$60
Fuel3642	39	$65
Saw4352	48	$95
Saw5368	61	$130
Saw6980	75	$172
Saw8196	89	$207
Saw97++	139	$252

4.10 Land Market in Region 9

Information provided by local sources about land prices to purchase is widely variable and reflect the lack of a formal land market where prices are determined according to rational, structured analysis of the land features. Table 4.6 shows a summary of land market information collected locally.

Table 4.6. Purchase prices of land in Region 9 (values expressed in $US per hectare)

Source	Purchase Price	Observation[33]
Company X, 2010	$1,695	2010 land valuation model, lower bound
Company X, 2010	$2,639	2010 land valuation model, non-flat land average value
Pilones de Antigua, 2013	$3,516	Agricultural use in Suchitepequez
Pilones de Antigua, 2013	$4,219	Agricultural use in Retalhuleu
Smaller land owner, 2013	$5,560	Agricultural use in Santa Lucia Cotzumalguapa
Pilones de Antigua, 2013	$8,439	Agricultural use in Tiquisate

For purposes of this study, land market prices were classified according to class ranges. Purchase price ranges PPC_1, PPC_2 and PPC_3 were bounded in the ranges [US$1,500-3,833], [US$3,833-6,167] and [US$6,167-8,500] respectively. Table 4.7 shows the details of the land market prices classification features.

Table 4.7. Land purchase price classification for Region 9 land market (values expressed in $US per hectare)

Purchase Price Class	Lower Bound	Upper Bound	Class Value	Recommended Use
PC_1	$1,500	$3,833	$2,667	Forestry
PC_2	$3,833	$6,167	$5,000	Forestry and Agriculture
PC_3	$6,167	$8,500	$7,333	Agriculture

Some preliminary results of the analysis of the land market information restricted the scope of the economic analysis of land use as part of the teak project investment analysis. Considerations and assumption for this study were:

- Some alternative land uses in Region 9 are much more lucrative than forestry. Even the land lease market could be more lucrative for some landowners. Because of this, it was assumed that the potential areas identified as to be allocated in teak plantation projects in the future are only suitable for forestry, thus they cannot be allocated in any other agricultural crop. It was also assumed that the alternative option for the landowner (to set the basis for the opportunity cost evaluation) was to sell the land and invest the money in the Guatemalan banking system.

[33] Referenced sites are Municipalities or Departments of Region 9

- The PINFOR database of past teak project enrollment in the program indicates that almost hundred percent of the projects are owned by private companies or small landowners. In either case, land is owned by the applicant, thus it is assumed that potential projects to be established in the future will not need to acquire the tract of land. According to this assumption, land acquisition was not included as part of the forest investment analysis in the study. Land purchase prices were exclusively employed in the evaluation of opportunity cost of land ownership.

- It was not possible to find accurate information to correlate site quality and purchase prices. Because of this situation, it was assumed that either of the purchase price categories could represent the market value of tracts of land in either of the site quality classes. In the project simulation, purchase price-site class assignation was performed randomly.

4.11 Spatial Analysis of Potential Areas for Teak in Region 9

A spatial analysis of Region 9 was included as part of the research in order to provide a realistic description of local geographic features that helps perform an adequate forest investment analysis on teak plantations potentially establishable in the future. Such aspects as agricultural capacity of soils, regional altitude database, water bodies, streams and watersheds, local precipitation and temperature, regional road network, SIGAP protected areas, and towns, cities and ports were considered. This information was combined with the site requirements of teak trees (reported in world literature) that allow a teak plantation be successful.

Site conditions that world literature reports as suitable for successful teak crops are the following (Krishnapillay, 2000; Pandey & Brown, 2000; Fonseca, 2004):

- Optimal rainfall for teak ranges between 1250 and 3750 mm/year, but places having less than 2500 mm/year are reported in Central America as the best ones to establish teak.

- Adequate elevation for plantations reported in literature is below 1000 m.a.s.l., but best places to establish teak in Central America are reported as being below 500 m.a.s.l.

- Optimal ground slope should range between 0 - 25%.

To determine the best location for teak within Region 9, conditions previously mentioned were taken into consideration for the spatial analysis. Additionally, status of local land use was also included. Aspects of current land use in Region 9 are:

- SIGAP sites are not allowed to establish plantations, so they must be discarded as potential areas.

- Soil Use categories I and II were excluded as they are more suitable for agriculture. It is assumed that all of these areas are currently in some agricultural use.

- Soil Use categories VII and VIII were also excluded as they comprise areas that exceed 25% slope and/or are covered by natural forests. Forest vegetation substitution is not allowed.

- Soil Use categories III to VI were assumed as associated to site quality in the following way: category III relates to site class 1 (S_1), categories IV and V relate to site class (S_2), and category VI relates to site class (S_3).

- Regional water bodies as well as 40 meters-wide protection strip of the most important regional water streams were excluded as part of the available areas for forest plantations.

Finally, only areas with direct access to the regional road network were included as part of the areas suitable for teak projects in the near future. The argument for this is that the economic assessment of teak projects didn't consider construction of public road infrastructure. All these areas were delimited as polygons that represent potential future locations of teak projects[34]. They were bounded by roads, water streams, soil use category change, recommended altitude range and/or recommended precipitation rate. Each polygon was identified, codified and spatially located through a centroid point. This point worked as a common spot for timber production from potential projects to be theoretically established within the polygon.

The spatial analysis generated 146 polygons or areas differentiated by their spatial location, access to road network and biophysical features. Segregation of regional areas addressed to identify potential areas to establish teak plantations in the near future according to the criteria previously indicated was obtained through a GIS-based work. Results of the spatial analysis are shown in the Figure 17.

[34] Future projects within a certain polygon were determined through performing a simulation of projects based on stochastic assignment. See details in section 4.12 'Project Simulation'

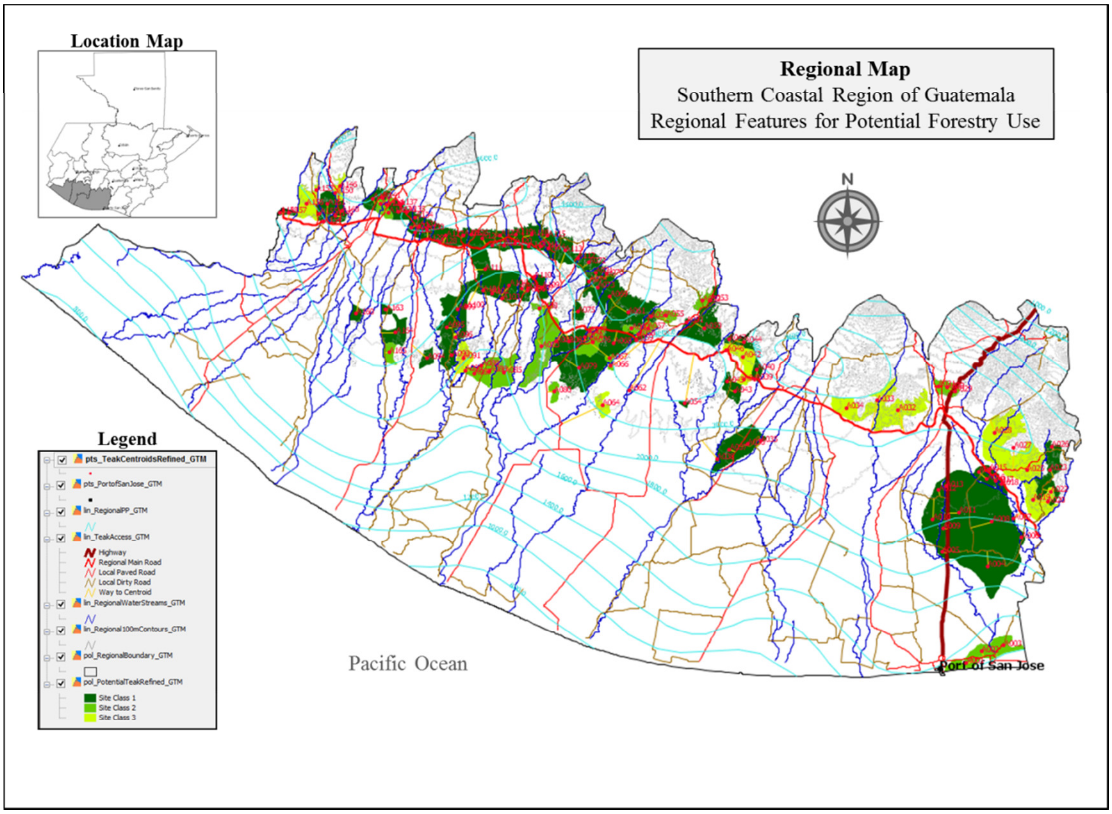

Figure 17. Map of Potential Areas to Establish Teak in Region 9 (adapted from GIS-based work on IGN shapefiles)

4.12 Project Simulation

Guatemalan cadastral information of agricultural landowners lacks accurate detail to identify potential applicants to the PINFOR program. However, there is a well-managed record of projects granted in the PINFOR program framework within the past fifteen years. By analyzing the PINFOR's regional projects database it was possible to obtained valuable information about the yearly amount of teak projects granted, their size (area approved to enroll in the program) and their ownership traits.

According to this, a simulation of projects performed by stochastic assignment of project features was conducted. Among the features considered as part of the assignment were:

- Number of projects: in each polygon, a potential project occurrence of 0 or 1 (having project or not, accordingly) was determined randomly. This generated a simulated scenario of either one project or no project in each of the 146 polygons. A total amount of 101 polygons having one project each were accounted as result of the simulation.

- Project area: the stochastic assignment of areas was conducted through a random selection of values that followed the probability distribution of project areas enrolled in the program in the past. Figure 5 (in section 1.3 'Teak Plantations of Region 9 in the PINFOR') shows the probability distribution of past project areas in Region 9. Simulated projects within the size range [0.7-93.6] hectares were randomly generated accounting a total of 1,410.6 hectares of teak plantations to be theoretically established in the future PINFOR program.

- Silvicultural management regime: once the 101 potential teak projects were generated, each one was randomly assigned with one of the three silvicultural management regimes described in section 4.6 'Silvicultural Management of Teak Plantations in Region 9'.

- Thinning regime: once the 101 potential teak projects were generated, each one was also randomly assigned with one of the three thinning regimes described in section 4.8 'Timber Production Features in Teak Plantations of Guatemala'.

- Land market: once the 101 potential teak projects were generated, each one was also randomly assigned with one of the three purchase prices described in section 4.10 'Land Market in Region 9'.

- Site class: site quality was automatically assigned as each of the 101 projects associates to each of the 146 polygons defined the spatial analysis. See section 4.11 'Spatial Analysis of Potential Areas for Teak in Region 9' for details.

Table 4.8 shows the list of projects simulated and their relevant features for the economic and financial assessment.

Table 4.8. The 101 simulated teak projects of Region 9 for future allocation and potential enrollment in the PINFOR program (SCC is silvicultural cost class, TR is thinning regime and PPC is purchase price class)

Project ID	Site Class	Area (hectares)	One-way Distance to Port (Kilometers)	SCC	TR	PPC
A001/S2/SCC3/TR3/PPC2	S2	71.0	6.5	3	3	2
A003/S2/SCC3/TR1/PPC3	S2	2.3	11.2	3	1	3
A004/S1/SCC2/TR2/PPC2	S1	55.0	27.7	2	2	2
A005/S1/SCC3/TR2/PPC2	S1	23.1	18.4	3	2	2
A006/S1/SCC1/TR2/PPC2	S1	9.6	35.6	1	2	2
A007/S1/SCC2/TR3/PPC1	S1	10.3	59.6	2	3	1
A008/S1/SCC1/TR1/PPC2	S1	5.9	30.4	1	1	2
A010/S1/SCC2/TR1/PPC1	S1	4.4	32.2	2	1	1
A012/S1/SCC1/TR3/PPC1	S1	22.2	28.7	1	3	1
A013/S1/SCC1/TR3/PPC2	S1	21.2	28.4	1	3	2
A014/S1/SCC1/TR3/PPC1	S1	21.6	49.6	1	3	1
A015/S1/SCC2/TR1/PPC3	S1	6.2	49.2	2	1	3
A016/S1/SCC1/TR1/PPC1	S1	2.3	50.4	1	1	1
A017/S1/SCC3/TR3/PPC1	S1	5.4	50.8	3	3	1
A018/S1/SCC3/TR2/PPC2	S1	4.7	52.8	3	2	2
A019/S3/SCC1/TR2/PPC3	S3	34.6	66.8	1	2	3
A022/S1/SCC2/TR3/PPC3	S1	21.4	69.1	2	3	3
A023/S1/SCC2/TR1/PPC3	S1	36.7	72.0	2	1	3
A025/S3/SCC2/TR3/PPC1	S3	9.1	56.7	2	3	1
A026/S1/SCC3/TR3/PPC3	S1	76.9	62.4	3	3	3
A027/S3/SCC3/TR2/PPC1	S3	4.4	57.5	3	2	1
A029/S2/SCC2/TR1/PPC2	S2	12.9	45.3	2	1	2
A030/S2/SCC2/TR3/PPC1	S2	0.7	45.8	2	3	1
A035/S1/SCC1/TR1/PPC1	S1	2.8	92.1	1	1	1
A036/S1/SCC1/TR2/PPC1	S1	9.7	86.3	1	2	1
A037/S1/SCC1/TR2/PPC2	S1	2.3	87.1	1	2	2
A038/S1/SCC3/TR3/PPC3	S1	2.8	102.7	3	3	3
A039/S1/SCC2/TR1/PPC1	S1	3.9	78.1	2	1	1
A040/S1/SCC3/TR1/PPC2	S1	1.6	79.3	3	1	2
A041/S3/SCC2/TR3/PPC3	S3	2.4	80.0	2	3	3
A043/S1/SCC3/TR2/PPC3	S1	57.5	88.9	3	2	3
A044/S1/SCC2/TR1/PPC2	S1	2.0	88.8	2	1	2
A046/S3/SCC3/TR1/PPC2	S3	3.6	85.8	3	1	2
A047/S1/SCC2/TR3/PPC2	S1	1.4	87.1	2	3	2
A051/S1/SCC1/TR3/PPC3	S1	4.1	103.4	1	3	3
A052/S2/SCC2/TR1/PPC2	S2	8.9	108.1	2	1	2
A053/S1/SCC1/TR1/PPC2	S1	17.1	108.9	1	1	2
A055/S2/SCC1/TR2/PPC2	S2	4.6	105.3	1	2	2
A057/S2/SCC3/TR2/PPC2	S2	8.2	104.6	3	2	2
A058/S2/SCC1/TR2/PPC3	S2	3.9	102.7	1	2	3
A061/S1/SCC1/TR3/PPC2	S1	21.0	114.8	1	3	2
A064/S3/SCC2/TR1/PPC2	S3	32.1	136.6	2	1	2
A067/S2/SCC1/TR1/PPC3	S2	5.4	115.7	1	1	3
A069/S1/SCC3/TR3/PPC2	S1	28.2	113.7	3	3	2
A070/S1/SCC1/TR2/PPC2	S1	2.9	125.0	1	2	2
A071/S1/SCC1/TR1/PPC3	S1	32.2	124.3	1	1	3
A074/S1/SCC1/TR2/PPC1	S1	3.1	124.8	1	2	1
A075/S1/SCC3/TR2/PPC1	S1	47.7	116.8	3	2	1

A076/S2/SCC3/TR1/PPC1	S2	1.4	111.7	3	1	1
A077/S2/SCC1/TR1/PPC2	S2	5.6	110.7	1	1	2
A078/S1/SCC3/TR2/PPC3	S1	3.9	112.3	3	2	3
A080/S2/SCC1/TR3/PPC1	S2	9.3	124.6	1	3	1
A081/S1/SCC1/TR2/PPC3	S1	4.6	116.3	1	2	3
A082/S2/SCC2/TR1/PPC3	S2	5.9	117.2	2	1	3
A083/S2/SCC3/TR1/PPC3	S2	6.4	122.6	3	1	3
A085/S2/SCC2/TR3/PPC3	S2	4.6	145.8	2	3	3
A086/S2/SCC2/TR1/PPC3	S2	52.4	146.3	2	1	3
A087/S2/SCC1/TR1/PPC3	S2	1.2	148.0	1	1	3
A088/S2/SCC1/TR2/PPC1	S2	36.4	145.6	1	2	1
A091/S3/SCC2/TR1/PPC2	S3	29.1	171.5	2	1	2
A096/S3/SCC3/TR2/PPC2	S3	1.9	158.5	3	2	2
A099/S1/SCC2/TR3/PPC2	S1	5.5	153.2	2	3	2
A100/S1/SCC1/TR2/PPC1	S1	93.6	153.5	1	2	1
A101/S1/SCC1/TR2/PPC3	S1	2.0	151.4	1	2	3
A104/S1/SCC3/TR3/PPC3	S1	8.2	138.5	3	3	3
A105/S1/SCC2/TR2/PPC3	S1	3.8	131.3	2	2	3
A106/S1/SCC2/TR3/PPC3	S1	6.7	130.3	2	3	3
A107/S1/SCC2/TR3/PPC3	S1	4.5	123.4	2	3	3
A108/S2/SCC2/TR3/PPC3	S2	10.2	121.3	2	3	3
A110/S1/SCC1/TR3/PPC3	S1	1.4	125.6	1	3	3
A111/S1/SCC2/TR2/PPC3	S1	25.5	148.6	2	2	3
A112/S1/SCC2/TR1/PPC2	S1	4.4	129.9	2	1	2
A113/S1/SCC1/TR1/PPC1	S1	30.6	130.1	1	1	1
A114/S1/SCC1/TR2/PPC2	S1	6.4	131.2	1	2	2
A117/S1/SCC2/TR3/PPC1	S1	4.5	133.2	2	3	1
A119/S1/SCC3/TR3/PPC2	S1	22.0	134.1	3	3	2
A120/S1/SCC1/TR1/PPC1	S1	9.4	133.0	1	1	1
A121/S1/SCC3/TR1/PPC1	S1	8.6	136.3	3	1	1
A123/S1/SCC1/TR2/PPC3	S1	10.4	137.3	1	2	3
A126/S1/SCC1/TR3/PPC1	S1	10.8	144.0	1	3	1
A129/S1/SCC1/TR2/PPC2	S1	1.2	152.4	1	2	2
A131/S1/SCC1/TR3/PPC3	S1	12.0	157.5	1	3	3
A132/S1/SCC1/TR1/PPC1	S1	1.3	155.9	1	1	1
A133/S1/SCC3/TR2/PPC2	S1	21.7	157.7	3	2	2
A134/S1/SCC3/TR1/PPC1	S1	15.7	158.6	3	1	1
A136/S1/SCC3/TR2/PPC3	S1	4.8	161.2	3	2	3
A138/S2/SCC3/TR3/PPC1	S2	7.4	166.0	3	3	1
A139/S2/SCC3/TR1/PPC1	S2	7.0	166.5	3	1	1
A140/S2/SCC3/TR3/PPC3	S2	19.7	169.5	3	3	3
A141/S1/SCC1/TR3/PPC3	S1	31.3	170.2	1	3	3
A146/S3/SCC3/TR2/PPC1	S3	2.4	176.5	3	2	1
A148/S1/SCC1/TR2/PPC2	S1	3.0	172.3	1	2	2
A149/S1/SCC1/TR1/PPC1	S1	2.8	172.2	1	1	1
A150/S3/SCC3/TR3/PPC2	S3	13.5	175.7	3	3	2
A151/S1/SCC1/TR3/PPC1	S1	18.3	175.4	1	3	1
A154/S1/SCC1/TR1/PPC1	S1	25.5	175.3	1	1	1
A155/S1/SCC2/TR2/PPC2	S1	1.0	176.3	2	2	2
A157/S1/SCC3/TR3/PPC3	S1	9.9	180.4	3	3	3
A158/S1/SCC3/TR2/PPC3	S1	2.3	181.0	3	2	3
A160/S1/SCC2/TR1/PPC2	S1	3.1	173.6	2	1	2
A164/S1/SCC2/TR3/PPC2	S1	3.9	174.3	2	3	2

Simulation allowed the study to account for a potential realistic scenario of local small non-industrial landowning applicants to the PINFOR program in the near future. It is not guaranteed that this simulated scenario of applicants will likely happen, but it presents a realistic theoretical scenario from which it was possible to develop valuable conclusions about the economically efficient allocation of funding provided by the PINFOR program.

4.13 Economic Analysis of Teak Projects in Region 9

4.13.1 Forest Management Regimes

Using the information generated in previous stages of the research and integrating it in a forest management analysis, nine alternative silvicultural management regimes for teak projects potentially developable in Region 9 were derived. The relevant variables were:

- Cost-based silvicultural regimes (SCC_1, SCC_2, SCC_3), each with its corresponding silviculture investment and labor force requirement distribution;

- Thinning regimes (TR_1, TR_2, TR_3), each with its corresponding production schedule, timber yield and labor force requirement.

Regardless of the technical prescriptions of silviculture employed in each regime, an economic and financial analysis was performed using the nine options of management derived from the combination of silviculture and thinning classes in each simulated project according to the stochastic assignment described before. Projected cash flows were derived from silviculture investment, projected timber sales and production cost according to both thinning regimes and final cuts scheduled through a case-by-case analysis of financial optimal rotation in the 101 simulated projects (see section 4.13.3 'Financial Optimal Rotation Age Analysis' for details). To economically assess forest management regimes in each case, the projected net cash flow at optimal rotation was discounted to present by using a private discount rate (see section 4.13.2 'Private and Social Discount Rates' for details). This procedure generated 101 different economic evaluations corresponding to the simulated projects included in the study.

4.13.2 Private and Social Discount Rates

The private discount rate of forestry activities (r_f) employed in the financial analysis was estimated through the Capital Asset Pricing Model (CAPM). According to the author's professional judgment and experience in Latin American countries, this methodology is accepted and widely used for forest asset appraisals and valuation purposes. Analogous methodology is cited by Wagner (2012) where the risk-free real interest rate and risk premium are included to estimate a no-inflation discount rate. Basically, after accounting for the risk-free real interest of the U.S. Treasury bills plus the risk premium for emerging markets and taking market expectation risk away[35], a no-inflation discount rate of 10 percent is obtained. This rate was considered as an adequate private discount rate for private forestry business in Guatemala and it seems to be adequate in forestry business economic analysis in other Latin American countries (Bussoni and Cabris, 2006). Nonetheless, in order to conduct a sensitivity analysis that examines the discount rate effect in long-term investments, alternative no-inflation discount rates of 12 and 14 percent were also included as part of the economic assessment of the simulated teak projects. The main argument for this is that private forest investments are seen differently among small landowners as they would not have the same age, living conditions, family dynamics and household income (Atmadja and Sills, 2009).

To implement Gregersen *et al.*'s economic methodology to select and rank projects suitable to be allocated in a forest subsidy program, it becomes necessary to determine the following rates in addition to the private discount rate for forestry activities: a rate of value increase of land (r_l), an alternative rate of return (r_a) and a

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[35] It was assumed that foreign log market represents a reliable destination for Guatemalan teakwood according to the trading observed within the last five-year period.

social rate of return (r_s) to complete de discount rate analysis. Table 4.10 shows the value chosen for these parameters and the justification of their use in the study.

Determination of discount rates is usually controversial. According to Flick and Horton (1981), the practical problem is to select a range of rates wide enough to satisfy any analytical standpoint; in their study, five different discount rates between 4 and 12 percent were employed in the economic analysis of the six first years of a reforestation program. Bullard *et al.* (2002) found that “hurdle rates”—the lowest rates of return a non-industrial private forest landowner consider acceptable— in Mississippi were 8% for forestry investments lasting 5 yr, 11.3% for those lasting 15 yr, and 13.1% for those lasting 25 yr. (in nominal terms before taxes), which demonstrates that discount rates also depend on the forest rotation. Cruz and Muñoz (2005) suggested that the social discount rate should not be constant but declining depending on the way people discount an uncertain future or simply by considering replacement of the “present value” concept for another one that incorporates sustainability. According to this, the selection of an adequate social discount rate should be based not only on economic variables (Cruz and Muñoz, 2005). According to Baum (2009), approaches to determine a social discount rate could be addressed in a descriptive or prescriptive manner depending on whether the analysis accounts for accurate description (and measurements) of how society discounts or whether experts are providing their own discounting view on society, which often happens.

Evaluating projects from the social standpoint is a difficult task if all social benefits and costs are considered, especially in forestry, as it provides society with not only an economic contribution but also with social and environmental long-term impacts. Disagreement occurs when the descriptive and the prescriptive approaches are confronted and especially when “measurement” aspects are debated (Harrison, 2010). However, the social discount rate is an important component of the Gregersen *et al.* methodology in the first project selection stage.

Performing a thorough cost-benefit or any other economic analysis of teak projects in Region 9 of Guatemala employing the social perspective is beyond the scope of the research. Thus the determination of a social discount rate was made according to local expert opinions and literature review of the topic in order to meet the study objectives as efficiently as possible. Some recommendations suggested that a social discount rate in Guatemala should not be estimated below a value of about three percentage points lower than the private discount rate. Zhuang *et al.* (2007) stated that there are significant variations in public discount rate policies in countries around the world, with developing countries in general applying higher social discount rates (8–15 percent) than developed countries (3–7 percent). According to this, r_s values used in the study were equal to 8, 9 and 10 percent to economically assess the simulated teak projects when they privately discount at r_f equal to 10, 12 and 14 percent respectively. Sensitivity analysis scenarios were determined as follows: a higher discounting scenario with private-social discount rates of 14%-10%, an intermediate discounting scenario with private-social discount rates of 12%-9%, and a lower discounting scenario with private-social discount rates of 10%-8%. Table 4.9 shows the summary of discount and interest rates used in the study. It was assumed that all the benefits and costs form the private standpoint and from the social one are the same.

Table 4.9. Discount and interest rates employed in the study

Rate	Value	Justification
Private discount rate for forestry[36]	10% 12% 14%	Values from CAPM methodology for Guatemala. Three different rates were employed to assess different discounting effects in the forest investment.
Land value increase rate[37]	5%	Rate provided with local economist's support
Alternative discount rate[38]	2.87%	2013 bank interest rate for deposit in foreign currency
Social discount rate	8% 9% 10%	Prescriptive approach from De Leon and Zhuang *et al.* Three different rates were employed to assess discounting scenarios with the private discount rates.

[36] Capital Asset Pricing Model (CAPM) for Guatemalan teak forest business.
[37] Information obtained through personal communication with Paulo De Leon, economist and senior analyst in Central American Business Intelligence –CABI-, Guatemala
[38] BANGUAT, 2013

4.13.3 Financial Optimal Rotation Age Analysis

Following the Gregersen *et al.* methodology for the economic analysis of forest plantation projects, each of the 101 simulated projects was evaluated in terms of their financial optimal rotation age to determine the rotation period to be considered in the model formulation. Specifically projected net cash flow due to thinning operations, final clear-cut at different rotation ages and silviculture was employed in the economic analysis. The final production period is met when plantations reach the optimal rotation age, but in this sense two alternative forestry land use scenarios were also evaluated: simulated projects potentially established under either a single rotation regime or a multiple rotation regime. In the first scenario, the optimal rotation was calculated for only one production cycle and the economic indicator selected to determine the plantation age that maximizes project profitability was the discounted value of net cash flows obtained from forestry activities (NPV_{fi}). In the second scenario, the optimal rotation was calculated for infinite production cycles and the economic indicator selected to determine the plantation age that maximizes project profitability was the land expected value (LEV_{fi}) or the discounted value of infinite net cash flows obtained from forestry activities. Results of the analysis of financial optimal rotation age for each simulated project are shown in Table 4.10 and Table 4.11. Appendix 5 shows an example of the calculation basis for the optimal rotation age estimation according to both indicators.

Some of the simulated projects appear as unprofitable according to the NPV_f analysis even in the optimal rotation age. The next step was to determine which of these projects should be included as part of the subsidies program due to its social profitability performance.

Table 4.10. Financial optimal rotation age and maximum value of NPV_{fi} (single rotation regime) of the simulated projects of Region 9 (values expressed according to: age in years, private discount rates in percentage and NPV_{fi} in total dollars per project; numbers in parenthesis represent negative values)

Project ID	14% Private Disc. Rate		12% Private Disc. Rate		10% Private Disc. Rate	
	NPV_{fi}	Optimal Age	NPV_{fi}	Optimal Age	NPV_{fi}	Optimal Age
A001/S2/SCC3/TR3/PPC2	($86,534)	10	($52,124)	11	($1,957)	11
A003/S2/SCC3/TR1/PPC3	($2,378)	11	($1,021)	11	$738	11
A004/S1/SCC2/TR2/PPC2	$96,846	09	$169,337	14	$273,861	14
A005/S1/SCC3/TR2/PPC2	$32,675	09	$61,290	14	$105,642	14
A006/S1/SCC1/TR2/PPC2	$20,234	09	$33,668	14	$51,747	14
A007/S1/SCC2/TR3/PPC1	$15,418	14	$29,748	14	$48,905	14
A008/S1/SCC1/TR1/PPC2	$18,860	14	$28,532	14	$41,290	14
A010/S1/SCC2/TR1/PPC1	$11,403	14	$18,474	14	$27,831	14
A012/S1/SCC1/TR3/PPC1	$60,156	14	$94,661	14	$140,441	14
A013/S1/SCC1/TR3/PPC2	$58,171	14	$91,344	14	$135,352	14
A014/S1/SCC1/TR3/PPC1	$51,577	14	$83,597	14	$126,157	14
A015/S1/SCC2/TR1/PPC3	$14,337	14	$23,928	14	$36,642	14
A016/S1/SCC1/TR1/PPC1	$6,802	14	$10,438	14	$15,241	14
A017/S1/SCC3/TR3/PPC1	$5,324	14	$12,790	14	$22,807	14
A018/S1/SCC3/TR2/PPC2	$3,470	09	$9,104	14	$17,295	14
A019/S3/SCC1/TR2/PPC3	($74,080)	12	($66,656)	12	($56,070)	12
A022/S1/SCC2/TR3/PPC3	$26,866	14	$55,365	14	$93,531	14
A023/S1/SCC2/TR1/PPC3	$60,782	14	$112,083	14	$180,407	14
A025/S3/SCC2/TR3/PPC1	($23,898)	12	($21,990)	12	($19,224)	12
A026/S1/SCC3/TR3/PPC3	$54,823	14	$156,354	14	$292,855	14
A027/S3/SCC3/TR2/PPC1	($14,982)	12	($14,301)	12	($13,239)	12
A029/S2/SCC2/TR1/PPC2	($7,615)	11	($232)	11	$9,298	11
A030/S2/SCC2/TR3/PPC1	($588)	10	($283)	11	$184	11
A035/S1/SCC1/TR1/PPC1	$5,113	14	$8,814	14	$13,739	14
A036/S1/SCC1/TR2/PPC1	$12,329	14	$24,253	14	$40,256	14
A037/S1/SCC1/TR2/PPC2	$2,876	14	$5,689	14	$9,465	14
A038/S1/SCC3/TR3/PPC3	($611)	14	$2,531	14	$6,793	14
A039/S1/SCC2/TR1/PPC1	$6,381	14	$11,856	14	$19,151	14
A040/S1/SCC3/TR1/PPC2	$1,431	14	$3,574	14	$6,444	14
A041/S3/SCC2/TR3/PPC3	($6,714)	12	($6,328)	12	($5,745)	12
A043/S1/SCC3/TR2/PPC3	($8,972)	14	$55,712	14	$143,601	14
A044/S1/SCC2/TR1/PPC2	$2,629	14	$5,267	14	$8,789	14
A046/S3/SCC3/TR1/PPC2	($12,336)	12	($11,896)	12	($11,183)	12
A047/S1/SCC2/TR3/PPC2	$1,326	14	$3,092	14	$5,464	14
A051/S1/SCC1/TR3/PPC3	$5,256	14	$10,295	14	$17,044	14
A052/S2/SCC2/TR1/PPC2	($15,135)	10	($12,519)	10	($9,090)	10
A053/S1/SCC1/TR1/PPC2	$24,792	14	$45,979	14	$74,267	14
A055/S2/SCC1/TR2/PPC2	($5,315)	10	($3,815)	10	($1,874)	10
A057/S2/SCC3/TR2/PPC2	($19,956)	10	($17,834)	10	($14,983)	10
A058/S2/SCC1/TR2/PPC3	($4,218)	10	($2,897)	10	($1,193)	10
A061/S1/SCC1/TR3/PPC2	$20,889	14	$45,139	14	$77,697	14
A064/S3/SCC2/TR1/PPC2	($113,026)	12	($112,754)	12	($111,052)	12
A067/S2/SCC1/TR1/PPC3	($6,385)	10	($4,712)	10	($2,546)	10
A069/S1/SCC3/TR3/PPC2	($9,810)	14	$20,371	14	$61,387	14
A070/S1/SCC1/TR2/PPC2	$982	14	$3,957	14	$7,990	14
A071/S1/SCC1/TR1/PPC3	$31,486	14	$67,936	14	$116,833	14
A074/S1/SCC1/TR2/PPC1	$1,070	14	$4,276	14	$8,622	14
A075/S1/SCC3/TR2/PPC1	($37,289)	14	$9,794	14	$74,324	14
A076/S2/SCC3/TR1/PPC1	($3,357)	10	($3,005)	10	($2,532)	10
A077/S2/SCC1/TR1/PPC2	($5,996)	10	($4,144)	10	($1,756)	10
A078/S1/SCC3/TR2/PPC3	($2,600)	14	$1,344	14	$6,740	14
A080/S2/SCC1/TR3/PPC1	($13,171)	10	($10,569)	10	($7,169)	10
A081/S1/SCC1/TR2/PPC3	$2,866	14	$7,876	14	$14,644	14

A082/S2/SCC2/TR1/PPC3	($10,817)	10	($9,217)	10	($7,106)	10
A083/S2/SCC3/TR1/PPC3	($16,662)	10	($15,284)	10	($13,403)	10
A085/S2/SCC2/TR3/PPC3	($11,241)	10	($10,428)	10	($9,303)	10
A086/S2/SCC2/TR1/PPC3	($126,633)	10	($117,837)	10	($105,614)	10
A087/S2/SCC1/TR1/PPC3	($2,187)	10	($1,949)	10	($1,628)	10
A088/S2/SCC1/TR2/PPC1	($72,340)	10	($65,594)	10	($56,395)	10
A091/S3/SCC2/TR1/PPC2	($117,854)	12	($120,761)	12	($123,122)	12
A096/S3/SCC3/TR2/PPC2	($8,815)	12	($8,970)	12	($9,067)	12
A099/S1/SCC2/TR3/PPC2	($3,066)	14	$1,942	14	$8,783	14
A100/S1/SCC1/TR2/PPC1	($28,355)	14	$53,879	14	$166,433	14
A101/S1/SCC1/TR2/PPC3	($467)	14	$1,320	14	$3,763	14
A104/S1/SCC3/TR3/PPC3	($7,507)	14	$158	14	$10,660	14
A105/S1/SCC2/TR2/PPC3	($1,625)	14	$2,055	14	$7,086	14
A106/S1/SCC2/TR3/PPC3	$21	14	$7,015	14	$16,494	14
A107/S1/SCC2/TR3/PPC3	$762	14	$5,654	14	$12,272	14
A108/S2/SCC2/TR3/PPC3	($20,193)	10	($17,551)	10	($14,041)	10
A110/S1/SCC1/TR3/PPC3	$1,101	14	$2,616	14	$4,653	14
A111/S1/SCC2/TR2/PPC3	($21,470)	14	$644	14	$31,094	14
A112/S1/SCC2/TR1/PPC2	$860	14	$5,547	14	$11,882	14
A113/S1/SCC1/TR1/PPC1	$26,436	14	$60,295	14	$105,772	14
A114/S1/SCC1/TR2/PPC2	$1,492	14	$7,891	14	$16,579	14
A117/S1/SCC2/TR3/PPC1	($227)	14	$4,381	14	$10,631	14
A119/S1/SCC3/TR3/PPC2	($16,645)	14	$4,808	14	$34,125	14
A120/S1/SCC1/TR1/PPC1	$7,912	14	$18,257	14	$32,155	14
A121/S1/SCC3/TR1/PPC1	($5,378)	14	$3,175	14	$14,836	14
A123/S1/SCC1/TR2/PPC3	$2,311	14	$12,686	14	$26,772	14
A126/S1/SCC1/TR3/PPC1	$4,211	14	$15,106	14	$29,824	14
A129/S1/SCC1/TR2/PPC2	($299)	14	$815	14	$2,339	14
A131/S1/SCC1/TR3/PPC3	$700	14	$11,916	14	$27,135	14
A132/S1/SCC1/TR1/PPC1	$234	14	$1,445	14	$3,087	14
A133/S1/SCC3/TR2/PPC2	($38,078)	14	($21,343)	14	$2,043	14
A134/S1/SCC3/TR1/PPC1	($20,221)	14	($7,016)	14	$11,212	14
A136/S1/SCC3/TR2/PPC3	($8,978)	14	($5,350)	14	($267)	14
A138/S2/SCC3/TR3/PPC1	($24,583)	10	($23,969)	10	($22,975)	10
A139/S2/SCC3/TR1/PPC1	($23,551)	10	($22,973)	10	($22,034)	10
A140/S2/SCC3/TR3/PPC3	($67,089)	10	($65,414)	10	($62,708)	10
A141/S1/SCC1/TR3/PPC3	($7,132)	14	$20,071	14	$57,140	14
A146/S3/SCC3/TR2/PPC1	($11,238)	12	($11,513)	12	($11,738)	12
A148/S1/SCC1/TR2/PPC2	($2,157)	14	$199	14	$3,448	14
A149/S1/SCC1/TR1/PPC1	($738)	14	$1,607	14	$4,809	14
A150/S3/SCC3/TR3/PPC2	($62,102)	12	($63,476)	12	($64,541)	12
A151/S1/SCC1/TR3/PPC1	($6,325)	14	$9,010	14	$29,946	14
A154/S1/SCC1/TR1/PPC1	($9,433)	14	$11,619	14	$40,424	14
A155/S1/SCC2/TR2/PPC2	($1,515)	14	($789)	14	$226	14
A157/S1/SCC3/TR3/PPC3	($18,039)	14	($10,828)	14	($764)	14
A158/S1/SCC3/TR2/PPC3	($5,325)	14	($3,837)	14	($1,722)	14
A160/S1/SCC2/TR1/PPC2	($3,497)	14	($1,159)	14	$2,077	14
A164/S1/SCC2/TR3/PPC2	($4,491)	14	($1,509)	14	$2,610	14

Table 4.11. Financial optimal rotation age and maximum value of LEV_{fi} (multiple rotations regime) of the simulated projects of Region 9 (values expressed according to: age in years, private discount rates in percentage and LEV_{fi} in total dollars per project; numbers in parenthesis represent negative values)

Project ID	14% Private Disc. Rate		12% Private Disc. Rate		10% Private Disc. Rate	
	LEV_{fi}	Optimal Age	LEV_{fi}	Optimal Age	LEV_{fi}	Optimal Age
A001/S2/SCC3/TR3/PPC2	($160,742)	11	($128,001)	11	($76,371)	11
A003/S2/SCC3/TR1/PPC3	($4,507)	11	($3,244)	11	($1,286)	11
A004/S1/SCC2/TR2/PPC2	$98,959	09	$189,211	14	$338,838	14
A005/S1/SCC3/TR2/PPC2	$28,501	10	$65,666	14	$127,576	14
A006/S1/SCC1/TR2/PPC2	$23,106	09	$38,788	14	$65,324	14
A007/S1/SCC2/TR3/PPC1	$15,063	14	$32,953	14	$60,206	14
A008/S1/SCC1/TR1/PPC2	$20,834	14	$33,691	14	$53,020	14
A010/S1/SCC2/TR1/PPC1	$12,175	14	$21,337	14	$35,154	14
A012/S1/SCC1/TR3/PPC1	$65,564	14	$110,858	14	$179,311	14
A013/S1/SCC1/TR3/PPC2	$63,458	14	$107,034	14	$172,884	14
A014/S1/SCC1/TR3/PPC1	$55,495	14	$97,138	14	$160,186	14
A015/S1/SCC2/TR1/PPC3	$15,089	14	$27,412	14	$46,028	14
A016/S1/SCC1/TR1/PPC1	$7,469	14	$12,277	14	$19,513	14
A017/S1/SCC3/TR3/PPC1	$4,372	14	$13,423	14	$27,266	14
A018/S1/SCC3/TR2/PPC2	$1,903	14	$9,149	14	$20,285	14
A019/S3/SCC1/TR2/PPC3	($106,440)	12	($106,754)	12	($105,423)	12
A022/S1/SCC2/TR3/PPC3	$25,165	14	$60,394	14	$114,161	14
A023/S1/SCC2/TR1/PPC3	$60,650	14	$125,102	14	$222,920	14
A025/S3/SCC2/TR3/PPC1	($27,671)	12	($25,963)	12	($23,248)	12
A026/S1/SCC3/TR3/PPC3	$37,242	14	$158,677	14	$344,878	14
A027/S3/SCC3/TR2/PPC1	($21,128)	12	($22,170)	12	($23,399)	12
A029/S2/SCC2/TR1/PPC2	($16,676)	11	($9,048)	11	$2,649	11
A030/S2/SCC2/TR3/PPC1	($1,202)	11	($865)	11	($342)	11
A035/S1/SCC1/TR1/PPC1	$5,326	14	$10,054	14	$17,222	14
A036/S1/SCC1/TR2/PPC1	$12,030	14	$26,917	14	$49,678	14
A037/S1/SCC1/TR2/PPC2	$2,797	14	$6,306	14	$11,672	14
A038/S1/SCC3/TR3/PPC3	($1,764)	14	$1,778	14	$7,271	14
A039/S1/SCC2/TR1/PPC1	$6,339	14	$13,208	14	$23,637	14
A040/S1/SCC3/TR1/PPC2	$1,118	14	$3,702	14	$7,647	14
A041/S3/SCC2/TR3/PPC3	($9,507)	12	($9,876)	12	($10,279)	12
A043/S1/SCC3/TR2/PPC3	($31,593)	14	$41,733	14	$155,595	14
A044/S1/SCC2/TR1/PPC2	$2,493	14	$5,761	14	$10,735	14
A046/S3/SCC3/TR1/PPC2	($17,363)	12	($18,372)	12	($19,538)	13
A047/S1/SCC2/TR3/PPC2	$1,132	14	$3,284	14	$6,578	14
A051/S1/SCC1/TR3/PPC3	$5,131	14	$11,422	14	$21,023	14
A052/S2/SCC2/TR1/PPC2	($25,981)	10	($25,220)	10	($23,231)	11
A053/S1/SCC1/TR1/PPC2	$24,853	14	$51,511	14	$92,066	14
A055/S2/SCC1/TR2/PPC2	($9,599)	10	($8,610)	10	($6,992)	10
A057/S2/SCC3/TR2/PPC2	($32,885)	10	($33,429)	11	($33,330)	11
A058/S2/SCC1/TR2/PPC3	($7,742)	10	($6,801)	10	($5,283)	10
A061/S1/SCC1/TR3/PPC2	$19,147	14	$49,020	14	$94,726	14
A064/S3/SCC2/TR1/PPC2	($155,968)	13	($168,690)	13	($184,958)	15
A067/S2/SCC1/TR1/PPC3	($11,487)	10	($10,476)	10	($8,803)	10
A069/S1/SCC3/TR3/PPC2	($21,928)	14	$11,733	14	$64,046	14
A070/S1/SCC1/TR2/PPC2	$376	14	$3,902	14	$9,356	14
A071/S1/SCC1/TR1/PPC3	$28,708	14	$73,554	14	$142,117	14
A074/S1/SCC1/TR2/PPC1	$420	14	$4,221	14	$10,099	14
A075/S1/SCC3/TR2/PPC1	($61,740)	14	($11,188)	14	$68,237	14
A076/S2/SCC3/TR1/PPC1	($5,547)	10	($5,608)	11	($5,597)	12
A077/S2/SCC1/TR1/PPC2	($11,060)	10	($9,774)	10	($7,697)	10
A078/S1/SCC3/TR2/PPC3	($4,513)	14	($230)	14	$6,482	14
A080/S2/SCC1/TR3/PPC1	($22,749)	10	($21,647)	10	($19,673)	10
A081/S1/SCC1/TR2/PPC3	$2,153	14	$8,200	14	$17,514	14

A082/S2/SCC2/TR1/PPC3	($18,302)	10	($18,081)	10	($17,491)	11
A083/S2/SCC3/TR1/PPC3	($27,164)	10	($28,131)	10	($28,887)	12
A085/S2/SCC2/TR3/PPC3	($18,119)	10	($18,885)	10	($19,772)	10
A086/S2/SCC2/TR1/PPC3	($204,476)	10	($213,733)	10	($224,655)	10
A087/S2/SCC1/TR1/PPC3	($3,609)	10	($3,664)	10	($3,693)	10
A088/S2/SCC1/TR2/PPC1	($117,500)	10	($119,823)	11	($119,821)	12
A091/S3/SCC2/TR1/PPC2	($158,084)	15	($173,526)	16	($193,811)	16
A096/S3/SCC3/TR2/PPC2	($11,850)	15	($12,939)	16	($14,364)	16
A099/S1/SCC2/TR3/PPC2	($5,404)	14	$66	14	$8,621	14
A100/S1/SCC1/TR2/PPC1	($59,184)	14	$33,307	14	$178,082	14
A101/S1/SCC1/TR2/PPC3	($1,099)	14	$924	14	$4,086	14
A104/S1/SCC3/TR3/PPC3	($11,908)	14	($3,828)	14	$8,875	14
A105/S1/SCC2/TR2/PPC3	($3,153)	14	$933	14	$7,325	14
A106/S1/SCC2/TR3/PPC3	($2,117)	14	$5,919	14	$18,361	14
A107/S1/SCC2/TR3/PPC3	($538)	14	$5,153	14	$13,941	14
A108/S2/SCC2/TR3/PPC3	($33,699)	10	($33,659)	10	($33,122)	10
A110/S1/SCC1/TR3/PPC3	$939	14	$2,786	14	$5,619	14
A111/S1/SCC2/TR2/PPC3	($33,663)	14	($10,170)	14	$26,952	14
A112/S1/SCC2/TR1/PPC2	($377)	14	$5,079	14	$13,496	14
A113/S1/SCC1/TR1/PPC1	$23,130	14	$64,531	14	$127,914	14
A114/S1/SCC1/TR2/PPC2	$31	14	$7,561	14	$19,225	14
A117/S1/SCC2/TR3/PPC1	($1,699)	14	$3,574	14	$11,744	14
A119/S1/SCC3/TR3/PPC2	($27,812)	14	($4,789)	14	$31,271	14
A120/S1/SCC1/TR1/PPC1	$6,860	14	$19,494	14	$38,842	14
A121/S1/SCC3/TR1/PPC1	($9,546)	14	($266)	14	$14,223	14
A123/S1/SCC1/TR2/PPC3	($84)	14	$12,113	14	$31,010	14
A126/S1/SCC1/TR3/PPC1	$2,088	14	$15,034	14	$34,986	14
A129/S1/SCC1/TR2/PPC2	($695)	14	$566	14	$2,537	14
A131/S1/SCC1/TR3/PPC3	($2,428)	14	$10,567	14	$30,700	14
A132/S1/SCC1/TR1/PPC1	($68)	14	$1,348	14	$3,539	14
A133/S1/SCC3/TR2/PPC2	($53,213)	14	($37,522)	14	($12,079)	14
A134/S1/SCC3/TR1/PPC1	($29,793)	14	($16,574)	14	$4,446	14
A136/S1/SCC3/TR2/PPC3	($12,447)	14	($9,112)	14	($3,677)	14
A138/S2/SCC3/TR3/PPC1	($38,667)	10	($41,782)	10	($45,888)	10
A139/S2/SCC3/TR1/PPC1	($37,033)	10	($40,030)	10	($43,982)	10
A140/S2/SCC3/TR3/PPC3	($96,814)	18	($97,625)	18	($96,272)	18
A141/S1/SCC1/TR3/PPC3	($17,009)	14	$13,702	14	$61,540	14
A146/S3/SCC3/TR2/PPC1	($14,922)	16	($16,339)	18	($18,189)	19
A148/S1/SCC1/TR2/PPC2	($3,381)	14	($853)	14	$3,150	14
A149/S1/SCC1/TR1/PPC1	($1,631)	14	$1,003	14	$5,115	14
A150/S3/SCC3/TR3/PPC2	($82,445)	16	($90,170)	18	($100,139)	18
A151/S1/SCC1/TR3/PPC1	($12,489)	14	$4,611	14	$31,318	14
A154/S1/SCC1/TR1/PPC1	($18,163)	14	$5,217	14	$41,825	14
A155/S1/SCC2/TR2/PPC2	($2,123)	14	($1,425)	14	($296)	14
A157/S1/SCC3/TR3/PPC3	($25,078)	14	($18,500)	14	($7,827)	14
A158/S1/SCC3/TR2/PPC3	($7,175)	14	($5,957)	14	($3,912)	14
A160/S1/SCC2/TR1/PPC2	($5,139)	14	($2,779)	14	$982	14
A164/S1/SCC2/TR3/PPC2	($6,581)	14	($3,571)	14	$1,218	14

4.13.4 Land Economics in the Forest Investment Analysis

Basic land market features used in the study were presented in section 4.10 'Land Market in Region 9'. As mentioned, it was assumed that all the land was already owned, thus no land purchase was included as part of the forest investment analysis. However, both land resale and opportunity cost were aspects included as part of the societal economic assessment of the simulated projects.

Resale value of land was included only in the economic assessment of projects under single rotation regimes. It was a study assumption that the landowner would resell the tract of land after performing the final cut at the optimal rotation age. The resale value was estimated by increasing the land value over time according to the rate of value increase of land defined in the study (r_l) and the period in which land would be resold. In the evaluation of simulated projects under multiple rotations regime this calculation was not performed as the land will be theoretically used in infinite cycles of production.

The opportunity cost of land on a particular simulated project was basically estimated since the landowner is foregoing income forgone due to the interest that current land value would gain in a bank if he sells the tract and deposit the money. The interest rate corresponds to the alternative rate of return or r_a defined in the study. This represents a potential cash outflow that affects the societal economic assessment of the simulated projects due to employing the land in a teak plantation.

4.13.5 Ex-Ante Economic Analysis of Teak Project

Using Gregersen *et al.*'s methodology to economically assess teak projects in Region 9 with an ex-ante approach, the social economic contribution of each of the 101 simulated projects was calculated at the optimal rotation age by using the three social discount rates defined in section 4.12.2 'Private and Social Discount Rates' for this purpose. See Table 4.12 and Table 4.13 for the details.

Table 4.12. Contribution to social benefits at optimal rotation age under single rotation regime (NPV_{si}) of the simulated projects of Region 9 (values expressed according to: private discount rates in percentage and NPV_{si} in total dollars per project; numbers in parenthesis represent negative values)

Project	10% Social Disc. Rate	9% Social Disc. Rate	8% Social Disc. Rate
A001/S2/SCC3/TR3/PPC2	$69,992	$110,266	$155,158
A003/S2/SCC3/TR1/PPC3	$5,374	$7,060	$8,939
A004/S1/SCC2/TR2/PPC2	$301,829	$375,040	$459,290
A005/S1/SCC3/TR2/PPC2	$117,388	$148,464	$184,261
A006/S1/SCC1/TR2/PPC2	$58,090	$70,949	$85,747
A007/S1/SCC2/TR3/PPC1	$46,682	$58,709	$72,533
A008/S1/SCC1/TR1/PPC2	$45,194	$54,063	$64,233
A010/S1/SCC2/TR1/PPC1	$26,887	$32,714	$39,390
A012/S1/SCC1/TR3/PPC1	$139,019	$168,052	$201,381
A013/S1/SCC1/TR3/PPC2	$149,337	$180,165	$215,587
A014/S1/SCC1/TR3/PPC1	$124,768	$151,825	$182,900
A015/S1/SCC2/TR1/PPC3	$44,285	$53,926	$64,998
A016/S1/SCC1/TR1/PPC1	$15,093	$18,130	$21,608
A017/S1/SCC3/TR3/PPC1	$20,832	$27,022	$34,138
A018/S1/SCC3/TR2/PPC2	$18,960	$24,676	$31,262
A019/S3/SCC1/TR2/PPC3	$10,962	$28,290	$47,939
A022/S1/SCC2/TR3/PPC3	$119,894	$149,795	$184,230
A023/S1/SCC2/TR1/PPC3	$225,656	$278,574	$339,412
A025/S3/SCC2/TR3/PPC1	($18,851)	($16,845)	($14,576)
A026/S1/SCC3/TR3/PPC3	$375,952	$481,599	$603,291
A027/S3/SCC3/TR2/PPC1	($13,677)	($12,940)	($12,105)
A029/S2/SCC2/TR1/PPC2	$24,118	$31,869	$40,505
A030/S2/SCC2/TR3/PPC1	$311	$614	$952
A035/S1/SCC1/TR1/PPC1	$13,559	$16,702	$20,311
A036/S1/SCC1/TR2/PPC1	$39,633	$49,924	$61,777
A037/S1/SCC1/TR2/PPC2	$10,981	$13,726	$16,891
A038/S1/SCC3/TR3/PPC3	$9,870	$13,304	$17,267
A039/S1/SCC2/TR1/PPC1	$18,302	$22,871	$28,114
A040/S1/SCC3/TR1/PPC2	$7,017	$9,009	$11,299
A041/S3/SCC2/TR3/PPC3	($1,498)	($437)	$766
A043/S1/SCC3/TR2/PPC3	$205,674	($509,120)	($535,399)
A044/S1/SCC2/TR1/PPC2	$9,805	$12,292	$15,151
A046/S3/SCC3/TR1/PPC2	($8,389)	($7,412)	($6,304)
A047/S1/SCC2/TR3/PPC2	$6,177	$7,866	$9,809
A051/S1/SCC1/TR3/PPC3	$22,758	$28,233	$34,542
A052/S2/SCC2/TR1/PPC2	$3,219	$6,660	$10,450
A053/S1/SCC1/TR1/PPC2	$85,543	$106,029	$129,595
A055/S2/SCC1/TR2/PPC2	$5,060	$7,003	$9,148
A057/S2/SCC3/TR2/PPC2	($4,644)	($1,760)	$1,414
A058/S2/SCC1/TR2/PPC3	$8,768	$10,921	$13,301
A061/S1/SCC1/TR3/PPC2	$91,545	$115,421	$142,932
A064/S3/SCC2/TR1/PPC2	($81,558)	($75,032)	($67,582)
A067/S2/SCC1/TR1/PPC3	$11,347	$14,226	$17,407
A069/S1/SCC3/TR3/PPC2	$71,446	$100,838	$134,745
A070/S1/SCC1/TR2/PPC2	$9,912	$12,939	$16,437
A071/S1/SCC1/TR1/PPC3	$161,382	$201,783	$248,346
A074/S1/SCC1/TR2/PPC1	$8,420	$11,249	$14,516
A075/S1/SCC3/TR2/PPC1	$56,863	$97,192	$143,805
A076/S2/SCC3/TR1/PPC1	($2,239)	($1,926)	($1,583)
A077/S2/SCC1/TR1/PPC2	$6,756	$9,141	$11,772
A078/S1/SCC3/TR2/PPC3	$10,949	$15,392	$20,530
A080/S2/SCC1/TR3/PPC1	($2,882)	($382)	$2,369
A081/S1/SCC1/TR2/PPC3	$21,037	$26,700	$33,240
A082/S2/SCC2/TR1/PPC3	$7,269	$10,175	$13,383
A083/S2/SCC3/TR1/PPC3	$1,431	$4,262	$7,383

A085/S2/SCC2/TR3/PPC3	$1,926	$3,896	$6,071
A086/S2/SCC2/TR1/PPC3	$22,341	$44,427	$68,812
A087/S2/SCC1/TR1/PPC3	$1,481	$2,031	$2,639
A088/S2/SCC1/TR2/PPC1	($39,620)	($32,189)	($24,006)
A091/S3/SCC2/TR1/PPC2	($96,354)	($92,727)	($88,531)
A096/S3/SCC3/TR2/PPC2	($7,558)	($7,312)	($7,027)
A099/S1/SCC2/TR3/PPC2	$11,588	$16,726	$22,664
A100/S1/SCC1/TR2/PPC1	$160,429	$234,541	$320,322
A101/S1/SCC1/TR2/PPC3	$6,525	$8,682	$11,179
A104/S1/SCC3/TR3/PPC3	$19,489	$28,299	$38,482
A105/S1/SCC2/TR2/PPC3	$11,808	$16,084	$21,030
A106/S1/SCC2/TR3/PPC3	$24,791	$32,673	$41,772
A107/S1/SCC2/TR3/PPC3	$17,867	$23,319	$29,609
A108/S2/SCC2/TR3/PPC3	$10,865	$15,819	$21,290
A110/S1/SCC1/TR3/PPC3	$6,539	$8,231	$10,183
A111/S1/SCC2/TR2/PPC3	$62,510	$89,138	$119,980
A112/S1/SCC2/TR1/PPC2	$14,119	$18,744	$24,075
A113/S1/SCC1/TR1/PPC1	$103,806	$133,164	$166,959
A114/S1/SCC1/TR2/PPC2	$20,807	$27,356	$34,924
A117/S1/SCC2/TR3/PPC1	$9,664	$13,639	$18,222
A119/S1/SCC3/TR3/PPC2	$41,977	$63,291	$87,905
A120/S1/SCC1/TR1/PPC1	$31,552	$40,527	$50,859
A121/S1/SCC3/TR1/PPC1	$11,672	$18,934	$27,310
A123/S1/SCC1/TR2/PPC3	$41,182	$53,243	$67,186
A126/S1/SCC1/TR3/PPC1	$29,134	$38,699	$49,727
A129/S1/SCC1/TR2/PPC2	$3,161	$4,335	$5,694
A131/S1/SCC1/TR3/PPC3	$43,717	$56,969	$72,280
A132/S1/SCC1/TR1/PPC1	$3,005	$4,076	$5,312
A133/S1/SCC3/TR2/PPC2	$9,789	$27,535	$48,129
A134/S1/SCC3/TR1/PPC1	$5,451	$16,874	$30,087
A136/S1/SCC3/TR2/PPC3	$4,963	$9,509	$14,786
A138/S2/SCC3/TR3/PPC1	($21,430)	($20,642)	($19,788)
A139/S2/SCC3/TR1/PPC1	($20,557)	($19,810)	($19,001)
A140/S2/SCC3/TR3/PPC3	($17,097)	($10,160)	($2,509)
A141/S1/SCC1/TR3/PPC3	$100,462	$133,460	$171,613
A146/S3/SCC3/TR2/PPC1	($11,972)	($12,044)	($12,118)
A148/S1/SCC1/TR2/PPC2	$5,422	$7,995	$10,978
A149/S1/SCC1/TR1/PPC1	$4,632	$6,741	$9,180
A150/S3/SCC3/TR3/PPC2	($53,990)	($52,511)	($50,798)
A151/S1/SCC1/TR3/PPC1	$28,775	$42,568	$58,509
A154/S1/SCC1/TR1/PPC1	$38,786	$57,803	$79,798
A155/S1/SCC2/TR2/PPC2	$738	$1,537	$2,466
A157/S1/SCC3/TR3/PPC3	$9,950	$19,025	$29,543
A158/S1/SCC3/TR2/PPC3	$762	$2,741	$5,043
A160/S1/SCC2/TR1/PPC2	$3,637	$6,154	$9,070
A164/S1/SCC2/TR3/PPC2	$4,586	$7,784	$11,486

Table 4.13 Contribution to social benefits at optimal rotation age under multiple rotations regime (LEV_{si}) of the simulated projects of Region 9 (values expressed according to: private discount rates in percentage and LEV_{si} in total dollars per project; numbers in parenthesis represent negative values)

Project	10% Social Disc. Rate	9% Social Disc. Rate	8% Social Disc. Rate
A001/S2/SCC3/TR3/PPC2	($293,121)	($290,016)	($286,196)
A003/S2/SCC3/TR1/PPC3	($10,014)	($9,917)	($9,798)
A004/S1/SCC2/TR2/PPC2	$182,012	$263,167	$367,547
A005/S1/SCC3/TR2/PPC2	$61,710	$95,219	$138,376
A006/S1/SCC1/TR2/PPC2	$39,878	$54,684	$73,725
A007/S1/SCC2/TR3/PPC1	$37,684	$53,096	$72,884
A008/S1/SCC1/TR1/PPC2	$37,356	$48,486	$62,741
A010/S1/SCC2/TR1/PPC1	$25,586	$33,648	$43,966
A012/S1/SCC1/TR3/PPC1	$135,556	$176,313	$228,573
A013/S1/SCC1/TR3/PPC2	$116,776	$154,431	$202,764
A014/S1/SCC1/TR3/PPC1	$117,450	$154,636	$202,339
A015/S1/SCC2/TR1/PPC3	$24,188	$34,035	$46,669
A016/S1/SCC1/TR1/PPC1	$14,972	$19,281	$24,796
A017/S1/SCC3/TR3/PPC1	$14,405	$21,987	$31,725
A018/S1/SCC3/TR2/PPC2	$6,049	$11,694	$18,969
A019/S3/SCC1/TR2/PPC3	($220,020)	($234,642)	($253,054)
A022/S1/SCC2/TR3/PPC3	$38,822	$65,713	$100,365
A023/S1/SCC2/TR1/PPC3	$93,614	$143,430	$207,453
A025/S3/SCC2/TR3/PPC1	($55,187)	($58,605)	($62,942)
A026/S1/SCC3/TR3/PPC3	$58,469	$147,439	$262,170
A027/S3/SCC3/TR2/PPC1	($33,962)	($36,465)	($39,643)
A029/S2/SCC2/TR1/PPC2	($34,169)	($31,572)	($28,303)
A030/S2/SCC2/TR3/PPC1	($1,852)	($1,730)	($1,578)
A035/S1/SCC1/TR1/PPC1	$11,708	$15,833	$21,123
A036/S1/SCC1/TR2/PPC1	$30,490	$43,396	$60,005
A037/S1/SCC1/TR2/PPC2	$5,590	$8,459	$12,158
A038/S1/SCC3/TR3/PPC3	($3,335)	($1,005)	$2,015
A039/S1/SCC2/TR1/PPC1	$15,038	$20,922	$28,466
A040/S1/SCC3/TR1/PPC2	$2,740	$4,750	$7,331
A041/S3/SCC2/TR3/PPC3	($18,586)	($20,011)	($21,812)
A043/S1/SCC3/TR2/PPC3	($58,349)	($9,094)	$54,806
A044/S1/SCC2/TR1/PPC2	$5,037	$7,658	$11,025
A046/S3/SCC3/TR1/PPC2	($30,474)	($32,863)	($35,888)
A047/S1/SCC2/TR3/PPC2	$2,578	$4,287	$6,487
A051/S1/SCC1/TR3/PPC3	$7,325	$12,134	$18,337
A052/S2/SCC2/TR1/PPC2	($48,472)	($50,777)	($53,705)
A053/S1/SCC1/TR1/PPC2	$46,827	$68,525	$96,424
A055/S2/SCC1/TR2/PPC2	($19,090)	($19,724)	($20,535)
A057/S2/SCC3/TR2/PPC2	($58,318)	($61,942)	($66,542)
A058/S2/SCC1/TR2/PPC3	($18,131)	($18,857)	($19,779)
A061/S1/SCC1/TR3/PPC2	$39,169	$63,047	$93,823
A064/S3/SCC2/TR1/PPC2	($276,313)	($299,942)	($329,744)
A067/S2/SCC1/TR1/PPC3	($26,722)	($28,040)	($29,717)
A069/S1/SCC3/TR3/PPC2	($21,973)	$1,789	$32,515
A070/S1/SCC1/TR2/PPC2	$1,648	$4,360	$7,872
A071/S1/SCC1/TR1/PPC3	$35,320	$68,438	$111,191
A074/S1/SCC1/TR2/PPC1	$3,903	$7,060	$11,138
A075/S1/SCC3/TR2/PPC1	($45,481)	($7,850)	$40,891
A076/S2/SCC3/TR1/PPC1	($8,932)	($9,412)	($10,020)
A077/S2/SCC1/TR1/PPC2	($22,549)	($23,271)	($24,200)
A078/S1/SCC3/TR2/PPC3	($8,023)	($5,375)	($1,922)
A080/S2/SCC1/TR3/PPC1	($38,017)	($39,506)	($41,420)
A081/S1/SCC1/TR2/PPC3	$2,188	$6,601	$12,320
A082/S2/SCC2/TR1/PPC3	($38,193)	($40,498)	($43,416)
A083/S2/SCC3/TR1/PPC3	($52,722)	($56,412)	($61,074)

A085/S2/SCC2/TR3/PPC3	($35,944)	($38,804)	($42,431)
A086/S2/SCC2/TR1/PPC3	($408,928)	($442,091)	($484,167)
A087/S2/SCC1/TR1/PPC3	($7,703)	($8,272)	($8,993)
A088/S2/SCC1/TR2/PPC1	($191,593)	($201,896)	($214,847)
A091/S3/SCC2/TR1/PPC2	($276,723)	($302,417)	($334,841)
A096/S3/SCC3/TR2/PPC2	($20,269)	($22,101)	($24,414)
A099/S1/SCC2/TR3/PPC2	($7,106)	($3,412)	$1,386
A100/S1/SCC1/TR2/PPC1	($6,662)	$66,577	$161,565
A101/S1/SCC1/TR2/PPC3	($2,536)	($1,221)	$497
A104/S1/SCC3/TR3/PPC3	($21,555)	($16,971)	($10,985)
A105/S1/SCC2/TR2/PPC3	($6,172)	($3,570)	($175)
A106/S1/SCC2/TR3/PPC3	($5,348)	$34	$7,015
A107/S1/SCC2/TR3/PPC3	($2,049)	$1,854	$6,910
A108/S2/SCC2/TR3/PPC3	($68,989)	($73,632)	($79,529)
A110/S1/SCC1/TR3/PPC3	$1,097	$2,453	$4,205
A111/S1/SCC2/TR2/PPC3	($62,822)	($49,216)	($31,344)
A112/S1/SCC2/TR1/PPC2	$949	$4,985	$10,195
A113/S1/SCC1/TR1/PPC1	$67,419	$102,232	$147,013
A114/S1/SCC1/TR2/PPC2	$2,262	$7,998	$15,431
A117/S1/SCC2/TR3/PPC1	$1,950	$6,121	$11,500
A119/S1/SCC3/TR3/PPC2	($35,871)	($20,606)	($805)
A120/S1/SCC1/TR1/PPC1	$20,277	$30,890	$44,543
A121/S1/SCC3/TR1/PPC1	($6,380)	$470	$9,313
A123/S1/SCC1/TR2/PPC3	($3,537)	$4,970	$16,030
A126/S1/SCC1/TR3/PPC1	$13,752	$24,407	$38,144
A129/S1/SCC1/TR2/PPC2	($763)	$148	$1,334
A131/S1/SCC1/TR3/PPC3	($9,053)	($412)	$10,819
A132/S1/SCC1/TR1/PPC1	$1,023	$2,166	$3,641
A133/S1/SCC3/TR2/PPC2	($78,326)	($70,153)	($59,326)
A134/S1/SCC3/TR1/PPC1	($33,073)	($24,269)	($12,828)
A136/S1/SCC3/TR2/PPC3	($21,703)	($20,406)	($18,652)
A138/S2/SCC3/TR3/PPC1	($63,451)	($69,043)	($76,158)
A139/S2/SCC3/TR1/PPC1	($60,771)	($66,135)	($72,960)
A140/S2/SCC3/TR3/PPC3	($169,560)	($178,373)	($189,041)
A141/S1/SCC1/TR3/PPC3	($42,315)	($23,014)	$2,157
A146/S3/SCC3/TR2/PPC1	($23,841)	($25,968)	($28,654)
A148/S1/SCC1/TR2/PPC2	($4,769)	($3,081)	($871)
A149/S1/SCC1/TR1/PPC1	($344)	$1,698	$4,342
A150/S3/SCC3/TR3/PPC2	($141,438)	($154,245)	($170,416)
A151/S1/SCC1/TR3/PPC1	($4,720)	$8,444	$25,489
A154/S1/SCC1/TR1/PPC1	($8,557)	$9,366	$32,600
A155/S1/SCC2/TR2/PPC2	($3,167)	($2,786)	($2,281)
A157/S1/SCC3/TR3/PPC3	($44,755)	($42,453)	($39,344)
A158/S1/SCC3/TR2/PPC3	($12,474)	($12,226)	($11,861)
A160/S1/SCC2/TR1/PPC2	($7,767)	($6,394)	($4,593)
A164/S1/SCC2/TR3/PPC2	($9,861)	($8,110)	($5,815)

Economic assumptions for the forest investment analysis were:

- Private profitability analysis employed the r_f as discount rate (10, 12 and 14 percent); and social profitability analysis employed r_s as discount rate (8, 9 and 10 percent). For the sensitivity analysis, a pairwise combination of the defined discount rates was stated according to the following scenarios: higher discounting scenario (14% private / 10% social), intermediate discounting scenario (12% private / 9% social) and low discounting scenario (10% private / 8% social).

- Net cash flow from both inflows due to sales and outflows due to operational expenses was considered as the measure of economic contribution of the project. No overhead, fixed cost, taxes or financial expenses were included in the economic and financial analysis, so the net balance of operational inflows and outflows became the economic contribution to cover those costs.

- Production cycle options of single rotation and multiple rotations regimes (at financially optimal rotation age) were alternatively modeled in the forest investment analysis; nothing is instructed in the Guatemalan Forest Law that forces a landowner to re-plant the area harvested, so future land use becomes independent of the PINFOR program[39]. Nonetheless, it resulted interesting for the study to analyze the possibility of replanting the harvested area and enrolling it again in the PINFOR program.

- For the analysis of each simulated project it was assumed that the land was owned by the project, so land purchase (at market price) was not included in the capital budgeting. The projected resale value was calculated according to the purchase price capitalization over time at value increase rate r_l only for the cases in which the project is under single rotation regime.

- Opportunity cost in the forest investment analysis considered two components: the opportunity cost of the land (it was assumed that if land is not allocated in forestry use, then the investment capital could be invested at the alternative rate of return r_a for a period equal to the optimal rotation age), and the opportunity cost of the total expenditure in silviculture (similar criterion to that employed in the investment capital for land purchase was applied for the silvicultural total expenditure).

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[39] This statement sets an analogous condition in the forest investment analysis to that in Flick and Horton (1981) where one rotation was chosen because future land use was independent of the Reforestation of Timberland Program in Virginia.

- Financial contribution of each simulated project was calculated from the net cash flow generated by forestry activities (silviculture, thinnings, final cut and, eventually, land resale) through estimating the NPV_{fi} or LEV_{fi} indicators. Economic performance of projects (as a measure of the social contribution) was calculated by including the opportunity costs described before in the forest investment analysis through estimating the NPV_{si} or LEV_{si} indicators.

- All yields, prices and costs were assumed from data currently available in Region 9. Discount rates are real and prices and costs and future effects of inflation are neutral to the analysis (prices and costs do not inflate differentially).

As seen in Table 4.12 and Table 4.13, some projects are socially profitable and others are not. The socially profitable simulated projects are passed to the next selection stage as each demonstrated positive social contribution in the economic analysis. The next step was to check whether they are (or are not) privately profitable by performing a private forest investment analysis and checking their corresponding NPV_{fi} (and NPV_{ri} which includes the land cost) and LEV_{fi} (and LEV_{ri} which includes the land cost) indicators.

In case of a positive outcome of the three indicator types (NPV_f, NPV_r and NPV_s, or LEV_f, LEV_r and LEV_s), the project associated happened to be both socially and privately profitable; conversely, in those where NPV_f and/or NPV_r, *or* LEV_f and/or LEV_r resulted in a negative outcome, the project associated happened to be socially profitable but privately unprofitable. The latter case indicates that a subsidy is necessary in the form of financial inflow in the project to make the forest investment possible (or at least attractive for the landowner). An overview of the comparison between NPV_f -NPV_r-NPV_s or LEV_f–LEV_r–LEV_s for the pool of simulated projects is shown in Table 4.14. The comparison sets the basis for the model formulation.

Table 4.14. Summary of the profitability analysis of simulated projects of Region 9

Single rotation regime			
Discounting scenario	14% private -10% social	12% private -9% social	10% private -8% social
Total projects	101	101	101
$NPV_s > 0$	85	85	88
NPV_f and/or $NPV_r < 0$	62	42	32
Financial aid required	46	26	19
Multiple rotations regime			
Discounting scenario	14% private -10% social	12% private -9% social	10% private -8% social
Total projects	101	101	101
$LEV_s > 0$	38	48	55
LEV_f and/or $LEV_r < 0$	92	79	64
Financial aid required	29	26	18

As seen in the table, the profitability evaluation of a project strongly relies on the magnitude of the discounting effect and on the rotation regime. Conversely, the requirement of financial aid likely to be provided through a subsidy relies in the discounting scenario more than in the rotation regime. It is interesting to observe that more projects are socially profitable under single rotation than under multiple rotations. But a not so different amount of socially profitable projects require financial assistance when established under either a single or a multiple rotations regime, except at the highest discount rate.

If those simulated projects that have NPV_s or LEV_s higher than zero (i.e. projects socially profitable) are selected apart from the regional pool and at the same time those that belong to this selection that have [NPV_f ; NPV_r] or [LEV_f ; LEV_r] less than zero are identified as projects that require financial aid, then it is possible to formulate an optimization model that determines the adequate way to allocate and to apportion funding from the PINFOR program among projects to maximize overall social benefits due to the regional forest activity in teak. By formulating the model, it is also possible to allocate each project in a recommended rotation regime and in a certain establishment period along the 15 year planning horizon previously defined. All this process provides insights to state a regional strategy of approval and establishment of teak projects potentially found in a near future based on an efficient economic criteria.

The next step was to provide the analysis with investment deficit (*ID*) estimations. By definition, a project ID_i corresponds to the absolute value of the smallest of either NPV_{fi} or NPV_{ri} when negative (similar definition for the LEV_i). By relating each of the selected projects' NPV_s (all positive values) with their corresponding absolute value of NPV_f *or* NPV_r when negative, it is possible to account for the variables important to define the optimization criteria and to formulate the MILP model. The general idea is to maximize the region long-term economic contribution (NPV_s or LEV_s) of teak projects subject to a constraint flow that includes budget limitation of the PINFOR program, forest cover and employment creation obtained since the simulated projects are established in the region. Table 4.15 shows an example in which a comparison is made between selectable simulated projects and non-selectable simulated projects of the study.

Table 4.15. Example of comparison and selection of projects assessed under the selection criteria of the long-term social and private benefits.

Example project*	*A019/S3 /SCC1/TR2 /PPC3/SROT12*	*A057/S2 /SCC3/TR2 /PPC2/SROT10*	*A104/S1 /SCC3/TR3 /PPC3/SROT14*
NPV_s (1)	\$47,939	\$1,414	\$38,482
NPV_f (2)	(\$56,070)	(\$14,983)	\$10,660
NPV_r (3)	\$6,202	(\$6,004)	\$17,861
ID_i (4)=|(2)| or |(3)|, if (2) or (3) < 0	\$56,070	\$14,983	-
Socially profitable? (1) > 0	Yes	Yes	Yes
Privately unprofitable? (2) or (3) < 0	Yes	Yes	No
Selectable for subsidy?	Yes	Yes	No
Enters the optimization model?	Yes	Yes	Yes

*Key example: *A019*: polygon ID; *S3*: site class 3; *SCC1*: silviculture cost class 1; *TR2*: thinning regime 2; *PPC3*: land purchase price class 3; *SROT12*: single rotation regime, 12 year optimal rotation age.

The indicator 'overall long-term social benefits from the regional simulated projects' (NPV_s or LEV_s depending on the most adequate rotation regime in each case) was employed as the driver to conduct the optimization model's objective function formulation. This indicator served as the driver to define the priority order of projects in the allocation of public funds coming from a subsidy program. If a "by-hand" procedure of funding assignment is applied, each project option would be granted according to its financial need (the project's *ID*) one by one in the priority order until the budget is exhausted. But the by-hand solution gets complicated to obtain in this case as 101 different projects with different economic performance were simulated and they have to be also allocated over time in order to maximize long-term social benefits. For this, an optimization model helps find an adequate solution.

In our case this driver (NPV_s or LEV_s) conducted the allocation in the direction of maximizing the long-term social return obtained from teak projects in Region 9 by allocating the funds according to what the optimization model defines as optimal over time. The model, then, replaces the “by-hand” allocation procedure as a multi-period optimal allocation of funds would be difficult to perform manually.

4.14 Overall Employment Generation Capacity of Projects

Employment generation is a matter of interest in Guatemala’s National Forest Policy. In order to include this variable in the model formulation, estimation of the case-by-case overall employment generation capacity of the selected projects was made. Estimations were based on the silvicultural regime assigned, the thinning regime assigned and the rotation length provided by the optimal financial rotation analysis in each simulated project. For each case, an employment flow over time was determined according to both the single rotation regime and the multiple rotations regime. Appendix 6 shows results of the employment estimation for all the simulated projects.

4.15 Estimation of the Program Budget for Region 9

According to Guatemalan National Forest Policy (Article 72), one percent of Guatemala’s Annual Ordinary Income Budget is assigned to INAB to provide forest subsidies in the PINFOR program framework. The regulation states that this amount must be apportioned in the relationship 80/20 percent to be delivered to between forest plantation projects and natural forest management projects respectively, and that nine percent of the total amount must be set aside for covering the administrative cost of the program, thus 91 percent of the annual program's whole budget can be allocated to subsidies.

Information provided by the administrator of the PINFOR program in INAB[40] indicated that about 9.7% of the annual program's budget has been assigned to Region 9 since 2009. That percentage represents about $1.6 million annually assigned to projects in the Southern-Coastal region of Guatemala (Table 4.16)

Table 4.16. Annual payments of forest subsidies delivered nationally and within Region 9 between 2009 and 2013 (values expressed in Guatemalan Quetzals and U.S. dollars).

Period	Country, Q.	Region 9, Q.	Exchange rate[41] (Q./US$.)	Country, US$.	Region 9, US$.	Proportion %
2009	Q153,350,005	Q13,745,301	Q8.1615	$18,789,331	$1,684,154	9.0%
2010	Q145,513,517	Q13,088,590	Q8.0566	$18,061,332	$1,624,573	9.0%
2011	Q114,578,618	Q10,790,416	Q7.7854	$14,717,089	$1,385,979	9.4%
2012	Q110,193,397	Q13,376,025	Q7.8336	$14,066,751	$1,707,518	12.1%
2013	Q127,441,964	Q11,807,892	Q7.8568	$16,220,572	$1,502,886	9.3%
Total	Q651,077,501	Q62,808,224		$81,855,075	$7,905,110	9.7%
			Annually	**$16,371,015**	**$1,581,022**	

If it is assumed that US$1,581,022 are available to provide forest subsidies within Region 9, but twenty percent of this amount should be delivered to natural forest management projects (which are beyond of the scope of the study), thus the resulting budget to allocate it in forest plantation projects with financial needs amounts to US$1,264,818 yearly (the nine percent corresponding to the administrative financial burden is accounted out of this amount). For the purpose of the study and regarding the information provided by the INAB, it was assumed that the annual amount determined will be valid in the long term as budget limitation of the program in Region 9.

[40] Personal communication hold with Edgar B. Martinez, Administrator of the PINFOR program in the INAB

[41] BANGUAT, 2013

5 Model Development

5.1 Justification for the Use of Linear Programming (LP)

Linear programming (LP) was specifically developed for analyzing complex problems involving multiple resources constraints (Teeguarden and Von Sperber, 1968; Murphy, 1976a; Dykstra, 1984).

Regarding the contribution of management science in helping solve problems and its relationship with the natural resources management, Dykstra (1984) stated a variety of arguments that justify its role as a mathematical programming technique helpful in solving complex problems.

Justifications for the use of an optimization model to solve the funds allocation problem instead of using a by-hand economic contribution-based ranking relies in this case in the following features of the problem:

- There is a decision to make and the problem is too complex to make it intuitively. The funding allocation problem involves a decision making process that can be addressed among different "courses of action" or alternatives (i.e. in which potential projects to make the funding assignment and simultaneously in what time to make it). Use of multi-period mixed integer linear programming (MILP) is appropriate for this argument.

- There are diverse objectives to be achieved by making the decision (e.g. maximizing social benefits from the program, as well as ensuring a certain employment creation over time from the projects).

- It is not clear (and likely not easy to define it) which course of action is the best in achieving the objectives just by making an intuitive decision or by selecting a solution made "by hand".

- Resources are limited. As usual in this type of programs, the budget to be apportioned in a funding allocation process is limited and, thus, the problem is constrained. And as usual in forestry, bare land availability and site potential are also limited resources to be considered.

- The problem's variables can be quantified. In the case, this is quite obvious. Land availability, cost-based silvicultural management classes, timber production and market features, site productivity, program budget and financial and economic outputs of the assessment are all variables able to be quantified.

Some other specific features of this particular problem can be also outlined to justify the use of the LP technique in solving the funding allocation problem:

- Optimal solution for a potential regional project: particular teak plantation projects generated according to a simulation were economically assessed. The aim of the model was to make a prospective future optimal allocation of funds into realistically simulated projects suitable for the region. Because of this, alternative forest management regimes were characterized and classified into potential project for the employ of the *ex ante* economic approach and for the LP-based model formulation. A variety of conditions regarding site, cost-based silvicultural regimes and timber production schedules (thinning and final clear-cut) were considered in the classification[42].

- Long-term planning horizon: the model is aimed at providing a long-term solution to the funding allocation problem assuming prices, costs, funding levels, and all other factors are constant including competing land uses. The planning horizon is set at 15 years for this study because of the length of the program in similar period in the past from where the program data for the study were collected. A long-term solution is important because allows the program to estimate a priori total assignation of funds over time and the

[42] For the details, go back to the Chapter 4.13 'Economic Analysis of Teak Projects of Region 9'.

budget required in each period[43]. Thus, it was easily realized that making a year-by-year allocation of funds "by hand" in a 15 years-long period involving several thousand hectares of potential teak and a variety of combinations of forest management, production regimes, land market conditions, site quality and rotation length might become difficult or virtually impossible to perform. Employment of a mathematical programming technique such as LP is useful in this case.

- Linearity, divisibility, non-negativity of the decision variables and known coefficients are requirements according to that stated by Dykstra (1984). Mandatory conditions for using LP are: linear relationship between the problem's variables and coefficients; real values for variables and coefficients; non-negative values to decision variables[44]; and known, fixed constants for coefficients and right-hand side values. In this case, these conditions are satisfied.

- Constrained nature of the problem's resources: as previously mentioned, subsidy programs are subject to a limited budget. Similarly, other resources of this particular problem could be also limited: total bare land available for new teak plantations within the region and productive capacity of the different site quality classes identified within the region.

- Basic elements for MILP-based model formulation: all the basic elements stated by Dykstra (1984) as critical ones in a LP-based model structure can be identified in the funding allocation problem, namely[45]:

[43] Virtually, the optimal long-term solution could be reviewed annually by rerunning the model in order to reflect changes in the variables.
[44] Although this is a mandatory condition of the model formulation, negative values can either be addressed by variable substitution or change in simplex rules.
[45] See Chapter 5.2 'Model Formulation' for a detailed description of all these elements.

- Activity levels, expressed in the form of decision variables;
- Objective(s) as the linear combination of decision variables;
- Resources associated to the activity levels;
- Relationship between activity levels and resources, expressed in the form of technological coefficients;
- Restriction or availability levels, expressed in the form of right-hand side coefficients;
- Mathematical relationships between resources, activity levels and availability levels, expressed in the form of equations and/or inequalities;
- Consistency in all these elements as a whole in the model formulation regarding the problem nature.

5.2 Model Formulation

5.2.1 Components and Description of the Funding Allocation Problem in Region 9

In general terms, each of the 101 simulated projects was evaluated in terms of its economic performance associated to one rotation (expressed through NPV_s) or multiple rotations (expressed through LEV_s) in 27 different combinations of silviculture/thinning/land purchase price. By performing a forest investment analysis of the projects that are socially profitable, it was determined that some of them need financial aid, so the investment deficit of those projects necessary to be supplied was determined in each case. Financial aid magnitude depended on the discounting scenario evaluated and the rotation regime assigned to the projects.

The assumption that underlies the economic analysis is that a subsidy addressed to selected teak projects in the region should supply the financial need estimated through the investment deficit analysis. Currently, Region 9 would have 61,217 hectares[46] available for new teak plantation projects from where about 1,411 hectares were assigned to simulated projects suitable to be established in a near future according to certain spatial distribution criteria (see section 4.11 'Spatial Analysis of Potential Areas for Teak in Region 9' for the details). US$1,264,818 annually would be available to deliver it as subsidies in the PINFOR program framework.

At this point, it became worthwhile for the study to derive a forest planning analysis in which an "approval and establishment strategy" for new Teak plantation projects in the region is defined in order to employ these resources in a profitable manner in the long term. As the economic contribution of the selected projects is well known, it become feasible to determine the best strategy for the PINFOR program to approve and establish teak plantation projects within the region in the future by allocating projects in such a way that maximizes the overall economic contribution of local teak projects in the long term assuming everything else remains constant for the next 15 years. Apportionment of funding, then, derives from the financial need of each case in the proportion of land allocated (project size) and the particular investment deficit.

In Guatemala, sustainable forest management has become an important concern among the different players and stakeholders of the local forestry sector. So it is of importance that any forestry long-term strategy of development involves sustainable forest management principles. Specifically, positive social and environmental impacts are desirable from any action addressed to stimulate forestry activity. In the study context, this objective was effectively included as part of the optimization model formulation. Maximization of the economic contribution of teak

[46] Just the site quality class S_1 as it is the only site class that demonstrated to be socially profitable in the NPV_s analysis. Additional 39,550 hectares would be available in lower quality site classes within the region.

plantations projects in the Southern-Coastal region of Guatemala is constrained to achieve the following social and environmental impacts:

- A positive social impact obtained from the ability of the regional establishment strategy to generate a non-declining employment flow from teak projects established in the region over time;

- A positive environmental impact obtained from the ability of the regional establishment strategy to produce non-declining total area with growing trees throughout the region over time.

Planning horizon for the problem was a period of 15 years. As most of the data collected is updated to 2012-2013, it was considered that an adequate starting year in the analysis is 2014. According to this, the whole planning period theoretically runs between 2014 and 2028. Results are interpretable within this future period.

5.2.2 Mathematical Formulation

The problem to solve has been described previously in general terms. In this chapter the model is mathematically formulated by translating the items and conditions into equations.

- Decision Variable (*DV*)

All the economic, forest and employment indicators generated in the investment analysis referred to entire projects. According to this, the model's decision variable was defined as binary and represents the probability of occurrence of a project within the timespan and under a certain rotation regime. The optimal solution comes from the allocation of the simulated projects into periods and rotation regimes in such a way that the overall regional economic contribution of teak-based forest activity is maximized.

The model was formulated to allocate selected projects into periods and alternative rotation regimes of single or multiple cycles. From here, the decision variable is

$$X_{ijk} = [0, 1]$$

Where:

i: simulated project selected from the social economic assessment that combines a cost-based silvicultural scheme (SSC_1, SSC_2 or SSC_3), a thinning regime (TR_1, TR_2 or TR_3), a land purchase price (PPC_1, PPC_2 or PPC_3) and an optimal rotation age-based clear-cut regime. Value of i goes from 1 to M depending on the amount of projects that were selected as socially profitable in a certain discounting scenario (higher, intermediate or lower) and a particular rotation regime (see Table 5.1 for details);

j: period of the planning horizon (1 to 15, corresponding to the actual planning period 2014-2028);

k: rotation regime: k=1 if single rotation and k=2 if multiple rotation.

Table 5.1. Summary of values for i = [1; M] according to discounting scenario and rotation regime.

Single rotation regime			
Discounting scenario	14% private -10% social	12% private -9% social	10% private -8% social
$NPV_s > 0$	85	85	88
Multiple rotations regime			
Discounting scenario	14% private -10% social	12% private -9% social	10% private -8% social
$LEV_s > 0$	38	48	55

- Objective Function (*OF*)

The objective function is to maximize the present value of the overall contribution to social benefits in the region obtained from teak projects established in the program framework. Mathematically and in generic terms, the function can be drawn as follows:

$$Max\ PVOCSB = \sum_{j=1}^{N}\sum_{i=1}^{M} SDF_j * NPVs_{ij1} * X_{ij1} + \sum_{j=1}^{N}\sum_{i=1}^{M} SDF_j * LEVs_{ij2} * X_{ij2} \quad (Eq.1)$$

With

$$SDF_j = \frac{1}{(1+r_s)^{j-1}} \quad (Eq.2)$$

Where

PVOCSB: present value of the overall contribution to social benefits generated by simulated projects of teak in Region 9 potentially established within the next 15 years;

$NPVs_{ij1}$: social net present value (in period *j*-1) of project *i* if established in period *j* under single rotation regime *k*=1;

$LEVs_{ij2}$: social land expected value (in period *j*-1) of project *i* if established in period *j* under multiple rotations regime *k*=2;

SDF_j: social discount factor at period *j*-1 when a project is allocated to be established in period *j* (see Table 5.2 which includes values for r_s equal to 8, 9 and 10 percent);

r_s: social discount rate (8%, 9% and 10% depending on the discounting scenario in which the $NPVs_{ij1}$ and $LEVs_{ij2}$ indicators were calculated);

X_{ij1}, X_{ij2}: binary decision variables when *k*=1 and *k*=2 respectively;

M: total amount of selected simulated projects (see Table 5.1);

N: total periods within the planning horizon (15 periods);

Table 5.2. Social discount factors in the model

Period *j*-1	*SDFj* (r_s=8%)	*SDFj* (r_s=9%)	*SDFj* (r_s=10%)
0	1.000	1.000	1.000
1	0.926	0.917	0.909
2	0.857	0.842	0.826
3	0.794	0.772	0.751
4	0.735	0.708	0.683
5	0.681	0.650	0.621
6	0.630	0.596	0.564
7	0.583	0.547	0.513
8	0.540	0.502	0.467
9	0.500	0.460	0.424
10	0.463	0.422	0.386
11	0.429	0.388	0.350
12	0.397	0.356	0.319
13	0.368	0.326	0.290
14	0.340	0.299	0.263

- Constraint 1: Annual Budget Limitation in the PINFOR program (*C1*)

According to the information provided by the INAB, the estimation of the budget available to be delivered as subsidies to forest projects in the region is US$1,264,818. According to this, the formulation of the budget constraint was expressed as follows:

$$TS_j = \sum_{j=1}^{N}\sum_{i=1}^{M} ID_{i1} * X_{ij1} + \sum_{j=1}^{N}\sum_{i=1}^{M} ID_{i2} * X_{ij2} \leq B_j \ (Eq. 3)$$

Where

TS_j: total subsidy to be delivered in the period *j*;

ID_{i1}, ID_{i2}: investment deficit accounted by the project *i* economically evaluated under the rotation regimes *k*=1 (single rotation) or *k*=2 (multiple rotations) respectively;

X_{ij1}, X_{ij2}: binary decision variables when *k*=1 and *k*=2 respectively;

B_j: annual budget available in period *j*, equal to US$1,264,818 as defined in section 4.15 'Estimation of the Program Budget for Region 9';

M: total amount of selected projects;

N: total periods within the planning horizon;

An annual fixed budget of US$1,264,818 is an assumption of this particular case. However, the constraint is flexible to be modified to a variable annual amount whether the budget availability changes in the future.

- Constraint 2: Non-Declining Planted Forests Cover (*C2*)

As it was stated in regard of the desired positive environmental impact of the future teak regional strategy, the requirement of a non-declining total planted area with teak projects in the region over time was included as a model constraint. The expression of this plan's requirement resulted as follows:

$$FC_r \leq FC_{r+1}, \forall\, r = 1, \ldots, N-1 \; (Eq. 4)$$

With

$$FC_r = \sum_{i=1}^{M}\sum_{j=1}^{N} A_{ir1} * X_{ij1} + \sum_{i=1}^{M}\sum_{j=1}^{N} A_{ir2} * X_{ij2} \; (Eq. 5)$$

Where

FC_r: total teak growing in period r;

A_{ir1}, A_{ir2}: vectors of covered area [$A_{i1,1}$, $A_{i2,1}$,…, $A_{i15,1}$] and [$A_{i1,1}$, $A_{i2,1}$,…, $A_{i15,1}$] respectively where:

- $A_{ir1} = \{^{A_i \; if \; r \in [j'; min(j' + R_{i1}; N)]}_{0 \; otherwise}$
- $A_{ir2} = \{^{A_i \; if \; r \in [j'; N]}_{0 \; otherwise}$
- A_i = project i area
- $j' = j$ when $X_{ij1} = 1$ or $X_{ij2} = 1$
- R_{i1} = project i optimal rotation under single rotation regime

X_{ij1}, X_{ij2}: binary decision variables when k=1 and k=2 respectively;

M: total amount of selected projects;

N: total periods within the planning horizon;

Equation 5 thus represents the calculation procedure to estimate the per-period cumulative area planted when the different projects have been optimally allocated to both a period and a rotation regime. Binary decision variable X_{ijk} governs the allocation.

- Constraint 3: Non-Declining Employment Flow (*C3*)

As it was stated in regard of the desired positive social impact of any forest regional strategy, the requirement of a non-declining employment flow generated from teak projects in the region over time was included as a model constraint. The expression of this plan's requirement resulted as follows:

$$TE_r \leq TE_{r+1}, \forall\, r = 1, \dots, N-1 \; (Eq.6)$$

With

$$TE_r = \sum_{i=1}^{M}\sum_{j=1}^{N} E_{ir1} * X_{ij1} + \sum_{i=1}^{M}\sum_{j=1}^{N} E_{ir2} * X_{ij2} \; (Eq.7)$$

Where

TE_r: total employment demanded or required by projects in period *r*;

E_{ir1}, E_{ir2}: vectors of employment flow per project *i* [$E_{i1,1}$, $E_{i2,1}$,…, $E_{i15,1}$] and [$E_{i1,1}$, $E_{i2,1}$,…, $E_{i15,1}$] for rotation regimes *k*=1 or *k*=2 respectively (see Appendix 6 for details):

- $E_{ir1} = \{ \begin{matrix} EGC_i \; if \; r \in [j'; min(j' + R_{i1}; N)] \\ 0 \; otherwise \end{matrix}$
- $E_{ir2} = \{ \begin{matrix} EGC_i \; if \; r \in [j'; N] \\ 0 \; otherwise \end{matrix}$
- EGC_i = employment generation capacity from a project *i* in each period of the optimal rotation
- $j' = j$ when $X_{ij1} = 1$ or $X_{ij2} = 1$
- R_{i1} = project *i* optimal rotation under single rotation regime

X_{ij1}, X_{ij2}: binary decision variables when *k*=1 and *k*=2 respectively;

M: total amount of selected projects;

N: total periods within the planning horizon;

- Constraint 4: One Rotation Regime Only (*C4*)

A particular project could not be allocated to both single and multiple rotation regimes simultaneously. The underlying assumption is that a landowner faces rotation regime options and he has to choose between allocating land to only one production cycle or allocating land to perpetual land use in teak, or neither. In the end, and according to the way in which the MILP model allocates the different projects over time, the model identifies the project allocation which maximizes the value of the objective function.

Formulation of this constraint was based on an arrangement of the binary decision variables X_{ij1} and X_{ij2} as follows:

$$X_{ij1} + X_{ij2} \leq 1, \forall\ i = 1, \dots, M; j = 1, \dots, N\ (Eq. 8)$$

- Constraint 5: Allocation just Once within the Planning Horizon (*C5*)

Similar to the previous allocation condition, a project can be allocated just once along the timespan. It would be interesting to analyze alternative rotation options but this is beyond the scope of the study.

Formulation of this constraint was based on an arrangement of the binary decision variables X_{ij1} and X_{ij2} as follows:

$$X_{i1,1} + X_{i2,1} + \cdots + X_{i15,1} + X_{i1,2} + X_{i2,2} + \cdots + X_{i15,2} \leq 1, \forall\ i = 1, \dots, M\ (Eq. 9)$$

- Constraint-6: Binary Condition of the Decision Variable (*C6*)

Adding the binary constraints,

$$X_{ijk} = [0; 1]\ (Eq. 10)$$
$$\forall\ i = 1, \dots, M$$
$$\forall\ j = 1, \dots, N$$
$$\forall\ k = 1, 2$$

6 Analysis

6.1 LP System and Method Employed

The multi-period MILP model was formulated and implemented in the linear programming MS Excel© add-in called *What'sBest!*©. The model's generic structure included 3,030 binary decision variables, 81 accounting variables and 1,734 constraint rows. However the model reduces due to the elimination of projects in the economic assessment (those that resulted socially unprofitable) and due to the incorporation of different discounting scenarios that also determines differentiated amount of projects that require financial assistance. Table 6.1 shows differentiated model sizes and solving parameters, and Appendix 7 shows the output reports from *What'sBest*© of each case.

Table 6.1. General structure and solving parameters of the multi-period mixed integer linear programming models generated in the study

Discounting scenario[47]	SP810	SP912	SP1014
Binary decision variables	2,145	1,995	1,845
Accounting variables	81	81	81
Constraint rows	1,533	1,485	1,484
Iterations	785,927	951,495	1,022,524
Solving time	2min 55sec	2min 55sec	2min 58sec
Optimality tolerance	1%	1%	1%

The problem solving was generically set by building a 3,111 column by 1,734 row detached coefficient matrix (*DCM*) using the 'Model I' formulation widely used in resources allocation (Johnson and Scheurman, 1977; cited by Dykstra, 1984).

6.2 Optimal Solution of the Problem

The optimal solution found in each of the three discounting scenarios for the funding allocation problem of the particular simulated projects scenario of the study is described through the following indicators and outcomes:

[47] SP810: lower discounting scenario (social 8%, private 10%); SP912: intermediate discounting scenario (social 9%, private 12%); SP1014: higher discounting scenario (social 10%, private 14%).

- Present value of the overall contribution to social benefits (*PVOCSB*);
- Number of projects allocated to both rotations and periods;
- Area allocated to both rotations and periods;
- Per-period present value of social benefits;
- Per-period subsidy allocation;
- Per-period overall area of growing teak;
- Per-period overall employment flow;
- Spatial allocation of projects over time.

A summary of these indicators for each scenario is shown in Tables 6.2, 6.3 and 6.4. A graphical approach of the solutions is shown in next sections where each one is treated separately.

Table 6.2. Indicators of the SP810 scenario's optimal solution (Proj: number of projects; S: single rotation; M: multiple rotation; *PVSB*: present value of social benefits in US dollars; *PVSu*: present value of subsidy to be allocated in US dollars; *Cov*: forest cover in hectares; *E*: employment in work-days)

Period	Proj	S	M	Area	S	M	*PVSB*	*PVSu*	*Cov*	*E*
0							$1,633,488	$0		
1	17	6	11	190.5	80.7	109.8	$2,446,118	$0	190.5	14,609
2	19	19	0	343.6	343.6	0.0	$1,007,001	$11,650	534.1	31,294
3	18	18	0	186.9	186.9	0.0	$330,351	$3,577	721.0	31,719
4	13	13	0	94.5	94.5	0.0	$48,129	$0	815.5	31,726
5	1	1	0	21.7	21.7	0.0	$21,030	$0	837.2	31,751
6	1	1	0	3.8	3.8	0.0	$190,345	$13,403	841.0	32,429
7	4	4	0	72.9	72.9	0.0	$176,448	$15,998	913.9	32,723
8	2	2	0	81.2	81.2	0.0	$387,980	$1,874	995.1	32,781
9	3	3	0	116.4	116.4	0.0	$952	$0	1,111.5	32,832
10	1	1	0	0.7	0.7	0.0	$11,772	$1,756	1,112.2	32,838
11	1	1	0	5.6	5.6	0.0	$47,939	$56,070	1,117.8	32,902
12	1	1	0	34.6	34.6	0.0	$16,521	$18,394	1,139.5	33,246
13	2	2	0	13.5	13.5	0.0	$1,414	$14,983	1,139.6	33,441
14	1	1	0	8.2	8.2	0.0	$105,187	$118,529	1,142.4	53,148
15	4	4	0	68.6	68.6	0.0	***PVOCSB***	**Subsidy**	1,143.3	73,436
Total	88	77	11	1,242.7	1,132.9	109.8	**$5,575,586**	**$90,706**		
Avg	6			82.8			$428,312	$17,082		

Table 6.3. Indicators of the SP912 scenario's optimal solution (Proj: number of projects; S: single rotation; M: multiple rotation; *PVSB*: present value of social benefits in US dollars; *PVSu*: present value of subsidy to be allocated in US dollars; *Cov*: forest cover in hectares; *E*: employment in work-days)

Period	Proj	S	M	Area	S	M	*PVSB*	*PVSu*	*Cov*	*E*
0							$1,090,059	$1,253		
1	18	10	8	161.3	84.0	77.3	$2,086,433	$0	161.3	12,255
2	16	16	0	352.0	352.0	0.0	$861,311	$2,897	513.4	31,351
3	21	21	0	199.4	199.4	0.0	$245,581	$12,683	712.8	31,582
4	7	7	0	86.7	86.7	0.0	$39,784	$32,278	799.4	31,656
5	3	3	0	28.8	28.8	0.0	$14,226	$4,712	828.3	31,665
6	1	1	0	5.4	5.4	0.0	$121,850	$35,651	833.7	31,926
7	3	3	0	67.3	67.3	0.0	$110,266	$52,124	901.0	32,340
8	1	1	0	71.0	71.0	0.0	$285,650	$4,604	972.0	32,346
9	4	4	0	117.4	117.4	0.0	$9,141	$4,144	1,089.4	32,378
10	1	1	0	5.6	5.6	0.0	$614	$316	1,095.0	32,404
11	1	1	0	0.7	0.7	0.0	$28,290	$66,656	1,095.7	32,408
12	1	1	0	34.6	34.6	0.0	$22,112	$34,784	1,115.0	32,450
13	3	3	0	17.8	17.8	0.0	$0	$0	1,128.9	32,464
14	0	0	0	0.0	0.0	0.0	$71,312	$151,160	1,128.9	46,072
15	5	5	0	74.8	74.8	0.0	***PVOCSB***	**Subsidy**	1,134.9	74,652
Total	85	77	8	1,222.9	1,145.6	77.3	**$4,277,196**	**$139,892**		
Avg	6			81.5			$332,442	$26,884		

Table 6.4. Indicators of the SP1014 scenario's optimal solution (Proj: number of projects; S: single rotation; M: multiple rotation; *PVSB*: present value of social benefits in US dollars; *PVSu*: present value of subsidy to be allocated in US dollars; *Cov*: forest cover in hectares; *E*: employment in work-days)

Period	Proj	S	M	Area	S	M	PVSB	PVSu	Cov	E
0							$1,090,766	$0		
1	11	8	3	184.2	155.4	28.9	$1,494,600	$24,491	184.2	14,020
2	24	24	0	331.7	331.7	0.0	$497,425	$83,833	515.9	30,065
3	20	20	0	176.3	176.3	0.0	$213,459	$60,225	692.2	30,313
4	6	6	0	93.5	93.5	0.0	$43,717	$0	785.7	30,320
5	1	1	0	12.0	12.0	0.0	$0	$0	797.7	30,653
6	0	0	0	0.0	0.0	0.0	$60,500	$69,219	797.7	30,654
7	2	2	0	50.8	50.8	0.0	$74,578	$95,534	848.5	30,701
8	2	2	0	74.9	74.9	0.0	$171,294	$80,532	923.3	31,017
9	2	2	0	103.8	103.8	0.0	$83,415	$123,549	1,027.1	31,779
10	11	11	0	87.9	87.9	0.0	$0	$0	1,027.2	32,317
11	0	0	0	0.0	0.0	0.0	$2,664	$12,885	1,027.2	32,339
12	2	2	0	5.6	5.6	0.0	$10,962	$74,080	1,028.2	32,370
13	1	1	0	34.6	34.6	0.0	$0	$0	1,032.3	32,600
14	0	0	0	0.0	0.0	0.0	$26,991	$158,430	1,032.3	49,226
15	3	3	0	67.6	67.6	0.0	***PVOCSB***	**Subsidy**	1,032.4	65,972
Total	85	82	3	1,222.9	1,194.0	28.9	**$3,250,064**	**$306,305**		
Avg	6			81.5			$251,358	$52,185		

6.2.1 Optimal Objective Function Value: *PVOCSB*

The overall optimal social return obtained from the simulated teak projects in the different discounting scenarios for a fifteen year economic evaluation distributes between \$3,250,064 and \$5,575,586 when the discounting effect moves from the higher level (10% social discount rate) to the lower level (8% social discount rate). This value was obtained discounting to present the per-period present value of social benefits (*PVSB*) gotten from the establishment strategy (period-based allocation of projects) provided by the model. Figure 18 shows the three scenarios' social benefit flow (*PVSB*) from the optimal allocation graphically.

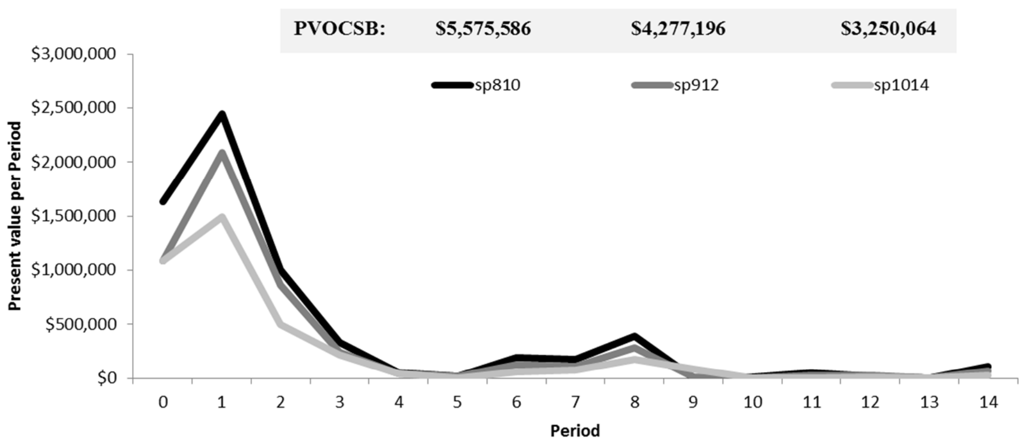

Figure 18. Optimal per-period present value flow of social benefits (*PVSB*) obtained from the simulated projects allocated in Region 9

6.2.2 Optimal Allocation of Projects: Amount and Area

Allocation of projects in the optimal solutions strongly favored the single rotation regime and the first years of the timespan. In either of the discounting scenarios, between 72% and 76% of the projects were allocated in the four first periods, which represents between 64% and 66% of the projects' total area allocated over time. Similarly, between 88% and 96% of the projects allocated into a single rotation regime, which represents between 91% and 97% of the total area allocated. It was observed that the higher the discounting effect, the fewer projects and area allocated into multiple rotations regime. Figures 19 and 20 show the account and area of projects allocated over time in the optimal solution of the three discounting scenarios. Figure 21 and Figure 22 show the distribution of projects and area between the two rotation regimes in the optimal allocation under the three discounting scenarios.

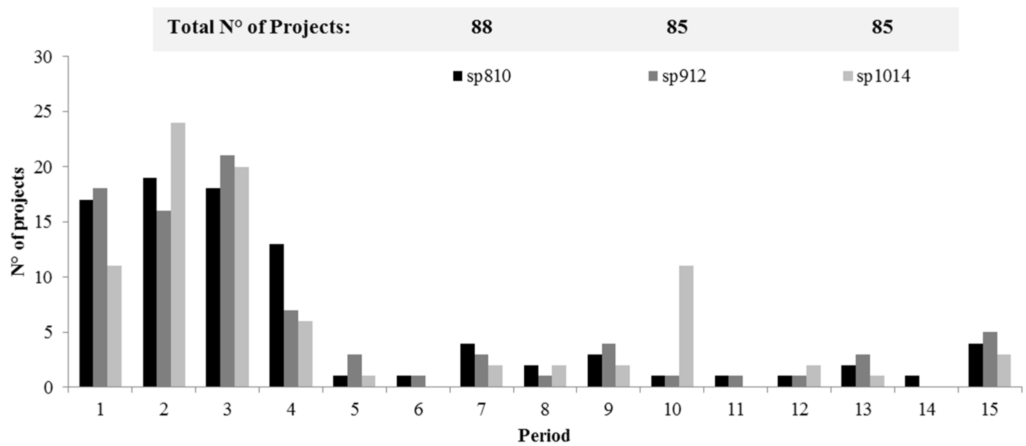

Figure 19. Optimal allocation of projects along the 15 year planning horizon under the three discounting scenarios modeled for teak projects in Region 9

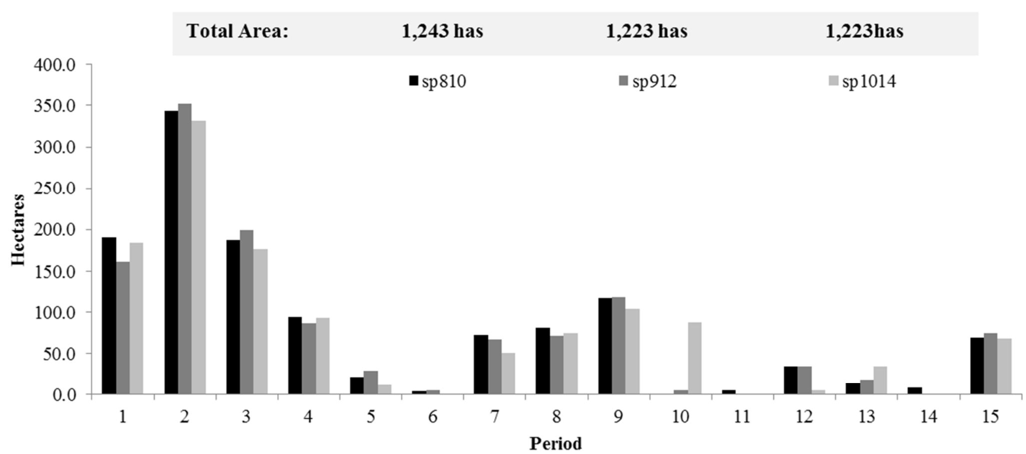

Figure 20. Optimal allocation of project area along the 15 year planning horizon under the three discounting scenarios modeled for teak projects in Region 9

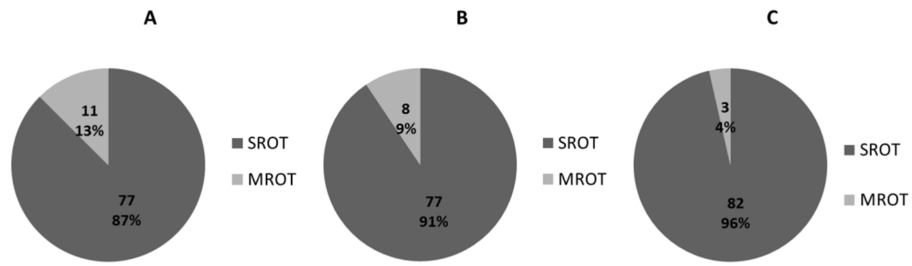

Figure 21. Optimal allocation of projects into rotation regimes under the three discounting scenarios modeled for teak projects in Region 9 (A: discounting scenario SP810; B: discounting scenario SP912; C: discounting scenario SP1014)

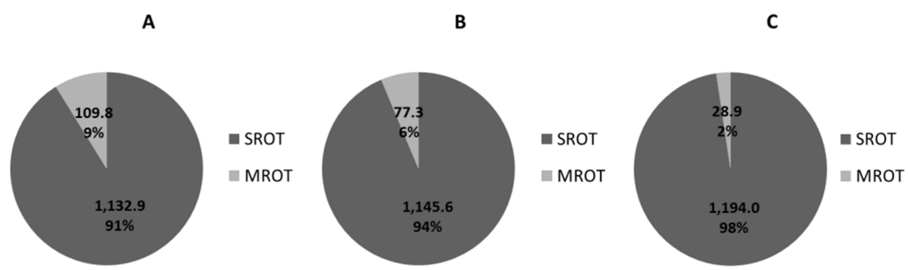

Figure 22. Optimal allocation of project area into rotation regimes under the three discounting scenarios modeled for teak projects in Region 9 (A: discounting scenario SP810; B: discounting scenario SP912; C: discounting scenario SP1014)

6.2.3 Subsidy Allocation: *PVSu*

In context with the optimal solution, the allocation of funds could be defined according to the particular financial need of the simulated projects and the way the model allocates them over time and into alternative rotation regimes. Figures 23 to 25 show the optimal yearly allocation and delivery of funding to simulated teak projects in the fifteen year period for Region 9 under the three discounting scenarios.

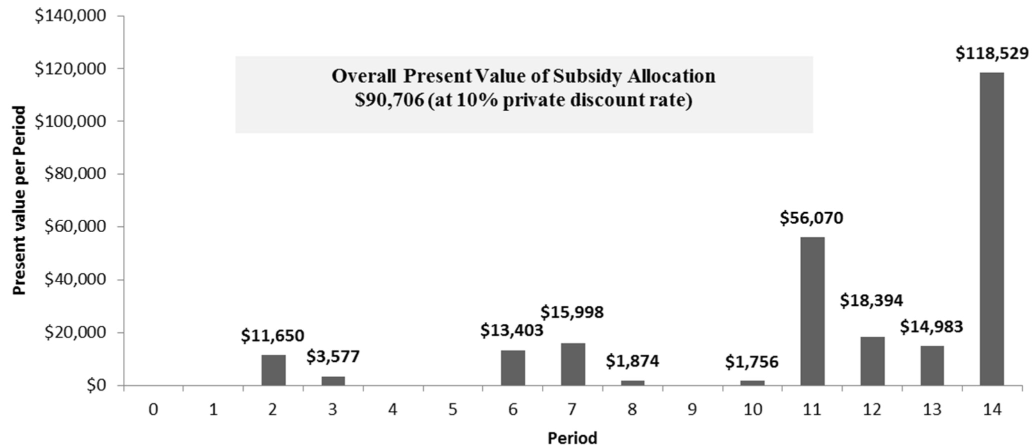

Figure 23. Allocation of subsidies over time according to the optimal teak strategy obtained from the optimization model for the discounting scenario SP810

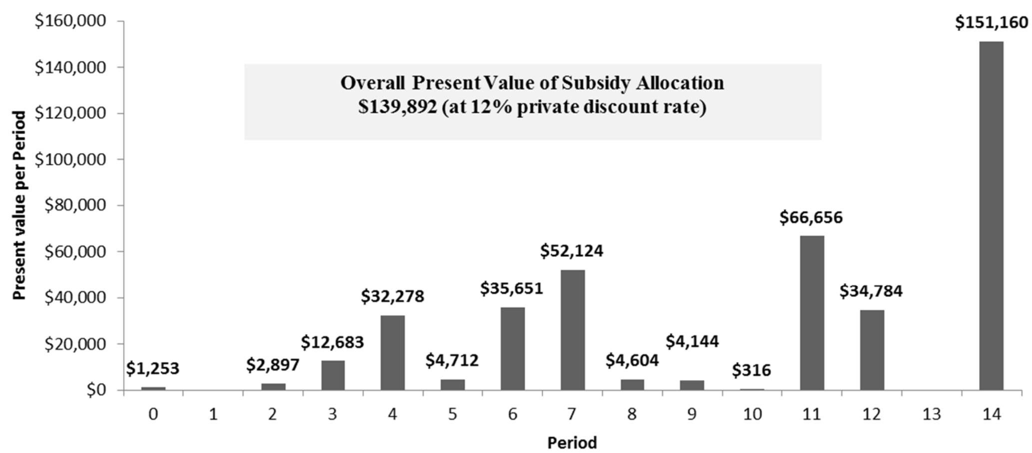

Figure 24. Allocation of subsidies over time according to the optimal teak strategy obtained from the optimization model for the discounting scenario SP912

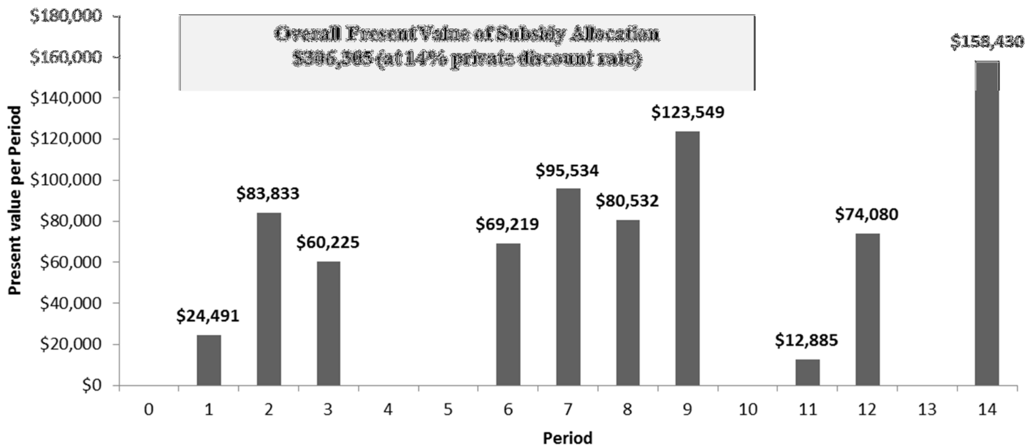

Figure 25. Allocation of subsidies over time according to the optimal teak strategy obtained from the optimization model for the discounting scenario SP1014

Curiously, none of the allocated projects was granted under the multiple rotations regime. The 11, 8 and 3 simulated projects corresponding to the discounting scenarios SP810, SP912 and SP1014 respectively that were allocated into multiple rotations regime in the teak strategy were selected because they were demonstrated to be socially profitable, but none of them demonstrated a financial need. From here, it was possible to infer that they were financially evaluated as privately profitable in both LEV_f and LEV_r indicators. In such cases, these projects were part of the project selection (the financial and economic assessment) and included to pass to the next stage (the optimal allocation process), and the model made the decision of allocating them into multiple rotations regime as their contribution to overall social benefit subject to the model's constraints was better under this rotation regime rather than under a single production cycle.

The results show that only projects under single rotation regime would be granted in the forest subsidy program. Optimal allocation of subsidies shown in the figures represents the amounts (*NPV*-based) that the program should deliver to the allocated projects prior to be established (period *j*-1) in each assigned period (*j*) to supply the *ID* that would make the investment in teak possible. A general trend of small amounts at the beginning of the planning horizon and larger amounts at the end is evident which may be explained by the unit social contribution of the projects: as the objective function is affected by a discounting effect, the model tends to allocate projects that return higher social benefits earlier and projects that return lower social benefits later. In the economic assessment of projects it was checked that, in general, projects that return higher social benefits have lower or null investment deficit. Table 6.5, Table 6.6 and Table 6.7 show the mean unit social profitability (*PVSB* per hectare) and the mean unit financial need (*PVSu* per hectare) of projects according to their establishment schedule in the optimal allocation for the three discounting scenarios.

Table 6.5. Mean unit social profitability (*PVSB* per hectare) and mean unit investment deficit (*PVSu* per hectare) of projects allocated according to the discounting scenario SP810

Period	Area Allocated	*PVSB*	*PVSu*	*PVSB*/Ha	*PVSu*/Ha
0		$1,633,488	$0	$8,574	$0
1	190.5	$2,446,118	$0	$7,119	$0
2	343.6	$1,007,001	$11,650	$5,389	$62
3	186.9	$330,351	$3,577	$3,495	$38
4	94.5	$48,129	$0	$2,219	$0
5	21.7	$21,030	$0	$5,483	$0
6	3.8	$190,345	$13,403	$2,611	$184
7	72.9	$176,448	$15,998	$2,174	$197
8	81.2	$387,980	$1,874	$3,333	$16
9	116.4	$952	$0	$1,373	$0
10	0.7	$11,772	$1,756	$2,096	$313
11	5.6	$47,939	$56,070	$1,386	$1,621
12	34.6	$16,521	$18,394	$1,228	$1,367
13	13.5	$1,414	$14,983	$173	$1,831
14	8.2	$105,187	$118,529	$1,532	$1,727
15	68.6				

Table 6.6. Mean unit social profitability (*PVSB* per hectare) and mean unit investment deficit (*PVSu* per hectare) of projects allocated according to the discounting scenario SP912

Period	Area Allocated	*PVSB*	*PVSu*	*PVSB*/Ha	*PVSu*/Ha
0		$1,090,059	$1,253	$6,757	$8
1	161.3	$2,086,433	$0	$5,927	$0
2	352.0	$861,311	$2,897	$4,319	$15
3	199.4	$245,581	$12,683	$2,834	$146
4	86.7	$39,784	$32,278	$1,380	$1,120
5	28.8	$14,226	$4,712	$2,631	$871
6	5.4	$121,850	$35,651	$1,810	$530
7	67.3	$110,266	$52,124	$1,554	$734
8	71.0	$285,650	$4,604	$2,433	$39
9	117.4	$9,141	$4,144	$1,627	$738
10	5.6	$614	$316	$886	$456
11	0.7	$28,290	$66,656	$818	$1,927
12	34.6	$22,112	$34,784	$1,242	$1,954
13	17.8	$0	$0	-	-
14	0.0	$71,312	$151,160	$954	$2,021
15	74.8				

Table 6.7. Mean unit social profitability (*PVSB* per hectare) and mean unit investment deficit (*PVSu* per hectare) of projects allocated according to the discounting scenario SP1014

Period	Area Allocated	*PVSB*	*PVSu*	*PVSB*/Ha	*PVSu*/Ha
0		$1,090,766	$0	$5,920	$0
1	184.2	$1,494,600	$24,491	$4,506	$74
2	331.7	$497,425	$83,833	$2,821	$475
3	176.3	$213,459	$60,225	$2,283	$644
4	93.5	$43,717	$0	$3,644	$0
5	12.0	$0	$0	-	-
6	0.0	$60,500	$69,219	$1,192	$1,364
7	50.8	$74,578	$95,534	$996	$1,276
8	74.9	$171,294	$80,532	$1,651	$776
9	103.8	$83,415	$123,549	$949	$1,405
10	87.9	$0	$0	-	-
11	0.0	$2,664	$12,885	$475	$2,299
12	5.6	$10,962	$74,080	$317	$2,142
13	34.6	$0	$0	-	-
14	0.0	$26,991	$158,430	$399	$2,343
15	67.6				

6.2.4 Constraints Review

The optimal solution in the three discounting scenarios achieved the resources limitation stated for the problem. The following analysis shows evidence of feasibility and optimality of the solutions.

- Constraint 1: Annual Budget Limitation in the PINFOR program (*C1*)

Figures 22, 23 and 24 showed the allocation of subsidies in each period. As seen, the highest amount of financial assistance to be delivered corresponds to particularly that in the period 14 of the discounting scenario SP1014 whose value equals $158,430. This value is 12.5% of the total annual available budget of the program. According to this, the budget constraint of the problem was met as none of the subsidy amounts exceed 12.5% of the program's annual budget within the specific simulated scenario of projects generated through the study. It can be also stated that probably this constraint is not binding in the problem's solution because of the broad gap between the annual subsidy allocation suggested by the solution and the budget available.

- Constraint 2: Non-Declining Planted Forest Cover (*C2*)

Figure 26 shows the yearly total planted area resulting from the annual establishment strategy suggested by the optimal solution in each of the three discounting scenarios. As seen, the three scenarios show similar trend in the cumulative allocation of area in such a way that each period has a total area of growing teak bigger than the previous one.

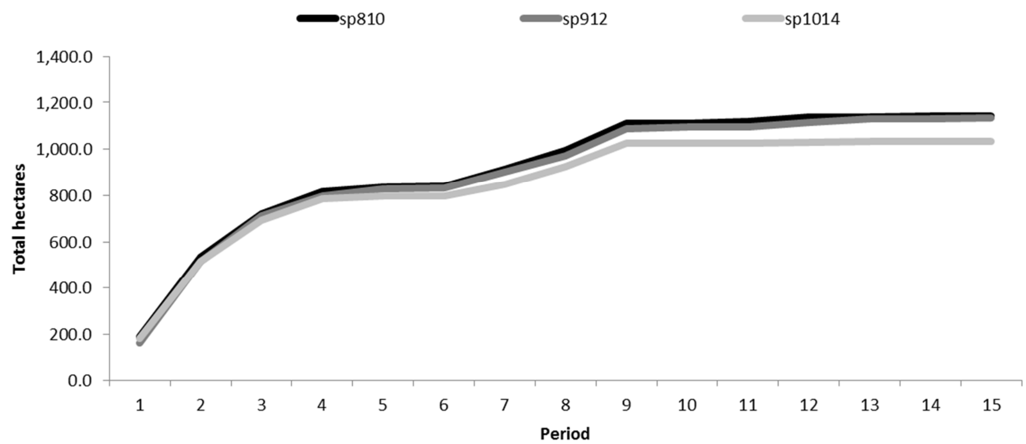

Figure 26. Non-declining total planted area along the planning horizon

- Constraint 3: Non-Declining Employment Flow (*C3*)

The requirement of non-declining employment flow over time is met in the optimal solutions of the three discounting scenarios. Similarly to the non-declining forest cover constraint, non-declining employment flow trend is similar in the three discounting scenarios. Figure 27 shows the long-term employment flow resulting from the optimal allocation of projects in the regional teak strategy modeled in the three discounting scenario.

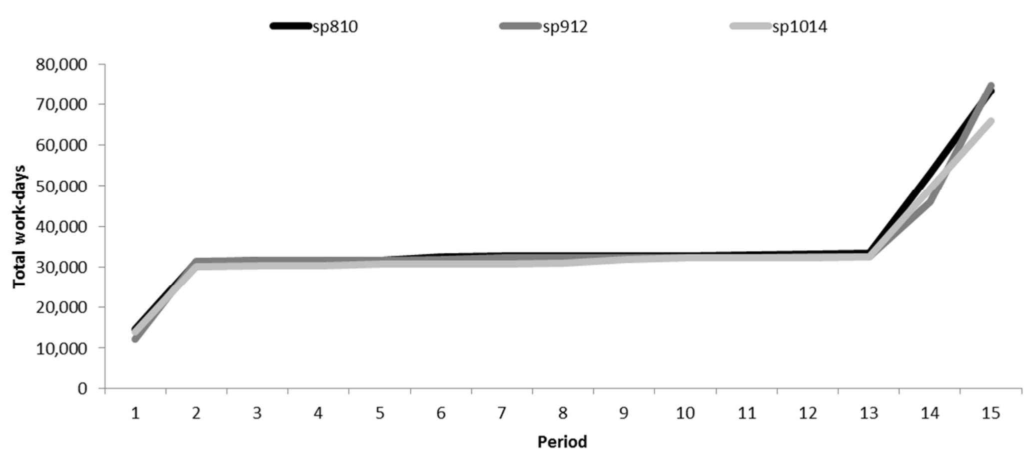

Figure 27. Non-declining employment flow along the planning horizon

- Constraints 4 and 5: One Rotation Only and Allocation Just Once (*C4* and *C5*)

The number of projects selected from the economic assessment in each discounting scenario was part of the model formulation in each case (see Table 5.1 for details on the number of projects per scenario). As a result of the optimal allocation, each project was independently assigned to a period and to a rotation regime, and no one repeated or duplicated in the assignment. Tables 6.8, 6.9 and 6.10 show the project-by-project detail of the optimal allocation in each discounting scenario.

Table 6.8. Project-by-project optimal allocation according to the discounting scenario SP810

Project ID	Period Assigned	Rotation Age	Rotation Regime
A001/S2/SCC3/TR3/PPC2	8	11	Single
A003/S2/SCC3/TR1/PPC3	2	11	Single
A004/S1/SCC2/TR2/PPC2	2	14	Single
A005/S1/SCC3/TR2/PPC2	3	14	Single
A006/S1/SCC1/TR2/PPC2	2	14	Single
A007/S1/SCC2/TR3/PPC1	1	14	Multiple
A008/S1/SCC1/TR1/PPC2	1	14	Multiple
A010/S1/SCC2/TR1/PPC1	1	14	Multiple
A012/S1/SCC1/TR3/PPC1	1	14	Multiple
A013/S1/SCC1/TR3/PPC2	1	14	Multiple
A014/S1/SCC1/TR3/PPC1	1	14	Multiple
A015/S1/SCC2/TR1/PPC3	1	14	Single
A016/S1/SCC1/TR1/PPC1	1	14	Multiple
A017/S1/SCC3/TR3/PPC1	1	14	Multiple
A018/S1/SCC3/TR2/PPC2	2	14	Single
A019/S3/SCC1/TR2/PPC3	12	12	Single
A022/S1/SCC2/TR3/PPC3	1	14	Single
A023/S1/SCC2/TR1/PPC3	1	14	Single
A026/S1/SCC3/TR3/PPC3	2	14	Single
A029/S2/SCC2/TR1/PPC2	1	11	Single
A030/S2/SCC2/TR3/PPC1	10	11	Single
A035/S1/SCC1/TR1/PPC1	1	14	Multiple
A036/S1/SCC1/TR2/PPC1	1	14	Multiple
A037/S1/SCC1/TR2/PPC2	2	14	Single
A038/S1/SCC3/TR3/PPC3	3	14	Single
A039/S1/SCC2/TR1/PPC1	1	14	Multiple
A040/S1/SCC3/TR1/PPC2	2	14	Single
A041/S3/SCC2/TR3/PPC3	15	12	Single
A043/S1/SCC3/TR2/PPC3	2	14	Single
A044/S1/SCC2/TR1/PPC2	1	14	Single
A047/S1/SCC2/TR3/PPC2	1	14	Single
A051/S1/SCC1/TR3/PPC3	2	14	Single
A052/S2/SCC2/TR1/PPC2	13	10	Single
A053/S1/SCC1/TR1/PPC2	2	14	Single
A055/S2/SCC1/TR2/PPC2	9	10	Single
A057/S2/SCC3/TR2/PPC2	14	10	Single
A058/S2/SCC1/TR2/PPC3	3	10	Single
A061/S1/SCC1/TR3/PPC2	2	14	Single

A067/S2/SCC1/TR1/PPC3	4	10	Single
A069/S1/SCC3/TR3/PPC2	2	14	Single
A070/S1/SCC1/TR2/PPC2	4	14	Single
A071/S1/SCC1/TR1/PPC3	2	14	Single
A074/S1/SCC1/TR2/PPC1	4	14	Single
A075/S1/SCC3/TR2/PPC1	7	14	Single
A077/S2/SCC1/TR1/PPC2	11	10	Single
A078/S1/SCC3/TR2/PPC3	3	14	Single
A080/S2/SCC1/TR3/PPC1	15	10	Single
A081/S1/SCC1/TR2/PPC3	15	14	Single
A082/S2/SCC2/TR1/PPC3	3	10	Single
A083/S2/SCC3/TR1/PPC3	7	10	Single
A085/S2/SCC2/TR3/PPC3	13	10	Single
A086/S2/SCC2/TR1/PPC3	15	10	Single
A087/S2/SCC1/TR1/PPC3	3	10	Single
A099/S1/SCC2/TR3/PPC2	3	14	Single
A100/S1/SCC1/TR2/PPC1	9	14	Single
A101/S1/SCC1/TR2/PPC3	2	14	Single
A104/S1/SCC3/TR3/PPC3	3	14	Single
A105/S1/SCC2/TR2/PPC3	6	14	Single
A106/S1/SCC2/TR3/PPC3	2	14	Single
A107/S1/SCC2/TR3/PPC3	3	14	Single
A108/S2/SCC2/TR3/PPC3	8	10	Single
A110/S1/SCC1/TR3/PPC3	3	14	Single
A111/S1/SCC2/TR2/PPC3	3	14	Single
A112/S1/SCC2/TR1/PPC2	2	14	Single
A113/S1/SCC1/TR1/PPC1	3	14	Single
A114/S1/SCC1/TR2/PPC2	2	14	Single
A117/S1/SCC2/TR3/PPC1	3	14	Single
A119/S1/SCC3/TR3/PPC2	4	14	Single
A120/S1/SCC1/TR1/PPC1	3	14	Single
A121/S1/SCC3/TR1/PPC1	4	14	Single
A123/S1/SCC1/TR2/PPC3	2	14	Single
A126/S1/SCC1/TR3/PPC1	3	14	Single
A129/S1/SCC1/TR2/PPC2	4	14	Single
A131/S1/SCC1/TR3/PPC3	3	14	Single
A132/S1/SCC1/TR1/PPC1	4	14	Single
A133/S1/SCC3/TR2/PPC2	5	14	Single
A134/S1/SCC3/TR1/PPC1	7	14	Single
A136/S1/SCC3/TR2/PPC3	4	14	Single
A141/S1/SCC1/TR3/PPC3	3	14	Single
A148/S1/SCC1/TR2/PPC2	4	14	Single
A149/S1/SCC1/TR1/PPC1	4	14	Single
A151/S1/SCC1/TR3/PPC1	9	14	Single
A154/S1/SCC1/TR1/PPC1	4	14	Single
A155/S1/SCC2/TR2/PPC2	2	14	Single
A157/S1/SCC3/TR3/PPC3	4	14	Single
A158/S1/SCC3/TR2/PPC3	3	14	Single
A160/S1/SCC2/TR1/PPC2	7	14	Single
A164/S1/SCC2/TR3/PPC2	4	14	Single

Table 6.9. Project-by-project optimal allocation according to the discounting scenario SP912

Project ID	Period Assigned	Rotation Age	Rotation Regime
A001/S2/SCC3/TR3/PPC2	8	11	Single
A003/S2/SCC3/TR1/PPC3	1	11	Single
A004/S1/SCC2/TR2/PPC2	2	14	Single
A005/S1/SCC3/TR2/PPC2	2	14	Single
A006/S1/SCC1/TR2/PPC2	1	14	Single
A007/S1/SCC2/TR3/PPC1	1	14	Multiple
A008/S1/SCC1/TR1/PPC2	1	14	Single
A010/S1/SCC2/TR1/PPC1	1	14	Multiple
A012/S1/SCC1/TR3/PPC1	1	14	Multiple
A013/S1/SCC1/TR3/PPC2	1	14	Single
A014/S1/SCC1/TR3/PPC1	1	14	Multiple
A015/S1/SCC2/TR1/PPC3	1	14	Single
A016/S1/SCC1/TR1/PPC1	1	14	Multiple
A017/S1/SCC3/TR3/PPC1	3	14	Single
A018/S1/SCC3/TR2/PPC2	3	14	Single
A019/S3/SCC1/TR2/PPC3	12	12	Single
A022/S1/SCC2/TR3/PPC3	1	14	Single
A023/S1/SCC2/TR1/PPC3	2	14	Single
A026/S1/SCC3/TR3/PPC3	2	14	Single
A029/S2/SCC2/TR1/PPC2	1	11	Single
A030/S2/SCC2/TR3/PPC1	11	11	Single
A035/S1/SCC1/TR1/PPC1	1	14	Multiple
A036/S1/SCC1/TR2/PPC1	1	14	Multiple
A037/S1/SCC1/TR2/PPC2	2	14	Single
A038/S1/SCC3/TR3/PPC3	3	14	Single
A039/S1/SCC2/TR1/PPC1	1	14	Multiple
A040/S1/SCC3/TR1/PPC2	1	14	Single
A043/S1/SCC3/TR2/PPC3	2	14	Single
A044/S1/SCC2/TR1/PPC2	2	14	Single
A047/S1/SCC2/TR3/PPC2	1	14	Single
A051/S1/SCC1/TR3/PPC3	2	14	Single
A052/S2/SCC2/TR1/PPC2	15	10	Single
A053/S1/SCC1/TR1/PPC2	2	14	Single
A055/S2/SCC1/TR2/PPC2	9	10	Single
A058/S2/SCC1/TR2/PPC3	3	10	Single
A061/S1/SCC1/TR3/PPC2	3	14	Single
A067/S2/SCC1/TR1/PPC3	6	10	Single
A069/S1/SCC3/TR3/PPC2	3	14	Single
A070/S1/SCC1/TR2/PPC2	3	14	Single
A071/S1/SCC1/TR1/PPC3	2	14	Single
A074/S1/SCC1/TR2/PPC1	3	14	Single
A075/S1/SCC3/TR2/PPC1	7	14	Single
A077/S2/SCC1/TR1/PPC2	10	10	Single
A078/S1/SCC3/TR2/PPC3	2	14	Single
A081/S1/SCC1/TR2/PPC3	3	14	Single
A082/S2/SCC2/TR1/PPC3	15	10	Single
A083/S2/SCC3/TR1/PPC3	13	10	Single
A085/S2/SCC2/TR3/PPC3	15	10	Single
A086/S2/SCC2/TR1/PPC3	15	10	Single
A087/S2/SCC1/TR1/PPC3	13	10	Single
A099/S1/SCC2/TR3/PPC2	3	14	Single
A100/S1/SCC1/TR2/PPC1	9	14	Single
A101/S1/SCC1/TR2/PPC3	2	14	Single
A104/S1/SCC3/TR3/PPC3	4	14	Single
A105/S1/SCC2/TR2/PPC3	2	14	Single
A106/S1/SCC2/TR3/PPC3	3	14	Single
A107/S1/SCC2/TR3/PPC3	3	14	Single
A108/S2/SCC2/TR3/PPC3	13	10	Single

A110/S1/SCC1/TR3/PPC3	1	14	Single
A111/S1/SCC2/TR2/PPC3	4	14	Single
A112/S1/SCC2/TR1/PPC2	4	14	Single
A113/S1/SCC1/TR1/PPC1	3	14	Single
A114/S1/SCC1/TR2/PPC2	3	14	Single
A117/S1/SCC2/TR3/PPC1	4	14	Single
A119/S1/SCC3/TR3/PPC2	2	14	Single
A120/S1/SCC1/TR1/PPC1	3	14	Single
A121/S1/SCC3/TR1/PPC1	4	14	Single
A123/S1/SCC1/TR2/PPC3	3	14	Single
A126/S1/SCC1/TR3/PPC1	3	14	Single
A129/S1/SCC1/TR2/PPC2	3	14	Single
A131/S1/SCC1/TR3/PPC3	2	14	Single
A132/S1/SCC1/TR1/PPC1	2	14	Single
A133/S1/SCC3/TR2/PPC2	5	14	Single
A134/S1/SCC3/TR1/PPC1	7	14	Single
A136/S1/SCC3/TR2/PPC3	5	14	Single
A141/S1/SCC1/TR3/PPC3	3	14	Single
A148/S1/SCC1/TR2/PPC2	3	14	Single
A149/S1/SCC1/TR1/PPC1	3	14	Single
A151/S1/SCC1/TR3/PPC1	9	14	Single
A154/S1/SCC1/TR1/PPC1	4	14	Single
A155/S1/SCC2/TR2/PPC2	9	14	Single
A157/S1/SCC3/TR3/PPC3	4	14	Single
A158/S1/SCC3/TR2/PPC3	5	14	Single
A160/S1/SCC2/TR1/PPC2	15	14	Single
A164/S1/SCC2/TR3/PPC2	7	14	Single

Table 6.10. Project-by-project optimal allocation according to the discounting scenario SP1014

Project ID	Period Assigned	Rotation Age	Rotation Regime
A001/S2/SCC3/TR3/PPC2	8	10	Single
A003/S2/SCC3/TR1/PPC3	2	11	Single
A004/S1/SCC2/TR2/PPC2	1	9	Single
A005/S1/SCC3/TR2/PPC2	1	9	Single
A006/S1/SCC1/TR2/PPC2	1	9	Single
A007/S1/SCC2/TR3/PPC1	2	14	Single
A008/S1/SCC1/TR1/PPC2	1	14	Single
A010/S1/SCC2/TR1/PPC1	1	14	Multiple
A012/S1/SCC1/TR3/PPC1	1	14	Multiple
A013/S1/SCC1/TR3/PPC2	1	14	Single
A014/S1/SCC1/TR3/PPC1	2	14	Single
A015/S1/SCC2/TR1/PPC3	2	14	Single
A016/S1/SCC1/TR1/PPC1	1	14	Multiple
A017/S1/SCC3/TR3/PPC1	2	14	Single
A018/S1/SCC3/TR2/PPC2	3	9	Single
A019/S3/SCC1/TR2/PPC3	13	12	Single
A022/S1/SCC2/TR3/PPC3	2	14	Single
A023/S1/SCC2/TR1/PPC3	1	14	Single
A026/S1/SCC3/TR3/PPC3	2	14	Single
A029/S2/SCC2/TR1/PPC2	2	11	Single
A030/S2/SCC2/TR3/PPC1	10	10	Single
A035/S1/SCC1/TR1/PPC1	2	14	Single
A036/S1/SCC1/TR2/PPC1	3	14	Single
A037/S1/SCC1/TR2/PPC2	1	14	Single
A038/S1/SCC3/TR3/PPC3	2	14	Single
A039/S1/SCC2/TR1/PPC1	2	14	Single
A040/S1/SCC3/TR1/PPC2	2	14	Single
A043/S1/SCC3/TR2/PPC3	2	14	Single
A044/S1/SCC2/TR1/PPC2	2	14	Single

A047/S1/SCC2/TR3/PPC2	1	14	Single
A051/S1/SCC1/TR3/PPC3	2	14	Single
A052/S2/SCC2/TR1/PPC2	15	10	Single
A053/S1/SCC1/TR1/PPC2	2	14	Single
A055/S2/SCC1/TR2/PPC2	10	10	Single
A058/S2/SCC1/TR2/PPC3	3	10	Single
A061/S1/SCC1/TR3/PPC2	2	14	Single
A067/S2/SCC1/TR1/PPC3	3	10	Single
A069/S1/SCC3/TR3/PPC2	3	14	Single
A070/S1/SCC1/TR2/PPC2	3	14	Single
A071/S1/SCC1/TR1/PPC3	2	14	Single
A074/S1/SCC1/TR2/PPC1	3	14	Single
A075/S1/SCC3/TR2/PPC1	7	14	Single
A077/S2/SCC1/TR1/PPC2	10	10	Single
A078/S1/SCC3/TR2/PPC3	2	14	Single
A081/S1/SCC1/TR2/PPC3	2	14	Single
A082/S2/SCC2/TR1/PPC3	3	10	Single
A083/S2/SCC3/TR1/PPC3	15	10	Single
A085/S2/SCC2/TR3/PPC3	12	10	Single
A086/S2/SCC2/TR1/PPC3	15	10	Single
A087/S2/SCC1/TR1/PPC3	10	10	Single
A099/S1/SCC2/TR3/PPC2	3	14	Single
A100/S1/SCC1/TR2/PPC1	9	14	Single
A101/S1/SCC1/TR2/PPC3	3	14	Single
A104/S1/SCC3/TR3/PPC3	3	14	Single
A105/S1/SCC2/TR2/PPC3	3	14	Single
A106/S1/SCC2/TR3/PPC3	3	14	Single
A107/S1/SCC2/TR3/PPC3	2	14	Single
A108/S2/SCC2/TR3/PPC3	9	10	Single
A110/S1/SCC1/TR3/PPC3	2	14	Single
A111/S1/SCC2/TR2/PPC3	3	14	Single
A112/S1/SCC2/TR1/PPC2	3	14	Single
A113/S1/SCC1/TR1/PPC1	3	14	Single
A114/S1/SCC1/TR2/PPC2	3	14	Single
A117/S1/SCC2/TR3/PPC1	2	14	Single
A119/S1/SCC3/TR3/PPC2	4	14	Single
A120/S1/SCC1/TR1/PPC1	3	14	Single
A121/S1/SCC3/TR1/PPC1	3	14	Single
A123/S1/SCC1/TR2/PPC3	2	14	Single
A126/S1/SCC1/TR3/PPC1	4	14	Single
A129/S1/SCC1/TR2/PPC2	4	14	Single
A131/S1/SCC1/TR3/PPC3	5	14	Single
A132/S1/SCC1/TR1/PPC1	3	14	Single
A133/S1/SCC3/TR2/PPC2	10	14	Single
A134/S1/SCC3/TR1/PPC1	10	14	Single
A136/S1/SCC3/TR2/PPC3	10	14	Single
A141/S1/SCC1/TR3/PPC3	4	14	Single
A148/S1/SCC1/TR2/PPC2	10	14	Single
A149/S1/SCC1/TR1/PPC1	10	14	Single
A151/S1/SCC1/TR3/PPC1	4	14	Single
A154/S1/SCC1/TR1/PPC1	10	14	Single
A155/S1/SCC2/TR2/PPC2	12	14	Single
A157/S1/SCC3/TR3/PPC3	4	14	Single
A158/S1/SCC3/TR2/PPC3	10	14	Single
A160/S1/SCC2/TR1/PPC2	7	14	Single
A164/S1/SCC2/TR3/PPC2	8	14	Single

6.2.5 Spatial Allocation

By performing a GIS analysis to identify the project allocation spatially in Region 9, the following results were obtained in each discounting scenario. Figures 28 to 33 show the summary maps in next sections.

- Allocation to Periods

Figures 28, 29 and 30 show the spatial allocation into periods in the three discounting scenarios modeled. It is important to mention that the polygon areas do not represent project areas; they just represent spatial location of the future projects simulated for the region. Thus interpretation of the spatial allocation must be addressed towards geographic distribution rather than towards magnitude-related conclusions.

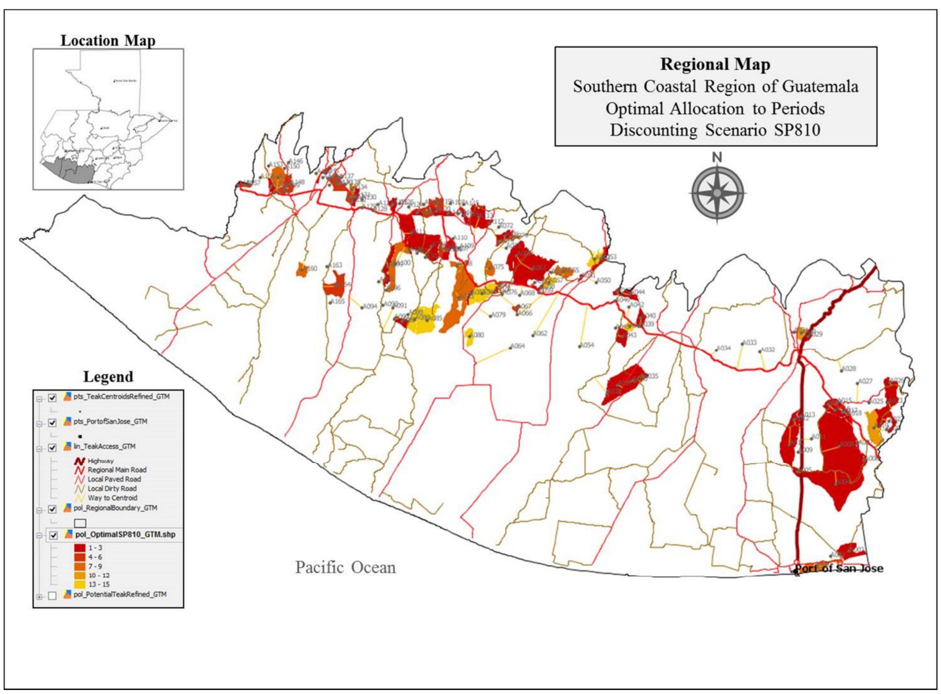

Figure 28. Regional map of the optimal allocation of simulated projects by three year intervals in the discounting scenario SP810

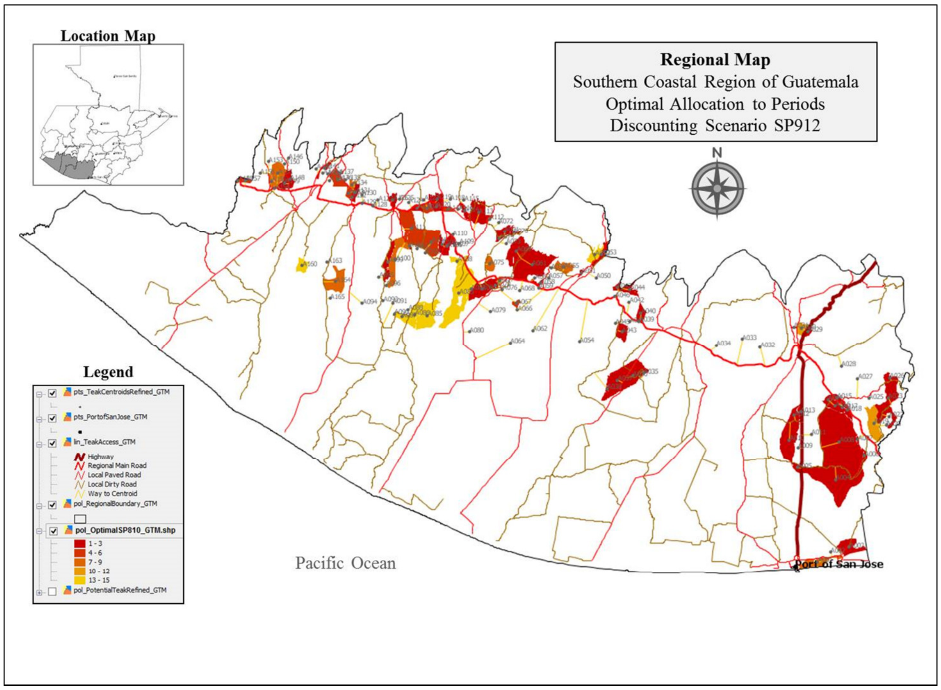

Figure 29. Regional map of the optimal allocation of simulated projects by three year intervals in the discounting scenario SP912

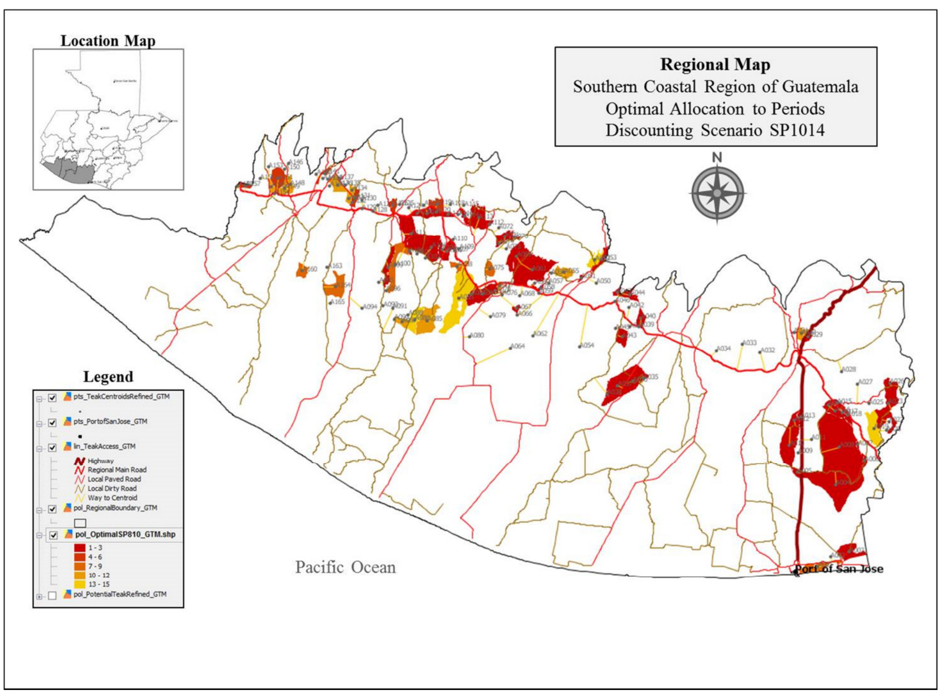

Figure 30. Regional map of the optimal allocation of simulated projects by three year intervals in the discounting scenario SP1014

Although changes in the allocation of projects to periods are subtle, they exist. A closer look at the polygons indicates that some of them report a period change beyond a 3 year interval. In general terms, this change occurs more likely in further polygons rather than in closer polygons respect to the destination port. Regarding the direction of the change, it is not so clear if a change in the discounting scenario from lower to higher promotes a change of period from earlier to later or vice versa. Actually, some of the polygons changed to a later period when the discounting scenario moved from SP810 to SP912, and then they change back to an earlier period when the discounting scenario moved from SP912 to SP1014. According to this, it is not easy to state a change direction of the optimal allocation into periods when there is a change in the discounting scenario in which the economic assessment is performed.

- Allocation to Rotation Regimes

Figures 31, 32 and 33 show the spatial allocation of simulated projects to rotation regimes in the three discounting scenarios modeled. This analysis sets the basis to understand the effect of a changing discounting scenario in the economic assessment of projects regarding the long-term projection of land use. This is a relevant aspect of the study in the sense that the option of allocating land into teak use perpetually might depend on the spatial features of the project.

Several observations can be inferred from this analysis. At first, very few projects were allocated to a multiple rotations regime. This regional phenomenon may be explained by the economic effect of the land resale in the single rotation regime and opportunity cost of the land which becomes a strong financial burden as a project inflows have to cover it perpetually under this rotation regime. Probably a land purchase price class value of $2,667 per hectare becomes affordable for teak projects in the long term, but land price class values of $5,000 and $7,333 per hectare happen to be unaffordable when silviculture is expensive and site quality is not high. This is the case that represents several projects in which a single rotation regime is more suitable given the high cost burden over time and the important inflow obtained from reselling the tract (projects simulated in the polygons A001, A003 and A019, where the NPV_s indicator is strongly superior compared to the LEV_s indicator, are good examples of this). The phenomenon is present in all the discounting scenarios modeled.

Second, and associated to that explained before, the effect of a change in the discounting scenario from lower to higher reduces the number of projects to be allocated into a multiple rotations regime. Analogously to the effect of the both inflow and opportunity cost of land, higher discount rates promote allocation more likely in the short term rather than in the long term, so perpetual investments with high financial burden tend to be displaced. In this case, the effect shown is the massive allocation of projects into the single rotation regime.

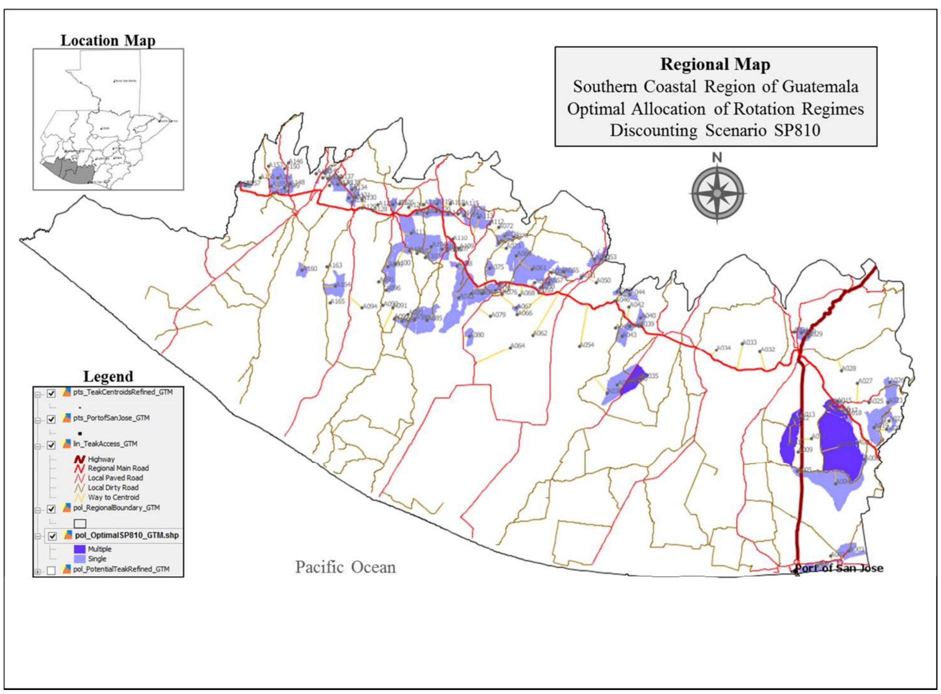

Figure 31. Regional map of the optimal allocation of simulated projects to single or multiple rotations regime in the discounting scenario SP810

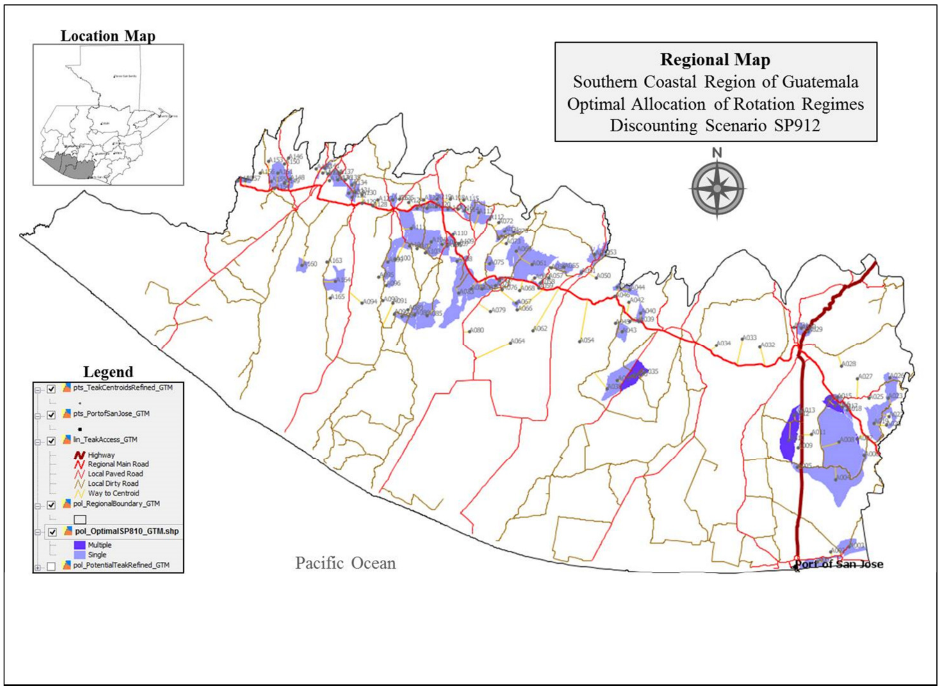

Figure 32. Regional map of the optimal allocation of simulated projects to single or multiple rotations regime in the discounting scenario SP912

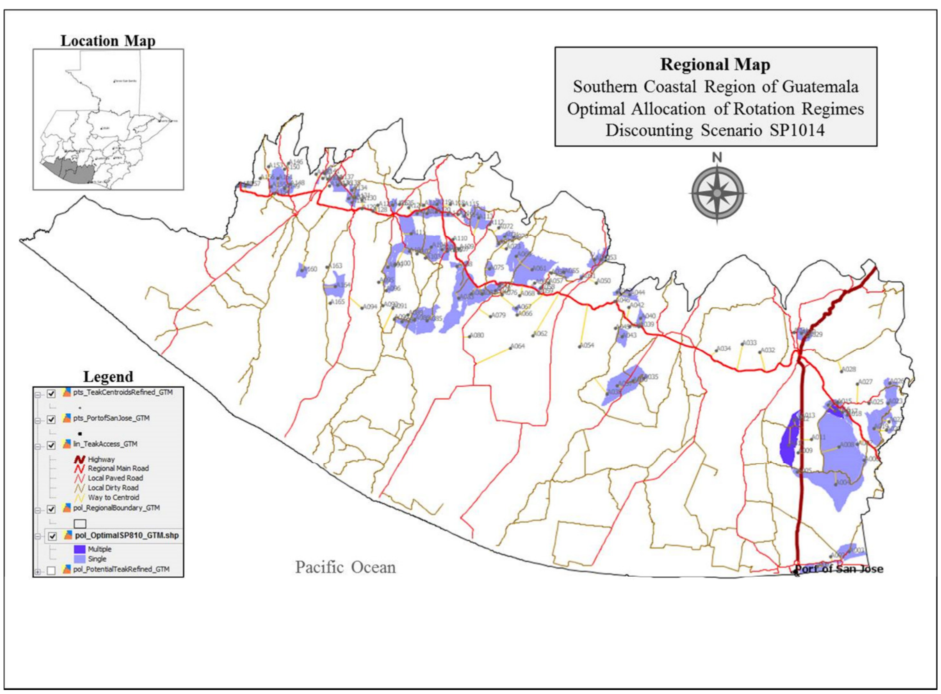

Figure 33. Regional map of the optimal allocation of simulated projects to single or multiple rotations regime in the discounting scenario SP1014

Third, all the projects allocated into multiple rotations regimes are close to the destination port. No project far from the port was allocated to this regime. Yet the reduction reported by the change in the discounting scenario from lower to higher had a systematic behavior according to the location respect the port: the further the project, the more preferred in the change of its rotation regime from multiple to single.

Finally, there is an effect of the discounting scenario in the optimal rotation length. This is not shown in the maps, but by inspecting the database of projects' optimal financial rotation age it is possible to check that the higher the discounting rate, the shorter the optimal rotation length. This is more evident in the change from the discounting scenario SP912 to SP1014 in which some projects reduced their optimal financial rotation age from 14 to 9 years (projects simulated for the polygons A004 and A006 are good examples of this). The argument to explain this phenomenon is similar to that mentioned previously about the time preference related to the change of discount rates.

6.3 Removal of Forest Cover and Employment Constraints

As part of the sensitivity analysis, the optimal solution of an unconstrained version of the model was run and obtained. The unconstrained problem was defined as the allocation of subsidies among simulated projects of teak in Region 9 of Guatemala not considering both non-declining forest cover and non-declining employment flow constraints along 15 year of planning horizon. The aim of getting the optimal solution of the unconstrained problem was basically to quantify the change (expected to be a loss) in the present value of the overall contribution to social benefits of the simulated projects due to forcing the long-term regional strategy to generate social and environmental positive impacts from future teak activity.

Although quantification of the change in the *PVOCSB* from the teak strategy was the main objective of running the unconstrained problem, the alternative unconstrained allocation of projects into periods and rotation regimes was also expected as result. Anyway, it was predictable that, if there were no budget issues in the allocation, the discounting nature of the objective function would tend to allocate all the projects as soon as possible and according to the best rotation regime regarding the LEV_s value in comparison to the single rotation's NPV_s value.

Table 6.11 shows the results of the optimal solution of the unconstrained problem according to the three discounting scenarios modeled compared to the constrained models' optimal solution.

Table 6.11. Optimal solution of the unconstrained problem and estimation of change of the OF value due to removal of forest cover and employment constraints

Discounting scenario	SP810	SP912	SP1014
OF value – Constrained Model	$5,575,586	$4,277,196	$3,250,064
OF value – Unconstrained Model	$6,443,174	$5,001,588	$3,775,256
Change $	+$867,588	+$724,392	+525,192
Change %	+15.6%	+16.9%	+16.1%

Table 6.12 shows a summary of the optimal allocation of projects in the unconstrained problem. As expected, all the projects were allocated into period 1 because there was no budget limitation enough to restrict full subsidy delivery in that period.

Table 6.12. Summary of the optimal allocation of projects into periods and rotation regimes in the unconstrained problem

Discounting scenario	SP810	SP912	SP1014
Total amount of projects	88	85	85
Allocated into period 1	88	85	85
Allocated into single rotation	81	81	85
Allocated into multiple rotation	7	4	0

7 Discussion

Results are a reflection of a rational method for the optimal allocation of public funds into teak projects through the PINFOR program in the Southern-Coastal region of Guatemala. In practical terms, a straight interpretation of the results is as follows:

According to the particular pool of projects simulated through the study as potential future teak plantations within Region 9, an optimal long-term economic contribution to social benefits ranges between US$3,250,064 and US$5,575,586 of discounted social return. It would be obtained by allocating between 1,223 and 1,243 hectares of land into teak use within the next fifteen years. This particular optimal allocation strategy would require less than 12% of the PINFOR program annual budget assigned as subsidies among teak projects that are socially profitable but privately unprofitable considering local conditions of site quality, silviculture, timber production and land market commonly found in the region. An annual average public investment that ranges between US$17,082 and US$52,185 would be required for a pool of 101 potential applicants from which only a fraction reports contribution to social profitability and, simultaneously, investment deficit (thus a financial need) to perform the investment. These future potential applicants would apply to teak projects of between 0.7 and 93.6 hectares of size, so they belong to the local social segment of NIPF landowners. An annual average establishment rate of 82 hectares would be expected according to the optimal allocation over time, but with a strong concentration of projects in the first three periods of the planning horizon. In context with the optimal solution for the allocation of the 101 projects (which have to be economically assessed and selected previously according to the social profitability criterion), few projects are selected and allocated to a multiple rotations regime in which the perpetual land use in forestry would happen. Conversely, most of them are allocated into a single rotation regime implementable by scheduling an optimal financial rotation length calculated case by case. Finally, by implementing the establishment strategy according to the particular optimal solution provided by the model, a non-declining local employment flow and a non-declining total planted forest cover within the period 2014-2028 will be obtained. Variability of the results and indicators strongly depends on the discount rates employed in the projects' economic assessment; as general rule, it was checked that both the best overall social return obtained from the projects and the overall financial requirement of projects enrolled in the program rely on social and private discount rates that range between [8%; 10%] and [10%; 14%] respectively.

The optimal solution found through the economic assessment and the multi-period MILP-based optimization model designed and run throughout the study was constrained to specific conditions and assumptions. Discussion of the results starts at this point. Discussion focused on three main aspects of the methodology proposed: general assumptions of the forest investment analysis performed (in which assumptions taken form Gregersen *et al.*'s economic model gain importance), the factors that affect the economic assessment (whose outcomes have direct influence on the model coefficients) and the sensitivity analysis performed from the unconstrained model.

7.1 General Assumptions and Considerations of the Forest Investment Analysis

The economic assessment based on the Gregersen *et al.*'s methodology to rank projects according to their economic performance takes on several general assumptions mostly related with the forest investment analysis, the non-industrial private forest owner behavior and the regulations that drive the way in which the PINFOR program delivers the funds. They are:

- The pool of project evaluated and included in the subsidy allocation methodology was the result of testing a project simulation and a spatial analysis performed through stochastic assignment of size, location (site quality class), silvicultural regime, timber production regime and land market class as a way of projecting a potential future teak reality within the region. It was assumed that these conditions, whose features were the result of a comprehensive regional research about forest management, represent as realistic as possible, future scenarios of project enrollment in the PINFOR program.

- There is an economic contribution to society in the development of forest projects that is possible to quantify. If a certain project is socially profitable, then it would be socially desirable to support it, otherwise it would not.

- Among all the options, some projects would be socially profitable but privately unprofitable. In this case, and in order to promote effective development, a certain financial support would be needed to make them possible. The financial need is assumed to be quantifiable.

- As a financial support is available to assist projects socially profitable but privately unprofitable (e.g. through a forest subsidies program), landowners can estimate their corresponding financial need and, then, apply for the assistance.

- Once landowners get the financial assistance according to the estimate of the financial aid that would make the project privately profitable, the landowner would carry out the forest investment effectively. Delivery of funds to cover the investment deficit that makes the project privately unprofitable would be the driver that would induce the investment. It is assumed the landowner to behave in an economically rational way once the funds are obtained.

- Economic analysis is established according to an *ex-ante* approach. In this sense, the economic assessment and the optimization model become together an articulated tool to assist future allocation of funding among projects socially profitable but privately unprofitable. It is assumed that any other project already granted by an existing forest subsidies program would not be part of the funding allocation strategy from the model as they were (supposedly) part of a prior *ex-post* analysis.

- Allocation of funds according to the forest investment analysis performed using a stochastic simulation of projects, a regional spatial analysis, an economic assessment and an optimization model presents a simulated local forest reality for the regional forestry. It was assumed as part of the study foundation that similar reality could be found in the near future, so results are valid to get adequate insights of the subsidy allocation problem in Guatemala.

- It has been observed that the way in which the Guatemalan PINFOR program delivers funds doesn't match with that proposed by the study's funding allocation strategy. In the first case, a total payment of US$1,800-1,900 per hectare is delivered in six partial payments after the second year of the plantation's life regardless of considerations about site quality, land market, silviculture and timber production; financially speaking, its present value is US$1,278 per hectare at 10 percent discount rate, US$1,205 per hectare at 12 percent private discount rate, and US$1,138 per hectare at 14 percent private discount rate. In the second case, financial need of the projects selected by the funding allocation strategy is variable and ranges between US$0 and: US$2,433 per hectare at 10 percent discount rate, US$2,388 per hectare at 12 percent discount rate, and US$2,603 per hectare at 14% private discount rate. This inconsistency suggests a complementary research to perform the following analyses[48]:

  - Effectiveness analysis of the PINFOR program's current funding allocation strategy;

  - Efficiency analysis of the public investment performed through the PINFOR program;

  - Case-by-case *ex-post* economic analysis of projects granted by the PINFOR program prior to 2014;

[48] All the analysis suggested are beyond the scope of this study. It is strongly recommended to perform these analyses in order to complement the study results in a broader scope.

- Analysis of financial need (or investment deficit) of forest investments in a regional framework throughout the country.

- It was assumed that all the preventive and protective measures to avoid loss of value of the projects simulated are implemented. Gregersen *et al.* (1979) stated a similar warning when evaluated the 1974 FIP in Minnesota: "all of the increased timber production associated with the program will be available for harvest when it becomes financially mature, assuming that there would be no impact caused by fire, diseases, pest attack or even change in the willingness to sell at the prices of the analysis or in the new owners' intentions".

- As stated by Harou (1984), an improved societal analysis of benefits and costs of the potential forestry projects could be made. By including the best estimations of the opportunity cost for all the inputs and the willingness to pay for all the outputs in a social profitability calculation similarly to that of a financial analysis (but employing the social discount rate already defined), the economic assessment would appraise the projects in a more complete way. However, a social profitability analysis could become a non-easy task especially in the part of the economic evaluation of externalities associated to forestry projects. The analysis, then, constitutes a complementary research work by itself and becomes beyond of the scope of this study.

7.2 Variables of the Economic Assessment

In the prior section, general assumptions about the problem statement and the way in which the solution was sought were discussed. In this section, specific economic aspects considered of major relevance were discussed as part of the sensitivity analysis of the results. However, it is important to recall at this point that the main purpose of the study was to provide a rational, objective methodology to orient the allocation of long-term funding by including the variables discussed in the following sections as structural components of the model. Analyzing accuracy of the data sources of variability is beyond the scope of this study.

- Discount rates

Social, private, alternative and land rates of return are important variables that modify the economic performance of a forest project evaluated through forest investment analysis. There is no general consensus about the right way to define the social discount rate. Higher social discount rates downplay future allocation of resources favoring the short term instead of the long term. According to Gregersen *et al.* (1979), the magnitude of the net present social value is particularly sensitive to the social discount rate. This was checked through the study indeed. While a variety of arguments can be set to defend the usage of lower rates for social evaluation of forestry projects, they cannot be considered as a special case of public investment to justify the use of lower rates. In developing countries like Guatemala this is especially applicable.

As the main objective stated for this study was to generate a methodology based upon an economic assessment and an optimization model to helps allocate funds coming from a forest subsidies program into long-term forest projects in an optimal way, it was interesting to analyze the effect of different discounting scenarios in the optimal allocation. Discount rates in the study used are those that more likely represent the discounting scenarios in Guatemala for evaluating forestry business. In the author's opinion, it would difficult to find private discount rates lower than 10 percent or higher than 14% in teak project evaluations or appraisals. And according to the expert's opinion and the literature review, the social discount rates used in the study represent societal time preference in adequate way for a developing country like Guatemala.

A change in the private discount rate changed the NPV_f, NPV_r, LEV_f and LEV_r value and, in some cases, the optimal rotation age of projects. It altered variables such as the long-term financial inflow-outflow balance, the individual overall employment generation flow of projects and, finally, the estimate of the investment deficit that would make the forest investment privately profitable. This affected the identification and selection process of projects socially profitable but privately unprofitable and, in the end, the model formulation.

A change in the alternative rate of return was beyond the scope of the study, so there are no results in this regard. But if applicable, it would change the forest investment analysis outcome as it would affect the opportunity costs (land and operational expenditure). Similarly to the case of the private discount rate, it would alter the identification and selection process of projects socially profitable but privately unprofitable.

A change in the land rate of return (or specifically in the purchase price increase rate) was beyond the scope of the study, so there are no results in this regard. But if applicable, it would produce a change in the resale price of the land what would modify the project inflow at the end of the rotation. This would affect the investment analysis when the land use and property resale is included as part of the financial flow. Similarly to the both previous cases, it would alter the identification and selection process of projects socially profitable but privately unprofitable.

As general comment about the effect of the different discounting scenarios modeled in the study, it can be stated that as the discounting scenario gets higher (e.g., from SP810 to SP1014), the number of projects that are selectable as socially profitable in the economic assessment are reduced. The allocation of projects to periods changes in a direction that is not clearly predictable. As the overall contribution to long-term social benefits gets lower, the allocation to single rotation becomes more preferable, the allocation to multiple rotations is less probable, the annual allocation of financial assistance gets higher and the area allocated to teak projects is reduced.

- Silviculture and timber production regimes

Cost-based analysis of silvicultural and production regimes were evaluated using information collected among local sources. Nonetheless, variability and uncertainty is present in cost estimations. A list of variability and uncertainty sources for the variables employed in the economic assessment of projects that were not considered as part of the analysis are discussed below.

- Inflation: The CAPM excludes inflation factor in the calculation. The assumption is that the "real" discount rate is being used.

- Labor cost increase: the national labor cost in Guatemala is adjusted annually. However, while labor cost increase should behave according to inflation, adjustment magnitude depends on the political scenario year-by-year. Because of this, an increase rate of the local labor cost was not included in the economic analysis as there is true uncertainty about it in the long-term.

- Timber production technology: as explained in the Chapter 4.8 'Timber Production Features in Teak Plantations of Guatemala', it is expected an upgraded forest production technology and improvements in the road infrastructure to be implemented in the future. Production cost employed in the analysis reflects the current basic technology of timber production of the country which assumes slightly upgraded mechanized production technology. In the same context, transportation cost was calculated according to estimated distances, transit velocity, transport configuration and a pre-defined hauling truck type. If these conditions change in a near future, economic assessment of project will have changes, so the optimal allocation of projects and subsidies could change too.

- Land market: regional land market happens to be distorted apparently because of the effect of the intensive agricultural development of the region. This is evident by inspecting the wide range of purchase prices from the local information. In context with the contribution to long-term social benefits, the rule becomes clear: the methodology allocates projects with the highest unit social return first (or earlier) regardless of the land market class, which is comparable to the criteria employed by Gregersen *et al.*'s methodology applied over the economic assessment of the 1974 FIP in Minnesota. Regarding the effect of the land market class of a project in the allocation, it may be stated that the model would allocate projects earlier in cases in which the opportunity cost of land is not a key factor affecting the contribution to social benefits. A good example of this is the high likelihood of the model to allocate projects into single rotation regime rather than multiple rotations when the opportunity cost of the land becomes a heavy financial burden for the project.

- Administration, tax, interest and depreciation/amortization costs: as stated in the Chapter 4.5 'Data Collection', administrative and non-operational costs were not considered as part of the economic assessment. Reasons for that were clearly described in the chapter and can be summarized in the fact that the methodology employed in the study prioritized operational cost in order to obtain the margin of contribution of forestry activities to administration, tax, interest and depreciation/amortization cost as they could not be structured in a homogenous pattern throughout the regional data collection. Interpretation of the results must be clear in this regard. However, a more complete forest investment analysis would result from the inclusion of these cost items as they are clearly identified in the projects' cost structure.

- Timber production yields

Estimation of timber yield in each site quality class was an important stage of the study. Production yields, and consequently sales income, are fundamental components of the forest investment analysis as they provided the basis for the calculation of the projects' optimal rotation age and financial inflow-outflow balance.

The information base for these estimations was provided by the INAB's growth monitoring program database, which was enriched with individual inventory databases of the sources. A total of 188 sample plots were processed develop inventory information for projecting growth and yields of future teak projects in the region. If the region currently has about 2,800 hectares of teak plantations, then the statistical sampling intensity measured as the area per sample plot becomes about 15 hectares per plot.

Although this value seems to reflect low sampling intensity given the high fragmentation degree and variability of the projects established through the PINFOR program until 2014, it provided statistical outcomes realistic enough to project timber yields in context with the study purpose. In this regard it is highly recommended to perform a detailed analysis of probability distribution of the growth and yield estimations of Teak projects established in the region in order to improve projections by incorporating confidence intervals' lower and upper limits of the parameters. This would provide a thorough sensitivity analysis to evaluate the way in which changes in the local timber growth and yields modify the long-term funding allocation strategy. Preliminarily, it can be stated that lower bounds of timber yield estimations will produce less sales inflow, and conversely upper bounds will produce larger sales inflow. Thus the economic performance of the projects would be affected (in one direction or another) what would induce changes in the projects' selection stage.

Another aspect of importance in a project's income projection are the product yields. In order to meet the purpose of the study and considering that it was not possible to gather local data about teak log grade distribution, a study from outside of Guatemala was employed. According to the author's experience and professional judgment, it is unlikely to find big differences between the non-Guatemalan teak's product grade distribution and the local one, so it was considered that the table of log grade distribution employed in the study was valid to meet the study objectives. Anyway, it is strongly recommended to perform local research about log grade yield of teak plantations countrywide.

Conclusions regarding the way in which this variable would affect the allocation strategy go in the same direction than those related to timber growth and yield: if the commercial management of the teak trees is oriented to produce more volume in bigger logs, the plantation will produce more valuable timber which will increase the sales income due to harvesting operations. This will modify the project selection process in the economic assessment stage as impact on rotation age and management intensity will occur.

As the usage of the data collected from the sources provided the research with adequate information to meet the objectives, it was stated that any complementary analysis of accuracy of the information was beyond the scope of the study.

- Sales prices projection

The estimation of FOB prices was carried out from data that came from log sales of the period 2007-2010 in Guatemala. No rate of price increase over time was included in the economic assessment of projects. In real terms, the economic assessment doesn't assume that prices will remain constant along the whole rotation. Actually they won't. However, in context with the opinion of some forest investors that have established important teak projects in the country, teak projects should stand by themselves at the current sales prices level regardless of what the future rate of price increase will be. Actually several forest investments in teak plantations have been economically evaluated without considering a rate of sales price increase[49].

By incorporating a rate of price increase in the economic assessment of projects it is expected that future income due to log sales increase as well, which alter the project selection process as economic indicators of profitability would improve. The actual direction of the change must be evaluated accurately: a higher income level means improved profitability from both the social and the private perspective. An improved social profitability is a desirable outcome, but an improved private profitability would make the project non-selectable from the investment deficit analysis standpoint. In this case, thus, there would be no justification to financially assist a project.

In the study context and under the conditions described, a variable number of projects happened to be selectable as some of them provide an actual contribution to long-term social benefits and account an investment deficit necessary to be covered in order to induce the investment; the number of projects in this condition strongly relied in the discounting scenario modeled (19 in SP810, 26 in SP912, and 46 in SP1014). If a rate of sales price increase is included in the economic assessment of the 101 simulated projects, probably some of the selected ones would be discarded and the investment deficit analysis would provide a less “needy” investment scenario. In such a case, the funding allocation strategy would change radically. This is an event that should be tested in depth by performing a complementary research work.

7.3 Sensitivity Analysis

The sensitivity analysis of the optimal solution was focused in the unconstrained problem specifically. The problem was run after relaxing the constraints that require non-declining forest cover and non-declining employment

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[49] Information taken from a lecture given by Roberto Montano, CEO of Green Millennium, company that operates the largest teak plantation developed in Guatemala.

flow within the planning horizon. Details can be found in previous sections 6.3 ‘Removal of Forest Cover and Employment Constraints’.

Due to the binary nature of the problem formulated, interpretation of the shadow price and reduced cost is not straight forward (Liao *et al.*, 2009). Future research about average shadow price instead of marginal contribution analysis in mixed integer linear programming problems (Crema, 1995) is highly recommended. Similarly, systematic iterations of the optimal solution by modifying project’s individual *NPV* or *LEV* to induce a variable enter the basis is also recommended as future research (Sessions, 2014; personal communication).

Regarding the unconstrained problem, it could be checked that there is a loss due to constraining the model to include environmental (non-declining forest cover over time) and direct social (non-declining employment flow over time) impacts. As stated in the formulation of the problem, Guatemalan Forest Policy declares as of national importance the inclusion of sustainable forest management principles in the development of local forestry. Positive environmental impact and employment generation from forest activity are desirable results expected to occur from any national strategy oriented to foster local forestry. However, nothing definite (in the practical sense) is stated in the law or in sectorial regulations about the way in which local forest institutions should implement forestry-based means to contribute to sectorial employment or to increase the environmental positive impact coming from planted forest over time.

Inclusion of employment and forest cover constraints was considered as a good way to provide the methodology (which drives the solution search mainly with economic indicators), with capabilities that ensure an effective result in increasing non-economic impacts. However, including non-economic aspects in the model formulation has an economic cost. A measure of this cost is shown in Table 6.10 for the three discounting scenarios modeled in the study. Cost expressed as loss of overall contribution of teak projects to long-term regional social benefits ranges between

15.6% and 16.9%. This means that between US$525,192 and US$867,588 of *PVOCSB* are lost due to ensuring positive environmental and direct social impacts provided by non-declining forest cover and non-declining employment generation over time. To avoid this loss it is necessary to eliminate the associated constraints in the model which results in allocation of all the selected simulated projects into the first period of the planning horizon. This is possible within the budget but it does not guarantee sustainability of local forestry.

8 Conclusions and Future Research

This research developed a model of economic assessment and optimization for the allocation of long-term public funds administered by the Guatemalan forest subsidy program (PINFOR) in teak projects of the Southern-Coastal region of Guatemala. The model can select among simulated projects to be theoretically enrolled in the program between 2014 and 2028. The most important contributions of the methodology proposed are that a rational economic criterion and a mechanism to objectively prioritize the allocation are developed in an analytical tool that currently does not exist in the Guatemalan forestry industry.

Based on a comprehensive review of global literature about performance of forest subsidies program, forest investment analysis, subsidies allocation, forestry policy, forest planning techniques and interrelated topics, the model developed here constitutes a pilot model to assist forest planning unique in its type in Latin American countries with emerging forest economies. The case study also provides an analytical methodology of potential systematic application in forestry that combines spatial analysis, economic and financial evaluation, investment analysis and an optimization technique to provide decision makers with strong orientation for the delivery of public funding addressed to promote forestry activities. The model may serve as a technical means to review current political drivers of the implementation of public funding to foster sectorial development. This way, the statement of "the more trees planted the better" may be no longer accepted as just a rhetoric dictum in Latin America.

The economic assessment and the optimization model were developed and formulated to become a technical tool based on a sound analytical methodology that could help administrators of the PINFOR program orient the assignment of usual limited budgets towards public forest investment in a socially and privately profitable manner. In order to make the model more complete and consistent with Guatemalan forestry reality and the local forestry policy, requirements of employment generation and non-declining total planted area in the long term were features incorporated as part of the model structure. The model's solutions identify an optimal solution for the allocation of funding among simulated future projects located in the Guatemalan Southern-Coastal region over fifteen years in the future. Information collected allowed this project to develop an economically-based model of the most commonly used silvicultural and timber production regimes in the Southern-Coastal region of Guatemala. The project also considered the most relevant regional land market features and their effect in the forest investment analysis. The result was development of a multi-period linear programming model built with local realistic variables, coefficients and constraints.

Although some values could be influenced by uncertainty and variability, they were considered as representative enough in their role of descriptors of the local forestry reality. In the same context, research outcomes were also considered as realistic and interpretable (eventually implementable locally). This is the first work in which a full economic evaluation of teak projects of the Southern-Coastal region of Guatemala is linked to an optimization technique in which economic indicators of forest investment are employed in the role of decision making drivers.

The methodological basis for the economic assessment of projects potentially subsidizable was provided by Gregersen *et al.*'s work of 1979 in which the 1974 FIP performance was analyzed in a study case of pine plantations in Minnesota. Gregersen *et al.*'s contribution was adapted to forest conditions of the Guatemalan Southern-Coastal region. It allowed the study develop a rational way to assess not only the private financial performance of teak projects within the region but also the social economic performance and the real financial requirement of them when evaluated under forest investment rationale. This methodology can be considered as one of the main contributions of the study. It is acknowledged in INAB and among the PINFOR program administrators that there is no economic assessment in the application of projects to the public benefit so far. Thus nothing can be declared in regard to private financial projections and social profitability due to the projects or long-term return to society due to the public investment related to the program in Guatemala. This research work contributes to the local knowledge by filling this gap.

As the methodology employed an *ex-ante* approach for the economic assessment of projects that currently does not exist, real projects should be identified and included as part of an actual economic assessment. The adaptation of Gregersen *et al.*'s work allowed the research to define stylized management regimes that represent what is likely to be found in the near future around silviculture and timber production of Guatemalan teak. This allowed the research to formulate a multi-period linear programming model that employs stylized, cost-based management classes assigned to simulated potential future teak projects and allocates them optimally in a problem environment of financial and spatial limitations.

Evidence of this is that an optimal (thus feasible) solution can be identified in the multi-period linear programming model formulation. In other words, the model is capable of allocating regional land to new teak projects by determining the time allocation and profitable rotation regime that will return the best social benefit to society in the long term. All this happening at the same time that allocation requirements and resource limitation are constraints effectively met.

The mathematical programming exercise solved the problem prioritizing among the selected projects regarding the magnitude of their economic contribution to social benefits and the estimation of the corresponding investment deficit. This resulted in the same pattern as the Gregersen *et al.* methodology which selects socially profitable projects and allocates funds to them by employing a case-by-case, manual mechanism.

Some conclusions derive from specific findings of the research. It is important to consider them as they provide important insights for future research or for the analysis of opportunities of improvement. Among the most important specific conclusion are:

- The current funding delivery scheme of the PINFOR program differs from that proposed by model results. The methodology proposes a project funding assignment which is variable, against the fixed amount provided by the PINFOR. It is important to consider this as an opportunity to review the current funding scheme rather than as a gap between the theoretical outcome and the current reality. Probably the final solution is in between in the sense that new public assistance mechanisms should be developed to assist socially and privately profitable projects wanting to enter the business with some support.

- In the same context, some proposed teak projects should be rejected even if funds are available. Politically this may sound questionable, but economically it provides rationale for an effective and efficient public funding program for forestry development. As said before, probably the right solution is in between of what is proposed and what is currently set.

- The Gregersen *et al*. methodology is improved by including sustainable forest management principles and a long-term strategy of funding allocation. It was interesting to check that the Gregersen *et al*. "by-hand" procedure oriented to select one-period projects matches with the inner selection criterion of the multi-period optimal allocation developed by the optimization model. It can be stated from here that an adequate economic criterion to allocate funding in order to maximize long-term social profitability should be based in prioritizing projects with higher profitability and low investment deficit, and leaving for later projects with opposite economic status.

- Among projects encountering similar economic performance, the magnitude of the financial aid depends on the discounting scenario (combination of social and private discount rates to assess the project) in which the economic assessment is performed and the rotation regime defined for the particular case.

- In this particular pool of projects and in this particular region, the land market features have a strong impact in the assessment of project profitability (social and private) which determines that a much larger number of projects are allocated to single rotation rather than to multiple rotations. It was observed that both the additional income due to the land resale and the financial burden due to the opportunity cost of the land make projects under single rotation regime more preferable in the allocation compared with the option of multiple rotations. In practical terms, this means that the region appears as not suitable for perpetual teak-based forestry development if the economics of forest activity (especially land market characteristics) remain in the same way they are currently. This suggests that, for certain cases, the perpetual use of land in forestry is not recommended regarding maximization of the contribution of teak projects to regional social benefits even if a subsidy is also provided perpetually.

- It will be interesting to adapt the model through an implementation strategy in which a sort of adaptive model include real projects applying to enroll in the program in year-by-year runs. This will provide adaptive solutions under a real application process. In the end, simulated projects employed in the model are a random representation of reality. If this happens, it would be recommended that each single landowner should determine his own discount rate for the economic assessment in order to enter the process.

- Inclusion of constraints that guarantee positive direct social and environmental impacts has a quantifiable cost as there is a higher net benefit when the total planted area and employment flow requirements are not included.

- When the discounting scenario changes, it can be stated that each project does not have a fixed, independent “role” in the overall regional allocation strategy. This means that the model assigns a certain “role” to each project when allocating, but it changes it according to what is more beneficial for the overall purpose. This produces that a project may go earlier or later depending on the convenience of a particular allocation strategy.

Limitations of the model set the stage for further research for not just teak production in Guatemala, but for other forestry realities that face the problem of adequate allocation of forest subsidies. Research topics that would complement this work include:

- Inclusion of administrative cost, inflation, price increase rate, taxes, etc., in the investment analysis;
- Extension to a broader scope of species, regions, markets, etc., even a nationwide forestry model;
- Inclusion of more accurate estimations of forest management aspects and market features (silviculture, timber production, site-based forest growth and yield, prices projection, product assortment, land market);
- More detailed sensitivity analysis of decision making's key drivers (discount rates, prices, program budget, land availability and spatial analysis);
- Inclusion of alternative or additional constraints associated to sustainable forest management principles;
- Application and validation of the model in other forestry realities;
- Analysis of social profitability of forest projects as economic basis for an optimization model formulation by including a full review of externalities, opportunity costs of inputs and willingness to pay for outputs.

Including these factors would probably require a different scale and scope in the model formulation. For example, larger spatial models would remain being mixed integer, but would likely be solved with heuristics to get an acceptably faster solution. In this sense, it important to recall that bigger models would require longer runtimes and better PC capabilities, especially when they are formulated as an integer linear programming problem.

Finally, it is important to state that the definitive answer to the allocation problem faced by PINFOR is not in the model outcome. As Gregersen *et al.* (1979) stated in their work's conclusions, "truth" is somewhere in between the politically acceptable solution and the academic solution. This is an accurate statement for this study given that rooted political mechanisms govern the incentive policies in developing countries like Guatemala. Nonetheless, the present research offers at least a currently nonexistent tool in Latin American countries' forest subsidies programs that supplies an objective, rational strategic planning mechanism in the usually controversial issue of the public assistance and the allocation of public funds for the development of emerging forestry.

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10 Appendices

Appendix 1. Schematic description of six teak silvicultural regimes found among companies and landowners in Region 9 of Guatemala.

Abbreviation:

ID: activity identification key (SP: site preparation; PE: plantation establishment, PM: plantation maintenance; CM: plantation management; PP: plantation protection; FI: forest inventory; TS: technical supervision)

TotLF: total unit labor force (workdays per hectare)

Tot$/ha: total unit cost of the activity (dollar per hectare)

PVC: present value of cost

Regime A: Pilones de Antigua

ID	Activity	TotLF	Tot$/ha	period/repetitions 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
SP01	Manual Cleaning - Soft Weed	16.0	$ 267.76																				
SP02	Manual Cleaning - Brush	22.0	$ 368.44	1																			
SP03	Cleaning with Chain Saw - Wooden Brush	11.0	$ 245.77																				
SP04	Cleaning with Broad Spectrum Herbicide	0.2	$ 137.50																				
SP05	Mechanized Cleaning	0.3	$ 179.42	1																			
SP06	Chisel Plowing	0.3	$ 24.34																				
SP07	Paraplowing	0.2	$ 79.15	1																			
SP08	Subsoiling	0.1	$ 70.89	1																			
SP09	Drainage Works	0.4	$ 271.25																				
SP10	Debris Piling and Burning	2.8	$ 55.89																				
PE01	Planting Marking	4.0	$ 64.85	1																			
PE02	Manual Plate Weeding for Planting	4.0	$ 67.00																				
PE03	Chemical Plate Weeding for Planting	3.7	$ 98.39																				
PE04	Manual Row Weeding for Planting	5.0	$ 83.57																				
PE05	Chemical Row Weeding for Planting	3.7	$ 128.45																				
PE06	Out Planting w/o hydrokeeper	3.7	$ 272.95																				
PE07	Out Planting w/ hydrokeeper	5.6	$ 368.02	1																			
PE08	Manual Full Weeding	10.0	$ 167.41	1																			
PE09	Re-Planting w/o hydrokeeper (5% replacement)	0.2	$ 13.92																				
PE10	Re-Planting w/ hydrokeeper (5% replacement)	0.4	$ 80.51	1																			
PE11	Fertilization	2.2	$ 53.76	1																			
PE12	Plague Control for Planting	1.5	$ 25.23	1																			
PM01	Manual Plate Weeding	4.4	$ 73.69																				
PM02	Chemical Plate Weeding	3.7	$ 98.39																				
PM03	Manual Row Weeding	11.0	$ 184.21																				
PM04	Chemical Row Weeding	4.4	$ 140.87																				
PM05	Manual Aisle Weeding	4.4	$ 73.69																				
PM06	Chemical Aisle Weeding	1.8	$ 94.82																				
PM07	Mechanized Aisle Weeding	0.3	$ 74.67																				
PM08	Aisle Chisel Plowing	0.3	$ 59.64																				
PM09	Manual Full Weeding	14.0	$ 234.29			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PM10	Chemical Full Weeding	6.9	$ 216.59		2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PM11	Vine Removal	1.4	$ 23.39	1																			
PM12	Sprout Removal	2.2	$ 36.78	3																			
PM13	Sanitary or Pre-Commercial Thinning	1.6	$ 80.40		1																		
CM01	Pruning with Machete	1.8	$ 30.30	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
CM02	Pruning with Shears	2.9	$ 48.66																				
CM03	1st Pruning with Extensible Saw	3.7	$ 62.08		1																		
CM04	2nd Pruning with Extensible Saw	6.9	$ 115.79					1															
CM05	3rd Pruning with Extensible Saw	7.8	$ 130.83							1													
PP01	Tree Tying (wind damage prevention)	1.1	$ 35.39																				
PP02	Manual Firebreak	2.7	$ 45.20																				
PP03	Mechanized Firebreak	0.0	$ 13.30																				
PP04	Chemical Firebreak	0.4	$ 13.42	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PP05	Fencing	3.2	$ 108.56																				
PP06	Plague Control	2.2	$ 38.99	1		1																	
PP07	Phitosanitary Control	2.2	$ 38.99																				
PP08	Surveillance and Fire Combat	8.0	$ 142.80	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
FI01	Sampling and Data Collection	0.1	$ 6.95		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
FI02	Data Management and Processing	0.0	$ 1.39		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
TS01	PINFOR Application Paperwork	1.0	$ 44.96	1																			
TS02	Technician Follow-Up and Counselling	0.2	$ 6.74		1	1	1	1	1	1													
	Yearly Unit Cost $/ha			**$ 1,862**	**$ 777**	**$ 691**	**$ 652**	**$ 768**	**$ 652**	**$ 783**	**$ 646**	**$ 646**	**$ 646**	**$ 646**	**$ 646**	**$ 646**	**$ 646**	**$ 646**	**$ 646**	**$ 646**	**$ 646**	**$ 646**	**$ 646**
	Laborforce Demand (workdays/ha)			**68**	**30**	**34**	**31**	**38**	**31**	**39**	**31**	**31**	**31**	**31**	**31**	**31**	**31**	**31**	**31**	**31**	**31**	**31**	**31**
	PVC per period			$ 1,693	$ 2,335	$ 2,855	$ 3,300	$ 3,777	$ 4,146	$ 4,547	$ 4,849	$ 5,123	$ 5,372	$ 5,598	$ 5,804	$ 5,991	$ 6,161	$ 6,315	$ 6,456	$ 6,584	$ 6,700	$ 6,805	$ 6,901
	Cummulative % of Investment			25%	34%	41%	48%	55%	60%	66%	70%	74%	78%	81%	84%	87%	89%	92%	94%	95%	97%	99%	100%
	Per-period % of Employment			10%	4%	5%	5%	6%	5%	6%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
	Private Discount Rate=	10%	**PVC=**	**$ 6,901**																			
	Total Employment Demand=			**678**																			

Regime B: Ingenio Magdalena

ID	Activity	TotLF	Tot$/ha	period/repetitions 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
SP01	Manual Cleaning - Soft Weed	16.0	$ 267.76	1																			
SP02	Manual Cleaning - Brush	22.0	$ 368.44																				
SP03	Cleaning with Chain Saw - Wooden Brush	11.0	$ 245.77	1																			
SP04	Cleaning with Broad Spectrum Herbicide	0.2	$ 137.50																				
SP05	Mechanized Cleaning	0.3	$ 179.42																				
SP06	Chisel Plowing	0.3	$ 24.34																				
SP07	Paraplowing	0.2	$ 79.15																				
SP08	Subsoiling	0.1	$ 70.89																				
SP09	Drainage Works	0.4	$ 271.25																				
SP10	Debris Piling and Burning	2.8	$ 55.89																				
PE01	Planting Marking	4.0	$ 64.85	1																			
PE02	Manual Plate Weeding for Planting	4.0	$ 67.00																				
PE03	Chemical Plate Weeding for Planting	3.7	$ 98.39	1																			
PE04	Manual Row Weeding for Planting	5.0	$ 83.57																				
PE05	Chemical Row Weeding for Planting	3.7	$ 128.45																				
PE06	Out Planting w/o hydrokeeper	3.7	$ 272.95	1																			
PE07	Out Planting w/ hydrokeeper	5.6	$ 368.02																				
PE08	Manual Full Weeding	10.0	$ 167.41	1																			
PE09	Re-Planting w/o hydrokeeper (5% replacement)	0.2	$ 13.92	1																			
PE10	Re-Planting w/ hydrokeeper (5% replacement)	0.4	$ 80.51																				
PE11	Fertilization	2.2	$ 53.76																				
PE12	Plague Control for Planting	1.5	$ 25.23																				
PM01	Manual Plate Weeding	4.4	$ 73.69																				
PM02	Chemical Plate Weeding	3.7	$ 98.39																				
PM03	Manual Row Weeding	11.0	$ 184.21																				
PM04	Chemical Row Weeding	4.4	$ 140.87	2	2	2	2	2	2	2													
PM05	Manual Aisle Weeding	4.4	$ 73.69																				
PM06	Chemical Aisle Weeding	1.8	$ 94.82																				
PM07	Mechanized Aisle Weeding	0.3	$ 74.67	1	1	1	1	1	1	1													
PM08	Aisle Chisel Plowing	0.3	$ 59.64	1	1	1	1	1	1	1													
PM09	Manual Full Weeding	14.0	$ 234.29																				
PM10	Chemical Full Weeding	6.9	$ 216.59																				
PM11	Vine Removal	1.4	$ 23.39	1	1	1																	
PM12	Sprout Removal	2.2	$ 36.78	1																			
PM13	Sanitary or Pre-Commercial Thinning	1.6	$ 80.40																				
CM01	Pruning with Machete	1.8	$ 30.30	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
CM02	Pruning with Shears	2.9	$ 48.66	1	1	1	1																
CM03	1st Pruning with Extensible Saw	3.7	$ 62.08																				
CM04	2nd Pruning with Extensible Saw	6.9	$ 115.79					1															
CM05	3rd Pruning with Extensible Saw	7.8	$ 130.83							1													
PP01	Tree Tying (wind damage prevention)	1.1	$ 35.39	1	1	1																	
PP02	Manual Firebreak	2.7	$ 45.20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PP03	Mechanized Firebreak	0.0	$ 13.30	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PP04	Chemical Firebreak	0.4	$ 13.42																				
PP05	Fencing	3.2	$ 108.56																				
PP06	Plague Control	2.2	$ 38.99																				
PP07	Phitosanitary Control	2.2	$ 38.99																				
PP08	Surveillance and Fire Combat	8.0	$ 142.80	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
FI01	Sampling and Data Collection	0.1	$ 6.95	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
FI02	Data Management and Processing	0.0	$ 1.39	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
TS01	PINFOR Application Paperwork	1.0	$ 44.96	1																			
TS02	Technician Follow-Up and Counselling	0.2	$ 6.74		1	1	1	1	1	1													
			Yearly Unit Cost $/ha	**$ 1,976**	**$ 770**	**$ 770**	**$ 711**	**$ 779**	**$ 663**	**$ 794**	**$ 240**	**$ 240**	**$ 240**	**$ 240**	**$ 240**	**$ 240**	**$ 240**	**$ 240**	**$ 240**	**$ 240**	**$ 240**	**$ 240**	**$ 240**
			Laborforce Demand (workdays/ha)	**79**	**28**	**28**	**25**	**29**	**22**	**30**	**13**	**13**	**13**	**13**	**13**	**13**	**13**	**13**	**13**	**13**	**13**	**13**	**13**
			PVC per period	$ 1,797	$ 2,433	$ 3,012	$ 3,498	$ 3,981	$ 4,355	$ 4,762	$ 4,874	$ 4,976	$ 5,069	$ 5,153	$ 5,229	$ 5,299	$ 5,362	$ 5,419	$ 5,471	$ 5,519	$ 5,562	$ 5,601	$ 5,637
			Cummulative % of Investment	32%	43%	53%	62%	71%	77%	84%	86%	88%	90%	91%	93%	94%	95%	96%	97%	98%	99%	99%	100%
			Per-period % of Employment	20%	7%	7%	6%	7%	5%	7%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
	Private Discount Rate=	10%	**PVC=**	**$ 5,637**																			
			Total Employment Demand=	**406**																			

Regime C: Small Owners - R1

ID	Activity	TotLF	Tot$/ha	period/repetitions 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
SP01	Manual Cleaning - Soft Weed	16.0	$ 267.76																				
SP02	Manual Cleaning - Brush	22.0	$ 368.44	1																			
SP03	Cleaning with Chain Saw - Wooden Brush	11.0	$ 245.77																				
SP04	Cleaning with Broad Spectrum Herbicide	0.2	$ 137.50																				
SP05	Mechanized Cleaning	0.3	$ 179.42																				
SP06	Chisel Plowing	0.3	$ 24.34	1																			
SP07	Paraplowing	0.2	$ 79.15																				
SP08	Subsoiling	0.1	$ 70.89	1																			
SP09	Drainage Works	0.4	$ 271.25																				
SP10	Debris Piling and Burning	2.8	$ 55.89																				
PE01	Planting Marking	4.0	$ 64.85	1																			
PE02	Manual Plate Weeding for Planting	4.0	$ 67.00	2																			
PE03	Chemical Plate Weeding for Planting	3.7	$ 98.39																				
PE04	Manual Row Weeding for Planting	5.0	$ 83.57																				
PE05	Chemical Row Weeding for Planting	3.7	$ 128.45																				
PE06	Out Planting w/o hydrokeeper	3.7	$ 272.95	1																			
PE07	Out Planting w/ hydrokeeper	5.6	$ 368.02																				
PE08	Manual Full Weeding	10.0	$ 167.41	1																			
PE09	Re-Planting w/o hydrokeeper (5% replacement)	0.2	$ 13.92	1																			
PE10	Re-Planting w/ hydrokeeper (5% replacement)	0.4	$ 80.51																				
PE11	Fertilization	2.2	$ 53.76																				
PE12	Plague Control for Planting	1.5	$ 25.23	1																			
PM01	Manual Plate Weeding	4.4	$ 73.69		1																		
PM02	Chemical Plate Weeding	3.7	$ 98.39																				
PM03	Manual Row Weeding	11.0	$ 184.21																				
PM04	Chemical Row Weeding	4.4	$ 140.87																				
PM05	Manual Aisle Weeding	4.4	$ 73.69																				
PM06	Chemical Aisle Weeding	1.8	$ 94.82																				
PM07	Mechanized Aisle Weeding	0.3	$ 74.67																				
PM08	Aisle Chisel Plowing	0.3	$ 59.64																				
PM09	Manual Full Weeding	14.0	$ 234.29		2	2	2	2															
PM10	Chemical Full Weeding	6.9	$ 216.59																				
PM11	Vine Removal	1.4	$ 23.39																				
PM12	Sprout Removal	2.2	$ 36.78																				
PM13	Sanitary or Pre-Commercial Thinning	1.6	$ 80.40				1																
CM01	Pruning with Machete	1.8	$ 30.30																				
CM02	Pruning with Shears	2.9	$ 48.66																				
CM03	1st Pruning with Extensible Saw	3.7	$ 62.08																				
CM04	2nd Pruning with Extensible Saw	6.9	$ 115.79																				
CM05	3rd Pruning with Extensible Saw	7.8	$ 130.83																				
PP01	Tree Tying (wind damage prevention)	1.1	$ 35.39																				
PP02	Manual Firebreak	2.7	$ 45.20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PP03	Mechanized Firebreak	0.0	$ 13.30																				
PP04	Chemical Firebreak	0.4	$ 13.42																				
PP05	Fencing	3.2	$ 108.56	1			1			1			1			1			1			1	
PP06	Plague Control	2.2	$ 38.99			1	1	1															
PP07	Phitosanitary Control	2.2	$ 38.99																				
PP08	Surveillance and Fire Combat	8.0	$ 142.80	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
FI01	Sampling and Data Collection	0.1	$ 6.95																				
FI02	Data Management and Processing	0.0	$ 1.39																				
TS01	PINFOR Application Paperwork	1.0	$ 44.96	1																			
TS02	Technician Follow-Up and Counselling	0.2	$ 6.74		1	1	1	1	1	1													
			Yearly Unit Cost $/ha	**$ 1,484**	**$ 737**	**$ 702**	**$ 891**	**$ 702**	**$ 195**	**$ 303**	**$ 188**	**$ 188**	**$ 297**	**$ 188**	**$ 188**	**$ 297**	**$ 188**	**$ 188**	**$ 297**	**$ 188**	**$ 188**	**$ 297**	**$ 188**
			Laborforce Demand (workdays/ha)	**65**	**43**	**41**	**46**	**41**	**11**	**14**	**11**	**11**	**14**	**11**	**11**	**14**	**11**	**11**	**14**	**11**	**11**	**14**	**11**
			PVC per period	$ 1,349	$ 1,958	$ 2,485	$ 3,094	$ 3,530	$ 3,640	$ 3,796	$ 3,884	$ 3,963	$ 4,078	$ 4,143	$ 4,203	$ 4,289	$ 4,339	$ 4,384	$ 4,448	$ 4,486	$ 4,519	$ 4,568	$ 4,596
			Cummulative % of Investment	29%	43%	54%	67%	77%	79%	83%	85%	86%	89%	90%	91%	93%	94%	95%	97%	98%	98%	99%	100%
			Per-period % of Employment	16%	10%	10%	11%	10%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
	Private Discount Rate=	10%	**PVC=**	**$ 4,596**																			
			Total Employment Demand=	**412**																			

Regime D: Small Owners - R2

ID	Activity	TotLF	Tot$/ha	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
				period/repetitions																			
SP01	Manual Cleaning - Soft Weed	16.0	$ 267.76																				
SP02	Manual Cleaning - Brush	22.0	$ 368.44	1																			
SP03	Cleaning with Chain Saw - Wooden Brush	11.0	$ 245.77																				
SP04	Cleaning with Broad Spectrum Herbicide	0.2	$ 137.50																				
SP05	Mechanized Cleaning	0.3	$ 179.42																				
SP06	Chisel Plowing	0.3	$ 24.34	1																			
SP07	Paraplowing	0.2	$ 79.15																				
SP08	Subsoiling	0.1	$ 70.89	1																			
SP09	Drainage Works	0.4	$ 271.25																				
SP10	Debris Piling and Burning	2.8	$ 55.89																				
PE01	Planting Marking	4.0	$ 64.85	1																			
PE02	Manual Plate Weeding for Planting	4.0	$ 67.00	2																			
PE03	Chemical Plate Weeding for Planting	3.7	$ 98.39																				
PE04	Manual Row Weeding for Planting	5.0	$ 83.57																				
PE05	Chemical Row Weeding for Planting	3.7	$ 128.45																				
PE06	Out Planting w/o hydrokeeper	3.7	$ 272.95	1																			
PE07	Out Planting w/ hydrokeeper	5.6	$ 368.02																				
PE08	Manual Full Weeding	10.0	$ 167.41	2																			
PE09	Re-Planting w/o hydrokeeper (5% replacement)	0.2	$ 13.92	1																			
PE10	Re-Planting w/ hydrokeeper (5% replacement)	0.4	$ 80.51																				
PE11	Fertilization	2.2	$ 53.76																				
PE12	Plague Control for Planting	1.5	$ 25.23																				
PM01	Manual Plate Weeding	4.4	$ 73.69		1																		
PM02	Chemical Plate Weeding	3.7	$ 98.39																				
PM03	Manual Row Weeding	11.0	$ 184.21																				
PM04	Chemical Row Weeding	4.4	$ 140.87																				
PM05	Manual Aisle Weeding	4.4	$ 73.69																				
PM06	Chemical Aisle Weeding	1.8	$ 94.82																				
PM07	Mechanized Aisle Weeding	0.3	$ 74.67																				
PM08	Aisle Chisel Plowing	0.3	$ 59.64																				
PM09	Manual Full Weeding	14.0	$ 234.29		2	2	2	2															
PM10	Chemical Full Weeding	6.9	$ 216.59																				
PM11	Vine Removal	1.4	$ 23.39																				
PM12	Sprout Removal	2.2	$ 36.78																				
PM13	Sanitary or Pre-Commercial Thinning	1.6	$ 80.40		1																		
CM01	Pruning with Machete	1.8	$ 30.30																				
CM02	Pruning with Shears	2.9	$ 48.66																				
CM03	1st Pruning with Extensible Saw	3.7	$ 62.08																				
CM04	2nd Pruning with Extensible Saw	6.9	$ 115.79																				
CM05	3rd Pruning with Extensible Saw	7.8	$ 130.83																				
PP01	Tree Tying (wind damage prevention)	1.1	$ 35.39																				
PP02	Manual Firebreak	2.7	$ 45.20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PP03	Mechanized Firebreak	0.0	$ 13.30																				
PP04	Chemical Firebreak	0.4	$ 13.42																				
PP05	Fencing	3.2	$ 108.56	1			1			1			1			1			1			1	
PP06	Plague Control	2.2	$ 38.99			1	1	1															
PP07	Phitosanitary Control	2.2	$ 38.99																				
PP08	Surveillance and Fire Combat	8.0	$ 142.80	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
FI01	Sampling and Data Collection	0.1	$ 6.95																				
FI02	Data Management and Processing	0.0	$ 1.39																				
TS01	PINFOR Application Paperwork	1.0	$ 44.96	1																			
TS02	Technician Follow-Up and Counselling	0.2	$ 6.74		1	1	1	1	1	1													
	Yearly Unit Cost $/ha			**$ 1,626**	**$ 817**	**$ 702**	**$ 811**	**$ 702**	**$ 195**	**$ 303**	**$ 188**	**$ 188**	**$ 297**	**$ 188**	**$ 188**	**$ 297**	**$ 188**	**$ 188**	**$ 297**	**$ 188**	**$ 188**	**$ 297**	**$ 188**
	Laborforce Demand (workdays/ha)			**73**	**45**	**41**	**44**	**41**	**11**	**14**	**11**	**11**	**14**	**11**	**11**	**14**	**11**	**11**	**14**	**11**	**11**	**14**	**11**
	PVC per period			$ 1,478	$ 2,153	$ 2,681	$ 3,235	$ 3,671	$ 3,781	$ 3,937	$ 4,024	$ 4,104	$ 4,218	$ 4,284	$ 4,344	$ 4,430	$ 4,480	$ 4,525	$ 4,589	$ 4,626	$ 4,660	$ 4,709	$ 4,737
	Cummulative % of Investment			31%	45%	57%	68%	78%	80%	83%	85%	87%	89%	90%	92%	94%	95%	96%	97%	98%	98%	99%	100%
	Per-period % of Employment			17%	11%	10%	11%	10%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
	Private Discount Rate=	10%	**PVC=**	**$ 4,737**																			
	Total Employment Demand=			**421**																			

Regime E: Small Owners - R3

ID	Activity	TotLF	Tot$/ha	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
				period/repetitions																			
SP01	Manual Cleaning - Soft Weed	16.0	$ 267.76																				
SP02	Manual Cleaning - Brush	22.0	$ 368.44	1																			
SP03	Cleaning with Chain Saw - Wooden Brush	11.0	$ 245.77																				
SP04	Cleaning with Broad Spectrum Herbicide	0.2	$ 137.50																				
SP05	Mechanized Cleaning	0.3	$ 179.42																				
SP06	Chisel Plowing	0.3	$ 24.34	1																			
SP07	Paraplowing	0.2	$ 79.15																				
SP08	Subsoiling	0.1	$ 70.89																				
SP09	Drainage Works	0.4	$ 271.25																				
SP10	Debris Piling and Burning	2.8	$ 55.89																				
PE01	Planting Marking	4.0	$ 64.85	1																			
PE02	Manual Plate Weeding for Planting	4.0	$ 67.00	2																			
PE03	Chemical Plate Weeding for Planting	3.7	$ 98.39																				
PE04	Manual Row Weeding for Planting	5.0	$ 83.57																				
PE05	Chemical Row Weeding for Planting	3.7	$ 128.45																				
PE06	Out Planting w/o hydrokeeper	3.7	$ 272.95	1																			
PE07	Out Planting w/ hydrokeeper	5.6	$ 368.02																				
PE08	Manual Full Weeding	10.0	$ 167.41	2																			
PE09	Re-Planting w/o hydrokeeper (5% replacement)	0.2	$ 13.92	1																			
PE10	Re-Planting w/ hydrokeeper (5% replacement)	0.4	$ 80.51																				
PE11	Fertilization	2.2	$ 53.76																				
PE12	Plague Control for Planting	1.5	$ 25.23																				
PM01	Manual Plate Weeding	4.4	$ 73.69		1																		
PM02	Chemical Plate Weeding	3.7	$ 98.39																				
PM03	Manual Row Weeding	11.0	$ 184.21																				
PM04	Chemical Row Weeding	4.4	$ 140.87																				
PM05	Manual Aisle Weeding	4.4	$ 73.69																				
PM06	Chemical Aisle Weeding	1.8	$ 94.82																				
PM07	Mechanized Aisle Weeding	0.3	$ 74.67																				
PM08	Aisle Chisel Plowing	0.3	$ 59.64																				
PM09	Manual Full Weeding	14.0	$ 234.29		2	2	2	2															
PM10	Chemical Full Weeding	6.9	$ 216.59																				
PM11	Vine Removal	1.4	$ 23.39																				
PM12	Sprout Removal	2.2	$ 36.78																				
PM13	Sanitary or Pre-Commercial Thinning	1.6	$ 80.40				1																
CM01	Pruning with Machete	1.8	$ 30.30																				
CM02	Pruning with Shears	2.9	$ 48.66																				
CM03	1st Pruning with Extensible Saw	3.7	$ 62.08																				
CM04	2nd Pruning with Extensible Saw	6.9	$ 115.79																				
CM05	3rd Pruning with Extensible Saw	7.8	$ 130.83																				
PP01	Tree Tying (wind damage prevention)	1.1	$ 35.39																				
PP02	Manual Firebreak	2.7	$ 45.20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PP03	Mechanized Firebreak	0.0	$ 13.30																				
PP04	Chemical Firebreak	0.4	$ 13.42																				
PP05	Fencing	3.2	$ 108.56	1			1			1			1			1			1			1	
PP06	Plague Control	2.2	$ 38.99			1	1	1															
PP07	Phitosanitary Control	2.2	$ 38.99																				
PP08	Surveillance and Fire Combat	8.0	$ 142.80	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
FI01	Sampling and Data Collection	0.1	$ 6.95																				
FI02	Data Management and Processing	0.0	$ 1.39																				
TS01	PINFOR Application Paperwork	1.0	$ 44.96	1																			
TS02	Technician Follow-Up and Counselling	0.2	$ 6.74		1	1	1	1	1	1													
	Yearly Unit Cost $/ha			**$ 1,555**	**$ 737**	**$ 702**	**$ 891**	**$ 702**	**$ 195**	**$ 303**	**$ 188**	**$ 188**	**$ 297**	**$ 188**	**$ 188**	**$ 297**	**$ 188**	**$ 188**	**$ 297**	**$ 188**	**$ 188**	**$ 297**	**$ 188**
	Laborforce Demand (workdays/ha)			**73**	**43**	**41**	**46**	**41**	**11**	**14**	**11**	**11**	**14**	**11**	**11**	**14**	**11**	**11**	**14**	**11**	**11**	**14**	**11**
	PVC per period			$ 1,413	$ 2,023	$ 2,550	$ 3,159	$ 3,595	$ 3,705	$ 3,861	$ 3,948	$ 4,028	$ 4,142	$ 4,208	$ 4,268	$ 4,354	$ 4,404	$ 4,449	$ 4,513	$ 4,550	$ 4,584	$ 4,633	$ 4,661
	Cummulative % of Investment			30%	43%	55%	68%	77%	79%	83%	85%	86%	89%	90%	92%	93%	94%	95%	97%	98%	98%	99%	100%
	Per-period % of Employment			17%	10%	10%	11%	10%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
	Private Discount Rate=	10%	**PVC=**	**$ 4,661**																			
	Total Employment Demand=			**421**																			

Regime F: Company X

ID	Activity	TotLF	Tot$/ha	period/repetitions 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
SP01	Manual Cleaning - Soft Weed	16.0	$ 267.76																				
SP02	Manual Cleaning - Brush	22.0	$ 368.44	1																			
SP03	Cleaning with Chain Saw - Wooden Brush	11.0	$ 245.77	1																			
SP04	Cleaning with Broad Spectrum Herbicide	0.2	$ 137.50	1																			
SP05	Mechanized Cleaning	0.3	$ 179.42																				
SP06	Chisel Plowing	0.3	$ 24.34																				
SP07	Paraplowing	0.2	$ 79.15																				
SP08	Subsoiling	0.1	$ 70.89	1																			
SP09	Drainage Works	0.4	$ 271.25																				
SP10	Debris Piling and Burning	2.8	$ 55.89																				
PE01	Planting Marking	4.0	$ 64.85	1																			
PE02	Manual Plate Weeding for Planting	4.0	$ 67.00																				
PE03	Chemical Plate Weeding for Planting	3.7	$ 98.39																				
PE04	Manual Row Weeding for Planting	5.0	$ 83.57																				
PE05	Chemical Row Weeding for Planting	3.7	$ 128.45	1																			
PE06	Out Planting w/o hydrokeeper	3.7	$ 272.95																				
PE07	Out Planting w/ hydrokeeper	5.6	$ 368.02	1																			
PE08	Manual Full Weeding	10.0	$ 167.41	2																			
PE09	Re-Planting w/o hydrokeeper (5% replacement)	0.2	$ 13.92																				
PE10	Re-Planting w/ hydrokeeper (5% replacement)	0.4	$ 80.51	1																			
PE11	Fertilization	2.2	$ 53.76	1																			
PE12	Plague Control for Planting	1.5	$ 25.23	1																			
PM01	Manual Plate Weeding	4.4	$ 73.69																				
PM02	Chemical Plate Weeding	3.7	$ 98.39																				
PM03	Manual Row Weeding	11.0	$ 184.21																				
PM04	Chemical Row Weeding	4.4	$ 140.87		2	2	2	2															
PM05	Manual Aisle Weeding	4.4	$ 73.69		3	3	3	3															
PM06	Chemical Aisle Weeding	1.8	$ 94.82																				
PM07	Mechanized Aisle Weeding	0.3	$ 74.67																				
PM08	Aisle Chisel Plowing	0.3	$ 59.64																				
PM09	Manual Full Weeding	14.0	$ 234.29																				
PM10	Chemical Full Weeding	6.9	$ 216.59																				
PM11	Vine Removal	1.4	$ 23.39	1	1	1																	
PM12	Sprout Removal	2.2	$ 36.78	2	2	2																	
PM13	Sanitary or Pre-Commercial Thinning	1.6	$ 80.40			1																	
CM01	Pruning with Machete	1.8	$ 30.30			1	1	1	1														
CM02	Pruning with Shears	2.9	$ 48.66																				
CM03	1st Pruning with Extensible Saw	3.7	$ 62.08					1															
CM04	2nd Pruning with Extensible Saw	6.9	$ 115.79							1													
CM05	3rd Pruning with Extensible Saw	7.8	$ 130.83																				
PP01	Tree Tying (wind damage prevention)	1.1	$ 35.39																				
PP02	Manual Firebreak	2.7	$ 45.20																				
PP03	Mechanized Firebreak	0.0	$ 13.30	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PP04	Chemical Firebreak	0.4	$ 13.42	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PP05	Fencing	3.2	$ 108.56																				
PP06	Plague Control	2.2	$ 38.99		1	1																	
PP07	Phitosanitary Control	2.2	$ 38.99																				
PP08	Surveillance and Fire Combat	8.0	$ 142.80	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
FI01	Sampling and Data Collection	0.1	$ 6.95	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
FI02	Data Management and Processing	0.0	$ 1.39	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
TS01	PINFOR Application Paperwork	1.0	$ 44.96	1																			
TS02	Technician Follow-Up and Counselling	0.2	$ 6.74		1	1	1	1	1	1													
	Yearly Unit Cost $/ha			**$ 2,198**	**$ 823**	**$ 934**	**$ 718**	**$ 780**	**$ 215**	**$ 300**	**$ 178**	**$ 178**	**$ 178**	**$ 178**	**$ 178**	**$ 178**	**$ 178**	**$ 178**	**$ 178**	**$ 178**	**$ 178**	**$ 178**	**$ 178**
	Laborforce Demand (workdays/ha)			**86**	**39**	**42**	**33**	**36**	**11**	**16**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**
	PVC per period			$ 1,998	$ 2,679	$ 3,380	$ 3,871	$ 4,355	$ 4,476	$ 4,630	$ 4,713	$ 4,789	$ 4,857	$ 4,920	$ 4,976	$ 5,028	$ 5,075	$ 5,117	$ 5,156	$ 5,191	$ 5,223	$ 5,252	$ 5,279
	Cummulative % of Investment			38%	51%	64%	73%	82%	85%	88%	89%	91%	92%	93%	94%	95%	96%	97%	98%	98%	99%	99%	100%
	Per-period % of Employment			23%	10%	11%	9%	10%	3%	4%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Private Discount Rate=	10%	**PVC=**	**$ 5,279**																			
	Total Employment Demand=			**374**																			

Appendix 2. *RStudio©* code, outcome and plots of the timber growth projection analysis made by fitting the Chapman-Richards equation in a non-linear mixed effect regression model of Region 9's teak inventory data

```
> nmem1.VAw<-nlme(V~b0*((1-exp(b1*A))^b2),fixed=b0+b1+b2~1,random=b
0~1|S,data=r9data.grouped,start=c(b0=300,b1=0.015,b2=5),weights=var Power(form=~A))
> summary(nmem1.VAw)

Nonlinear mixed-effects model fit by maximum likelihood
  Model: V ~ b0 * ((1 - exp(b1 * A))^b2)
 Data: r9data.grouped
       AIC      BIC    logLik
  3296.727 3319.943 -1642.363

Random effects:
 Formula: b0 ~ 1 | S
              b0   Residual
StdDev: 87.09662 0.03368286

Variance function:
 Structure: Power of variance covariate
 Formula: ~A
 Parameter estimates:
   power
1.644285
Fixed effects: b0 + b1 + b2 ~ 1
       Value Std.Error  DF   t-value p-value
b0 266.98096  71.80935 349  3.717914   2e-04
b1  -0.01807   0.00351 349 -5.149847   0e+00
b2   3.13507   0.34768 349  9.017190   0e+00
 Correlation:
   b0     b1
b1  0.685
b2 -0.602 -0.953

Standardized Within-Group Residuals:
       Min         Q1        Med         Q3        Max
-2.6517191 -0.7592940 -0.0511240  0.5621288  3.7753462

Number of Observations: 354
Number of Groups: 3

> fixef(nmem1.VAw)
          b0           b1           b2
266.98096491  -0.01807167   3.13507420

> ranef(nmem1.VAw)
          b0
S3 -97.30015
S2 -15.39454
S1 112.69469

> coef(nmem1.VAw)
         b0          b1       b2
S3 169.6808 -0.01807167 3.135074
S2 251.5864 -0.01807167 3.135074
S1 379.6757 -0.01807167 3.135074
```

Site Classes S_1, S_2 and S_3 Timber Growth Equations:

$$V = 379.6757 * [(1 - e^{-0.01807167*A})^{3.135074}]$$

$$V = 251.5864 * [(1 - e^{-0.01807167*A})^{3.135074}]$$

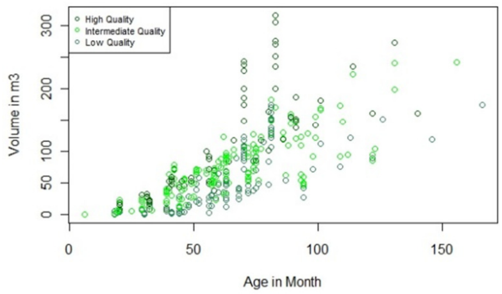
$$V = 169.6808 * [(1 - e^{-0.01807167*A})^{3.135074}]$$

Where

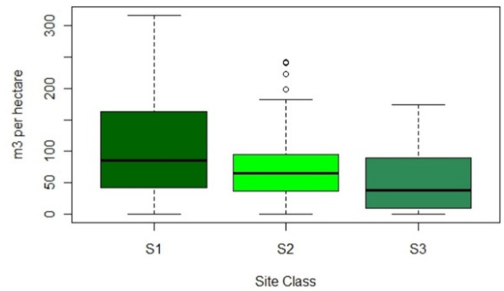
V: projected timber production per hectare (in solid cubic meter over bark per hectare)

A: plantation age (in years)

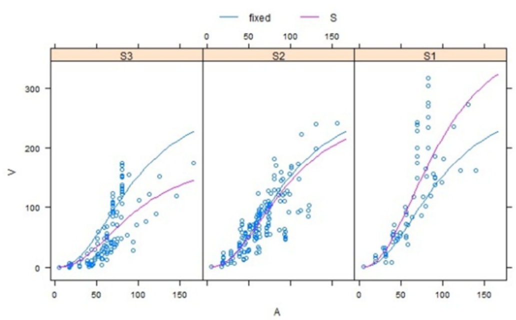
Scatterplots and Boxplots



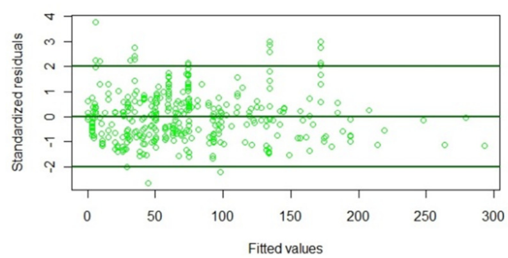
Scatterplot of volume (in solid cubic meters over bark) as a function of the plantation age (in month) for teak in Region 9



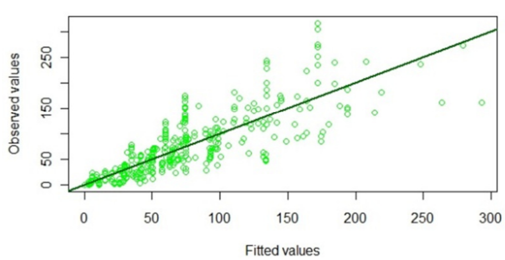
Boxplot of volume (in solid cubic meters over bark) as a function of the site class (S1: high quality; S2: intermediate quality; S3: low quality)



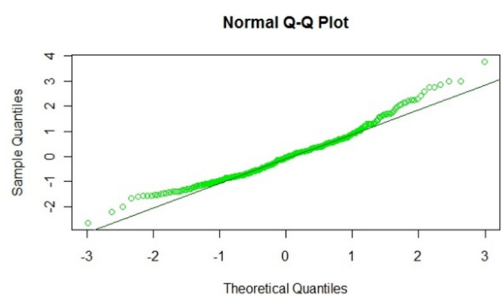
Scatterplot of volume as a function of the mixed effect of site quality and plantation age. Non-linear mixed effect regression model fitted based on the Chapman-Richards equation



Scatterplot of standardized residuals obtained from fitting the Chapman-Richards non-linear mixed effect regression model



Scatterplot of observed values as a function of the fitted values of the Chapman-Richards non-linear mixed effect regression model fitted for the analysis of teak volume in Region 9 as a function of the plantation age



Normal Q-Q plot obtained from fitting the non-linear mixed effect regression model for the teak volume as a function of the plantation age

Appendix 3. Teak harvest cost structure adapted from system PACE2HILL

Example conditions: Project A038

Road Cost: US$15,000/Km; Harvest Spacing: 400x400m; Timber Yield: 325 m3scc/ha; Volumen per Tree: 1.3 m3scc; Skidding Weave Factor: 1; Landing Cost: US$500/unit; Felling Equipment: Stilh MS261; Skidding Equipment: Massey Ferguson 5470 w/winch Fransgaard; Loading Equipment: Farmi log loader; Transport Equipment: Kenworth T800 w/15 m3 container (20'); One-Way Distance: 102.7 Km; Mean Unloaded Hauling Velocity: 47.8 Km/Hr; Mean Loaded Hauling Velocity: 38.2 Km/Hr.

Unit machine cost

FELLING/BUCKING EQUIP. (M10, M11, M12, M13)	GENERIC	STIHL-MS261 (chain saw)	TJACK-950 (fellerbunch)	PONSSE-HS10 (harvester)
Purchase price (P) - $	$680	**$830**	$432,944	$412,000
Machine horsepower rating (hp) - hp	2.41	**3.8**	230	210
Machine life (n) - yrs	2	**2**	5	6
Salvage value, percent of purchase price (rv%) - %	20	**20**	20	20
Utilization rate (ut%) - %	70	**90**	60	80
Repair and maintenance, percent of depreciation (rm%) - %	50	**50**	75	30
Interest rate (i%) - %	10	**13.6**	10	10
Insurance and tax rate (it%) - %	3	**3**	3.5	4
Fuel consumption rate (fcr) - gal/hp-hr	0.19400	**0.19400**	0.02633	0.02633
Fuel cost (fcg) - $/gal	$4.50	**$4.23**	$4.00	$4.00
Lube and oil, percent of fuel cost (lo%) - %	36.77	**36.77**	36.77	36.77
Scheduled machine hours (SMH) - hr/yr	2,000	**2,000**	2,000	2,000
Base wage for 1st crew position (operator) (WB1) - $/SMH	$15.75	**$2.70**	$13.50	$13.50
Base wage for 2nd crew position (laborer) (WB2) - $/SMH	$11.79	**$0.00**	$11.79	$11.79
Laborers crew (w) - amount	0	**0**	0	0
Fringe benefits (FB) - %	40	**50**	40	40
Supervision as % of Direct Labor (sv%) - %	10	**10**	10	10
CALCULATIONS				
Salvage value (S) = (P*rv%) - $		$166		
Annual depreciation (AD) = ((P-S)/n) - $		$332		
Average yearly investment (AYI) = ((((P-S)*(n+1))/(2*n))+S) - $		$664		
Productive machine hours (PMH) = (SMH*ut%) - hrs/yr		1,800		
Ownership Cost				
Interest cost (INC) = (i%*AYI) - $/yr		$93		
Insurance and tax cost (IT) = (it%*AYI) - $/yr		$20		
Yearly ownership cost (YF$) = (AD+INC+IT) - $/yr		$445		
Ownership cost per PMH (F_PMH) = (YF$/PMH) - $/hr		$0.25		
Ownership cost per SMH (F_SMH) = (YF$/SMH) - $/hr		$0.22		
Operating Cost				
Fuel cost (F) = (hp*fcr*fcg) - $/hr		$3.12		
Lube cost (L) = (F*lo%) - $/hr		$1.15		
Repair and Maintenance cost (RM) = (AD*rm%/PMH) - $/hr		$0.00		
Operating cost per PMH (V_PMH) = (F+L+RM) - $/hr		$4.27		
Operating cost per SMH (V_SMH) = (V_PMH*ut%) - $/hr		$3.84		
Labor Cost				
Operator labor and benefit cost (OL) = (WB1*(1+FB)/ut%) - $/hr		$4.50		
Laborers labor and benefit cost (LL) = (w*WB2*(1+FB)/ut%) - $/hr		$0.00		
Supervision labor and benefit cost (SL) = ((OL+LL)*sv%) - $/hr		$0.45		
Labor cost per PMH (L_PMH) = (OL+LL+SL) - $/PMH		$4.95		
Labor cost per SMH (L_SMH) = (L_PMH*ut%) - $/SMH		$4.46		
Total Machine Cost				
Total cost per PMH (T_PMH) = (F_PMH+V_PMH+L_PMH) - $/hr		$9.47		
Total cost per SMH (T_SMH) = (F_SMH+V_SMH+L_SMH) - $/hr		$8.52		

GENERIC

STIHL-MS261

TJACK-950

PONSSE-HS10

Stilh MS261: Guatemalan price (Ebay), Q33/Gl gasolina, 0.7425 Gl/hr consumo, Q3,500/mes salario operador

SKIDDING/YARDING EQUIP. (M1, M2, M3, M4)

	GENERIC	TJACK-660C (cable)	TIGERCAT-620 (grapple)	CAT-527 (grapple)
Purchase price (P) - $	**$25,000**	$199,003	$172,530	$280,851
Machine horsepower rating (hp) - hp	**125**	215	174	166
Machine life (n) - yrs	**5**	5	5	5
Salvage value, percent of purchase price (rv%) - %	**20**	20	20	20
Utilization rate (ut%) - %	**70**	60	60	60
Repair and maintenance, percent of depreciation (rm%) - %	**90**	90	90	90
Interest rate (i%) - %	**13.6**	10	10	10
Insurance and tax rate (it%) - %	**3**	5	5	2
Fuel consumption rate (fcr) - gal/hp-hr	**0.04808**	0.02800	0.02800	0.02800
Fuel cost (fcg) - $/gal	**$3.85**	$4.00	$4.00	$4.00
Lube and oil, percent of fuel cost (lo%) - %	**36.77**	36.77	36.77	36.77
Scheduled machine hours (SMH) - hr/yr	**2,000**	2,000	2,000	2,000
Base wage for 1st crew position (operator) (WB1) - $/SMH	**$3.85**	$13.50	$13.50	$13.50
Base wage for 2nd crew position (laborer) (WB2) - $/SMH	**$1.92**	$11.79	$11.79	$11.79
Laborers crew (w) - amount	**2**	0	0	0
Fringe benefits (FB) - %	**50**	40	40	40
Supervision as % of Direct Labor (sv%) - %	**10**	10	10	10

(•) GENERIC
( ) TJACK-660C
( ) TIGERCAT-620
( ) CAT-527

Generic: Massey Ferguson 5470 + winch Fransgaard, Guatemalan price (Ebay), Q30/Gl diesel, 6.01 Gl/hr consumption, Q5,000/month operator wage, Q2,500/mes laborer wage (2)

CALCULATIONS	
Salvage value (S) = (P*rv%) - $	$5,000
Annual depreciation (AD) = ((P-S)/n) - $	$4,000
Average yearly investment (AYI) = ((((P-S)*(n+1))/(2*n))+S) - $	$17,000
Productive machine hours (PMH) = (SMH*ut%) - hrs/yr	1,400
Ownership Cost	
Interest cost (INC) = (i%*AYI) - $/yr	$2,380
Insurance and tax cost (IT) = (it%*AYI) - $/yr	$510
Yearly ownership cost (YF$) = (AD+INC+IT) - $/yr	$6,890
Ownership cost per PMH (F_PMH) = (YF$/PMH) - $/hr	$4.92
Ownership cost per SMH (F_SMH) = (YF$/SMH) - $/hr	$3.45
Operating Cost	
Fuel cost (F) = (hp*fcr*fcg) - $/hr	$23.14
Lube cost (L) = (F*lo%) - $/hr	$8.56
Repair and Maintenance cost (RM) = (AD*rm%/PMH) - $/hr	$3.00
Operating cost per PMH (V_PMH) = (F+L+RM) - $/hr	$34.70
Operating cost per SMH (V_SMH) = (V_PMH*ut%) - $/hr	$24.29
Labor Cost	
Operator labor and benefit cost (OL) = (WB1*(1+FB)/ut%) - $/hr	$8.25
Laborers labor and benefit cost (LL) = (w*WB2*(1+FB)/ut%) - $/hr	$8.23
Supervision labor and benefit cost (SL) = ((OL+LL)*sv%) - $/hr	$1.65
Labor cost per PMH (L_PMH) = (OL+LL+SL) - $/PMH	$18.13
Labor cost per SMH (L_SMH) = (L_PMH*ut%) - $/SMH	$12.69
Total Machine Cost	
Total cost per PMH (T_PMH) = (F_PMH+V_PMH+L_PMH) - $/hr	$57.75
Total cost per SMH (T_SMH) = (F_SMH+V_SMH+L_SMH) - $/hr	$40.42

LOADING EQUIP. (M15, M16, M17, M18)

	GENERIC	BARKO 160D (truck)	HUSKY XL-175 (truck)	TIGERCAT T248 (tracked)
Purchase price (P) - $	**$33,000**	$100,505	$147,624	$205,225
Machine horsepower rating (hp) - hp	**125**	140	115	174
Machine life (n) - yrs	**5**	5	5	5
Salvage value, percent of purchase price (rv%) - %	**20**	20	20	20
Utilization rate (ut%) - %	**60**	65	65	65
Repair and maintenance, percent of depreciation (rm%) - %	**90**	90	90	90
Interest rate (i%) - %	**13.6**	10	10	10
Insurance and tax rate (it%) - %	**3**	1.5	1.5	1.5
Fuel consumption rate (fcr) - gal/hp-hr	**0.04808**	0.02166	0.02166	0.02166
Fuel cost (fcg) - $/gal	**$3.85**	$4.00	$4.00	$4.00
Lube and oil, percent of fuel cost (lo%) - %	**36.77**	36.77	36.77	36.77
Scheduled machine hours (SMH) - hr/yr	**2,000**	2,000	2,000	2,000
Base wage for 1st crew position (operator) (WB1) - $/SMH	**$3.85**	$13.50	$13.50	$13.50
Base wage for 2nd crew position (laborer) (WB2) - $/SMH	**$1.92**	$11.79	$11.79	$11.79
Laborers crew (w) - amount	**4**	0	0	0
Fringe benefits (FB) - %	**50**	40	40	40
Supervision as % of Direct Labor (sv%) - %	**10**	10	10	10

(•) GENERIC
( ) BARKO 160D
( ) HUSKY XL175
( ) TIGERCAT T248

Generic: Massey Ferguson 5470 + Farmi log loader, international price (UK), Q30/Gl diesel, 6.01 Gl/hr consumption, Q5,000/month operator wage, 4 laborers for container loading, Q2,500/month each

CALCULATIONS	
Salvage value (S) = (P*rv%) - $	$6,600
Annual depreciation (AD) = ((P-S)/n) - $	$5,280
Average yearly investment (AYI) = ((((P-S)*(n+1))/(2*n))+S) - $	$22,440
Productive machine hours (PMH) = (SMH*ut%) - hrs/yr	1,200
Ownership Cost	
Interest cost (INC) = (i%*AYI) - $/yr	$3,142
Insurance and tax cost (IT) = (it%*AYI) - $/yr	$673
Yearly ownership cost (YF$) = (AD+INC+IT) - $/yr	$9,095
Ownership cost per PMH (F_PMH) = (YF$/PMH) - $/hr	$7.58
Ownership cost per SMH (F_SMH) = (YF$/SMH) - $/hr	$4.55
Operating Cost	
Fuel cost (F) = (hp*fcr*fcg) - $/hr	$23.14
Lube cost (L) = (F*lo%) - $/hr	$8.56
Repair and Maintenance cost (RM) = (AD*rm%/PMH) - $/hr	$4.00
Operating cost per PMH (V_PMH) = (F+L+RM) - $/hr	$35.70
Operating cost per SMH (V_SMH) = (V_PMH*ut%) - $/hr	$21.42
Labor Cost	
Operator labor and benefit cost (OL) = (WB1*(1+FB)/ut%) - $/hr	$9.63
Laborers labor and benefit cost (LL) = (w*WB2*(1+FB)/ut%) - $/hr	$19.20
Supervision labor and benefit cost (SL) = ((OL+LL)*sv%) - $/hr	$2.88
Labor cost per PMH (L_PMH) = (OL+LL+SL) - $/PMH	$31.71
Labor cost per SMH (L_SMH) = (L_PMH*ut%) - $/SMH	$19.02
Total Machine Cost	
Total cost per PMH (T_PMH) = (F_PMH+V_PMH+L_PMH) - $/hr	$74.99
Total cost per SMH (T_SMH) = (F_SMH+V_SMH+L_SMH) - $/hr	$44.99

TRANSPORT EQUIP. (M20)

	GENERIC (Heavy Haul)
Purchase price (P) - $	**$135,000**
Machine horsepower rating (hp) - hp	**550**
Machine life (n) - yrs	**5**
Salvage value, percent of purchase price (rv%) - %	**20**
Utilization rate (ut%) - %	**90**
Repair and maintenance, percent of depreciation (rm%) - %	**70**
Interest rate (i%) - %	**13.6**
Insurance and tax rate (it%) - %	**3**
Fuel consumption rate (fcr) - gal/hp-hr	**0.02018**
Fuel cost (fcg) - $/gal	**$3.85**
Lube and oil, percent of fuel cost (lo%) - %	**36.77**
Scheduled machine hours (SMH) - hr/yr	**4,000**
Base wage for 1st crew position (operator) (WB1) - $/SMH	**$3.85**
Base wage for 2nd crew position (laborer) (WB2) - $/SMH	**$1.92**
Laborers crew (w) - amount	**0**
Fringe benefits (FB) - %	**50**
Supervision as % of Direct Labor (sv%) - %	**10**

◉ GENERIC

Generic: Kenworth T800 (US$130,000)+ 20' container, international price (US$5,000) (US), Q30/Gl diesel, 11.1 Gl/hr consumption, Q5,000/month operator wage

CALCULATIONS	
Salvage value (S) = (P*rv%) - $	$27,000
Annual depreciation (AD) = ((P-S)/n) - $	$21,600
Average yearly investment (AYI) = ((((P-S)*(n+1))/(2*n))+S) - $	$91,800
Productive machine hours (PMH) = (SMH*ut%) - hrs/yr	3,600
Ownership Cost	
Interest cost (INC) = (i%*AYI) - $/yr	$12,852
Insurance and tax cost (IT) = (it%*AYI) - $/yr	$2,754
Yearly ownership cost (YF$) = (AD+INC+IT) - $/yr	$37,206
Ownership cost per PMH (F_PMH) = (YF$/PMH) - $/hr	$10.34
Ownership cost per SMH (F_SMH) = (YF$/SMH) - $/hr	$9.30
Operating Cost	
Fuel cost (F) = (hp*fcr*fcg) - $/hr	$42.73
Lube cost (L) = (F*lo%) - $/hr	$15.81
Repair and Maintenance cost (RM) = (AD*rm%/PMH) - $/hr	$4.00
Operating cost per PMH (V_PMH) = (F+L+RM) - $/hr	$62.54
Operating cost per SMH (V_SMH) = (V_PMH*ut%) - $/hr	$56.29
Labor Cost	
Operator labor and benefit cost (OL) = (WB1*(1+FB)/ut%) - $/hr	$6.42
Laborers labor and benefit cost (LL) = (w*WB2*(1+FB)/ut%) - $/hr	$0.00
Supervision labor and benefit cost (SL) = ((OL+LL)*sv%) - $/hr	$0.64
Labor cost per PMH (L_PMH) = (OL+LL+SL) - $/PMH	$7.06
Labor cost per SMH (L_SMH) = (L_PMH*ut%) - $/SMH	$6.35
Total Machine Cost	
Total cost per PMH (T_PMH) = (F_PMH+V_PMH+L_PMH) - $/hr	$79.94
Total cost per SMH (T_SMH) = (F_SMH+V_SMH+L_SMH) - $/hr	$71.94

Harvest cost per operation stage

FELLING/BUCKING MODULE (M14✓)

Time to Fell and Buck Trees	2.0	min/tree
Volume per Tree	1.30	m3
Delay	20.0	min/hr

Unit Cost

CALCULATIONS		
Machine Cost	$8.52	/SMH
Total Volume to Fell and Buck		m3/unit
Effective Cycle Time (min)	3.0	min
Felling/Bucking Production per SMH (m3)	26.0	m3
Ownership in Felling/Bucking Unit Cost	$0.01	/m3
Operating in Felling/Bucking Unit Cost	$0.15	/m3
Labor in Felling/Bucking Unit Cost	$0.17	/m3
Total Unit Cost for Felling/Bucking	**$0.33**	**/m3**

SKIDDING/YARDING MODULE (M5✓, M7✓)

		Uphill	Downhill
Move-in Time	0.25 hr		
Volume per Cycle		2.9	2.9 m3
Outhaul Velocity (empty)		80	80 m/min
Lateral Outhaul Velocity (empty)	m/min		
Hook Time	10.0 min		
Lateral Inhaul Velocity (loaded)	m/min		
Inhaul Velocity (loaded)		25	25 m/min
Unhook Time	5.0 min		
Delay	25.0 min/hr		

Radial Unit Cost

Right-Angle Unit Cost

CALCULATIONS

		Uphill	Downhill	Full
Machine Cost	$40.42 /SMH			
Average Yarding Distance (m)		153.0	153.0	m
Effective Cycle Time (min)		39.5	39.5	min
Total Time (SMH)		590.0	590.0	1180.1 hr
Total Cycles		897	897	1,793 turns
Skidding Production per SMH (m3)		4.4	4.4	4.4 m3
Ownership in Skidding Unit Cost		$0.65	$0.65	$0.65 /m3
Operating in Skidding Unit Cost		$4.55	$4.55	$4.55 /m3
Labor in Skidding Unit Cost		$2.38	$2.38	$2.38 /m3
Total Unit Cost for Skidding		**$7.57**	**$7.57**	**$7.57 /m3**

LOADING MODULE (M19✓)

Cycle Time	5.0 min/cyc
Load Size	1.0 m3/cyc
Delay	10.0 min/hr

Unit Cost

CALCULATIONS

Machine Cost	$44.99 /SMH
Effective Cycle Time (min)	6.0 min
Total Cycles	5,200
Loading Production per SMH (m3)	10.0 m3
Ownership in Loading Unit Cost	$0.45 /m3
Operating in Loading Unit Cost	$2.14 /m3
Labor in Loading Unit Cost	$1.90 /m3
Total Unit Cost for Loading	**$4.50 /m3**

TRANSPORT MODULE (M21✓)

Distance (one-way)	102.7 Km
Volume per Load	15.0 m3
Velocity (unloaded)	47.8 Km/hr
Loading Time	60.0 min
Velocity (loaded)	38.2 Km/hr
Unloading Time	45.0 min
Delay	0.0 min/cycle

Unit Cost

CALCULATIONS

Machine Cost	$71.94 /SMH
Cycle Distance (Km)	205.4 Km
Cycle Time (hr)	6.59 hr
Effective Cycle Time (hr)	6.59 hr
Total Cycles	347
Transport Production per SMH (m3)	2.3 m3
Ownership in Transport Unit Cost	$4.08 /m3
Operating in Transport Unit Cost	$24.72 /m3
Labor in Transport Unit Cost	$2.79 /m3
Total Unit Cost for Transport	**$31.59 /m3**

ROAD/LANDING MODULE (M8✓)

Unit Cost

CALCULATIONS

Total Volume per Landing	5,200	m3/unit
Total Road Cost	$6,000.00	/unit
Total Landing Cost	$500.00	/unit
Equipment Placement	$10.11	/unit

Total Unit Cost for Road/Landing **$1.25 /m3**

Example of total harvest cost for Project A038

PACE2 MASTER SCREEN (M9✓, M22✓, M6✓)

Road Cost (R)	$15,000 /Km
Uphill Spacing (Su)	200.0 m
Downhill Spacing (Sd)	200.0 m
Landing Spacing (L)	400.0 m
Timber Yield (V)	325 m3/ha
Skidding Weave Factor	1.00 (≥1)
Cost per Landing	$500 /unit

Cost Report

Radial Optimal Spacing

Right-Angle Optimal Spacing

NEAR OPTIMUM - Radial Pattern

Uphill Spacing **Su***	240.0 m
Downhill Spacing **Sd***	240.0 m
Landing Spacing **L***	160.0 m
Uphill **ASD***	131.7 m
Downhill **ASD***	131.7 m

SUMMARY

Activity	Production (m3/SMH)	Ownership Cost ($/m3)	Operating Cost ($/m3)	Labor Cost ($/m3)	Total Cost ($/m3)
Felling/Bucking	26.0	$0.01	$0.15	$0.17	$0.33
Skidding	4.4	$0.65	$4.55	$2.38	$7.57
Loading	10.0	$0.45	$2.14	$1.90	$4.50
Transport	2.3	$4.08	$24.72	$2.79	$31.59
Road/Landing					$1.25
TOTAL		**$5.19**	**$31.56**	**$7.24**	**$45.24**

Appendix 4. Outcomes from the spatial analysis in regard of the transport features

Fields

Suit: total area suitable for teak (in hectares); Avai: total area truly available for teak (in hectares); RandArea: project area generated at random (in hectares); OnewayDist: one-way distance to port; Highway: tract of road of high-speed quality (in kilometers, 70 Km/Hr as average velocity); Regional: tract of road of medium-speed quality (in kilometers, 40 Km/Hr as average velocity); Paved: tract of paved road of low-speed quality (in kilometers, 30 Km/Hr as average velocity); Dirty: tract of dirty road (in kilometers, 20 Km/Hr as average velocity); ToBuild: distance between the polygon cengtroid and the nearest road network (in kilometers, 20 Km/Hr as average velocity); Mspeed (U): mean speed of unloaded equipment; Mspeed (L): mean speed of loaded equipment, estimated as 80% of Mspeed (U).

Polygon ID	Department	Suit	Avai	Site	Rand Area	Oneway Dist	High way	Regional	Paved	Dirty	To Build	Mspeed (U)	Mspeed (L)
A001	Escuintla	862.1	167.9	S2	71.0	6.5	0	0	5.6	0	0.9	28.6	22.9
A003	Escuintla	1013.3	197.3	S2	2.3	11.2	0	0	10.8	0	0.4	29.6	23.7
A004	Escuintla	4345.3	846.2	S1	55.0	27.7	17.2	0	0.7	7.4	2.5	51.4	41.1
A005	Escuintla	230.2	44.8	S1	23.1	18.4	16.8	0	0.7	0.2	0.7	66.0	52.8
A006	Escuintla	167.5	32.6	S1	9.6	35.6	17.2	0	0.7	17.6	0.2	44.4	35.5
A007	Escuintla	70.7	13.8	S1	10.3	59.6	37.1	19	2	0	1.5	57.8	46.3
A008	Escuintla	7648.3	1489.5	S1	5.9	30.4	17.2	0	0.7	8.8	3.7	48.5	38.8
A010	Escuintla	1997.3	389.0	S1	4.4	32.2	25.6	0	0.7	2.5	3.4	60.0	48.0
A012	Escuintla	417.8	81.4	S1	22.2	28.7	25.6	0	0.7	1.4	1	64.8	51.9
A013	Escuintla	197.3	38.4	S1	21.2	28.4	27.5	0	0.7	0	0.3	68.7	55.0
A014	Escuintla	215.2	41.9	S1	21.6	49.6	37.1	9	2	1	0.6	61.5	49.2
A015	Escuintla	143.7	28.0	S1	6.2	49.2	37.1	9.6	2	0	0.5	62.0	49.6
A016	Escuintla	463.7	90.3	S1	2.3	50.4	37.1	9	2	1	1.3	60.8	48.6
A017	Escuintla	132.7	25.8	S1	5.4	50.8	37.1	10.6	2	0	1.1	61.1	48.9
A018	Escuintla	261.2	50.9	S1	4.7	52.8	37.1	13.4	2	0	0.3	60.6	48.5
A019	Escuintla	1268.4	247.0	S3	34.6	66.8	37.1	22	2	4.6	1.2	54.7	43.7
A022	Escuintla	507.4	98.8	S1	21.4	69.1	37.1	22	2	6.6	1.4	53.5	42.8
A023	Escuintla	1391.5	271.0	S1	36.7	72.0	37.1	22	2	9.7	1.3	52.2	41.7
A025	Escuintla	1309.5	255.0	S3	9.1	56.7	37.1	11.2	7.9	0	0.5	58.1	46.4
A026	Escuintla	283.7	55.2	S1	76.9	62.4	37.1	11.2	11.1	2.3	0.6	55.1	44.1
A027	Escuintla	3653.6	711.5	S3	4.4	57.5	37.1	11.2	5.4	0	3.8	57.1	45.7
A029	Escuintla	220.7	43.0	S2	12.9	45.3	44.2	0	0.7	0	0.4	68.9	55.2
A030	Escuintla	415.2	80.9	S2	0.7	45.8	44.2	0	0.7	0	0.9	68.4	54.7
A035	Escuintla	143.9	28.0	S1	2.8	92.1	40.1	33	11.7	5.9	1.3	50.2	40.1
A036	Escuintla	1211.0	235.8	S1	9.7	86.3	40.1	33	11.7	1.3	0.2	52.2	41.8
A037	Escuintla	1762.9	343.3	S1	2.3	87.1	40.1	33	13	0	1	52.1	41.7
A038	Escuintla	49.7	9.7	S1	2.8	102.7	40.1	42	0.7	15.9	4.1	47.8	38.2
A039	Escuintla	40.8	7.9	S1	3.9	78.1	40.1	37.1	0.7	0	0.2	55.3	44.2
A040	Escuintla	432.4	84.2	S1	1.6	79.3	40.1	37.1	0.7	0	1.4	54.7	43.8
A041	Escuintla	284.1	55.3	S3	2.4	80.0	40.1	38.7	0.7	0	0.7	54.9	43.9
A043	Escuintla	610.9	119.0	S1	57.5	88.9	40.1	42	0.7	5	1.1	52.1	41.7
A044	Escuintla	443.3	86.3	S1	2.0	88.8	40.1	44.7	0.7	1.8	1.6	52.7	42.2
A046	Escuintla	21.4	4.2	S3	3.6	85.8	40.1	44.7	0.7	0	0.3	53.9	43.1
A047	Escuintla	152.0	29.6	S1	1.4	87.1	40.1	44.7	0.7	0.8	0.8	53.4	42.7
A051	Suchitepéquez	87.8	6.7	S1	4.1	103.4	40.1	57.2	6	0	0.1	51.0	40.8
A052	Suchitepéquez	543.2	41.4	S2	8.9	108.1	40.1	57.2	9.6	0.9	0.3	50.0	40.0
A053	Suchitepéquez	342.3	26.1	S1	17.1	108.9	40.1	57.2	11.5	0	0.1	50.0	40.0
A055	Suchitepéquez	614.1	46.8	S2	4.6	105.3	40.1	57.2	4.5	2.8	0.8	50.4	40.3
A057	Suchitepéquez	410.0	31.2	S2	8.2	104.6	40.1	60.4	3.4	0	0.7	51.0	40.8
A058	Suchitepéquez	65.0	4.9	S2	3.9	102.7	40.1	60.4	1.8	0	0.4	51.5	41.2
A061	Suchitepéquez	3191.6	243.1	S1	21.0	114.8	40.1	67.1	0.7	4.4	2.6	49.2	39.4
A064	Escuintla	656.1	127.8	S3	32.1	136.6	40.1	67.9	21.6	0	7.1	46.2	37.0
A067	Suchitepéquez	158.9	12.1	S2	5.4	115.7	40.1	67.9	3.6	0	4.1	49.4	39.5
A069	Suchitepéquez	1321.1	100.6	S1	28.2	113.7	40.1	67.1	0.7	4.4	1.4	49.5	39.6

A070	Suchitepéquez	126.0	9.6	S1	2.9	125.0	40.1	72.4	0.7	11.2	0.7	47.7	38.2
A071	Suchitepéquez	448.6	34.2	S1	32.2	124.3	40.1	72.4	0.7	10.3	0.9	47.9	38.3
A074	Suchitepéquez	127.5	9.7	S1	3.1	124.8	40.1	72.4	0.7	11	0.6	47.7	38.2
A075	Suchitepéquez	446.1	34.0	S1	47.7	116.8	40.1	72.4	0.7	2.7	0.9	49.6	39.7
A076	Suchitepéquez	1214.6	92.5	S2	1.4	111.7	40.1	67.9	3.4	0	0.3	50.4	40.3
A077	Suchitepéquez	138.0	10.5	S2	5.6	110.7	40.1	69.6	0.7	0	0.4	50.8	40.6
A078	Suchitepéquez	86.0	6.6	S1	3.9	112.3	40.1	67.9	3	1	0.4	50.2	40.2
A080	Suchitepéquez	429.2	32.7	S2	9.3	124.6	40.1	67.9	15.3	0	1.3	48.2	38.6
A081	Suchitepéquez	1196.2	91.1	S1	4.6	116.3	40.1	74	0.7	0	1.6	50.0	40.0
A082	Suchitepéquez	186.2	14.2	S2	5.9	117.2	40.1	74.6	0.7	0	1.9	49.9	39.9
A083	Suchitepéquez	3420.4	260.5	S2	6.4	122.6	40.1	76.5	0.7	4	1.4	48.9	39.1
A085	Suchitepéquez	1554.8	118.4	S2	4.6	145.8	40.1	86.3	6.7	11.1	1.6	46.0	36.8
A086	Suchitepéquez	786.1	59.9	S2	52.4	146.3	40.1	86.3	6.7	12.3	0.9	46.0	36.8
A087	Suchitepéquez	300.3	22.9	S2	1.2	148.0	40.1	86.3	6.7	14.3	0.6	45.7	36.5
A088	Suchitepéquez	299.7	22.8	S2	36.4	145.6	40.1	86.3	6.7	11.8	0.7	46.1	36.9
A091	Suchitepéquez	1060.6	80.8	S3	29.1	171.5	40.1	101.1	6.7	18.8	4.8	43.9	35.1
A096	Suchitepéquez	74.8	5.7	S3	1.9	158.5	40.1	101.1	6.7	10.2	0.4	45.8	36.7
A099	Suchitepéquez	683.9	52.1	S1	5.5	153.2	40.1	101.1	6.7	4.1	1.2	46.7	37.4
A100	Suchitepéquez	1266.4	96.5	S1	93.6	153.5	40.1	101.1	8.5	0	3.8	46.8	37.4
A101	Suchitepéquez	50.1	3.8	S1	2.0	151.4	40.1	101.1	8.5	1.6	0.2	47.2	37.7
A104	Suchitepéquez	1446.1	110.1	S1	8.2	138.5	40.1	86.3	6.7	3.5	1.9	47.4	37.9
A105	Suchitepéquez	280.2	21.3	S1	3.8	131.3	40.1	86.3	4.2	0	0.7	48.7	39.0
A106	Suchitepéquez	423.4	32.2	S1	6.7	130.3	40.1	86.3	3.4	0	0.5	48.9	39.1
A107	Suchitepéquez	114.8	8.7	S1	4.5	123.4	40.1	82.5	0.7	0	0.1	49.7	39.7
A108	Suchitepéquez	311.2	23.7	S2	10.2	121.3	40.1	79.3	0.7	0	1.3	49.7	39.7
A110	Suchitepéquez	29.9	2.3	S1	1.4	125.6	40.1	84.6	0.7	0	0.3	49.5	39.6
A111	Suchitepéquez	2118.4	161.4	S1	25.5	148.6	40.1	101.1	5.5	0	1.8	47.5	38.0
A112	Suchitepéquez	81.6	6.2	S1	4.4	129.9	40.1	79	10.6	0	0.3	48.4	38.7
A113	Suchitepéquez	1314.9	100.2	S1	30.6	130.1	40.1	79	7.7	0	3.4	48.2	38.5
A114	Suchitepéquez	218.1	16.6	S1	6.4	131.2	40.1	79	10.6	1.2	0.3	48.1	38.5
A117	Suchitepéquez	176.0	13.4	S1	4.5	133.2	40.1	91	1.7	0	0.5	48.9	39.1
A119	Suchitepéquez	457.6	34.9	S1	22.0	134.1	40.1	92.5	0.7	0	0.9	48.8	39.1
A120	Suchitepéquez	298.8	22.8	S1	9.4	133.0	40.1	91.7	0.7	0	0.6	48.9	39.1
A121	Suchitepéquez	337.7	25.7	S1	8.6	136.3	40.1	94.6	0.7	0	1	48.7	38.9
A123	Suchitepéquez	225.8	17.2	S1	10.4	137.3	40.1	95.9	0.7	0	0.6	48.6	38.9
A126	Suchitepéquez	313.5	23.9	S1	10.8	144.0	40.1	101.5	1.8	0	0.6	48.1	38.5
A129	Suchitepéquez	26.9	2.1	S1	1.2	152.4	40.1	107.9	0.7	3.6	0.2	47.4	37.9
A131	Suchitepéquez	302.2	23.0	S1	12.0	157.5	40.1	110	3.1	3.8	0.5	46.9	37.5
A132	Suchitepéquez	37.9	2.9	S1	1.3	155.9	40.1	110	2.1	3.6	0.1	47.1	37.7
A133	Retalhuleu	188.2	188.2	S1	21.7	157.7	40.1	110	3.3	3.6	0.7	46.9	37.5
A134	Retalhuleu	173.5	173.5	S1	15.7	158.6	40.1	110	3.1	5	0.5	46.7	37.4
A136	Retalhuleu	610.2	610.2	S1	4.8	161.2	40.1	110	6.7	3.6	0.8	46.5	37.2
A138	Retalhuleu	242.7	242.7	S2	7.4	166.0	40.1	119.4	2.3	3.6	0.7	46.6	37.3
A139	Retalhuleu	242.4	242.4	S2	7.0	166.5	40.1	119.4	3.2	3.6	0.4	46.6	37.3
A140	Retalhuleu	221.1	221.1	S2	19.7	169.5	40.1	121.1	3.9	3.6	0.9	46.4	37.1
A141	Retalhuleu	248.6	248.6	S1	31.3	170.2	40.1	121.1	5	3.6	0.5	46.3	37.1
A146	Retalhuleu	367.2	367.2	S3	2.4	176.5	40.1	125.8	6.3	3.6	0.8	46.0	36.8
A148	Retalhuleu	325.1	325.1	S1	3.0	172.3	40.1	125.8	2.6	3.6	0.3	46.4	37.1
A149	Retalhuleu	349.1	349.1	S1	2.8	172.2	40.1	125.8	2	3.6	0.8	46.4	37.1
A150	Retalhuleu	122.2	122.2	S3	13.5	175.7	40.1	125.8	5.9	3.6	0.4	46.1	36.9
A151	Retalhuleu	920.0	920.0	S1	18.3	175.4	40.1	128.4	0.7	3.6	2.6	46.1	36.9
A154	Retalhuleu	37.3	37.3	S1	25.5	175.3	40.1	129.8	0.7	4.1	0.7	46.3	37.0
A155	Retalhuleu	205.2	205.2	S1	1.0	176.3	40.1	130.1	1.9	3.6	0.6	46.2	37.0
A157	Retalhuleu	191.5	191.5	S1	9.9	180.4	40.1	135.1	0.7	3.6	1	46.1	36.9
A158	Retalhuleu	83.0	83.0	S1	2.3	181.0	40.1	136.7	0.7	0	0.5	45.9	36.7
A160	Retalhuleu	460.7	460.7	S1	3.1	173.6	40.1	114.4	0.7	16.5	2	44.8	35.8
A164	Retalhuleu	1241.9	1241.9	S1	3.9	174.3	40.1	110	2.9	18.9	2.4	44.3	35.4

Appendix 5. Example calculation basis for estimation of optimal rotation age according to single and multiple rotations regimes in the three discounting scenarios

Example Project: A005

PERIOD:				0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
DISC. FACTORS:	Private			1.000	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	0.319	0.290	0.263	0.239	0.218	0.198	0.180	0.164	0.149
	Social			1.000	0.926	0.857	0.794	0.735	0.681	0.630	0.583	0.540	0.500	0.463	0.429	0.397	0.368	0.340	0.315	0.292	0.270	0.250	0.232	0.215
PROJECT:	A005																							
SITE:	S1																							
AREA:	23.1																							
PRIVATE DISC. RATE:	10.00%																							
SOCIAL DISC. RATE:	8.00%																							
REGIME SCC3/TR2																								
UNIT CASHFLOW:	INFLOW	Thin							$1,688		$1,967		$1,284											
		Harv					$2,459	$4,501	$9,017	$12,143	$15,141	$24,458	$27,806	$30,717	$33,207	$35,308	$37,064	$47,965	$49,459	$50,685	$51,687	$52,503	$53,167	$53,705
	OUTFLOW	Silv			($2,234)	($983)	($950)	($1,002)	($931)	($415)	($556)	($319)	($319)	($396)	($319)	($319)	($396)	($319)	($319)	($396)	($319)	($319)	($396)	($319)
		Thin							($1,002)		($858)		($411)											
		Tran							($260)		($303)		($198)											
		Expo							($152)		($177)		($116)											
		FinC					($2,059)	($2,694)	($3,616)	($4,501)	($4,054)	($4,287)	($4,298)	($4,357)	($4,208)	($4,569)	($4,634)	($4,689)	($4,714)	($4,721)	($4,877)	($4,947)	($5,013)	($5,057)
		Tran					($379)	($693)	($1,048)	($1,412)	($1,761)	($2,081)	($2,365)	($2,613)	($2,825)	($3,003)	($3,153)	($3,277)	($3,379)	($3,463)	($3,531)	($3,587)	($3,632)	($3,669)
		Expo					($222)	($406)	($614)	($827)	($1,031)	($1,219)	($1,386)	($1,531)	($1,655)	($1,760)	($1,847)	($1,920)	($1,980)	($2,029)	($2,069)	($2,101)	($2,128)	($2,150)
SINGLE ROT.	NET10		$3,520		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	$21,821										
NPVf/Ha	NET11		$3,436		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	$24,200									
	NET12		$3,017		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	$25,657								
	NET13		$2,572		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	($319)	$27,035							
	NET14		$4,570		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	($319)	($396)	$37,760						
	NET15		$3,895		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	($319)	($396)	($319)	$39,068					
MULTIPLE ROT.	NET10		$4,574		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	$19,982										
LEVf/Ha	NET11		$4,257		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	$22,285									
	NET12		$3,533		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	$23,741								
	NET13		$2,871		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	($319)	$25,196							
	NET14		$5,518		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	($319)	($396)	$35,845						
	NET15		$4,517		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	($319)	($396)	($319)	$37,152					
SINGLE ROT																								
SROT/SCC3/TR2/NET14	NPVf		$4,570		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	($319)	($396)	$37,760						
Opportuniy Cost Silv	OCS2				($165)	($165)	($165)	($165)	($165)	($165)	($165)	($165)	($165)	($165)	($165)	($165)	($165)	($165)						
Land Purchase/Resale	PPC2																	$9,900						
Opportunity Cost Land	OCL2				($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)						
	NPVr		$4,904	$0	($2,543)	($1,292)	($1,258)	($1,310)	($966)	($723)	($235)	($628)	($68)	($704)	($628)	($628)	($704)	$47,351						
	NPVs		$7,970	$0	($2,543)	($1,292)	($1,258)	($1,310)	($966)	($723)	($235)	($628)	($68)	($704)	($628)	($628)	($704)	$47,351						
MULTIPLE ROT																								
MROT/SCC3/TR2/NET14	LEVf		$5,518		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	($319)	($396)	$35,845						
Opportuniy Cost Silv	OCS2				($165)	($165)	($165)	($165)	($165)	($165)	($165)	($165)	($165)	($165)	($165)	($165)	($165)	($165)						
Land Purchase/Resale	PPC2																							
Opportunity Cost Land	OCL2				($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)						
	LEVr		$2,433	$0	($2,543)	($1,292)	($1,258)	($1,310)	($966)	($723)	($235)	($628)	($68)	($704)	($628)	($628)	($704)	$35,536						
	LEVs		$5,985	$0	($2,543)	($1,292)	($1,258)	($1,310)	($966)	($723)	($235)	($628)	($68)	($704)	($628)	($628)	($704)	$35,536						
EMPLOYMENT - SINGLE ROT																								
Silv					68	30	34	31	38	31	39	31	31	31	31	31	31	31						
Thin					0	0	0	0	19	0	18	0	18	0	0	0	0	0						
Harv																		117						
TOTAL					68	30	34	31	57	31	57	31	49	31	31	31	31	148						
EMPLOYMENT - MULTIPLE ROT																								
Silv					68	30	34	31	38	31	39	31	31	31	31	31	31	99						
Thin					0	0	0	0	19	0	18	0	18	0	0	0	0	0						
Harv																		117						
TOTAL					68	30	34	31	57	31	57	31	49	31	31	31	31	216						

PERIOD:				0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
DISC. FACTORS:	Private			1.000	0.893	0.797	0.712	0.636	0.567	0.507	0.452	0.404	0.361	0.322	0.287	0.257	0.229	0.205	0.183	0.163	0.146	0.130	0.116	0.104
	Social			1.000	0.917	0.842	0.772	0.708	0.650	0.596	0.547	0.502	0.460	0.422	0.388	0.356	0.326	0.299	0.275	0.252	0.231	0.212	0.194	0.178
PROJECT:	A005																							
SITE:	S1																							
AREA:	23.1																							
PRIVATE DISC. RATE:	12.00%																							
SOCIAL DISC. RATE:	9.00%																							
SCHEME: SCC3/TR2																								
UNIT CASHFLOW:	INFLOW	Thin							$1,688		$1,967		$1,284											
		Harv					$2,459	$4,501	$9,017	$12,143	$15,141	$24,458	$27,806	$30,717	$33,207	$35,308	$37,064	$47,965	$49,459	$50,685	$51,687	$52,503	$53,167	$53,705
	OUTFLOW	Silv			($2,234)	($983)	($950)	($1,002)	($931)	($415)	($556)	($319)	($319)	($396)	($319)	($319)	($396)	($319)	($319)	($396)	($319)	($319)	($396)	($319)
		Thin							($1,002)		($858)		($411)											
		Tran							($260)		($303)		($198)											
		Expo							($152)		($177)		($116)											
		FinC					($2,059)	($2,694)	($3,616)	($4,501)	($4,054)	($4,287)	($4,298)	($4,357)	($4,208)	($4,569)	($4,634)	($4,689)	($4,714)	($4,721)	($4,877)	($4,947)	($5,013)	($5,057)
		Tran					($379)	($693)	($1,048)	($1,412)	($1,761)	($2,081)	($2,365)	($2,613)	($2,825)	($3,003)	($3,153)	($3,277)	($3,379)	($3,463)	($3,531)	($3,587)	($3,632)	($3,669)
		Expo					($222)	($406)	($614)	($827)	($1,031)	($1,219)	($1,386)	($1,531)	($1,655)	($1,760)	($1,847)	($1,920)	($1,980)	($2,029)	($2,069)	($2,101)	($2,128)	($2,150)
SINGLE ROT.	NET10		$2,342		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	$21,821										
NPVf/Ha	NET11		$2,146		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	$24,200									
	NET12		$1,683		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	$25,657								
	NET13		$1,211		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	($319)	$27,035							
	NET14		$2,651		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	($319)	($396)	$37,760						
	NET15		$1,997		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	($319)	($396)	($319)	$39,068					
MULTIPLE ROT.	NET10		$2,581		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	$19,982										
LEVf/Ha	NET11		$2,239		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	$22,285									
	NET12		$1,602		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	$23,741								
	NET13		$1,024		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	($319)	$25,196							
	NET14		$2,840		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	($319)	($396)	$35,845						
	NET15		$2,015		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	($319)	($396)	($319)	$37,152					
SINGLE ROT																								
SROT/SCC3/TR2/NET14	NPVf		$2,651		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	($319)	($396)	$37,760						
Opportuniy Cost Silv	OCS2				($152)	($152)	($152)	($152)	($152)	($152)	($152)	($152)	($152)	($152)	($152)	($152)	($152)	($152)						
Land Purchase/Resale	PPC2																	$9,900						
Opportunity Cost Land	OCL2				($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)						
	NPVr		$2,717	$0	($2,530)	($1,279)	($1,245)	($1,298)	($953)	($711)	($223)	($615)	($55)	($691)	($615)	($615)	($691)	$47,364						
	NPVs		$6,422	$0	($2,530)	($1,279)	($1,245)	($1,298)	($953)	($711)	($223)	($615)	($55)	($691)	($615)	($615)	($691)	$47,364						
MULTIPLE ROT																								
MROT/SCC3/TR2/NET14	LEVf		$2,840		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	($319)	($396)	$35,845						
Opportuniy Cost Silv	OCS2				($152)	($152)	($152)	($152)	($152)	($152)	($152)	($152)	($152)	($152)	($152)	($152)	($152)	($152)						
Land Purchase/Resale	PPC2																							
Opportunity Cost Land	OCL2				($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)						
	LEVr		$376	$0	($2,530)	($1,279)	($1,245)	($1,298)	($953)	($711)	($223)	($615)	($55)	($691)	($615)	($615)	($691)	$35,549						
	LEVs		$4,119	$0	($2,530)	($1,279)	($1,245)	($1,298)	($953)	($711)	($223)	($615)	($55)	($691)	($615)	($615)	($691)	$35,549						
EMPLOYMENT - SINGLE ROT																								
Silv					68	30	34	31	38	31	39	31	31	31	31	31	31	31						
Thin					0	0	0	0	19	0	18	0	18	0	0	0	0	0						
Harv																		117						
TOTAL					68	30	34	31	57	31	57	31	49	31	31	31	31	148						
EMPLOYMENT - MULTIPLE ROT																								
Silv					68	30	34	31	38	31	39	31	31	31	31	31	31	99						
Thin					0	0	0	0	19	0	18	0	18	0	0	0	0	0						
Harv																		117						
TOTAL					68	30	34	31	57	31	57	31	49	31	31	31	31	216						

PERIOD:			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
DISC. FACTORS:	Private		1.000	0.877	0.769	0.675	0.592	0.519	0.456	0.400	0.351	0.308	0.270	0.237	0.208	0.182	0.160	0.140	0.123	0.108	0.095	0.083	0.073
	Social		1.000	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	0.319	0.290	0.263	0.239	0.218	0.198	0.180	0.164	0.149
PROJECT:	A005																						
SITE:	S1																						
AREA:	23.1																						
PRIVATE DISC. RATE:	14.00%																						
SOCIAL DISC. RATE:	10.00%																						
SCHEME:	SCC3/TR2																						
UNIT CASHFLOW:	INFLOW	Thin						$1,688		$1,967		$1,284											
		Harv				$2,459	$4,501	$9,017	$12,143	$15,141	$24,458	$27,806	$30,717	$33,207	$35,308	$37,064	$47,965	$49,459	$50,685	$51,687	$52,503	$53,167	$53,705
	OUTFLOW	Silv		($2,234)	($983)	($950)	($1,002)	($931)	($415)	($556)	($319)	($319)	($396)	($319)	($319)	($396)	($319)	($319)	($396)	($319)	($319)	($396)	($319)
		Thin						($1,002)		($858)		($411)											
		Tran						($260)		($303)		($198)											
		Expo						($152)		($177)		($116)											
		FinC				($2,059)	($2,694)	($3,616)	($4,501)	($4,054)	($4,287)	($4,298)	($4,357)	($4,208)	($4,569)	($4,634)	($4,689)	($4,714)	($4,721)	($4,877)	($4,947)	($5,013)	($5,057)
		Tran				($379)	($693)	($1,048)	($1,412)	($1,761)	($2,081)	($2,365)	($2,613)	($2,825)	($3,003)	($3,153)	($3,277)	($3,379)	($3,463)	($3,531)	($3,587)	($3,632)	($3,669)
		Expo				($222)	($406)	($614)	($827)	($1,031)	($1,219)	($1,386)	($1,531)	($1,655)	($1,760)	($1,847)	($1,920)	($1,980)	($2,029)	($2,069)	($2,101)	($2,128)	($2,150)
SINGLE ROT.	NET08	$1,351		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	$16,553												
NPVf/Ha	NET09	$1,413		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$19,437											
	NET10	$1,396		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	$21,821										
	NET11	$1,130		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	$24,200									
	NET12	$653		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	$25,657								
	NET13	$184		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	($319)	$27,035							
	NET14	$1,220		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	($319)	($396)	$37,760						
	NET15	$612		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	($319)	($396)	($319)	$39,068					
MULTIPLE ROT.	NET08	$1,046		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	$14,637												
LEVf/Ha	NET09	$1,190		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$17,522											
	NET10	$1,233		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	$19,982										
	NET11	$886		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	$22,285									
	NET12	$323		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	$23,741								
	NET13	($184)		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	($319)	$25,196							
	NET14	$1,088		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	($319)	($396)	$35,845						
	NET15	$400		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	($396)	($319)	($319)	($396)	($319)	$37,152					
SINGLE ROT																							
SROT/SCC3/TR2/NET09	NPVf	$1,413		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$19,437											
Opportuniy Cost Silv	OCS2			($141)	($141)	($141)	($141)	($141)	($141)	($141)	($141)	($141)											
Land Purchase/Resale	PPC2											$7,757											
Opportunity Cost Land	OCL2			($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)											
	NPVr	$2,389	$0	($2,519)	($1,268)	($1,235)	($1,287)	($942)	($700)	($212)	($604)	$26,909											
	NPVs	$4,897	$0	($2,519)	($1,268)	($1,235)	($1,287)	($942)	($700)	($212)	($604)	$26,909											
MULTIPLE ROT																							
MROT/SCC3/TR2/NET10	LEVf	$1,233		($2,234)	($983)	($950)	($1,002)	($657)	($415)	$73	($319)	$240	$19,982										
Opportuniy Cost Silv	OCS2			($141)	($141)	($141)	($141)	($141)	($141)	($141)	($141)	($141)	($141)										
Land Purchase/Resale	PPC2																						
Opportunity Cost Land	OCL2			($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)	($144)										
	LEVr	($802)	$0	($2,519)	($1,268)	($1,235)	($1,287)	($942)	($700)	($212)	($604)	($44)	$19,698										
	LEVs	$1,725	$0	($2,519)	($1,268)	($1,235)	($1,287)	($942)	($700)	($212)	($604)	($44)	$19,698										
EMPLOYMENT - SINGLE ROT																							
Silv				68	30	34	31	38	31	39	31	31											
Thin				0	0	0	0	19	0	18	0	18											
Harv												117											
TOTAL				68	30	34	31	57	31	57	31	166											
EMPLOYMENT - MULTIPLE ROT																							
Silv				68	30	34	31	38	31	39	31	31	99										
Thin				0	0	0	0	19	0	18	0	18	0										
Harv													117										
TOTAL				68	30	34	31	57	31	57	31	49	216										

Appendix 6. Employment generation capacity per period of all the simulated projects under single and multiple rotations regime at optimal rotation age according to the three discounting scenarios (values in work-days of the entire project)

Single rotation regime, SP810

Project	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A001	4811	2103	2387	2231	3825	2231	2784	2220	2220	3259	8387	0	0	0	0
A003	159	69	79	74	90	74	128	73	73	108	277	0	0	0	0
A004	4364	1521	1521	1383	2625	1224	2624	699	1665	699	699	699	699	7127	0
A005	1567	685	777	727	1315	727	1315	723	1129	723	723	723	723	3423	0
A006	714	409	398	405	562	104	309	98	267	121	98	98	121	1222	0
A007	819	286	286	260	493	230	310	131	131	314	131	131	131	1338	0
A008	440	252	245	249	236	64	195	60	60	179	60	60	74	752	0
A010	348	121	121	110	128	98	213	56	56	133	56	56	56	568	0
A012	1645	942	916	933	1295	239	320	226	226	669	226	226	278	2814	0
A013	1575	902	877	893	1240	229	306	216	216	641	216	216	266	2694	0
A014	1607	921	895	911	1264	233	312	220	220	653	220	220	271	2748	0
A015	492	171	171	156	181	138	302	79	79	188	79	79	79	804	0
A016	171	98	95	97	92	25	76	23	23	69	23	23	29	292	0
A017	366	160	181	170	307	170	212	169	169	264	169	169	169	799	0
A018	316	138	157	147	265	147	265	146	228	146	146	146	146	690	0
A019	2567	1471	1429	1456	1817	373	906	352	756	434	352	2931	0	0	0
A022	1697	592	592	538	1021	476	643	272	272	650	272	272	272	2772	0
A023	2913	1015	1015	923	1070	817	1786	467	467	1115	467	467	467	4758	0
A025	722	252	252	229	381	202	274	116	116	223	116	795	0	0	0
A026	5214	2279	2587	2417	4376	2417	3017	2406	2406	3763	2406	2406	2406	11388	0
A027	300	131	149	139	226	139	226	139	190	139	139	139	139	469	0
A029	1025	357	357	325	376	287	589	164	164	353	1287	0	0	0	0
A030	55	19	19	17	31	15	21	9	9	19	69	0	0	0	0
A035	207	119	115	118	111	30	92	28	28	84	28	28	35	355	0
A036	721	413	402	409	568	105	312	99	269	122	99	99	122	1234	0
A037	171	98	95	97	134	25	74	23	64	29	23	23	29	292	0
A038	193	84	96	90	162	90	112	89	89	139	89	89	89	422	0
A039	313	109	109	99	115	88	192	50	50	120	50	50	50	511	0
A040	109	48	54	51	62	51	93	50	50	79	50	50	50	238	0
A041	187	65	65	59	99	52	71	30	30	58	30	206	0	0	0
A043	3895	1702	1932	1806	3269	1806	3268	1797	2805	1797	1797	1797	1797	8507	0
A044	159	55	55	50	58	44	97	25	25	61	25	25	25	259	0
A046	243	106	120	113	137	113	186	112	112	154	112	379	0	0	0
A047	111	39	39	35	67	31	42	18	18	43	18	18	18	182	0
A051	307	176	171	174	241	45	60	42	42	125	42	42	52	525	0
A052	702	245	245	223	258	197	404	113	113	1012	0	0	0	0	0
A053	1270	728	707	720	682	184	564	174	174	516	174	174	215	2172	0
A055	340	195	189	193	254	49	133	47	113	455	0	0	0	0	0
A057	555	242	275	257	441	257	441	256	375	967	0	0	0	0	0
A058	288	165	160	163	215	42	113	39	96	386	0	0	0	0	0
A061	1560	894	868	884	1227	227	303	214	214	634	214	214	264	2668	0
A064	2542	886	886	806	934	713	1370	407	407	785	407	2798	0	0	0
A067	401	230	223	228	216	58	162	55	55	617	0	0	0	0	0
A069	1909	835	947	885	1602	885	1105	881	881	1378	881	881	881	4170	0
A070	216	124	120	123	170	31	93	30	81	37	30	30	37	370	0
A071	2392	1371	1332	1357	1284	347	1063	328	328	973	328	328	404	4092	0
A074	233	133	130	132	183	34	101	32	87	39	32	32	39	398	0
A075	3233	1413	1604	1499	2713	1499	2712	1492	2329	1492	1492	1492	1492	7062	0
A076	95	41	47	44	54	44	77	44	44	186	0	0	0	0	0
A077	417	239	232	236	224	61	168	57	57	641	0	0	0	0	0
A078	264	115	131	122	222	122	222	122	190	122	122	122	122	577	0
A080	690	395	384	391	515	100	134	95	95	1060	0	0	0	0	0
A081	343	197	191	195	270	50	148	47	128	58	47	47	58	587	0
A082	466	163	163	148	171	131	268	75	75	672	0	0	0	0	0
A083	434	190	215	201	245	201	351	200	200	850	0	0	0	0	0
A085	364	127	127	115	205	102	138	58	58	525	0	0	0	0	0
A086	4152	1447	1447	1316	1526	1164	2388	665	665	5982	0	0	0	0	0
A087	90	51	50	51	48	13	36	12	12	138	0	0	0	0	0
A088	2698	1546	1502	1530	2014	392	1056	370	899	3614	0	0	0	0	0
A091	2307	804	804	731	848	647	1244	370	370	712	370	2540	0	0	0
A096	131	57	65	61	99	61	99	60	83	60	60	205	0	0	0
A099	438	153	153	139	263	123	166	70	70	167	70	70	70	715	0
A100	6945	3979	3867	3939	5466	1009	3000	953	2594	1174	953	953	1174	11879	0
A101	148	85	83	84	117	22	64	20	55	25	20	20	25	254	0
A104	554	242	275	257	465	257	321	256	256	400	256	256	256	1210	0
A105	304	106	106	96	183	85	183	49	116	49	49	49	49	497	0
A106	534	186	186	169	321	150	202	86	86	204	86	86	86	872	0
A107	360	126	126	114	217	101	136	58	58	138	58	58	58	588	0

A108	808	282	282	256	456	227	306	129	129	1164	0	0	0	0	0
A110	101	58	56	57	80	15	20	14	14	41	14	14	17	173	0
A111	2023	705	705	641	1217	567	1216	324	772	324	324	324	324	3303	0
A112	349	122	122	111	128	98	214	56	56	134	56	56	56	570	0
A113	2274	1303	1266	1290	1221	330	1010	312	312	925	312	312	384	3890	0
A114	476	273	265	270	375	69	206	65	178	80	65	65	80	814	0
A117	356	124	124	113	214	100	135	57	57	136	57	57	57	582	0
A119	1490	651	739	691	1251	691	862	688	688	1076	688	688	688	3255	0
A120	698	400	389	396	375	101	310	96	96	284	96	96	118	1194	0
A121	586	256	291	272	331	272	499	270	270	423	270	270	270	1279	0
A123	774	443	431	439	609	112	334	106	289	131	106	106	131	1324	0
A126	798	457	444	453	628	116	155	109	109	325	109	109	135	1365	0
A129	93	53	52	53	73	13	40	13	35	16	13	13	16	158	0
A131	890	510	496	505	701	129	173	122	122	362	122	122	150	1523	0
A132	95	54	53	54	51	14	42	13	13	38	13	13	16	162	0
A133	1471	643	730	682	1234	682	1234	679	1059	679	679	679	679	3212	0
A134	1067	466	529	495	603	495	909	492	492	770	492	492	492	2330	0
A136	328	143	163	152	275	152	275	151	236	151	151	151	151	717	0
A138	499	218	248	232	282	232	404	230	230	978	0	0	0	0	0
A139	477	209	237	221	270	221	386	220	220	935	0	0	0	0	0
A140	1334	583	662	619	1061	619	772	616	616	2614	0	0	0	0	0
A141	2326	1333	1295	1319	1831	338	452	319	319	946	319	319	393	3979	0
A146	161	70	80	75	121	75	121	74	102	74	74	251	0	0	0
A148	222	127	124	126	175	32	96	30	83	38	30	30	38	380	0
A149	205	118	114	116	110	30	91	28	28	83	28	28	35	351	0
A150	917	401	455	425	690	425	531	423	423	582	423	1431	0	0	0
A151	1355	776	754	768	1066	197	263	186	186	551	186	186	229	2317	0
A154	1894	1085	1055	1074	1017	275	842	260	260	770	260	260	320	3240	0
A155	80	28	28	25	48	22	48	13	30	13	13	13	13	130	0
A157	672	294	334	312	564	312	389	310	310	485	310	310	310	1468	0
A158	156	68	77	72	131	72	131	72	112	72	72	72	72	340	0
A160	243	85	85	77	89	68	149	39	39	93	39	39	39	398	0
A164	308	107	107	98	185	86	117	49	49	118	49	49	49	503	0

Single rotation regime, SP912

Project	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A001	4811	2103	2387	2231	3825	2231	2784	2220	2220	3259	8387	0	0	0	0
A003	159	69	79	74	90	74	128	73	73	108	277	0	0	0	0
A004	4364	1521	1521	1383	2625	1224	2624	699	1665	699	699	699	699	7127	0
A005	1567	685	777	727	1315	727	1315	723	1129	723	723	723	723	3423	0
A006	714	409	398	405	562	104	309	98	267	121	98	98	121	1222	0
A007	819	286	286	260	493	230	310	131	131	314	131	131	131	1338	0
A008	440	252	245	249	236	64	195	60	60	179	60	60	74	752	0
A010	348	121	121	110	128	98	213	56	56	133	56	56	56	568	0
A012	1645	942	916	933	1295	239	320	226	226	669	226	226	278	2814	0
A013	1575	902	877	893	1240	229	306	216	216	641	216	216	266	2694	0
A014	1607	921	895	911	1264	233	312	220	220	653	220	220	271	2748	0
A015	492	171	171	156	181	138	302	79	79	188	79	79	79	804	0
A016	171	98	95	97	92	25	76	23	23	69	23	23	29	292	0
A017	366	160	181	170	307	170	212	169	169	264	169	169	169	799	0
A018	316	138	157	147	265	147	265	146	228	146	146	146	146	690	0
A019	2567	1471	1429	1456	1817	373	906	352	756	434	352	2931	0	0	0
A022	1697	592	592	538	1021	476	643	272	272	650	272	272	272	2772	0
A023	2913	1015	1015	923	1070	817	1786	467	467	1115	467	467	467	4758	0
A025	722	252	252	229	381	202	274	116	116	223	116	795	0	0	0
A026	5214	2279	2587	2417	4376	2417	3017	2406	2406	3763	2406	2406	2406	11388	0
A027	300	131	149	139	226	139	226	139	190	139	139	139	139	469	0
A029	1025	357	357	325	376	287	589	164	164	353	1287	0	0	0	0
A030	55	19	19	17	31	15	21	9	9	19	69	0	0	0	0
A035	207	119	115	118	111	30	92	28	28	84	28	28	35	355	0
A036	721	413	402	409	568	105	312	99	269	122	99	99	122	1234	0
A037	171	98	95	97	134	25	74	23	64	29	23	23	29	292	0
A038	193	84	96	90	162	90	112	89	89	139	89	89	89	422	0
A039	313	109	109	99	115	88	192	50	50	120	50	50	50	511	0
A040	109	48	54	51	62	51	93	50	50	79	50	50	50	238	0
A041	187	65	65	59	99	52	71	30	30	58	30	206	0	0	0
A043	3895	1702	1932	1806	3269	1806	3268	1797	2805	1797	1797	1797	1797	8507	0
A044	159	55	55	50	58	44	97	25	25	61	25	25	25	259	0
A046	243	106	120	113	137	113	186	112	112	154	112	379	0	0	0
A047	111	39	39	35	67	31	42	18	18	43	18	18	18	182	0
A051	307	176	171	174	241	45	60	42	42	125	42	42	52	525	0
A052	702	245	245	223	258	197	404	113	113	1012	0	0	0	0	0
A053	1270	728	707	720	682	184	564	174	174	516	174	174	215	2172	0
A055	340	195	189	193	254	49	133	47	113	455	0	0	0	0	0
A057	555	242	275	257	441	257	441	256	375	967	0	0	0	0	0
A058	288	165	160	163	215	42	113	39	96	386	0	0	0	0	0
A061	1560	894	868	884	1227	227	303	214	214	634	214	214	264	2668	0
A064	2542	886	886	806	934	713	1370	407	407	785	407	2798	0	0	0
A067	401	230	223	228	216	58	162	55	55	617	0	0	0	0	0

A069	1909	835	947	885	1602	885	1105	881	881	1378	881	881	881	4170	0
A070	216	124	120	123	170	31	93	30	81	37	30	30	37	370	0
A071	2392	1371	1332	1357	1284	347	1063	328	328	973	328	328	404	4092	0
A074	233	133	130	132	183	34	101	32	87	39	32	32	39	398	0
A075	3233	1413	1604	1499	2713	1499	2712	1492	2329	1492	1492	1492	1492	7062	0
A076	95	41	47	44	54	44	77	44	44	186	0	0	0	0	0
A077	417	239	232	236	224	61	168	57	57	641	0	0	0	0	0
A078	264	115	131	122	222	122	222	122	190	122	122	122	122	577	0
A080	690	395	384	391	515	100	134	95	95	1060	0	0	0	0	0
A081	343	197	191	195	270	50	148	47	128	58	47	47	58	587	0
A082	466	163	163	148	171	131	268	75	75	672	0	0	0	0	0
A083	434	190	215	201	245	201	351	200	200	850	0	0	0	0	0
A085	364	127	127	115	205	102	138	58	58	525	0	0	0	0	0
A086	4152	1447	1447	1316	1526	1164	2388	665	665	5982	0	0	0	0	0
A087	90	51	50	51	48	13	36	12	12	138	0	0	0	0	0
A088	2698	1546	1502	1530	2014	392	1056	370	899	3614	0	0	0	0	0
A091	2307	804	804	731	848	647	1244	370	370	712	370	2540	0	0	0
A096	131	57	65	61	99	61	99	60	83	60	60	205	0	0	0
A099	438	153	153	139	263	123	166	70	70	167	70	70	70	715	0
A100	6945	3979	3867	3939	5466	1009	3000	953	2594	1174	953	953	1174	11879	0
A101	148	85	83	84	117	22	64	20	55	25	20	20	25	254	0
A104	554	242	275	257	465	257	321	256	256	400	256	256	256	1210	0
A105	304	106	106	96	183	85	183	49	116	49	49	49	49	497	0
A106	534	186	186	169	321	150	202	86	86	204	86	86	86	872	0
A107	360	126	126	114	217	101	136	58	58	138	58	58	58	588	0
A108	808	282	282	256	456	227	306	129	129	1164	0	0	0	0	0
A110	101	58	56	57	80	15	20	14	14	41	14	14	17	173	0
A111	2023	705	705	641	1217	567	1216	324	772	324	324	324	324	3303	0
A112	349	122	122	111	128	98	214	56	56	134	56	56	56	570	0
A113	2274	1303	1266	1290	1221	330	1010	312	312	925	312	312	384	3890	0
A114	476	273	265	270	375	69	206	65	178	80	65	65	80	814	0
A117	356	124	124	113	214	100	135	57	57	136	57	57	57	582	0
A119	1490	651	739	691	1251	691	862	688	688	1076	688	688	688	3255	0
A120	698	400	389	396	375	101	310	96	96	284	96	96	118	1194	0
A121	586	256	291	272	331	272	499	270	270	423	270	270	270	1279	0
A123	774	443	431	439	609	112	334	106	289	131	106	106	131	1324	0
A126	798	457	444	453	628	116	155	109	109	325	109	109	135	1365	0
A129	93	53	52	53	73	13	40	13	35	16	13	13	16	158	0
A131	890	510	496	505	701	129	173	122	122	362	122	122	150	1523	0
A132	95	54	53	54	51	14	42	13	13	38	13	13	16	162	0
A133	1471	643	730	682	1234	682	1234	679	1059	679	679	679	679	3212	0
A134	1067	466	529	495	603	495	909	492	492	770	492	492	492	2330	0
A136	328	143	163	152	275	152	275	151	236	151	151	151	151	717	0
A138	499	218	248	232	282	232	404	230	230	978	0	0	0	0	0
A139	477	209	237	221	270	221	386	220	220	935	0	0	0	0	0
A140	1334	583	662	619	1061	619	772	616	616	2614	0	0	0	0	0
A141	2326	1333	1295	1319	1831	338	452	319	319	946	319	319	393	3979	0
A146	161	70	80	75	121	75	121	74	102	74	74	251	0	0	0
A148	222	127	124	126	175	32	96	30	83	38	30	30	38	380	0
A149	205	118	114	116	110	30	91	28	28	83	28	28	35	351	0
A150	917	401	455	425	690	425	531	423	423	582	423	1431	0	0	0
A151	1355	776	754	768	1066	197	263	186	186	551	186	186	229	2317	0
A154	1894	1085	1055	1074	1017	275	842	260	260	770	260	260	320	3240	0
A155	80	28	28	25	48	22	48	13	30	13	13	13	13	130	0
A157	672	294	334	312	564	312	389	310	310	485	310	310	310	1468	0
A158	156	68	77	72	131	72	131	72	112	72	72	72	72	340	0
A160	243	85	85	77	89	68	149	39	39	93	39	39	39	398	0
A164	308	107	107	98	185	86	117	49	49	118	49	49	49	503	0

Single rotation regime, SP1014

Project	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A001	4811	2103	2387	2231	3825	2231	2784	2220	2220	8387	0	0	0	0	0
A003	159	69	79	74	90	74	128	73	73	108	277	0	0	0	0
A004	4364	1521	1521	1383	2625	1224	2624	699	7127	0	0	0	0	0	0
A005	1567	685	777	727	1315	727	1315	723	3423	0	0	0	0	0	0
A006	714	409	398	405	562	104	309	98	1222	0	0	0	0	0	0
A007	819	286	286	260	493	230	310	131	131	314	131	131	131	1338	0
A008	440	252	245	249	236	64	195	60	60	179	60	60	74	752	0
A010	348	121	121	110	128	98	213	56	56	133	56	56	56	568	0
A012	1645	942	916	933	1295	239	320	226	226	669	226	226	278	2814	0
A013	1575	902	877	893	1240	229	306	216	216	641	216	216	266	2694	0
A014	1607	921	895	911	1264	233	312	220	220	653	220	220	271	2748	0
A015	492	171	171	156	181	138	302	79	79	188	79	79	79	804	0
A016	171	98	95	97	92	25	76	23	23	69	23	23	29	292	0
A017	366	160	181	170	307	170	212	169	169	264	169	169	169	799	0
A018	316	138	157	147	265	147	265	146	690	0	0	0	0	0	0
A019	2567	1471	1429	1456	1817	373	906	352	756	434	352	2931	0	0	0
A022	1697	592	592	538	1021	476	643	272	272	650	272	272	272	2772	0
A023	2913	1015	1015	923	1070	817	1786	467	467	1115	467	467	467	4758	0

A025	722	252	252	229	381	202	274	116	116	223	116	795	0	0	0
A026	5214	2279	2587	2417	4376	2417	3017	2406	2406	3763	2406	2406	2406	11388	0
A027	300	131	149	139	226	139	226	139	190	139	139	469	0	0	0
A029	1025	357	357	325	376	287	589	164	164	353	1287	0	0	0	0
A030	55	19	19	17	31	15	21	9	9	69	0	0	0	0	0
A035	207	119	115	118	111	30	92	28	28	84	28	28	35	355	0
A036	721	413	402	409	568	105	312	99	269	122	99	99	122	1234	0
A037	171	98	95	97	134	25	74	23	64	29	23	23	29	292	0
A038	193	84	96	90	162	90	112	89	89	139	89	89	89	422	0
A039	313	109	109	99	115	88	192	50	50	120	50	50	50	511	0
A040	109	48	54	51	62	51	93	50	50	79	50	50	50	238	0
A041	187	65	65	59	99	52	71	30	30	58	30	206	0	0	0
A043	3895	1702	1932	1806	3269	1806	3268	1797	2805	1797	1797	1797	1797	8507	0
A044	159	55	55	50	58	44	97	25	25	61	25	25	25	259	0
A046	243	106	120	113	137	113	186	112	112	154	112	379	0	0	0
A047	111	39	39	35	67	31	42	18	18	43	18	18	18	182	0
A051	307	176	171	174	241	45	60	42	42	125	42	42	52	525	0
A052	702	245	245	223	258	197	404	113	113	1012	0	0	0	0	0
A053	1270	728	707	720	682	184	564	174	174	516	174	174	215	2172	0
A055	340	195	189	193	254	49	133	47	113	455	0	0	0	0	0
A057	555	242	275	257	441	257	441	256	375	967	0	0	0	0	0
A058	288	165	160	163	215	42	113	39	96	386	0	0	0	0	0
A061	1560	894	868	884	1227	227	303	214	214	634	214	214	264	2668	0
A064	2542	886	886	806	934	713	1370	407	407	785	407	2798	0	0	0
A067	401	230	223	228	216	58	162	55	55	617	0	0	0	0	0
A069	1909	835	947	885	1602	885	1105	881	881	1378	881	881	881	4170	0
A070	216	124	120	123	170	31	93	30	81	37	30	30	37	370	0
A071	2392	1371	1332	1357	1284	347	1063	328	328	973	328	328	404	4092	0
A074	233	133	130	132	183	34	101	32	87	39	32	32	39	398	0
A075	3233	1413	1604	1499	2713	1499	2712	1492	2329	1492	1492	1492	1492	7062	0
A076	95	41	47	44	54	44	77	44	44	186	0	0	0	0	0
A077	417	239	232	236	224	61	168	57	57	641	0	0	0	0	0
A078	264	115	131	122	222	122	222	122	190	122	122	122	122	577	0
A080	690	395	384	391	515	100	134	95	95	1060	0	0	0	0	0
A081	343	197	191	195	270	50	148	47	128	58	47	47	58	587	0
A082	466	163	163	148	171	131	268	75	75	672	0	0	0	0	0
A083	434	190	215	201	245	201	351	200	200	850	0	0	0	0	0
A085	364	127	127	115	205	102	138	58	58	525	0	0	0	0	0
A086	4152	1447	1447	1316	1526	1164	2388	665	665	5982	0	0	0	0	0
A087	90	51	50	51	48	13	36	12	12	138	0	0	0	0	0
A088	2698	1546	1502	1530	2014	392	1056	370	899	3614	0	0	0	0	0
A091	2307	804	804	731	848	647	1244	370	370	712	370	2540	0	0	0
A096	131	57	65	61	99	61	99	60	83	60	60	205	0	0	0
A099	438	153	153	139	263	123	166	70	70	167	70	70	70	715	0
A100	6945	3979	3867	3939	5466	1009	3000	953	2594	1174	953	953	1174	11879	0
A101	148	85	83	84	117	22	64	20	55	25	20	20	25	254	0
A104	554	242	275	257	465	257	321	256	256	400	256	256	256	1210	0
A105	304	106	106	96	183	85	183	49	116	49	49	49	49	497	0
A106	534	186	186	169	321	150	202	86	86	204	86	86	86	872	0
A107	360	126	126	114	217	101	136	58	58	138	58	58	58	588	0
A108	808	282	282	256	456	227	306	129	129	1164	0	0	0	0	0
A110	101	58	56	57	80	15	20	14	14	41	14	14	17	173	0
A111	2023	705	705	641	1217	567	1216	324	772	324	324	324	324	3303	0
A112	349	122	122	111	128	98	214	56	56	134	56	56	56	570	0
A113	2274	1303	1266	1290	1221	330	1010	312	312	925	312	312	384	3890	0
A114	476	273	265	270	375	69	206	65	178	80	65	65	80	814	0
A117	356	124	124	113	214	100	135	57	57	136	57	57	57	582	0
A119	1490	651	739	691	1251	691	862	688	688	1076	688	688	688	3255	0
A120	698	400	389	396	375	101	310	96	96	284	96	96	118	1194	0
A121	586	256	291	272	331	272	499	270	270	423	270	270	270	1279	0
A123	774	443	431	439	609	112	334	106	289	131	106	106	131	1324	0
A126	798	457	444	453	628	116	155	109	109	325	109	109	135	1365	0
A129	93	53	52	53	73	13	40	13	35	16	13	13	16	158	0
A131	890	510	496	505	701	129	173	122	122	362	122	122	150	1523	0
A132	95	54	53	54	51	14	42	13	13	38	13	13	16	162	0
A133	1471	643	730	682	1234	682	1234	679	1059	679	679	679	679	3212	0
A134	1067	466	529	495	603	495	909	492	492	770	492	492	492	2330	0
A136	328	143	163	152	275	152	275	151	236	151	151	151	151	717	0
A138	499	218	248	232	282	232	404	230	230	978	0	0	0	0	0
A139	477	209	237	221	270	221	386	220	220	935	0	0	0	0	0
A140	1334	583	662	619	1061	619	772	616	616	2614	0	0	0	0	0
A141	2326	1333	1295	1319	1831	338	452	319	319	946	319	319	393	3979	0
A146	161	70	80	75	121	75	121	74	102	74	74	251	0	0	0
A148	222	127	124	126	175	32	96	30	83	38	30	30	38	380	0
A149	205	118	114	116	110	30	91	28	28	83	28	28	35	351	0
A150	917	401	455	425	690	425	531	423	423	582	423	1431	0	0	0
A151	1355	776	754	768	1066	197	263	186	186	551	186	186	229	2317	0
A154	1894	1085	1055	1074	1017	275	842	260	260	770	260	260	320	3240	0
A155	80	28	28	25	48	22	48	13	30	13	13	13	13	130	0
A157	672	294	334	312	564	312	389	310	310	485	310	310	310	1468	0

A158	156	68	77	72	131	72	131	72	112	72	72	72	72	340	0
A160	243	85	85	77	89	68	149	39	39	93	39	39	39	398	0
A164	308	107	107	98	185	86	117	49	49	118	49	49	49	503	0

Multiple rotations regime, SP810

Project	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A001	4811	2103	2387	2231	3825	2231	2784	2220	2220	3259	13198	2103	2387	2231	3825
A003	159	69	79	74	90	74	128	73	73	108	436	69	79	74	90
A004	4364	1521	1521	1383	2625	1224	2624	699	13198	1521	1521	1383	2625	1224	2624
A005	1567	685	777	727	1315	727	1315	723	1129	5000	685	777	727	1315	727
A006	714	409	398	405	562	104	309	98	979	409	398	405	562	104	309
A007	819	286	286	260	493	230	310	131	131	314	131	131	131	2157	286
A008	440	252	245	249	236	64	195	60	60	179	60	60	74	1192	252
A010	348	121	121	110	128	98	213	56	56	133	56	56	56	917	121
A012	1645	942	916	933	1295	239	320	226	226	669	226	226	278	4458	942
A013	1575	902	877	893	1240	229	306	216	216	641	216	216	266	4269	902
A014	1607	921	895	911	1264	233	312	220	220	653	220	220	271	4355	921
A015	492	171	171	156	181	138	302	79	79	188	79	79	79	1296	171
A016	171	98	95	97	92	25	76	23	23	69	23	23	29	463	98
A017	366	160	181	170	307	170	212	169	169	264	169	169	169	1164	160
A018	316	138	157	147	265	147	265	146	228	146	146	146	146	1006	138
A019	2567	1471	1429	1456	1817	373	906	352	756	434	352	5498	1471	1429	1456
A022	1697	592	592	538	1021	476	643	272	272	650	272	272	272	4470	592
A023	2913	1015	1015	923	1070	817	1786	467	467	1115	467	467	467	7672	1015
A025	722	252	252	229	381	202	274	116	116	223	116	1517	252	252	229
A026	5214	2279	2587	2417	4376	2417	3017	2406	2406	3763	2406	2406	2406	16602	2279
A027	300	131	149	139	226	139	226	139	190	139	139	139	139	769	131
A029	1025	357	357	325	376	287	589	164	164	353	2311	357	357	325	376
A030	55	19	19	17	31	15	21	9	9	19	124	19	19	17	31
A035	207	119	115	118	111	30	92	28	28	84	28	28	35	562	119
A036	721	413	402	409	568	105	312	99	269	122	99	99	122	1955	413
A037	171	98	95	97	134	25	74	23	64	29	23	23	29	463	98
A038	193	84	96	90	162	90	112	89	89	139	89	89	89	615	84
A039	313	109	109	99	115	88	192	50	50	120	50	50	50	824	109
A040	109	48	54	51	62	51	93	50	50	79	50	50	50	347	48
A041	187	65	65	59	99	52	71	30	30	58	30	393	65	65	59
A043	3895	1702	1932	1806	3269	1806	3268	1797	2805	1797	1797	1797	1797	12402	1702
A044	159	55	55	50	58	44	97	25	25	61	25	25	25	418	55
A046	243	106	120	113	137	113	186	112	112	154	112	112	106	120	113
A047	111	39	39	35	67	31	42	18	18	43	18	18	18	293	39
A051	307	176	171	174	241	45	60	42	42	125	42	42	52	832	176
A052	702	245	245	223	258	197	404	113	113	242	245	245	223	258	197
A053	1270	728	707	720	682	184	564	174	174	516	174	174	215	3442	728
A055	340	195	189	193	254	49	133	47	113	795	195	189	193	254	49
A057	555	242	275	257	441	257	441	256	375	256	242	275	257	441	257
A058	288	165	160	163	215	42	113	39	96	673	165	160	163	215	42
A061	1560	894	868	884	1227	227	303	214	214	634	214	214	264	4227	894
A064	2542	886	886	806	934	713	1370	407	407	785	407	407	5340	886	886
A067	401	230	223	228	216	58	162	55	55	1018	230	223	228	216	58
A069	1909	835	947	885	1602	885	1105	881	881	1378	881	881	881	6080	835
A070	216	124	120	123	170	31	93	30	81	37	30	30	37	586	124
A071	2392	1371	1332	1357	1284	347	1063	328	328	973	328	328	404	6484	1371
A074	233	133	130	132	183	34	101	32	87	39	32	32	39	631	133
A075	3233	1413	1604	1499	2713	1499	2712	1492	2329	1492	1492	1492	1492	10295	1413
A076	95	41	47	44	54	44	77	44	44	64	41	47	44	54	44
A077	417	239	232	236	224	61	168	57	57	1058	239	232	236	224	61
A078	264	115	131	122	222	122	222	122	190	122	122	122	122	841	115
A080	690	395	384	391	515	100	134	95	95	1749	395	384	391	515	100
A081	343	197	191	195	270	50	148	47	128	58	47	47	58	930	197
A082	466	163	163	148	171	131	268	75	75	161	163	163	148	171	131
A083	434	190	215	201	245	201	351	200	200	294	190	215	201	245	201
A085	364	127	127	115	205	102	138	58	58	889	127	127	115	205	102
A086	4152	1447	1447	1316	1526	1164	2388	665	665	10134	1447	1447	1316	1526	1164
A087	90	51	50	51	48	13	36	12	12	228	51	50	51	48	13
A088	2698	1546	1502	1530	2014	392	1056	370	899	456	1546	1502	1530	2014	392
A091	2307	804	804	731	848	647	1244	370	370	712	370	370	370	370	4860
A096	131	57	65	61	99	61	99	60	83	60	60	60	60	60	331
A099	438	153	153	139	263	123	166	70	70	167	70	70	70	1152	153
A100	6945	3979	3867	3939	5466	1009	3000	953	2594	1174	953	953	1174	18825	3979
A101	148	85	83	84	117	22	64	20	55	25	20	20	25	402	85
A104	554	242	275	257	465	257	321	256	256	400	256	256	256	1764	242
A105	304	106	106	96	183	85	183	49	116	49	49	49	49	801	106
A106	534	186	186	169	321	150	202	86	86	204	86	86	86	1407	186
A107	360	126	126	114	217	101	136	58	58	138	58	58	58	949	126
A108	808	282	282	256	456	227	306	129	129	1972	282	282	256	456	227
A110	101	58	56	57	80	15	20	14	14	41	14	14	17	275	58
A111	2023	705	705	641	1217	567	1216	324	772	324	324	324	324	5326	705
A112	349	122	122	111	128	98	214	56	56	134	56	56	56	919	122
A113	2274	1303	1266	1290	1221	330	1010	312	312	925	312	312	384	6164	1303

A114	476	273	265	270	375	69	206	65	178	80	65	65	80	1291	273
A117	356	124	124	113	214	100	135	57	57	136	57	57	57	938	124
A119	1490	651	739	691	1251	691	862	688	688	1076	688	688	688	4745	651
A120	698	400	389	396	375	101	310	96	96	284	96	96	118	1892	400
A121	586	256	291	272	331	272	499	270	270	423	270	270	270	1865	256
A123	774	443	431	439	609	112	334	106	289	131	106	106	131	2097	443
A126	798	457	444	453	628	116	155	109	109	325	109	109	135	2164	457
A129	93	53	52	53	73	13	40	13	35	16	13	13	16	251	53
A131	890	510	496	505	701	129	173	122	122	362	122	122	150	2414	510
A132	95	54	53	54	51	14	42	13	13	38	13	13	16	256	54
A133	1471	643	730	682	1234	682	1234	679	1059	679	679	679	679	4682	643
A134	1067	466	529	495	603	495	909	492	492	770	492	492	492	3397	466
A136	328	143	163	152	275	152	275	151	236	151	151	151	151	1045	143
A138	499	218	248	232	282	232	404	230	230	1478	218	248	232	282	232
A139	477	209	237	221	270	221	386	220	220	1412	209	237	221	270	221
A140	1334	583	662	619	1061	619	772	616	616	904	616	616	616	616	902
A141	2326	1333	1295	1319	1831	338	452	319	319	946	319	319	393	6305	1333
A146	161	70	80	75	121	75	121	74	102	74	74	74	74	74	74
A148	222	127	124	126	175	32	96	30	83	38	30	30	38	603	127
A149	205	118	114	116	110	30	91	28	28	83	28	28	35	556	118
A150	917	401	455	425	690	425	531	423	423	582	423	423	423	423	581
A151	1355	776	754	768	1066	197	263	186	186	551	186	186	229	3672	776
A154	1894	1085	1055	1074	1017	275	842	260	260	770	260	260	320	5134	1085
A155	80	28	28	25	48	22	48	13	30	13	13	13	13	210	28
A157	672	294	334	312	564	312	389	310	310	485	310	310	310	2141	294
A158	156	68	77	72	131	72	131	72	112	72	72	72	72	496	68
A160	243	85	85	77	89	68	149	39	39	93	39	39	39	641	85
A164	308	107	107	98	185	86	117	49	49	118	49	49	49	812	107

Multiple rotations regime, SP912

Project	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A001	4811	2103	2387	2231	3825	2231	2784	2220	2220	3259	13198	2103	2387	2231	3825
A003	159	69	79	74	90	74	128	73	73	108	436	69	79	74	90
A004	4364	1521	1521	1383	2625	1224	2624	699	1665	699	699	699	699	11491	1521
A005	1567	685	777	727	1315	727	1315	723	1129	723	723	723	723	4990	685
A006	714	409	398	405	562	104	309	98	267	121	98	98	121	1936	409
A007	819	286	286	260	493	230	310	131	131	314	131	131	131	2157	286
A008	440	252	245	249	236	64	195	60	60	179	60	60	74	1192	252
A010	348	121	121	110	128	98	213	56	56	133	56	56	56	917	121
A012	1645	942	916	933	1295	239	320	226	226	669	226	226	278	4458	942
A013	1575	902	877	893	1240	229	306	216	216	641	216	216	266	4269	902
A014	1607	921	895	911	1264	233	312	220	220	653	220	220	271	4355	921
A015	492	171	171	156	181	138	302	79	79	188	79	79	79	1296	171
A016	171	98	95	97	92	25	76	23	23	69	23	23	29	463	98
A017	366	160	181	170	307	170	212	169	169	264	169	169	169	1164	160
A018	316	138	157	147	265	147	265	146	228	146	146	146	146	1006	138
A019	2567	1471	1429	1456	1817	373	906	352	756	434	352	5498	1471	1429	1456
A022	1697	592	592	538	1021	476	643	272	272	650	272	272	272	4470	592
A023	2913	1015	1015	923	1070	817	1786	467	467	1115	467	467	467	7672	1015
A025	722	252	252	229	381	202	274	116	116	223	116	1517	252	252	229
A026	5214	2279	2587	2417	4376	2417	3017	2406	2406	3763	2406	2406	2406	16602	2279
A027	300	131	149	139	226	139	226	139	190	139	139	139	139	769	131
A029	1025	357	357	325	376	287	589	164	164	353	2311	357	357	325	376
A030	55	19	19	17	31	15	21	9	9	19	124	19	19	17	31
A035	207	119	115	118	111	30	92	28	28	84	28	28	35	562	119
A036	721	413	402	409	568	105	312	99	269	122	99	99	122	1955	413
A037	171	98	95	97	134	25	74	23	64	29	23	23	29	463	98
A038	193	84	96	90	162	90	112	89	89	139	89	89	89	615	84
A039	313	109	109	99	115	88	192	50	50	120	50	50	50	824	109
A040	109	48	54	51	62	51	93	50	50	79	50	50	50	347	48
A041	187	65	65	59	99	52	71	30	30	58	30	393	65	65	59
A043	3895	1702	1932	1806	3269	1806	3268	1797	2805	1797	1797	1797	1797	12402	1702
A044	159	55	55	50	58	44	97	25	25	61	25	25	25	418	55
A046	243	106	120	113	137	113	186	112	112	154	112	112	622	106	120
A047	111	39	39	35	67	31	42	18	18	43	18	18	18	293	39
A051	307	176	171	174	241	45	60	42	42	125	42	42	52	832	176
A052	702	245	245	223	258	197	404	113	113	242	1585	245	245	223	258
A053	1270	728	707	720	682	184	564	174	174	516	174	174	215	3442	728
A055	340	195	189	193	254	49	133	47	113	795	195	189	193	254	49
A057	555	242	275	257	441	257	441	256	375	256	1522	242	275	257	441
A058	288	165	160	163	215	42	113	39	96	673	165	160	163	215	42
A061	1560	894	868	884	1227	227	303	214	214	634	214	214	264	4227	894
A064	2542	886	886	806	934	713	1370	407	407	785	407	407	407	407	5340
A067	401	230	223	228	216	58	162	55	55	1018	230	223	228	216	58
A069	1909	835	947	885	1602	885	1105	881	881	1378	881	881	881	6080	835
A070	216	124	120	123	170	31	93	30	81	37	30	30	37	586	124
A071	2392	1371	1332	1357	1284	347	1063	328	328	973	328	328	404	6484	1371
A074	233	133	130	132	183	34	101	32	87	39	32	32	39	631	133
A075	3233	1413	1604	1499	2713	1499	2712	1492	2329	1492	1492	1492	1492	10295	1413

A076	95	41	47	44	54	44	77	44	44	64	44	260	41	47	44
A077	417	239	232	236	224	61	168	57	57	1058	239	232	236	224	61
A078	264	115	131	122	222	122	222	122	190	122	122	122	122	841	115
A080	690	395	384	391	515	100	134	95	95	1749	395	384	391	515	100
A081	343	197	191	195	270	50	148	47	128	58	47	47	58	930	197
A082	466	163	163	148	171	131	268	75	75	161	1052	163	163	148	171
A083	434	190	215	201	245	201	351	200	200	294	200	1190	190	215	201
A085	364	127	127	115	205	102	138	58	58	889	127	127	127	115	205
A086	4152	1447	1447	1316	1526	1164	2388	665	665	10134	1447	1447	1447	1316	1526
A087	90	51	50	51	48	13	36	12	12	228	51	51	50	51	48
A088	2698	1546	1502	1530	2014	392	1056	370	899	456	370	6227	1546	1502	1530
A091	2307	804	804	731	848	647	1244	370	370	712	370	370	370	370	370
A096	131	57	65	61	99	61	99	60	83	60	60	60	60	60	60
A099	438	153	153	139	263	123	166	70	70	167	70	70	70	1152	153
A100	6945	3979	3867	3939	5466	1009	3000	953	2594	1174	953	953	1174	18825	3979
A101	148	85	83	84	117	22	64	20	55	25	20	20	25	402	85
A104	554	242	275	257	465	257	321	256	256	400	256	256	256	1764	242
A105	304	106	106	96	183	85	183	49	116	49	49	49	49	801	106
A106	534	186	186	169	321	150	202	86	86	204	86	86	86	1407	186
A107	360	126	126	114	217	101	136	58	58	138	58	58	58	949	126
A108	808	282	282	256	456	227	306	129	129	1972	282	282	256	456	227
A110	101	58	56	57	80	15	20	14	14	41	14	14	17	275	58
A111	2023	705	705	641	1217	567	1216	324	772	324	324	324	324	5326	705
A112	349	122	122	111	128	98	214	56	56	134	56	56	56	919	122
A113	2274	1303	1266	1290	1221	330	1010	312	312	925	312	312	384	6164	1303
A114	476	273	265	270	375	69	206	65	178	80	65	65	80	1291	273
A117	356	124	124	113	214	100	135	57	57	136	57	57	57	938	124
A119	1490	651	739	691	1251	691	862	688	688	1076	688	688	688	4745	651
A120	698	400	389	396	375	101	310	96	96	284	96	96	118	1892	400
A121	586	256	291	272	331	272	499	270	270	423	270	270	270	1865	256
A123	774	443	431	439	609	112	334	106	289	131	106	106	131	2097	443
A126	798	457	444	453	628	116	155	109	109	325	109	109	135	2164	457
A129	93	53	52	53	73	13	40	13	35	16	13	13	16	251	53
A131	890	510	496	505	701	129	173	122	122	362	122	122	150	2414	510
A132	95	54	53	54	51	14	42	13	13	38	13	13	16	256	54
A133	1471	643	730	682	1234	682	1234	679	1059	679	679	679	679	4682	643
A134	1067	466	529	495	603	495	909	492	492	770	492	492	492	3397	466
A136	328	143	163	152	275	152	275	151	236	151	151	151	151	1045	143
A138	499	218	248	232	282	232	404	230	230	1478	218	248	232	282	232
A139	477	209	237	221	270	221	386	220	220	1412	209	237	221	270	221
A140	1334	583	662	619	1061	619	772	616	616	904	616	616	616	616	902
A141	2326	1333	1295	1319	1831	338	452	319	319	946	319	319	393	6305	1333
A146	161	70	80	75	121	75	121	74	102	74	74	74	74	74	74
A148	222	127	124	126	175	32	96	30	83	38	30	30	38	603	127
A149	205	118	114	116	110	30	91	28	28	83	28	28	35	556	118
A150	917	401	455	425	690	425	531	423	423	582	423	423	423	423	581
A151	1355	776	754	768	1066	197	263	186	186	551	186	186	229	3672	776
A154	1894	1085	1055	1074	1017	275	842	260	260	770	260	260	320	5134	1085
A155	80	28	28	25	48	22	48	13	30	13	13	13	13	210	28
A157	672	294	334	312	564	312	389	310	310	485	310	310	310	2141	294
A158	156	68	77	72	131	72	131	72	112	72	72	72	72	496	68
A160	243	85	85	77	89	68	149	39	39	93	39	39	39	641	85
A164	308	107	107	98	185	86	117	49	49	118	49	49	49	812	107

Multiple rotations regime, SP1014

Project	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A001	4811	2103	2387	2231	3825	2231	2784	2220	2220	3259	13198	2103	2387	2231	3825
A003	159	69	79	74	90	74	128	73	73	108	436	69	79	74	90
A004	4364	1521	1521	1383	2625	1224	2624	699	13198	1521	1521	1383	2625	1224	2624
A005	1567	685	777	727	1315	727	1315	723	1129	5000	685	777	727	1315	727
A006	714	409	398	405	562	104	309	98	979	409	398	405	562	104	309
A007	819	286	286	260	493	230	310	131	131	314	131	131	131	2157	286
A008	440	252	245	249	236	64	195	60	60	179	60	60	74	1192	252
A010	348	121	121	110	128	98	213	56	56	133	56	56	56	917	121
A012	1645	942	916	933	1295	239	320	226	226	669	226	226	278	4458	942
A013	1575	902	877	893	1240	229	306	216	216	641	216	216	266	4269	902
A014	1607	921	895	911	1264	233	312	220	220	653	220	220	271	4355	921
A015	492	171	171	156	181	138	302	79	79	188	79	79	79	1296	171
A016	171	98	95	97	92	25	76	23	23	69	23	23	29	463	98
A017	366	160	181	170	307	170	212	169	169	264	169	169	169	1164	160
A018	316	138	157	147	265	147	265	146	228	146	146	146	146	1006	138
A019	2567	1471	1429	1456	1817	373	906	352	756	434	352	5498	1471	1429	1456
A022	1697	592	592	538	1021	476	643	272	272	650	272	272	272	4470	592
A023	2913	1015	1015	923	1070	817	1786	467	467	1115	467	467	467	7672	1015
A025	722	252	252	229	381	202	274	116	116	223	116	1517	252	252	229
A026	5214	2279	2587	2417	4376	2417	3017	2406	2406	3763	2406	2406	2406	16602	2279
A027	300	131	149	139	226	139	226	139	190	139	139	139	139	769	131
A029	1025	357	357	325	376	287	589	164	164	353	2311	357	357	325	376
A030	55	19	19	17	31	15	21	9	9	19	124	19	19	17	31

A035	207	119	115	118	111	30	92	28	28	84	28	28	35	562	119
A036	721	413	402	409	568	105	312	99	269	122	99	99	122	1955	413
A037	171	98	95	97	134	25	74	23	64	29	23	23	29	463	98
A038	193	84	96	90	162	90	112	89	89	139	89	89	89	615	84
A039	313	109	109	99	115	88	192	50	50	120	50	50	50	824	109
A040	109	48	54	51	62	51	93	50	50	79	50	50	50	347	48
A041	187	65	65	59	99	52	71	30	30	58	30	393	65	65	59
A043	3895	1702	1932	1806	3269	1806	3268	1797	2805	1797	1797	1797	1797	12402	1702
A044	159	55	55	50	58	44	97	25	25	61	25	25	25	418	55
A046	243	106	120	113	137	113	186	112	112	154	112	112	106	120	113
A047	111	39	39	35	67	31	42	18	18	43	18	18	18	293	39
A051	307	176	171	174	241	45	60	42	42	125	42	42	52	832	176
A052	702	245	245	223	258	197	404	113	113	242	245	245	223	258	197
A053	1270	728	707	720	682	184	564	174	174	516	174	174	215	3442	728
A055	340	195	189	193	254	49	133	47	113	795	195	189	193	254	49
A057	555	242	275	257	441	257	441	256	375	256	242	275	257	441	257
A058	288	165	160	163	215	42	113	39	96	673	165	160	163	215	42
A061	1560	894	868	884	1227	227	303	214	214	634	214	214	264	4227	894
A064	2542	886	886	806	934	713	1370	407	407	785	407	407	5340	886	886
A067	401	230	223	228	216	58	162	55	55	1018	230	223	228	216	58
A069	1909	835	947	885	1602	885	1105	881	881	1378	881	881	881	6080	835
A070	216	124	120	123	170	31	93	30	81	37	30	30	37	586	124
A071	2392	1371	1332	1357	1284	347	1063	328	328	973	328	328	404	6484	1371
A074	233	133	130	132	183	34	101	32	87	39	32	32	39	631	133
A075	3233	1413	1604	1499	2713	1499	2712	1492	2329	1492	1492	1492	1492	10295	1413
A076	95	41	47	44	54	44	77	44	44	64	41	47	44	54	44
A077	417	239	232	236	224	61	168	57	57	1058	239	232	236	224	61
A078	264	115	131	122	222	122	222	122	190	122	122	122	122	841	115
A080	690	395	384	391	515	100	134	95	95	1749	395	384	391	515	100
A081	343	197	191	195	270	50	148	47	128	58	47	47	58	930	197
A082	466	163	163	148	171	131	268	75	75	161	163	163	148	171	131
A083	434	190	215	201	245	201	351	200	200	294	190	215	201	245	201
A085	364	127	127	115	205	102	138	58	58	889	127	127	115	205	102
A086	4152	1447	1447	1316	1526	1164	2388	665	665	10134	1447	1447	1316	1526	1164
A087	90	51	50	51	48	13	36	12	12	228	51	50	51	48	13
A088	2698	1546	1502	1530	2014	392	1056	370	899	456	1546	1502	1530	2014	392
A091	2307	804	804	731	848	647	1244	370	370	712	370	370	370	370	4860
A096	131	57	65	61	99	61	99	60	83	60	60	60	60	60	331
A099	438	153	153	139	263	123	166	70	70	167	70	70	70	1152	153
A100	6945	3979	3867	3939	5466	1009	3000	953	2594	1174	953	953	1174	18825	3979
A101	148	85	83	84	117	22	64	20	55	25	20	20	25	402	85
A104	554	242	275	257	465	257	321	256	256	400	256	256	256	1764	242
A105	304	106	106	96	183	85	183	49	116	49	49	49	49	801	106
A106	534	186	186	169	321	150	202	86	86	204	86	86	86	1407	186
A107	360	126	126	114	217	101	136	58	58	138	58	58	58	949	126
A108	808	282	282	256	456	227	306	129	129	1972	282	282	256	456	227
A110	101	58	56	57	80	15	20	14	14	41	14	14	17	275	58
A111	2023	705	705	641	1217	567	1216	324	772	324	324	324	324	5326	705
A112	349	122	122	111	128	98	214	56	56	134	56	56	56	919	122
A113	2274	1303	1266	1290	1221	330	1010	312	312	925	312	312	384	6164	1303
A114	476	273	265	270	375	69	206	65	178	80	65	65	80	1291	273
A117	356	124	124	113	214	100	135	57	57	136	57	57	57	938	124
A119	1490	651	739	691	1251	691	862	688	688	1076	688	688	688	4745	651
A120	698	400	389	396	375	101	310	96	96	284	96	96	118	1892	400
A121	586	256	291	272	331	272	499	270	270	423	270	270	270	1865	256
A123	774	443	431	439	609	112	334	106	289	131	106	106	131	2097	443
A126	798	457	444	453	628	116	155	109	109	325	109	109	135	2164	457
A129	93	53	52	53	73	13	40	13	35	16	13	13	16	251	53
A131	890	510	496	505	701	129	173	122	122	362	122	122	150	2414	510
A132	95	54	53	54	51	14	42	13	13	38	13	13	16	256	54
A133	1471	643	730	682	1234	682	1234	679	1059	679	679	679	679	4682	643
A134	1067	466	529	495	603	495	909	492	492	770	492	492	492	3397	466
A136	328	143	163	152	275	152	275	151	236	151	151	151	151	1045	143
A138	499	218	248	232	282	232	404	230	230	1478	218	248	232	282	232
A139	477	209	237	221	270	221	386	220	220	1412	209	237	221	270	221
A140	1334	583	662	619	1061	619	772	616	616	904	616	616	616	616	902
A141	2326	1333	1295	1319	1831	338	452	319	319	946	319	319	393	6305	1333
A146	161	70	80	75	121	75	121	74	102	74	74	74	74	74	74
A148	222	127	124	126	175	32	96	30	83	38	30	30	38	603	127
A149	205	118	114	116	110	30	91	28	28	83	28	28	35	556	118
A150	917	401	455	425	690	425	531	423	423	582	423	423	423	423	581
A151	1355	776	754	768	1066	197	263	186	186	551	186	186	229	3672	776
A154	1894	1085	1055	1074	1017	275	842	260	260	770	260	260	320	5134	1085
A155	80	28	28	25	48	22	48	13	30	13	13	13	13	210	28
A157	672	294	334	312	564	312	389	310	310	485	310	310	310	2141	294
A158	156	68	77	72	131	72	131	72	112	72	72	72	72	496	68
A160	243	85	85	77	89	68	149	39	39	93	39	39	39	641	85
A164	308	107	107	98	185	86	117	49	49	118	49	49	49	812	107

Appendix 7. *What'sBest!©* output report of the MILP models for the three discounting scenarios

SP810

```
What'sBest!® 12.0.1.5 (May 01, 2014) - Lib. 8.0.1694.527 - 64-bit - Status Report -

DATE GENERATED:      may 29, 2014          03:22 PM


MODEL INFORMATION:

  CLASSIFICATION DATA            Current   Capacity Limits
  --------------------------------------------------------
  Total Cells                     3428703
    Numerics                      3427170
      Adjustables                    2226         Unlimited
        Continuous                     81
        Free                            0
        Integers/Binaries          0/2145         Unlimited
      Constants                   3419732
      Formulas                       5212
    Strings                             0
    Constraints                      1533         Unlimited
  Nonlinears                            0         Unlimited
  Coefficients                      47666

  Minimum coefficient value:        0.15970998955884  on Hoja1!CFH5
  Minimum coefficient in formula:   Hoja1!CGS1538
  Maximum coefficient value:        1264817.5976528  on <RHS>
  Maximum coefficient in formula:   Hoja1!CGT51

MODEL TYPE:             Mixed Integer / Linear (Mixed Integer Linear Program)

SOLUTION STATUS:        GLOBALLY OPTIMAL

OBJECTIVE VALUE:        5575586.0368741

DIRECTION:              Maximize

SOLVER TYPE:            Branch-and-Bound

TRIES:                  785927

INFEASIBILITY:          9.3132257461548e-010

BEST OBJECTIVE BOUND:   5631576.1167865

STEPS:                  33891

ACTIVE:                 358

SOLUTION TIME:          0 Hours  2 Minutes 55 Seconds

NON-DEFAULT SETTINGS:

  Integer Solver Options / Optimality / Relative:   1.000000e-002
  WBDUAL/WBLOWER/WBUPPER Function:   Detected

End of Report
```

SP912

```
What'sBest!® 12.0.1.5 (May 01, 2014) - Lib. 8.0.1694.527 - 64-bit - Status Report -

DATE GENERATED:      may 29, 2014          03:45 PM


MODEL INFORMATION:

  CLASSIFICATION DATA            Current   Capacity Limits
  --------------------------------------------------------
  Total Cells                     3098295
    Numerics                      3096810
      Adjustables                    2076        Unlimited
        Continuous                     81
        Free                            0
        Integers/Binaries          0/1995        Unlimited
      Constants                   3089768
      Formulas                       4966
    Strings                             0
    Constraints                      1485        Unlimited
  Nonlinears                            0        Unlimited
  Coefficients                      44819

  Minimum coefficient value:        0.15970998955884  on Hoja1!BZN5
  Minimum coefficient in formula:   Hoja1!CAY1490
  Maximum coefficient value:        1264817.5976528  on <RHS>
  Maximum coefficient in formula:   Hoja1!CAZ51

MODEL TYPE:             Mixed Integer / Linear (Mixed Integer Linear Program)

SOLUTION STATUS:        GLOBALLY OPTIMAL

OBJECTIVE VALUE:        4277195.6706246

DIRECTION:              Maximize

SOLVER TYPE:            Branch-and-Bound

TRIES:                  951495

INFEASIBILITY:          9.3132257461548e-010

BEST OBJECTIVE BOUND:   4312379.3820823

STEPS:                  14464

ACTIVE:                 0

SOLUTION TIME:          0 Hours  2 Minutes 55 Seconds

NON-DEFAULT SETTINGS:

  Integer Solver Options / Optimality / Relative:   1.000000e-002
  WBDUAL/WBLOWER/WBUPPER Function:   Detected

End of Report
```

SP1014

```
What'sBest!® 12.0.1.5 (May 01, 2014) - Lib. 8.0.1694.527 - 64-bit - Status Report -

DATE GENERATED:      may 29, 2014          03:52 PM


MODEL INFORMATION:

  CLASSIFICATION DATA            Current   Capacity Limits
  --------------------------------------------------------
  Total Cells                    2874945
    Numerics                     2873460
      Adjustables                   1926         Unlimited
        Continuous                    81
        Free                           0
        Integers/Binaries         0/1845         Unlimited
      Constants                  2866718
      Formulas                      4816
    Strings                            0
    Constraints                     1485         Unlimited
  Nonlinears                           0         Unlimited
  Coefficients                     42074

  Minimum coefficient value:        0.15970998955884  on Hoja1!BTT5
  Minimum coefficient in formula:   Hoja1!BVE1490
  Maximum coefficient value:        1264817.5976528  on <RHS>
  Maximum coefficient in formula:   Hoja1!BVF51

MODEL TYPE:             Mixed Integer / Linear (Mixed Integer Linear Program)

SOLUTION STATUS:        GLOBALLY OPTIMAL

OBJECTIVE VALUE:        3250064.0481901

DIRECTION:              Maximize

SOLVER TYPE:            Branch-and-Bound

TRIES:                  1022524

INFEASIBILITY:          4.6566128730774e-010

BEST OBJECTIVE BOUND:   3275536.2276119

STEPS:                  15362

ACTIVE:                 0

SOLUTION TIME:          0 Hours  2 Minutes 58 Seconds

NON-DEFAULT SETTINGS:

  Integer Solver Options / Optimality / Relative:   1.000000e-002
  WBDUAL/WBLOWER/WBUPPER Function:   Detected

End of Report
```