Incorporation of Ecosystem Services Valuation in System Dynamics Models: Case Study of Mekong Flooded Forest Landscape

By

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ABSTRACT

Aim of the thesis is to evaluate a monetary value of a flow of ecosystem services from forest area in rural tropical regions of Cambodia. Evaluation is used for deeper comprehension of costs and benefits of deforestation. A system dynamic model was developed to capture change in land use as consequence forest clearing. Assessment of effects of land use changes was conducted via calculation of many indicators portraying development in production of timber, government’s tax revenue, social cost of carbon, availability on non-timber forest products, profitability of tree plantations and more. A set of different future scenarios is presented based on which new policies for maximization of benefits can be implemented.

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LIST OF ACRONYMS

ELCs: Economic Land Concessions

NTFPs: Non-timber forest products

SD: System dynamics

CO_2: Carbon dioxide

ES: Ecosystem services

SFD: Stocks and flows diagram

CLD: Causal loop diagram

BAU: Business as usual

MPL: Maximum plantations

MPR: Maximum protection

M^3: Cubic meter

IR: Ideal run

LIM: Low impact management

C: Carbon

MFF: Mekong Flooded Forest

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CHAPTER 1. INTRODUCTION

1.1. LIVES project, study area and problem formulation

This thesis is based on a work done under the *Linked Indicators for Vital Ecosystem Services* (LIVES) project.[1] Founded by Luc Hoffman Institute, LIVES project aims to integrate multiple sciences and create new methodology of measuring ecosystem health. Center of attention is dedicated to analyze links between food, water and energy sectors in tropical river basins. During the research a system dynamics (SD) model was built to capture changes in land use following hydropower development. The IPS Mekong Flooded Forest SD model, which I briefly describe in chapter 3., serves as a foundation upon which I built my own model.

The study area is Mekong Flooded Forest landscape in Cambodian provinces Kratié and Strung Treng. In the generally rural area of 22 186 km^2 lives population largely dependent on subsidies farming and collection of non-timber forest products (NFTPs) (Kim, Sasaki, & Koike, 2008). Since the beginning of a new millennium a massive deforestation has taken place.[2] Large portions of land were allocated to large-scale agro-industrial plantations called Economic Land Concessions (ELCs) where most of the forest clearing have occurred. Since mid-2000s majority of wood harvest in Cambodia is so called “conversion timber” from ELCs areas. This practice proved to be deeply controversial on social, environmental and economical level (Forest Trends, 2015).

On one hand, there are governmental financial revenues from allocation of ELCs and tax income from exported timber as well as job opportunities in the newly established plantations or agricultural fields. On the other hand, besides obvious environmental damage, allocation process is often accompanied by dispossession of local farmers resulting in increase in rural poverty (Neef, 2016). Also, loss of the forest area leads to serious negative long-term consequences in terms of increased output of carbon dioxide (CO_2) and depreciation of forest ecosystem services.

[1] For more information about the LIVES project, visit http://luchoffmanninstitute.org/research/linked-indicators-for-vital-ecosystem-services/

[2] In Kratié province alone the size of forest area decreased from circa 1 million hectares to 600 000 between years 2004 to 2014.

1.2. Research objectives and research questions

The main goal of thesis is to use system dynamics model for ecosystem services evaluation. Source of ecosystem services is natural capital which represents a stock of natural resources, such as geology, soils, air, water and all living organisms. In simple terms, it means that different types of land (forest, river, lake) are stocks of natural assets that provides flows of ecosystem services.

Forest area is among the most important sources of ecosystem services. Since large-scale forest clearing is characteristic feature of the study area, then the process of deforestation is set to be a focal point in my ecosystem services evaluation. From that end I constituted two main research objectives.

Firstly, it is necessary to understand the dynamics and consequences of deforestation and how it affects flows of ecosystem services. Gaining this understanding enables me to construct an explanatory model which will show in clear monetary values the outcomes of historic development.

Secondly, use the explanatory model to make projections about possible future developments. Expanding the time frame of the simulation of the explanatory model allow us to predict what might happen if historic practices will continue to run its course. Such results can be called "business as usual" (BAU) scenario. By introduction of some key changes to the system the model will simulate multiple diverse outcomes. These outcomes will picture what possible scenarios might occur in future. Creation of a collection of different scenarios can guide us to discover what systemic changes are most desirable.

To accomplish the stated set of objectives a group of research questions were formulated for the research to answer:

1. What are the key ecosystem services provided by the forest land?
2. What are the main drivers for deforestation?
3. How is the forest land used after clearing?
4. How does deforestation affect government's and individual's income?
5. What policies would generate the best possible outcome?

Achieving the main goal and subsequent set of objectives will contribute valuable insights into growing field of sustainability science by showing a way of quantitative accounting of specific ecosystem services. The whole model is separated into different parts i.e. modules. (Each module is focused either on accounting of different ES or on accounting the same ES on different land type). This separation conveniently portrays to a reader how individual ES can be accounted on their own. Therefore, various parts of existing structure can be used as blueprints and expanded in future research of ecosystem services assessment without the necessity of reproducing whole model.

This research can also enrich SD field by showing an example on how to analyze and connect various literature unrelated to system dynamics and create models based on it. With the focus laid on the forest land the modules provide an inspiration on how the SD structure might look like in areas such as: calculation of wood product and government revenues in managed forest, dynamic calculation of amount of carbon in managed forest; calculation of wood product and individual and government revenues in forest plantations, dynamic calculation of timber market price and estimation of the value of non-timber forest products collection.

Lastly, by presenting consequences of deforestation in clear monetary terms on governmental (government revenues), private (plantation owner's revenue) and public (social cost of carbon, value of fuel wood and NTFPs collection) level, the model can serve as a powerful educational tool for decision makers to understand the value of forest land and how to maximize it.

1.3. Methodology and choice of software

The methodology applied in this research consists of relevant literature overview, quantitative system dynamics modeling and model simulations analysis. By changing chosen parameters in the model will produce different outcomes. Such changes are way of experimentation which enable to present different "what if" scenarios.

The software used for modeling is a visual programming language for system dynamics Stella Architect. Since the original MFF model was created in Vensim software a lot of consideration were given whether to continue to expand the model in Vensim or rebuilt it in Stella Architect. Features of both software are more than sufficient for the level of modeling presented in this thesis. It the end, I made the choice to use Stella Architect. Necessity of rebuilding the MFF model was seen opportunity to fully understand its structure. Another important reason of using Stella is a possibility to work in its "Explore Mode" where after simulation run a modeler can change values of model's parameters and see the new results in real time without the requirement of running new simulations. Minor advantage of Stella is also its more compelling visual interface in comparison with its counterpart.

CHAPTER 2. LITERATURE OVERVIEW

2.1. Ecosystem services

Ecosystem services can be defined as contributors that ecosystems provide to human well-being. They can be understood as outputs of ecological systems which can be consumed or used by people. Classification of these services in scientific community is not yet fully unified. Generally accepted are three main categories of services: provisioning (nutrition, materials, energy), regulating (regulation wastes, flow and physical and biotic environment) and cultural (symbolic, intellectual and experimental)[3]. Supporting services can be accounted as fourth category which is done in TEEB[4] classification. Examples of these services are maintenance of genetic diversity and habitats for species.

In this work, I decided to focus on three ecosystem services: two provisioning (timber and non-timber forest products) and one regulating (sequestration of CO_2). All the listed services are connected to the forest land. The reason of this choice is to portray and better understand the dynamics and consequences of the massive deforestation in the study area.

Accounting flows of ecosystem services and implementing that information in long-term decision making is necessary for achieving sustainable development (Obst & Vardon, 2014). There is a wide range of evaluation techniques of ecosystem services which can be used. Generally, different types of estimations are used in different places and for different services. Evaluation methods can be divided into two main categories: conventional economic valuation and non-monetizing valuation.

Among the vast collection of monetizing practices are for example: revealed-preference approaches (travel cost, market methods, hedonic methods, etc...), stated-preference approaches (contingent valuation, conjoint analysis) and cost-based approaches such as replacement cost and avoidance cost. Examples of non-monetizing approaches can be individual index-based or group-based methods such as expert opinion, focus groups or stakeholder analysis (Turner et al., 2016).

Short-coming of conventional economic valuation might be expectation that people have well-formed preferences and enough information about trade-offs that they can adequately judge

[3] In brackets, I am using examples of services by the Common International Classification of Ecosystem Services (CICES) developed by European Environment Agency (EEA). Supporting services are by this classification perceived just as a part of underlying structures and functions of ecosystems and are only indirectly consumed by people. Therefore, these services should be accounted in other ways (Haines-Young & Potschin, 2012).

[4] The Economics of Ecosystems and Biodiversity.

their "willingness-to-pay". These assumptions do not hold for many ecosystem services (Turner et al., 2016). Nevertheless, a failure to place monetary values on ecosystem goods and services can ultimately lead to their over-exploitation and loss (Krieger, 2001).

In my thesis, I chose a path of a conventional economic valuation of ecosystem services, i.e. I am calculating monetary value in USD of each service. This methodology fits into market based valuation approach. Since timber and NTFPs are all marketable goods it is reasonable to choose direct method of price-based assessment.

In the case of carbon sequestration, I am calculating the social cost caused by its release of CO_2 into environment. It is therefore cost-based evaluation of mitigation where the costs represent value of indirect damages caused by pollution.

Approach		**Method**	**Value**
Market valuation	Price-based	Market prices	Direct and indirect use
	Cost-based	Avoided cost	Direct and indirect use
		Replacement cost	Direct and indirect use
		Mitigation / Restoration cost	Direct and indirect use
	Production -based	Production function approach	Indirect use
		Factor Income	Indirect use
Revealed preference		Travel cost method	Direct (indirect) use
		Hedonic pricing	Direct and indirect use
Stated preference		Contingent Valuation	Use and non-use
		Choice modelling/ Conjoint Analysis	Use and non-use
		Contingent ranking	Use and non-use
		Deliberative group valuation	Use and non-use

Table 1. Relationship between valuation methods and value types (TEEB, 2010)

2.2. Social cost of carbon

Concept of social cost of carbon (SCC) was created to measure the long-term economic damage caused by CO_2 emissions or its equivalent. SCC is a very comprehensive estimate of climate change costs which includes changes in agricultural productivity, property damages, increased flood risk, human health, etc. (EPA, 2017). While the calculated value does not include all important damages it is still considered to be the most important single economic concept in the economics of climate change (Nordhaus, 2016). Units of SCC are US dollars and the value represent damage done by one ton of CO_2 per year. Estimation of the cost is calculated by linking global economic model and global climate model into Integrated Assessment Model. The values I am using are based on William Nordhaus' DICE model where the price of SCC is 31 USD per ton of CO_2 in 2015 and this value grows by 3% up to the year 2050 (Nordhaus, 2016). The reason for the annual increase of the cost is expectation of worsening effects of climate change. Growing global population will cope with intensified effects of global warming which will lead to more damages per ton of CO_2.

2.3. Non-timber forest products

Non-timber forest products (NTFPs) are any useful products, materials, services or commodities other than timber that are obtain from forest. They include vegetables, game animals, medicinal plants, nuts, resins, seeds, berries, oils, rattans, foliage and more. Resins collection is in case of rural Cambodia especially important (Hansen & Top, 2006). Given the wide variety of listed products, NTFPs collection can be rightly consider as vital forest ecosystem service. The importance of NTFPs on income generation, rural livelihoods, local economies and forest conservation has been over the last decades increasingly recognized in the research as well as public policy areas (Shackleton, Delang, Shackleton, & Shanley, 2011). NTFPs collection can play either supplementary (obtaining food and medicine) or commercial role in the livelihood of rural families. Extraction of NTFPs is usually characterized by low capital and low skill requirements and open access to resources. It is consequently available as a source of income even for the poorest segments of society. For that reason, NTFPs collection can constitute a social "safety net" in rural developing areas, such Stung Treng and Kratie happens to be (Hansen & Top, 2006).

According to (Hansen & Top, 2006) and (Clements, Suon, Wilkie, & Milner-Gulland, 2014), the total annual value obtain from NTFPs extraction is 424 USD per household in Kratie and average household size in Stung Treng is 5.7 people. Therefore, based on this sources I am operating with 74 USD per person as yearly value of NTFPs collection.

For the population to be able to gather the products there must be enough of forest land available in proximity of settlements. Required area during the collection is different for each of the main forest type which are: evergreen, semi-evergreen and deciduous. The value of NTFPs per hectare for each forest type can be based on NTFP inventories or on actual flows. The first method values all potential resources in the forest. By this methodology the densest forests are the most valuable because of the higher amounts of biomass per hectare. The second method considers valuation of NTFP use from the extractor point of view (Hansen & Top, 2006) which is the methodology used in my source. This method leads to more counter-intuitive results where deciduous not evergreen forest is the most valuable. Although evergreen forest is richer in its resources, its high density makes the extraction more complicated and travel costs higher.

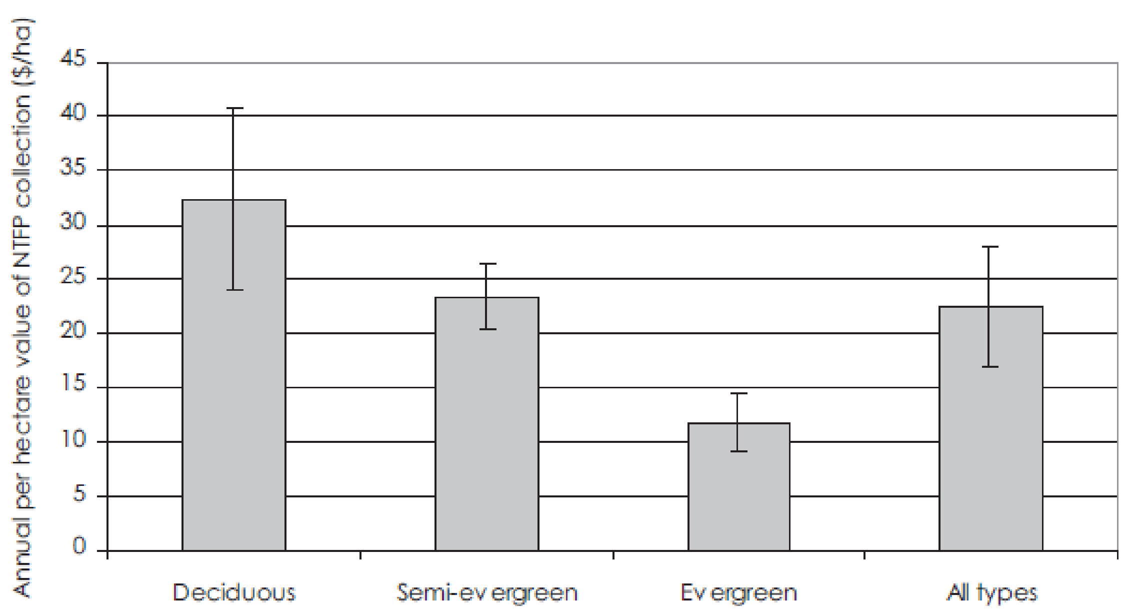

Figure 1. Per hectare direct values of NTFP use in selected forest types (Hansen & Top, 2006)

It is rather self-explanatory that deforestation negatively affects the obtainability of NTFPs. Developing tree plantations on previously forest land is still problematic. Based on the research done on of effects of industrial plantation of eucalyptus on ecosystem services conducted in southern China, the collection of NTFPs worsened after plantations development (D'Amato, Rekola, Wan, Cai, & Toppinen, 2017). Another problem which occurs specifically in Cambodia is that plantation owners prohibits local population to enter the plantations as it was documented in many cases (Dararath, Top, & Lic, 2011).

2.4. Managed forest area

Forests in Cambodia are state property so determining what areas can be cleared and what areas should be protected are political decisions. Nevertheless, these decisions are still driven by economic incentives. Understanding the flow of benefits from managed forest is crucial for offering an alternative to full deforestation. Because the owner is the state it is required to assess what are the government revenues from clearing a forest and what profit can be generated by managing a forest in a sustainable way. The profit in both cases represents mostly the tax income from exported timber. In this aspect, the most relevant study was conducted by (Kim, Phat, Koike, & Hayashi, 2006) in *Estimating actual and potential government revenues from timber harvesting in Cambodia*. In this report the researchers estimate revenues based on available information on harvested wood, operable logging area and forestry taxes under different management scenarios. Although this study is not part of SD literature it provides clear mathematical formulation for its calculations so it can be conceptualized in stocks and flows structure.

The drawback of this study is that it does not consider how different management practices alter the carbon stocks in the forest. As I already indicated, carbon release constitutes major costs to society hence its assessment is important when considering the optimal management regime. Among the existing literature a research done by (Sasaki et al., 2012) on managing production forest was a perfect fit into the missing link. This study presents equations on how different management practices, like cutting cycle time or logging mortality, change existing carbon pools in forest's above ground biomass. Based on the change in biomass I can estimate change in the volume of mature trees which creates a feedback loop to the calculation of government revenues.

By combining these sources, I could build two interconnected modules and present how different management regimes not only directly change amount of revenues from wood product but also indirectly change the dynamics of a growth of the forest which in turn also affects flow of revenue in the long run.

2.5. Plantations

Development of agri-industrial crops and tree plantations are among the key drivers of forest conversion in Cambodia (Forest Trends, 2014). The main types of emerging plantations are: cassava, rubber and different sorts of fast growing trees. Each of these crops represents different trade-offs in terms of ecosystem services. Unlike the other crops cassava is being used in human's diet and its ecosystem service characteristics are more similar to rice, beans and other food products than to the tree plantations. For that reason, I decided to include cassava in general stock of agriculture land and paid more focus on rubber and tree plantations.

Rubber can be considered as one of the most important Cambodia's commercial crops. In the last 20 years' size of rubber plantations more than quadrupled. Kratie region registered especially strong increase and rubber plantations become as widespread as traditional rice fields (CDC, 2014a).

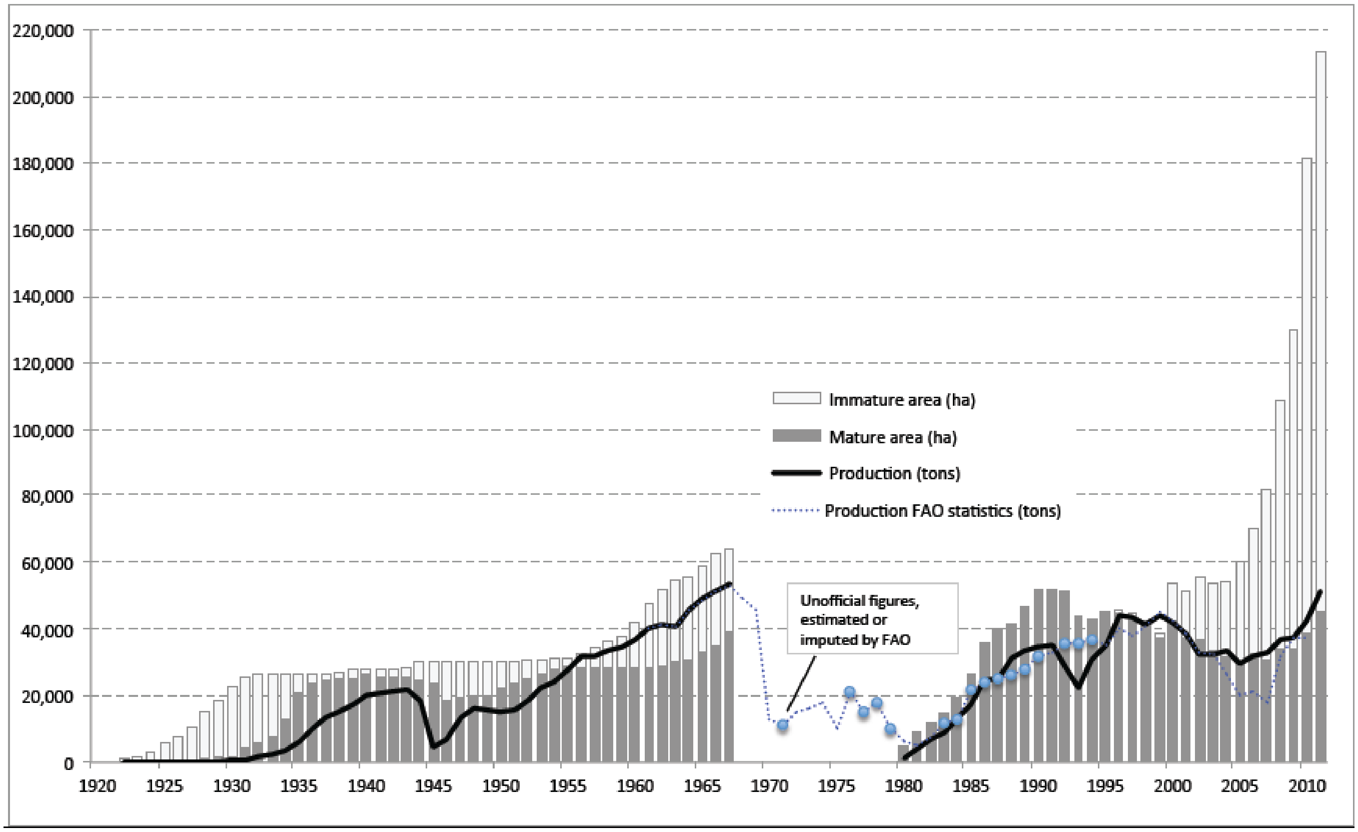

Figure 2. Natural rubber production in Cambodia, 1921---2011 (Ministry of Commerce, Cambodia, 2012)

Rubber plantations are primarily developed for latex collection. The life cycle of trees is 25 to 30 years after which they being cut and utilized as source of timber. Although considered to be an agricultural crop its characteristics are more close to tree plantations.[5] Due to the growing restriction on natural forest clearing, rubber plantations are becoming important source of timber and government revenues (Shigematsu et al., 2010).

Besides rubber other types of trees are being planted to be used as timber source as well. Most common species are acacia, eucalyptus and teak (Ra & Kimsun, 2012). They are not reliable data on which tree species are being planted in Stung Treng and Kratie but based on national data

[5] For example, provision of timber and NTFPs, larger carbon pools, etc.

acacia and eucalyptus are dominant. Both acacia and eucalyptus species have similar short life cycle so for simplicity all tree plantations in the model are presented as acacia.

Model calculating the amount of wood product from plantations is based on article *Estimation of rubberwood production in Cambodia* by (Shigematsu et al., 2010). Authors in this study provided lay out of production stages and yield rates of rubber processing which can be easily translated into SD stock and flow diagram. However, my model is just a simplification of the production stages presented in the article for reasons are explain in *limitations* section.

CHAPTER 3. MODEL DESCRIPTION

In this chapter I will explain model's structure. Firstly, I introduce IPS Mekong Flooded Forest SD model which serves as the main building block at the core of the structure. Since this model was already developed and presented in *LIVES: Modeling For Change With Nexus Thinking* (Watkins et al., 2016) I will describe just its general characteristics and be specific only with the modifications done by me.

Secondly, I will present rest of the structure which is separated into different parts called modules. The description will consist of conceptual explanation of the role of the module and presentation of its stocks and flows structure. Given the large size of the whole structure only some mathematical formulations will be displayed. The complete documentation of all variables and formulations will be provided in the Appendix G.

3.1. IPS Mekong Flooded Forest SD model and its modification

The purpose of the ISP-MFF model is to calculate and represent the main drivers of the food-energy-water nexus in the MFF landscape. The main areas the original model dealing with are: *Human population*, *Fish population*, *Dolphin population*, *Land*, *Sediments*, *Hydropower dam capacity*, *Road network length*, *Hydropower economic indicators* and *private sector*.

Because the focus of this thesis is laid on forest transformation the stocks and flows structure of *Land* becomes most relevant and requires closer examination. The original structure consisted of four stocks representing four different land types:

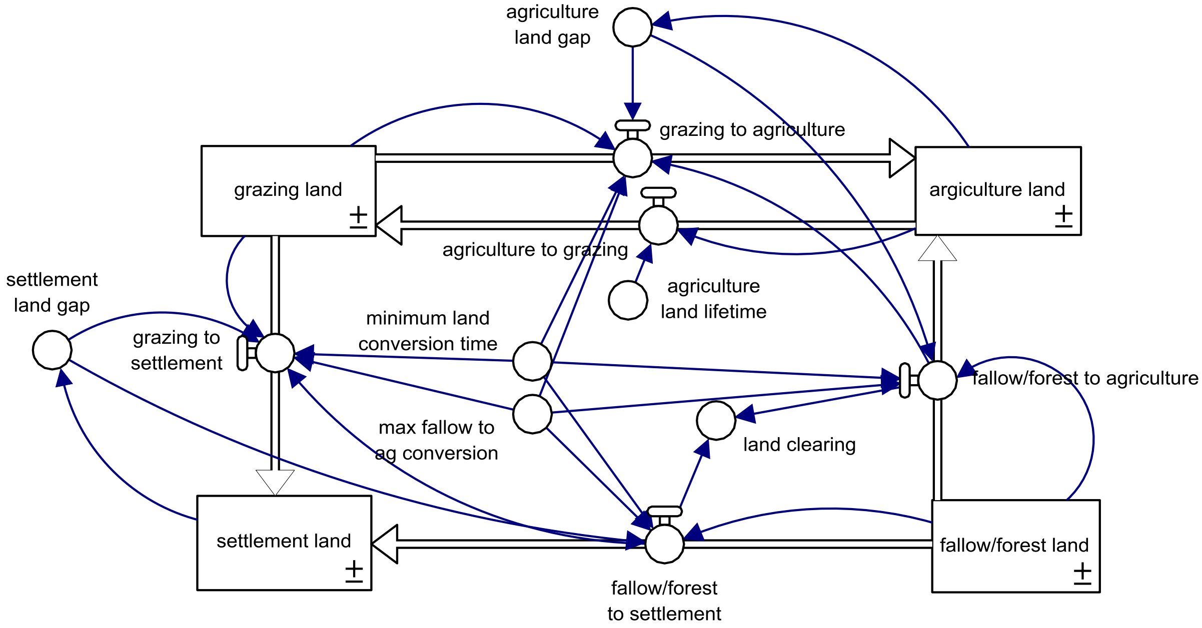

Figure 3. SFD of land types in original ISP-MFF

As the human population grows it requires more food and land which is represented by agriculture and settlement land gap. To satisfy these gaps a portion of forest area must be transitioned from *fallow/forest land*. The speed of this process is limited by *maximum fallow to agriculture conversion*. In case of insufficient flow rate from or depletion of *fallow/forest land* a *grazing land* can be also utilized for covering the gaps.

Over the time of my modeling effort this section had to be modified. First important change was to divide stock *fallow/forest land* into separate stocks of forest and fallow land respectively. Two reasons led me to make this change. First reason is to conceptualize more precisely the real chain of events. The nature of deforestation in Cambodia is first and foremost driven by timber exports not the necessity to acquire more settlement or agriculture land. This leads to a situation when large portions of forests are being cleared and transformed into fallow land which might be only potentially later used for plantations development, agriculture or settlements. Because the dynamics of fallow land and forest land are different, the ratio between them changes over time. Therefore, only by separating these two elements I can estimate the actual size of forest and fallow area. That is the second more practical reason for my decision. Knowing the actual size of a fallow land gives a is crucial for estimation of forest carbon pools. Based on that information I can understand what amounts of CO2 were released and calculate the social carbon cost.

Another change to the structure is inclusion of stocks of rubber and acacia plantations. Unlike acacia which might be consider as forest land, rubber plantations are officially classified as part of the agriculture. Nevertheless, they are both in fact tree plantations which provides different ecosystem services than typical agriculture crops like rice or cassava. Therefore, separation of rubber from agriculture as well as separation of acacia from forest land is needed.

New stocks and flows structure:

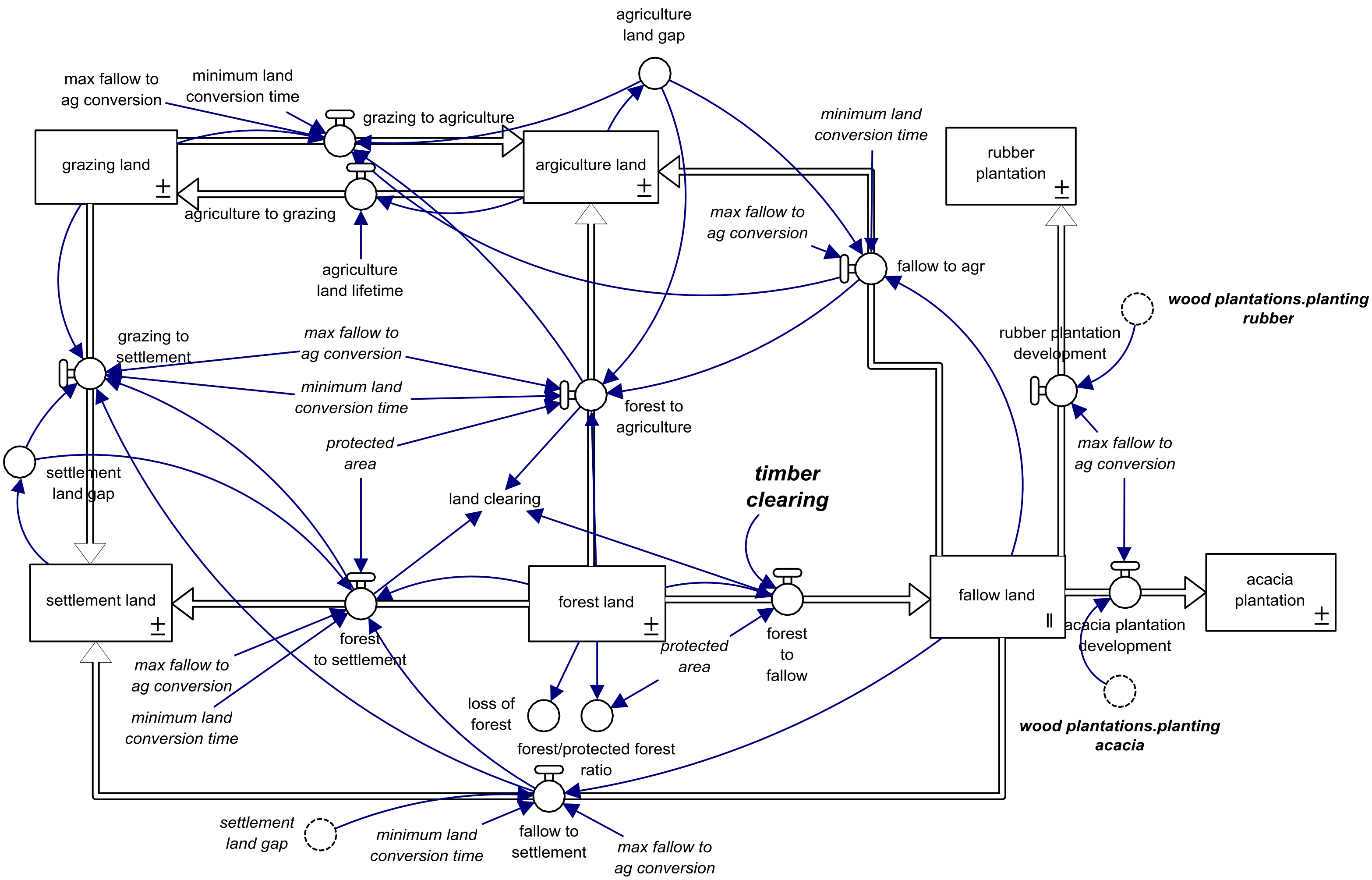

Figure 4. SFD of land types modified

As you can see besides three new stocks there are also five new flows. *Agriculture land* and *settlement land* can be increased by inflow from *fallow land*. Driver for this process continues to be either agricultural or settlement land gap. Direct flows from forest and grazing land are still possible but flows from *fallow land* are prioritized. Stock of *fallow land* is increased by *timber clearing* which is induce by market's demand for timber. Stocks of rubber and acacia plantations are increased by outflows from *fallow land*. Size of this outflows is related to the *forest to fallow* flow in a way which I describe later.

3.2. Government revenues from managing forest

Government revenues from managed forest are collection of different taxes and fees on wood product (timber) and its exports. The amount of wood product is dependent on size and type of forest area and management regime. Revenues from export are derived from the amount of exported timber and its market price which is calculated in different module.

3.2.1. Size of managed forest

First logical step is to know the total size of managed forest. In Cambodia, there are different categories of managed forest, namely*: protected area*, *protected forest* and *community forest* (Global Forestry Services, 2014). Although the areas are managed under various set of laws, due to their lax enforcement it is not oversimplification to consider them as homogenous. The size of *managed forest* gives a value to the variable *area which cannot be cleared* which serves as a limit under which the *forest land* stock cannot be decreased. On the other hand, the stock of a forest serves as the upper limit to the *managed forest* to ensure that during the scenario simulations a managed area will never be higher than the total size of forest land.

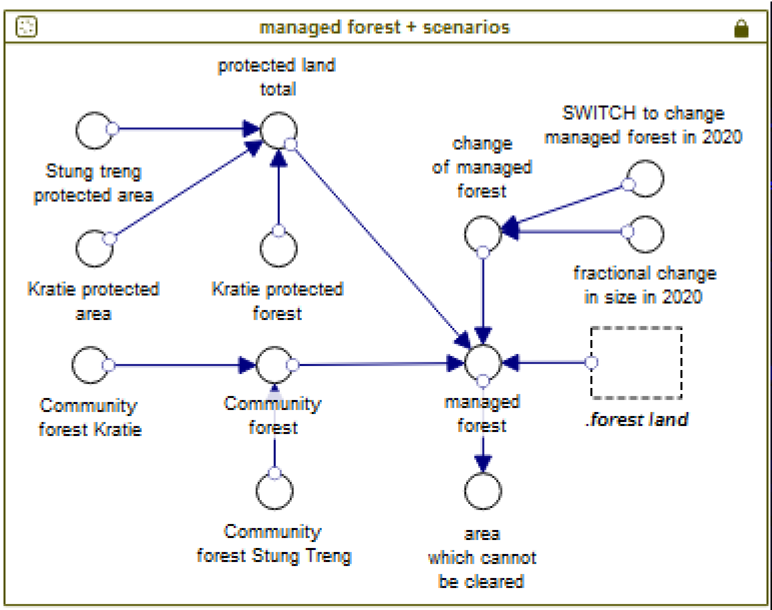

Figure 5. Size of managed forest

3.2.2. Proportions of forest covers and its wood volumes

After calculation of the size of managed forest it is necessary to know proportions of the main forest types which are: dense, deciduous and mixed. Each type of forest has different volume of mature trees per hectare. For both provinces, there are historic data on distributions of dense and mixed forest covers. Unfortunately, these proportions do not follow uniform trend. The model is therefore set up to change percentages of forest covers only to the year 2014 when last historic data are available. After that the proportions stay stable. Historic data on size of deciduous forest in Kratie and Stung Treng do not exist but based on the national data the size of this forest cover is 3.3 times larger than size of mixed cover (FAO, 2010). By multiplying fractions of *dense forest* and *mixed + deciduous forest* with the total size of *managed forest* the model calculate sizes of each forest type.

In the next step, each forest cover is multiplied by *annual operable area*. This variable characterizes a fraction from the forest where legal extraction is taking place. Size of this variable is dependent on the rate of illegal logging. Decrease in illegal logging would increase operable area which would lead to higher amounts of wood product and government revenues. The fraction of *annual operable area* is traditionally estimated to be 0.5 i.e. only half of the forest is being utilized (Kim et al., 2006).

Variables *max potential dense*, *deciduous* and *mixed* represents the amounts of wood product in cubic meters which can be extracted from each forest type. These values are calculated by multiplying the volume of mature trees per hectare in each forest type with its size. Information on the volumes per ha are fed from module *Carbon in managed forest*.

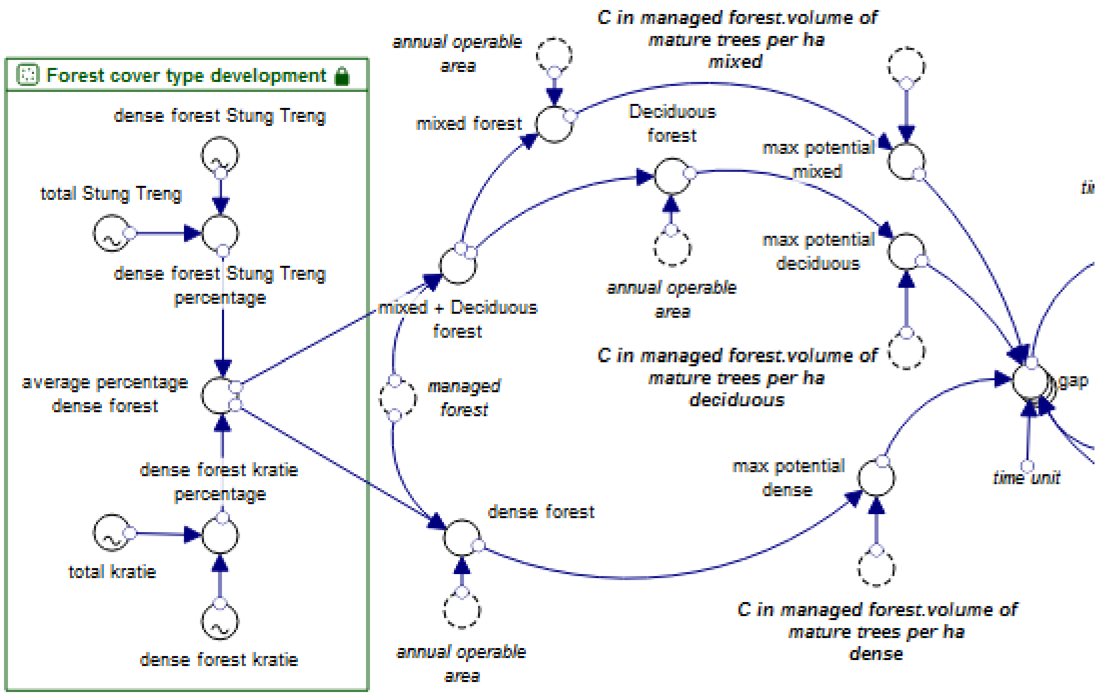

Figure 6. Forest covers and its wood volumes

3.2.3. Wood product in managed forest

The total amount of wood which can be extracted is represented by *potential wood harvest* stock which initial value is a sum of *max potential dense, deciduous* and *mixed* variables. As the values of theses variables change over time their sum becomes different than the total value in the stock. This discrepancy is expressed by variable *gap in potential* where the values of variables are deducted by the values in the stock. Values of this gap are then used in *change in potential* bi-flow which creates balancing loop between the stock and the variables and corrects the discrepancy.

The flow cut wood is dependent on the size of *potential wood harvest* and parameters *fraction of trees cut per cycle* and *cutting cycle time*. First parameter signifies what fraction of mature trees are cleared during one cutting cycle and the second indicates how long one cycle is. In normal settings 1/3 of all mature trees are cut every 30 years (Kim et al., 2006).

The stock *volume of cut wood* represents all the wood which has been cut down. Some wood is going to be damaged and wasted. Rest will be successfully logged and accounted as final wood product or timber. Fraction of wasted wood is dependent on the logging practices which expressed by parameter logging waste. Damaged wood can be collected and used as fuel wood. Wood product is afterwards sold on the local market or exported depending size of local and foreign demand. The ratio between these two demand is calculated in timber market price module.

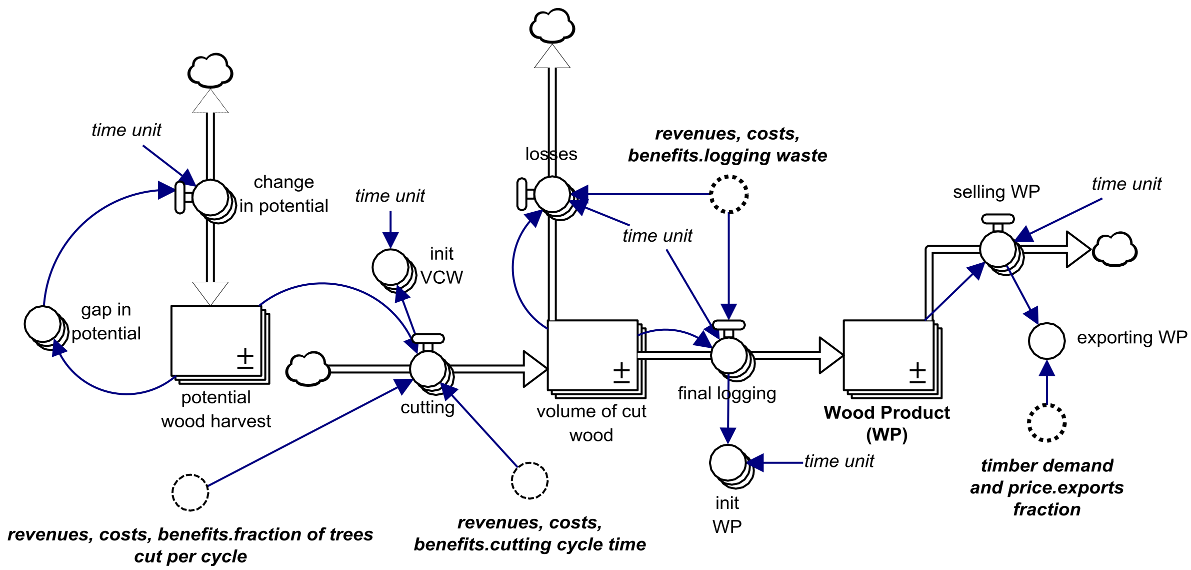

Figure 7. Wood product in managed forest

The stocks and flows presented in **Figure 7** are arrayed which means that the same structure is replicated multiple times. The reason for this design is that different forest covers have different ratios of dipterocarp, non-dipterocarp and unknown tree species. Royalty collected on extraction of each species are not uniform therefore it is necessary to separate them.

3.2.4. Volume of timber per hectare

The structure created for calculation an amount of timber per ha in managed forest does not feed any information to other modules and it's not essential for functioning of the model. Nevertheless, information on volume per hectare serves as an important indicator of the outcomes of various management regimes. Calculation is a sum of the volumes of mature trees in each forest cover in one hectare of forest multiplied by the rate of logging waste.

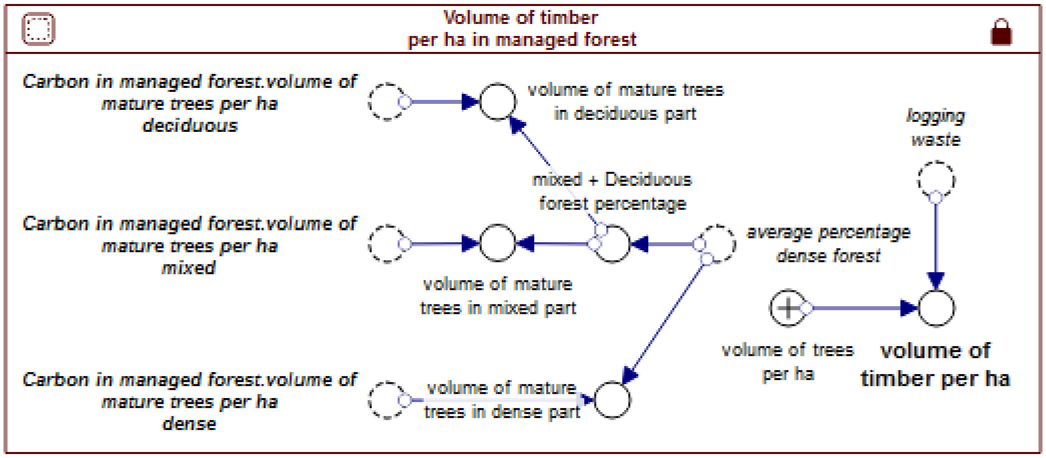

Figure 8. Volume of timber per hectare in managed forest

3.2.5. Government revenues

Government revenues are sum of various fees and taxes. The full list consists of:

- *Royalties on wood product*
- *Reforestation tax*
- *Export tax*
- *License fee*
- *Customs charge*

The royalties and reforestation tax are being charged on the volume of wood product and the rates different for each tree species. Export tax, license fee and customs charge are based solely on the amounts of timber exported and its market price. Because the ratio of species is different for each forest type three separate structures had to be built. However, the structure is always the same so in Figure 9 I present just structure for dense type of forest.

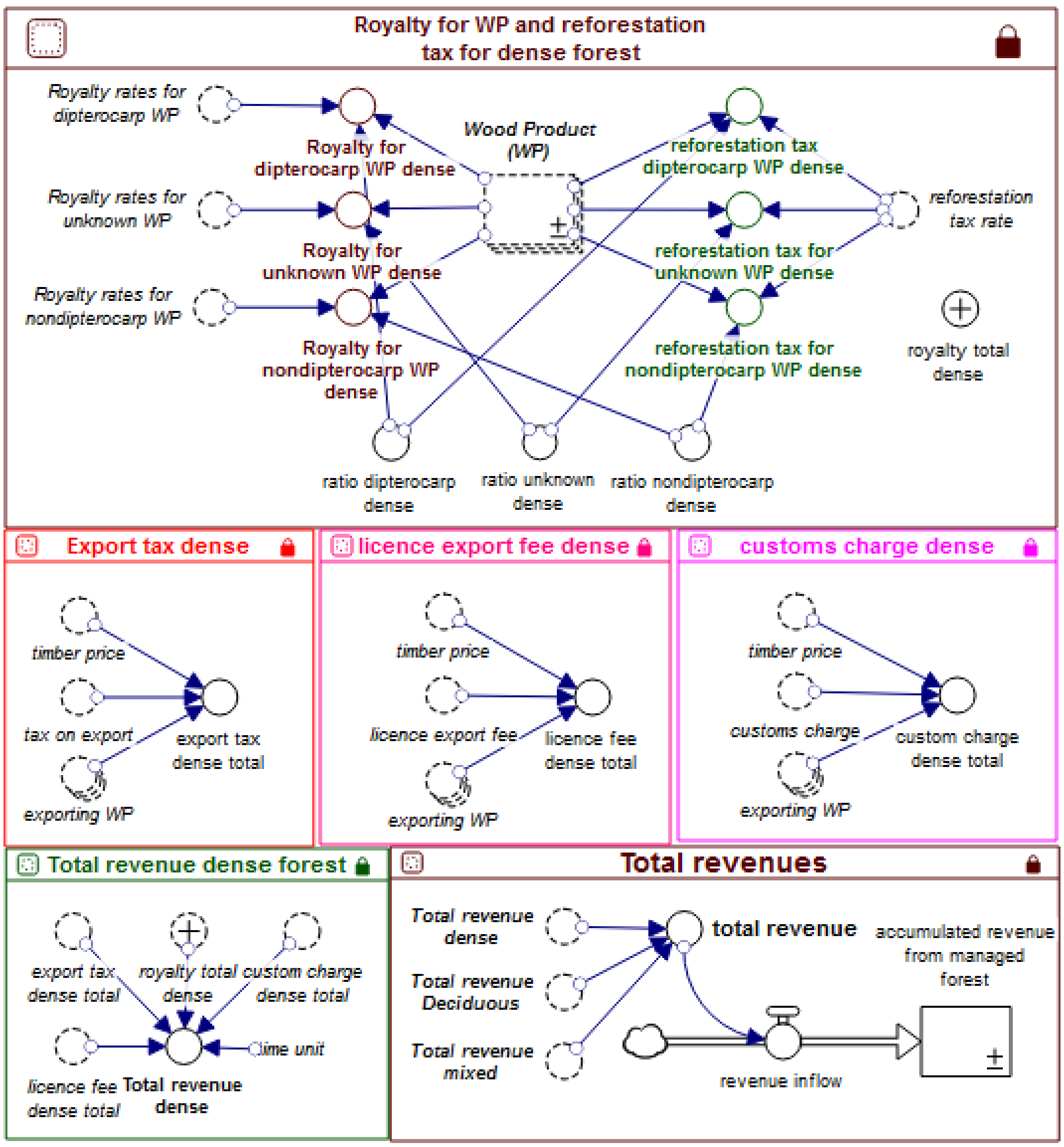

Figure 9. Government revenues from managed forest calculations

3.3. Government revenues from clearing forest

This module is based on the design of the previous one with few alterations, hence I portray only the parts of the structure which are different. Driver of this module is variable *land clearing* which represents decrease of the *forest land* stock. Volumes of mature trees are constant because they are not being affected by management practices. There is no stock of *potential wood harvest* because every time step full potential of every forest cover type is being utilized. The structure for calculating amount of timber per hectare also stays unchanged, but in this case the result is used in *timber demand and price* module and plays crucial role in model's simulation runs.

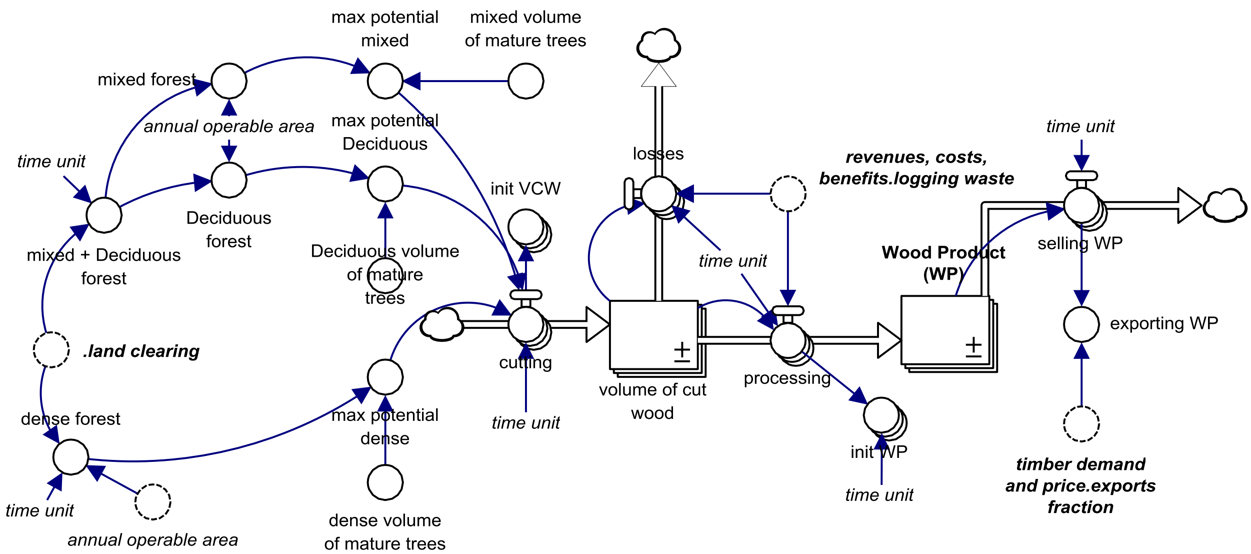

Figure 10. Government revenues from forest clearing

3.4. Carbon in managed forest

This sector calculates carbon stock of aboveground biomass per hectare of each forest cover type in managed forest based on management practices and uses this information for estimation of volume of trees per ha. It therefore operates under assumption that relative change in aboveground biomass is equal to relative change of volume of all trees. Each forest cover has different initial volume of trees per hectare so the change in the volume must be calculated separately for dense, mixed and deciduous type. Nevertheless, the structure is always identical hence it is sufficient to present in Figure 12 lay out of only one type, in this case dense forest.

Carbon stock of aboveground biomass is a stock variable. Its initial value is equal to average amount of aboveground carbon in each respective forest cover type. The stock can be increased or decreased by *inflow of change in above CS*. Relative change of value of the stock is expressed by *relative change in above biomass all* variable. *Initial volume of all trees* is then multiplied by the relative change in biomass and represented by *volume of all trees* variable. By deducting the initial volume of trees by the present volume model calculates *change in volume of all trees*. During timber extraction, only mature trees are targeted to be cut. Nevertheless, even young trees and other flora is being damaged. Parameter *alpha logging damage* denotes the proportion of untargeted trees killed by extraction.[6] Based on this parameter it is possible to calculate what is the change in volume of both immature and mature trees out of the total *change in volume of all trees.* The changes in volumes of immature and mature trees are then subtracted from their initial values. Variable *volume of mature trees per ha* provides feedback to the *Government revenues from managing forest* module where it affects the amount of wood product made from one hectare of forest.

Formulation of amount of harvested carbon will be probably best described by presenting the original equation from the source material:

$$H_i(t) = \frac{f_M \times f_H}{1 - r} \times \frac{CS_i(t)}{T_c \times BEF} ;$$

Figure 11. Formulation of harvested carbon (Sasaki et al., 2012)

Where in the model:

- f_M = *fM fraction of mature trees* variable
- f_H = *fraction of trees cut per cycle* parameter
- r = *illegal logging rate* parameter
- $CS_i(t)$ = *CS above biomass per ha* stock
- T_c = *cutting cycle time* parameter
- BEF = *BEF biomass expansion factor* parameter

For better clarity, each of the fraction in the formulation is separated into individual variables *H harvested carbon part 1* and *part II* and then multiplied in *H harvested carbon complete* variable. Increasing *cutting cycle time* or decreasing *fraction of trees cut per cycle* will decrease amount of harvested carbon and increase the carbon stock. *LM logging mortality* represents the amount of carbon lost due to logging damage. *Change in aboveground carbon stock* is calculated as subtraction of harvested and lost carbon from natural growth presented as *MAI mean annual increment.*

[6] Name of this parameter resembles parameter *logging waste* presented in *Government revenues from managed forest* module but there is important distinction. *Logging waste* represents the amount of material wasted during wood processing. For example, if *logging waste* coefficient is 0.5 it means out of 1 ton of cut trees only 0.5 ton becomes wood product after processing. *Logging damage* on the other hand, can be understood as kind of collateral damage representing proportion of trees not targeted for extraction but still killed by logging and skidding.

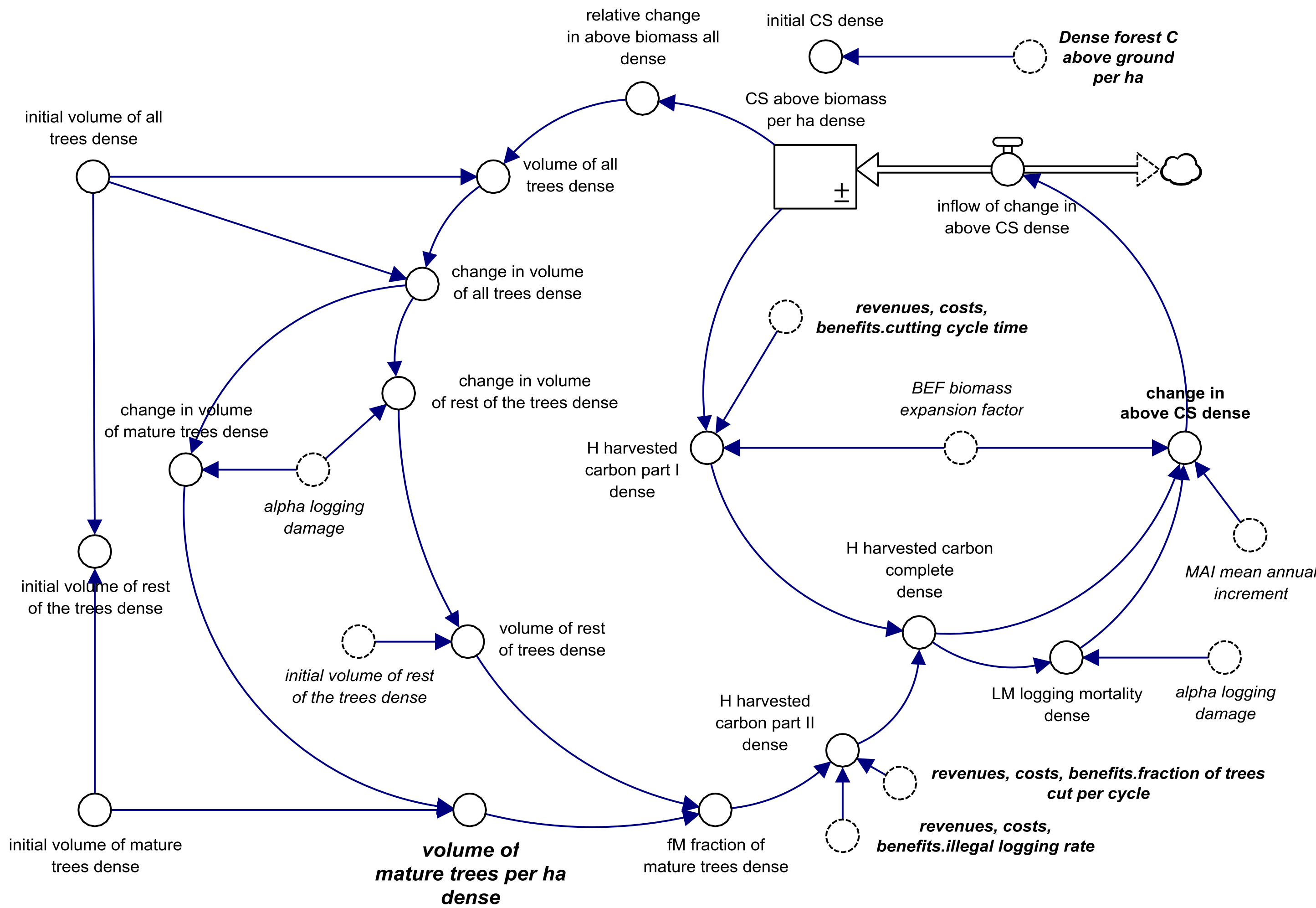

Figure 12. SFD carbon and volume of trees

3.4. Timber demand and price

Timber demand and price is one of the central modules in the model. It calculates supply and demand of timber, its price and provides feedback on how many hectares of forest are going to be cleared for the demand to be satisfied.

3.4.1. Demand and supply

Timber demand and supply are characterized by two stocks: *demand for timber* and *supply of timber*. Demand stock is increased by *inflow of demand* which calculation I present later in this section. *Supply of timber* is increased by two flows representing influx of timber from forest clearing and from plantations or managed forest area. *Outflow of supply* is equal to the *demand for* *timber*. The amount of timber drained from supply stocks denotes the amount of demand which is being satisfied and no longer exists. Outflow *fulfilled demand* is therefore equal to the *outflow of supply*.

The volume of timber determining the extent of clearing is expressed in variable *volume to clear*. The demanded volume is equal to the *inflow of demand* decreased by the amount of wood coming from plantations or managed forest. That is happening only under condition if demand decreased by supply is higher than negative value of *reserves policy* which is set to be 5% of the whole demand. For better clarity, I present the equation here:

Volume to clear = **IF** (*demand for timber – supply of timber*) < -*reserves policy* **THEN** 0 **ELSE** *inflow of demand – inflow from plantations and managed forest*

The result of this formulation is creation of small abundance of timber on the supply side. If the condition would be simple deduction between demand and supply it would lead to a situation when having even 1 cubic meter more on supply side than on the demand side the clearing of forest would immediately stop until the demand wouldn't become higher again. In simulation run it would lead to extremely sharp but short drops in clearing which is unrealistic. It is reasonable to assume that the timber extraction is being conduct with some reserves policies in place to protect the companies from short-term shortages or underestimation of demand.

Clearing for timber is a flow representing outflow from *forest land* into *fallow land*. Its size is dependent on the demanded *volume to clear* and amount of *volume of timber per ha*. This is the point where estimation of volume of timber per hectare from *government revenues from clearing* module comes in place. This flow can operate only if there is available forest to clear, i.e. if the *forest land* is higher than managed *forest*.

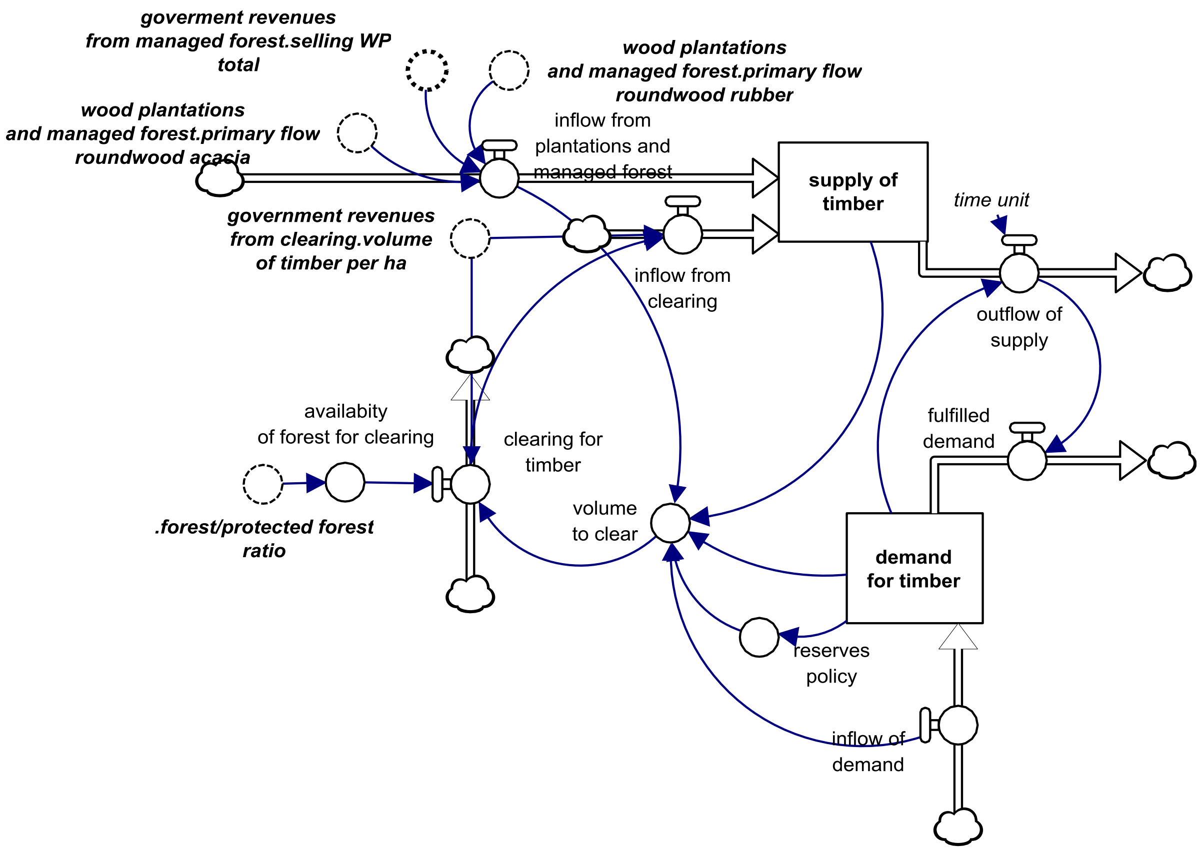

Figure 13. Supply and demand of timber

3.4.2. Historic demand

Estimation of historic demand serves as a starting point for calculation of future demand. Normally, data on historic demand could be easily obtain based on existing records of domestic imports and consumption and exports to foreign countries. Nevertheless, when comparing this statistical information with actual historical loss of forest the data does not match. Given the Cambodian's high rates of illegal logging I decided to estimate historic demand solely on deforestation statistics.

Historic forest loss is based on real statistics and represented by *historical loss approximation 2000-2014* variable.[7] *Forest to settlement* and *agriculture land gap* are outputs from the base level of model and their sum in *non-timber land demand* denotes the amount of forest cleared for reasons other than timber production. By deducting historic loss of forest by *non-timber*

[7] Data on deforestation are published by *Open Development Cambodia*. For more information visit: https://opendevelopmentcambodia.net/

land demand model calculates the *demand to clear land for timber*. Knowing the volume of timber per hectare I can calculate the *timber equivalent* of historic timber land demand.

Local timber demand depends on the size of local population and data on timber demand per capita. Foreign historic demand is based on the *timber equivalent* of land demand deduced by *local timber demand*. Sum of foreign and local demand deduced by timber equivalent of *non-timber land demand* is used as initial value for the stock of demand.

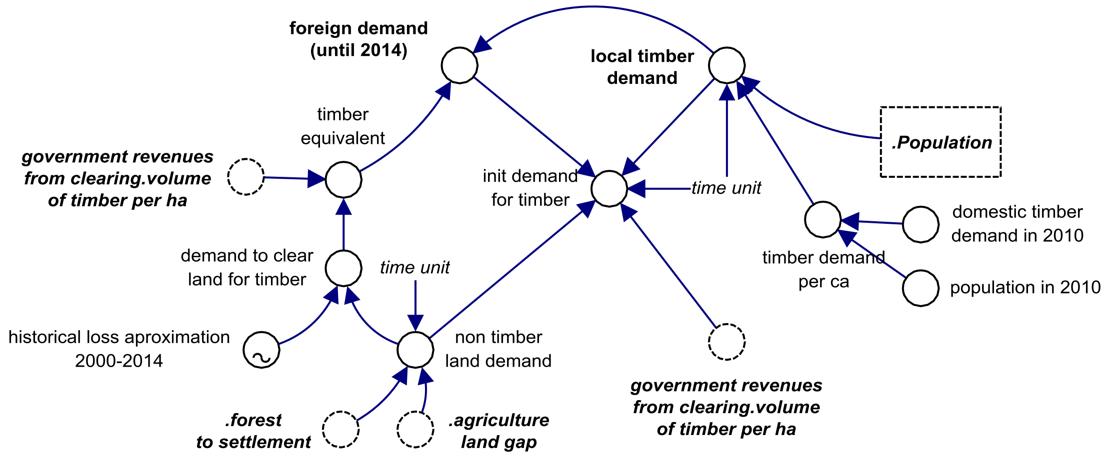

Figure 14. Historic timber demand

3.4.3. Foreign demand for timber

Foreign demand is based on *projected demand from rest of the world* and multiplied by *effect of timber price on foreign demand*. Projected demand is a stock variable initialized by a pulse which accounts last values of *foreign demand (until 2014)* and *inflow from plantations and managed forest* from year 2013. Stock of projected demand is set up to grow in accordance with actual growth in global demand. Global demand for timber is projected to annually grow by 1.8% until year 2020 followed by growth 1.3% until year 2030 (FAO, 2009).

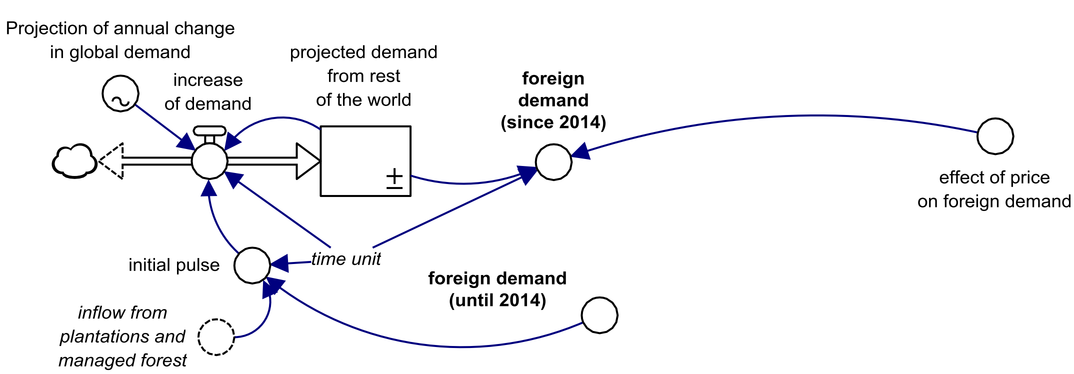

Figure 15. Foreign demand for timber

3.4.4. Timber price and its effects

Inflow of demand is divided into two periods – before and after year 2014. In the first period inflow is calculated as a sum of *foreign demand (until 2014), local timber demand* and *inflow from plantations and managed forest*. Foreign demand in this period is estimated from historical data on forest land loss so it is necessarily to include *inflow from plantations and managed forest* as well because this flow is not based on deforestation. In the second period, after year 2014, the *inflow of demand* calculation is wholly endogenous and consist only from *foreign demand (since 2014)* and *local timber demand*.

Timber price is based on four factors: *initial price, growth rate of demand, forest deterioration* and *extraction availability*. Variable *growth rate of demand* captures the trend in demand stock. If the stock is increasing the trend is positive and its size is proportional to the extent of increase. When the stock is decreasing, the mechanism is the same but the values of the trend are negative. Values of growth rate are accumulated in a stock *accumulated growth rate of demand.* The *effect of demand's growth rate* is multiplying the *timber price* and its value is equal to the size of the stock. The result effect is growing *timber price* with increasing *inflow of demand* or price drop in opposite situation. *Timber price* is also affected by forest degradation. The reasoning behind this effect is that with decreasing size of forest its products are becoming more precious and their extraction more expensive. As the *relative size of forest* decreases so does the *effect of forest deterioration* but the size of this effect is dampened by *magnitude of effect of depletion*. *Timber price* is being divided by *effect of forest deterioration* which leads to a price increase because the value of the effect is always smaller than 1. *Effect of extraction availability* increases *timber price* if managed forest area is expanded. *Initial price* is a parameter providing the initial value of *timber price*. *Initial price* is based on the historic price of timber in year 2000.

Increase in *timber price* starts to have an effect after the price becomes higher than recorder price in 2014. Magnitude of the effect is expected to be stronger on local demand than foreign demand. Both foreign and local demand are divided by their respective effects, so as the *timber price* growing its demands are decreasing.

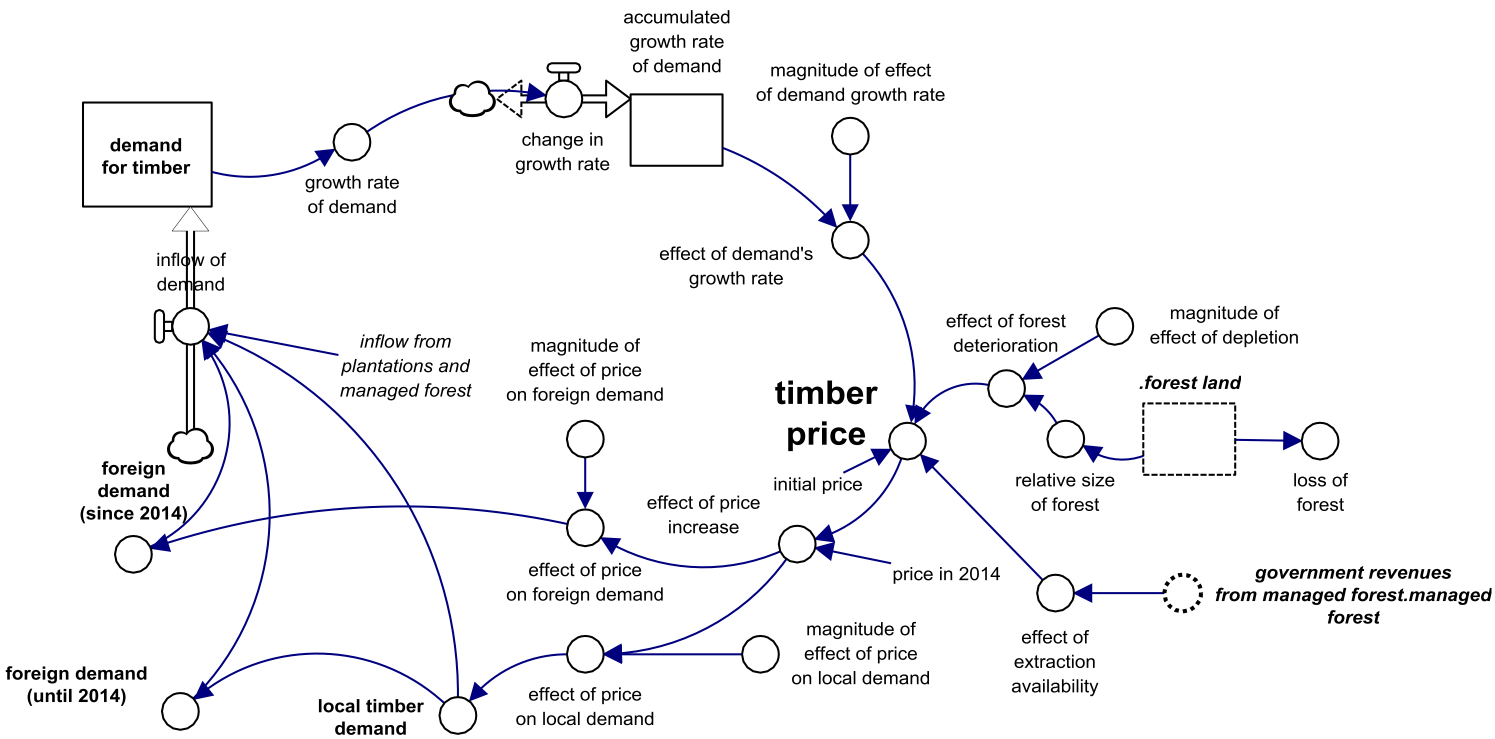

Figure 16. Timber price structure

3.4.5. Fraction of timber exported

Government's revenues from timber are mostly based on export fees. It is therefore necessary to distinguish what portion of total demand is foreign. This is calculated by simple division of local demand by total demand. In Figure 19 below you can see whole structure of *timber demand and price* module:

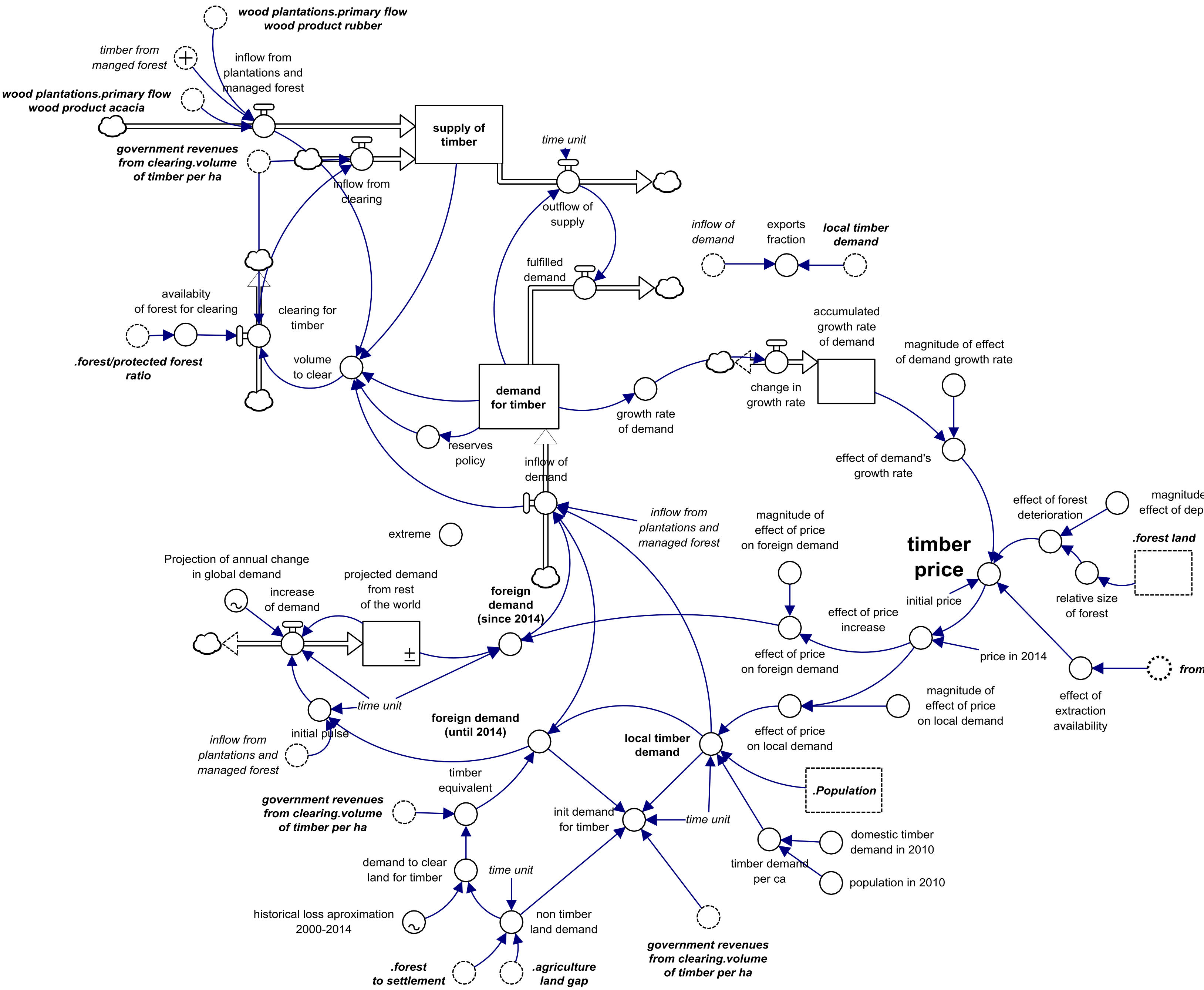

Figure 17. Timber demand and price

3.5. Plantations

Plantations are being developed as consequence of forest clearing for timber. Their increase is equal to a fraction of the *fallow to forest* outflow. Once the trees are planted they are going through the cycle of maturing, cutting and re-planting. When the trees are cut, their wood is processed into wood products and wood residuals. Wood products from plantations then create one of the inflows to the stock of *supply of timber* in *Timber demand and price* module. Running costs the plantations are accumulated and depend their size. Sales revenues depends on the amount of wood product and its price which is calculated in *Timber demand and price* module. Government revenues are again collection of fees and taxes on exported product. Owner’s profit from plantations is sum of sales revenues deducted by running costs and government revenues (taxes).

Along the structural description I will present stocks and flows diagrams of rubber plantations. Structure of acacia plantations is mostly identical only without the parts connected to latex production.

3.5.1. Size of plantations

Plantations development is divided into two periods: historical and simulated. Historical increase occurs in period 2000 – 2011 and is based on actual records on rubber expansion in two provinces. From year 2011 onwards the increase is calculated as fraction of timber clearing. Size of this fraction is based on the ratio between agriculture land and sum of forest and rubber plantations. On the provincial level, there are available data on the sizes of agriculture land and rubber plantations (CDC, 2014b). The ratio between agriculture and rubber plantations is 1:0.3. Nevertheless, data on sizes of forest plantations could be find only on national level. Based on the national data I calculate that the ratio between rubber and forest plantations is approximately 1:0.32. Assuming, that the national ratio between rubber and forest plantations is the same in the two provinces I could estimate that the ratio between the size of agriculture land and plantations is 1:0.4. Based on this aggregation of data fraction 0.4 was used to multiply *fallow to forest* outflow which constitutes *plantations development* flow, but after calibration based on historic behavior comparison fraction 0.3 is being used. This flow is divided between rubber and acacia inflows according to their respective ratio.

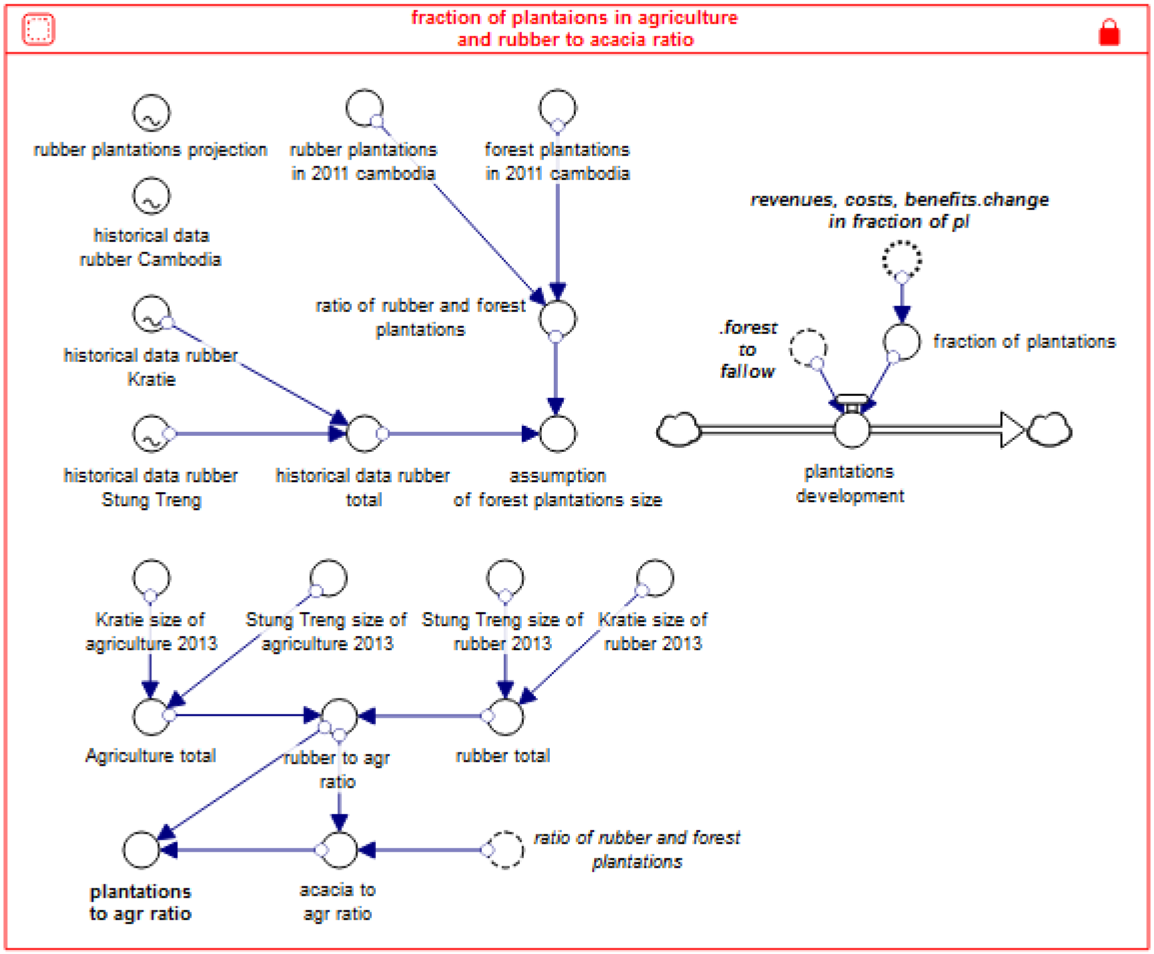

Figure 18. Plantation ratios calculation

3.5.2. Tree life cycle

Once the trees are planted they exist in a stock variable for a period equal to their *cutting age*. When the trees reach the *cutting age*, they are being cut and replanted. Rubber trees are going through one more stage of growth which is maturing. Young rubber trees are immature and unusable for natural latex collection. Length of maturing is equal to *avg maturing age rubber*. After maturing they provide latex inflow until they reach *cutting age*.

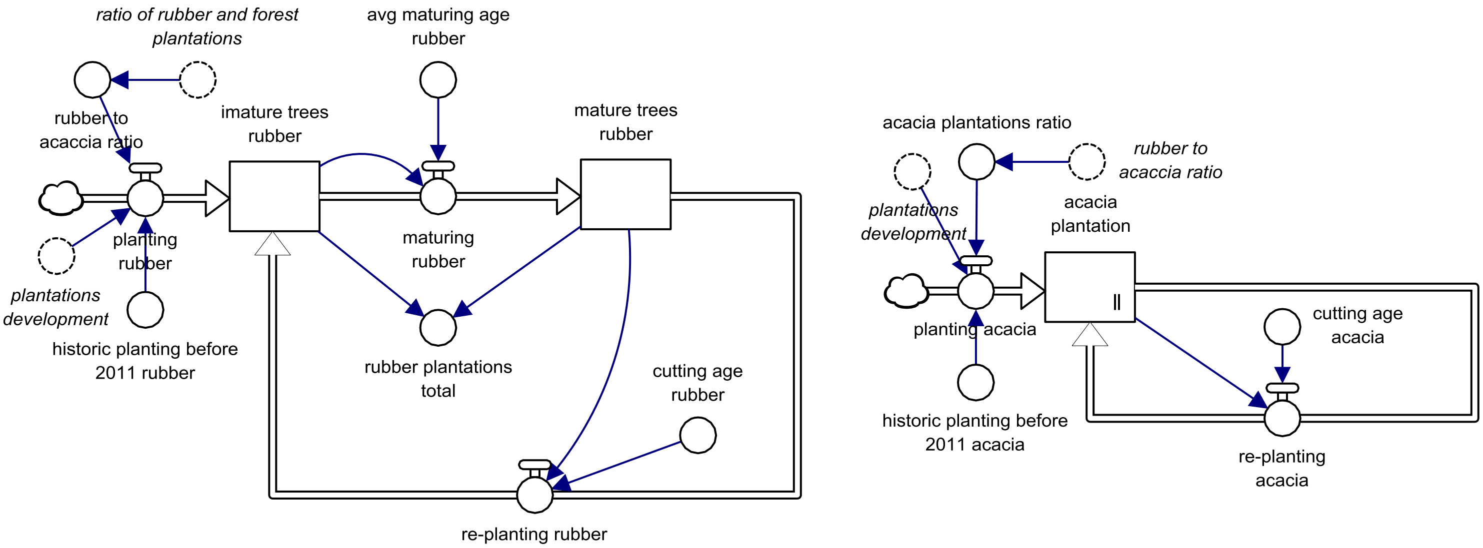

Figure 19. Life cycle of rubber and acacia

Stocks and flows structure for processing wood is same for both rubber and acacia. When trees are being re-planted, it means that they are first being cut. The amount of wood from clearing depends on the volumes per hectare in this case represented by variable *volume of rubberwood per ha*. The stock of cut wood is being further process into wood product and wood residuals. The ratio between residuals and wood product is given by *conversion factor* parameter. Residuals are then accumulated in *primary residuals* stock. Material from this stock is afterwards used either for veneer boards production or collected as fuel wood.

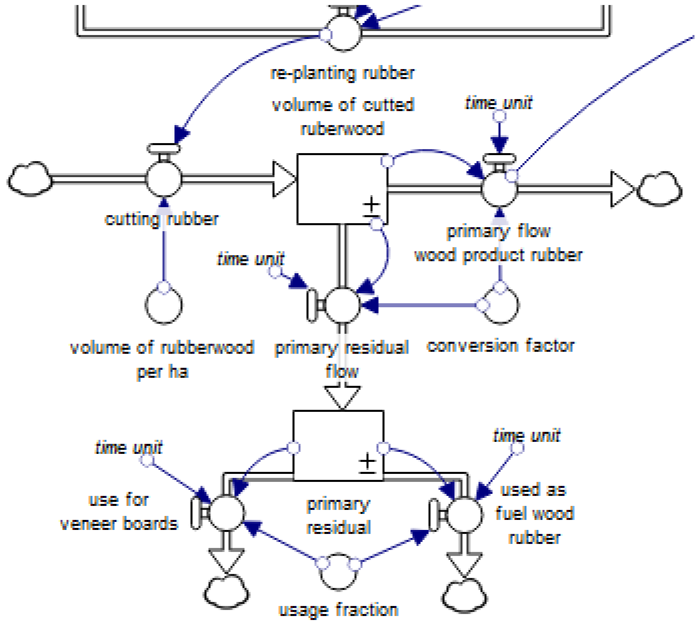

Figure 20. Wood processing in plantations

3.5.4. Sales and government's revenues from plantations

Sales and government's revenues are based on the amount of produced wood product respective wood product and latex in case of rubber plantation. Sales revenues are accumulated in a stock which inflows depends on the amount of wood product and timber price calculated in *Timber demand and price* module. *Sales revenue flow* is taxed by government by collection of export taxes presented in section 3.2.5. of *Government revenues from managing forest.*

Natural latex is being collected from mature rubber trees and accumulated in a stock. *Latex inflow* is dependent on the size of *mature trees rubber* stock and *rubber yield* parameter. *Latex sales revenues flow* is formulated as multiplication of *latex inflow* and *price per kg*. *Price per kg* is a table function with data on historic prices of natural latex and their projection to year 2020. Stock and flow diagram for government's revenues from rubber is the same as in case of wood products. Both governments' revenue inflows are multiplied by *exports fraction* from *Timber demand and price* module.

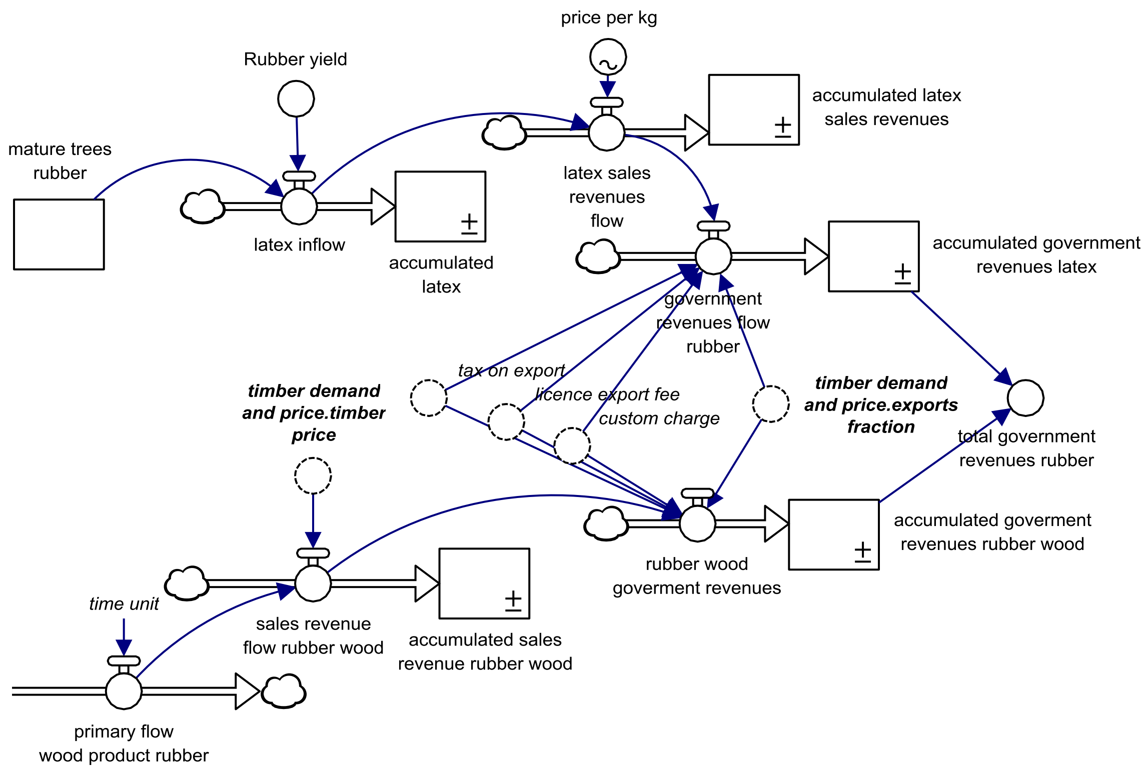

Figure 21. Plantations revenues structure

3.5.5. Owner's running costs and profit

Running costs for the owner of plantation is dependent on size of plantation and annual costs per hectare which tends to be higher for rubber than for acacia (Ra & Kimsun, 2012). The total profit is a sum of sales revenues deducted by government's revenues and running costs.

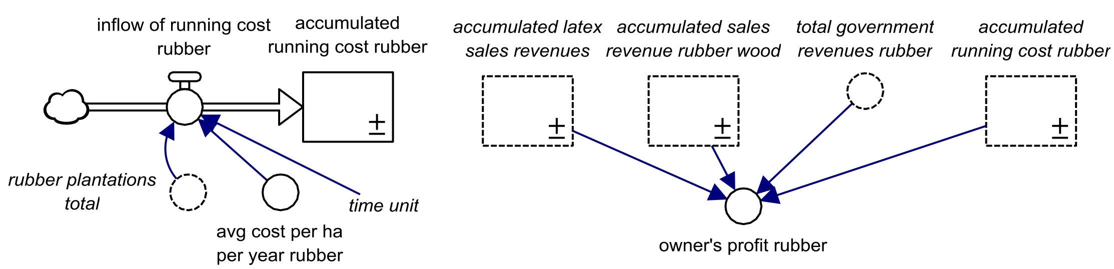

Figure 22. Running costs and profit of plantations

3.7. Social cost of carbon

Social cost of carbon is based on the amount of released CO_2 into atmosphere. The size of release is calculated from the change in land carbon pools. Each type of forest cover, plantation or agricultural crop holds carbon pool of different size and transformation of land from one type to another follows carbon release or sequestration. In Appendix A. I provide table with values and sources on carbon pool for each land cover type used in the model.

3.7.1. Carbon and CO_2 in natural forest

Pools of carbon and carbon dioxide in natural are based on the size of forest and proportion of each forest cover type. Change in pools are calculated as subtraction of initial pools size from the present sizes. The structure is build co compute change in only aboveground pools or above and below ground. User can switch between two calculation by setting a value 1 or 0 in *SWITCH* variable.

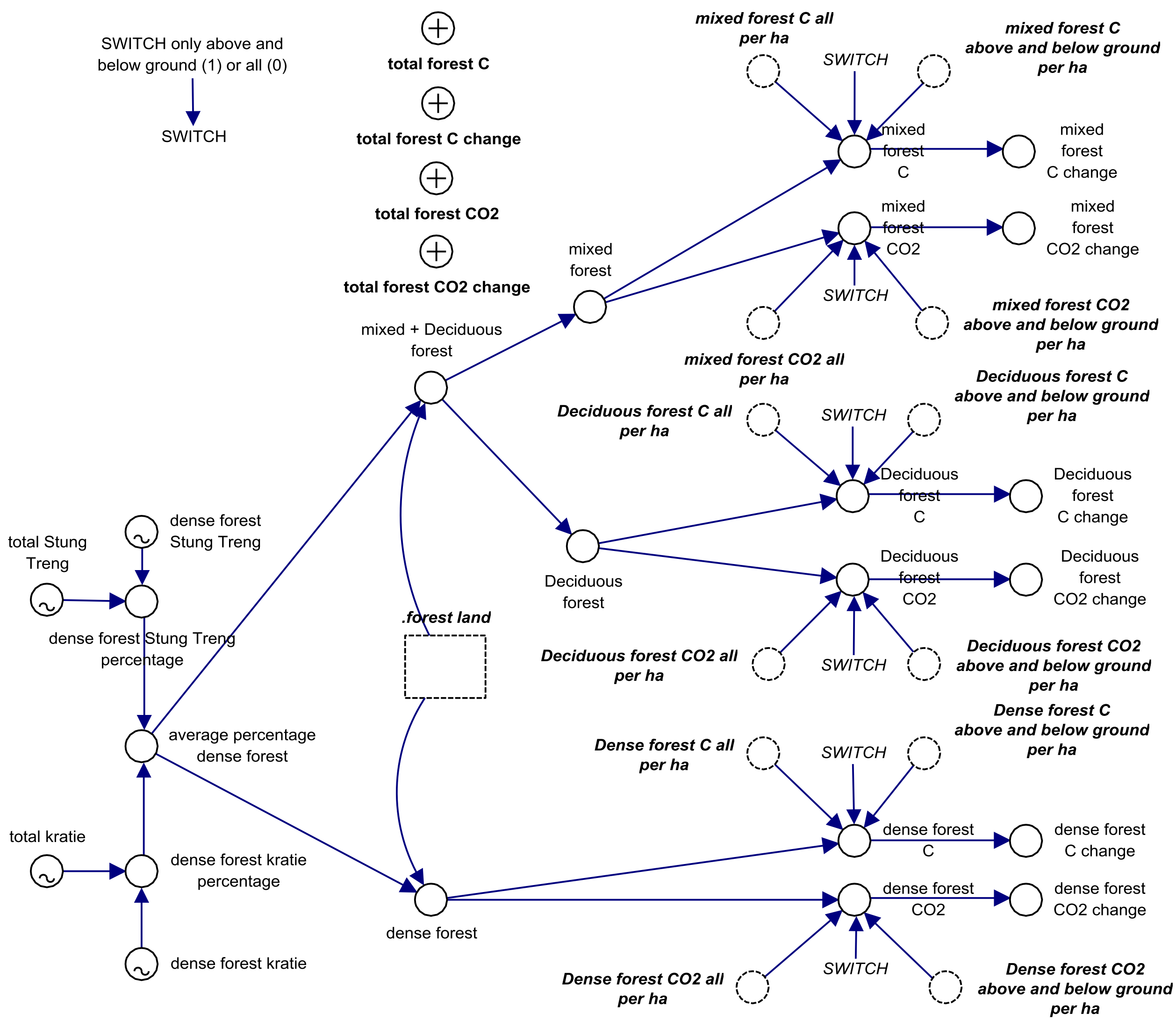

Figure 23. C and CO2 in natural forest

3.7.2. Carbon and CO_2 in plantations

Princip of carbon calculation is same as in case of natural forests. Size of plantations multiplied by amount of carbon per hectare give values on present size of carbon pools of acacia and rubber. *Change in carbon* pools is calculated by deducting the present amount by initial. *Change in carbon dioxide* is equal to *change in carbon* multiplied by *C to CO_2* coefficient.

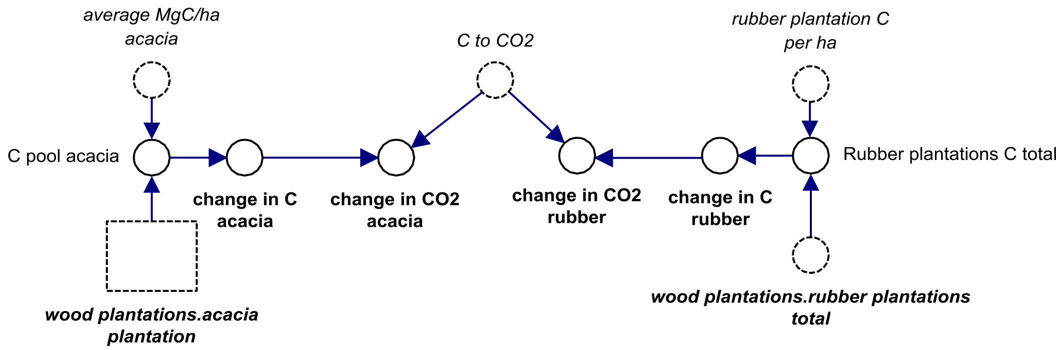

Figure 24. C and CO2 in plantations

3.7.3. Carbon and CO_2 in managed forest

Calculation of carbon in managed forest follows the same formula with the caveat that it is necessary to take into consideration changes in forest caused by management practices. Various management regimes will change the average amount of carbon per hectare in aboveground biomass. Present values on amounts of carbon per hectare are stocks variable provided from *Carbon in managed forest* module. The sizes of each forest cover types are outputs from *Managed forest area*. The *total change in CO_2 in managed forest* is multiplication of the sum of carbon changes in all cover types multiplied by *C to CO_2* coefficient. Structure of calculation is same for each forest type so in Figure 25 I am presenting only one carbon change in dense forest.

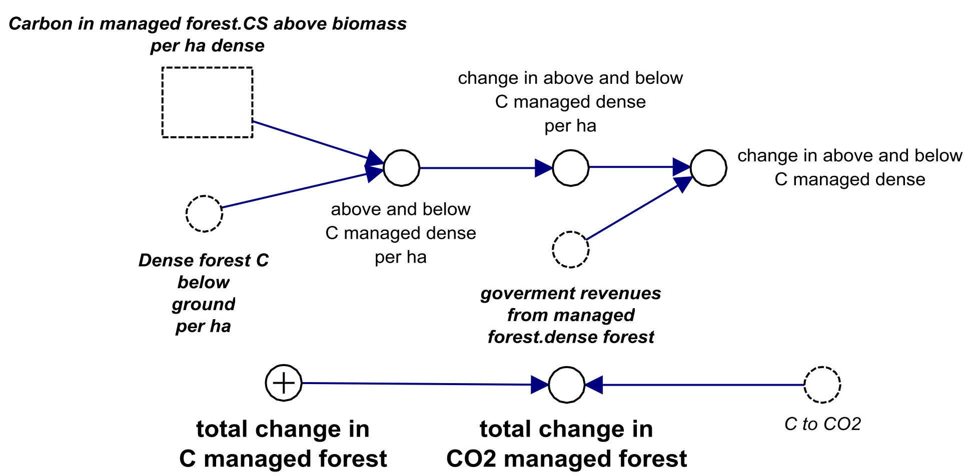

Figure 25. C and CO2 in managed forest

3.7.4. Carbon and CO_2 in agriculture land

There are many kinds of crops cultivated in agriculture land in Kratie and Stung Treng but only rice and cassava alone represents 93% of all fields (CDC, 2014a). For simplification, it is assumed that all agriculture consists of rice or cassava production.

Carbon pool in agriculture land is a sum of carbon pools of cassava and rice. Carbon pool of each plant is multiplication on the size of the fields on which they are planted and the amount of carbon per hectare. Size of the fields is based on ratio of rice and cassava within total agricultural land. The ratio is based on *fraction of cassava.* There is no annual data on sizes of each fields so the fraction is derived from historic records of rice and cassava production and yields.

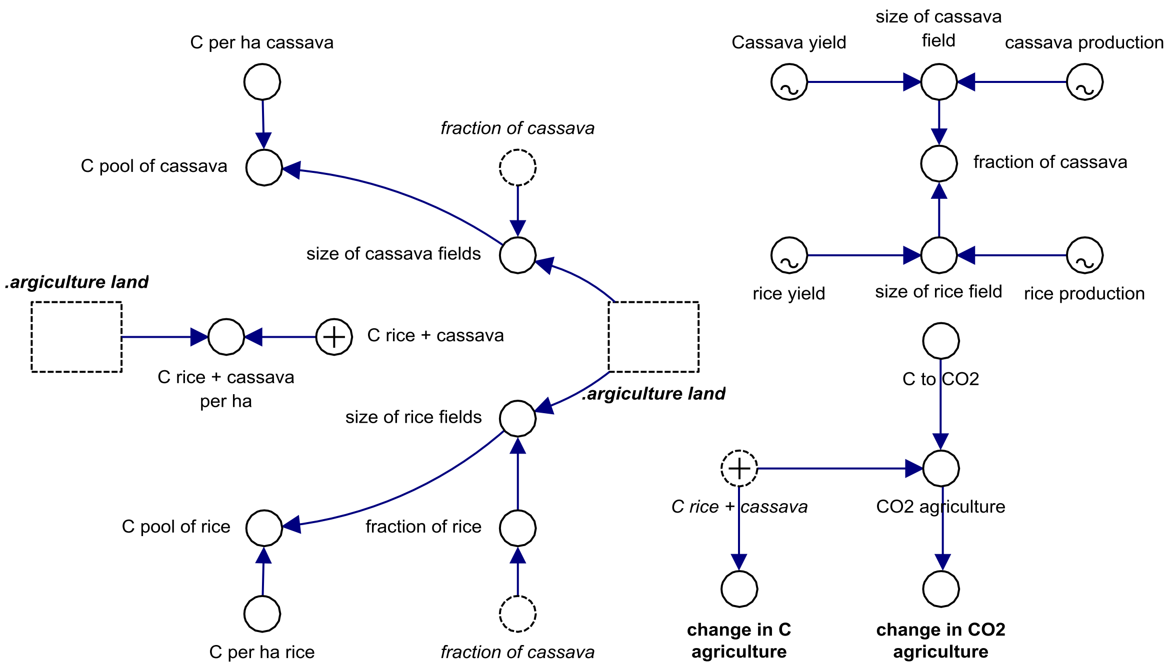

Figure 26. C and CO2 in agriculture land

3.7.5. Social cost of carbon structure

Social cost of carbon is based on price per ton of CO_2 release and the change in carbon pools in each land type. The price of ton of CO_2 is represented by a stock variable *Cost per ton.* Value of the stock increases annually by fraction of *annual increase.* According to (Nordhaus, 2016) the cost of ton CO_2 was 31 USD in 2015 with annual increase 3%. Based on the size of annual increase the of ton CO_2 in 2010 was calculated to be 20 USD and serves as initial value to the stock. The *total social cost of carbon* is a sum of costs of CO_2 releases from every land type.

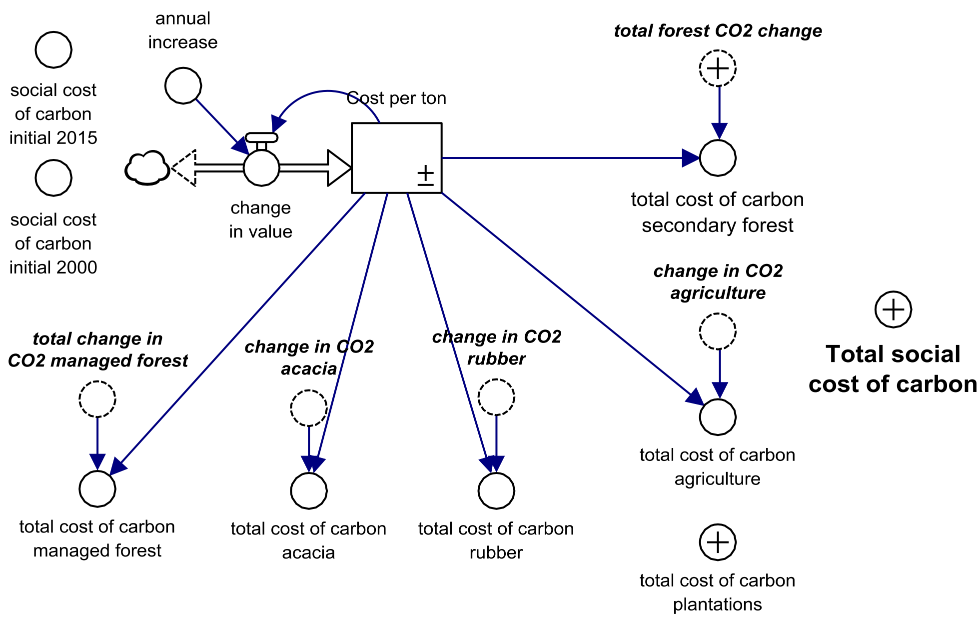

Figure 27. SCC structure

3.8. Non-timber forest products

In this module, I am calculating the accumulated value and accumulated lost value from NTFPs in USD. These values are represented by stock variables *accumulated value of collected NTFPs* and *accumulated loss of revenue from NTFPs.* Their inflows, *value of collected NTFPs* and *loss of revenue from collecting NTFPs*, are being influenced by *value of supply of NTFPs, value of Demanded NTFPs* and *supply/demand ratio* variables.

Accumulated loss of revenue from NTFPs inflow is active only under condition if demand for NTFPs is higher than supply. When this condition is met then the size of the inflow is equal to the *value of Demanded NTFPs* multiplied by a fraction corresponding to the ratio of unsatisfied demand. *Value of collected NTFPs* is equal to *value of Demanded NTFPs* when supply is larger than demand. If demand becomes higher than supply, then inflow is equal to *value of Demanded NTFPs* multiplied by fraction of satisfied demand provided by *supply/demand ratio* variable.

The value of demand is dependent on the size of *population* stock and the *livelihood value derived from NTFPs per person* variable, which is based on *livelihood value per household* divided by *average household size* (Clements et al., 2014). Supply is similarly calculated as multiplication of derived value per person and *NTFPs capacity total* which is a sum representing the present value of all non-timber forest products available for extraction. The sum consists of NTFPs capacities in each forest cover type. The capacities are dependent on size of forest cover and *average collection area per person* in each respective type.

Calculation of average collection areas for each forest cover type is based on the results survey conducted in multiple villages (Hansen & Top, 2006). Values from the survey are presented in Appendix B. Dense forest cover is calculated as average value in evergreen and semi-evergreen forest. Value of mixed forest type is average between dense and deciduous. Size of available land is equal to size of forest land with ¼ size of plantations.[8] Structure for determination of ratios of forest covers is already described in section 3.2.3.

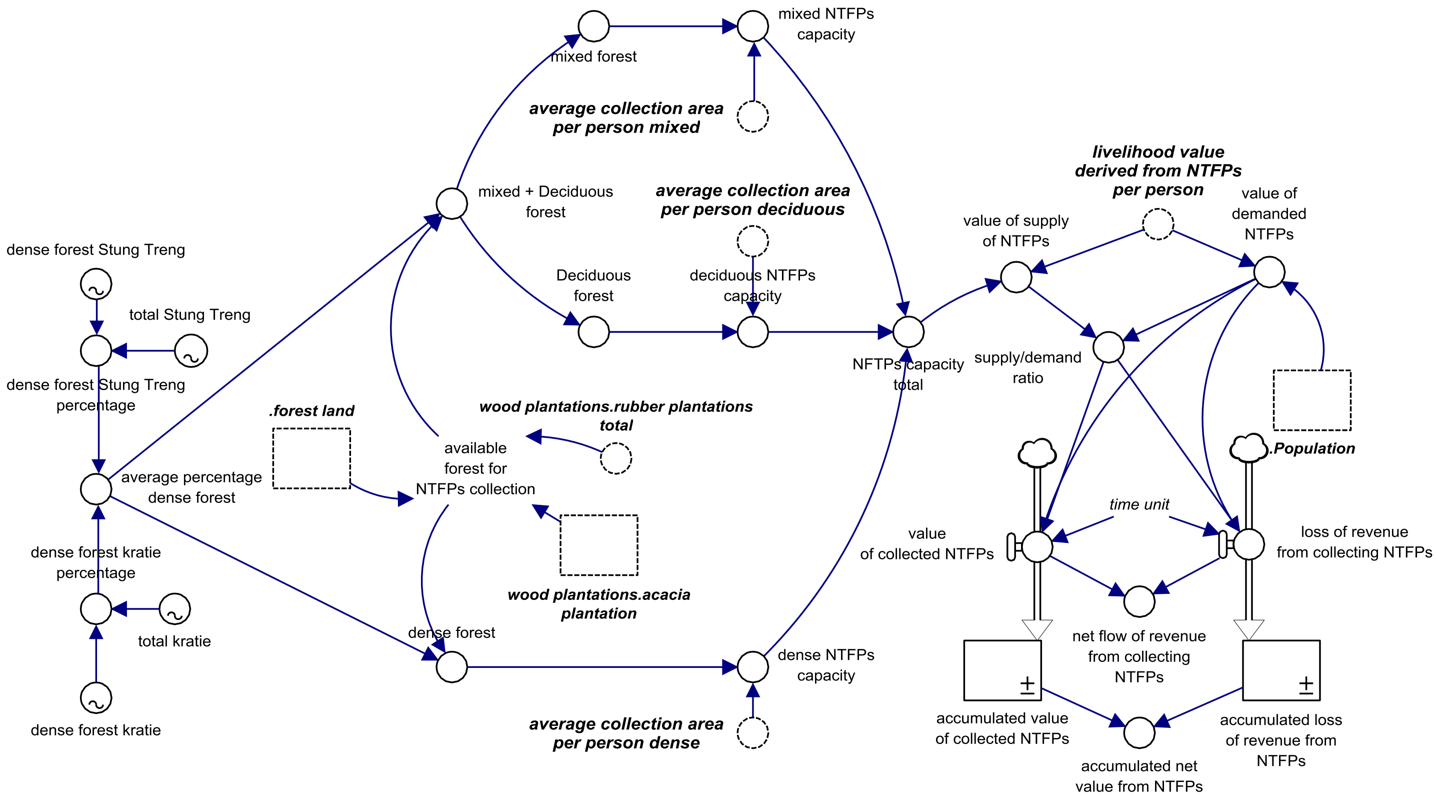

Figure 28. NTFPs structure

[8] The reason for accounting only a fraction of plantations is that the plantations are not as rich as natural forests for NTFPs collection (D'Amato et al., 2017) and the access is often restricted for local population (EFCT, 2006).

3.9. Feedback Structure

In the previous sections I described in detail the inner workings of every module. In this section I will present in Figure 29 a Causal Loop Diagram of the whole model to get a better picture of how are the modules causally connected and how the model operates. For a good understanding of the diagram few characteristics should be explain:

- The diagram portrays model's main components and their interactions. Some of the components are in the frame which symbolizes a stock variable. Causal links between components are represented with arrows. Each arrow has a positive or negative sign demonstrating its polarity.
- Positive polarity indicates positive causal relationship where change in first component in the link triggers change in second component in the same direction, e.g. increase in first causes increased in second. Negative polarity indicates opposite relationship where change in first component in one direction will trigger change in opposite direction in the second component, e.g. increase in first causes decrease in second.
- Straight arrows represent one directional causal connection where change in first component will cause change in the second component in the link, but change in the second component have no further influence on the first. Curved arrows on the other hand represent links where components are connected in feedback loop where change in second component perpetuate change in the first. Based on the polarities of the links the feedback loop can have reinforcing or balancing character.
- Thickness of the arrows represents the strength or importance of the link. Link with equals sing (=) signalizes delay in effect. Dashed arrow represents effect which is not produced automatically by model's behavior but as a policy intervention.

As you can see in diagram the are five main balancing feedback loops influencing the model behavior.[9] *Timber demand* can be identified as a key component as it is a part of loops B1-B4 and determines the extent of forest clearing. Because *Timber demand* represents a stock variable we must think in terms of its inflow and outflow when considering its change. Inflow of *Timber demand* consists foreign and local timber demand influenced by *Timber price*. Outflow of demand is driven by *Supply of timber*. Price of timber is the main constraining factor for demands increase.

[9] I am disregarding the structure of MFF model in the base level of the structure. The addition of the modules does not fundamentally change the behavior of the original model.

The behavior of price is characterized by loops B1 and B2. Growth of *Timber demand* increases both the growth rate of demand and forest deterioration which increases the price. The price increase is more sensitive to demand's growth rate than to forest deterioration. Price is also sensitive to increase or decrease in *Managed forest* land because it influences the size of forest land available for clearing, i.e. the rareness of the goods.

Forest clearing is determined largely by *Timber demand* and *Agriculture land demand* and to a lesser extent by *Settlement land demand.* Effects of *Forest clearing* are increase in *Social cost of carbon*, decrease in *NTFPs collection*, development of *Plantations* and increase in *Supply of timber.* The diagram shows that *Forest clearing* itself creates the main constrain for *Timber demand* growth because it increases the outflow of demand by increasing the amount of timber (directly B3 and indirectly through plantations B4) and at the same time it limits the inflow by increasing the price of timber product.

Plantations are developed as consequence of *Forest clearing* and after years of delay provide flow of timber supply. That creates very interesting dynamics which can be describe as "positive shifting of burden" relating to "shifting of burden" archetype (Senge, 2006). In this classical archetype, a problem (*Timber demand*) is being solved or "balanced" by both quick symptomatic solution (*Forest clearing*) and more sustainable but delayed fundamental solution (flow of timber from *Plantations*). Traditionally, applying a quick solution can create a side effect which makes it more difficult to invoke the fundamental solution. This is where the dynamics diverge from the archetype because pursuing a "quick fix" actually reinforces a long-term solution. Plantations also provide other ecosystem services such as NTFPs and carbon sequestration but as the thickness of the arrows indicates they do not fully compensate the loss caused by natural forest degradation.

Loop B5 characterizes how different managing regimes in *Managed forest* influence the amounts of *Wood product* and *Carbon loss.* Intensive extraction increases the amount of *Wood product* but it also increases the cost of released carbon and decreases the regrowth of the forest. Even with maximal increase of size of *Managed forest* the flow of supply

Total revenues are conceptual sum of profits from exporting timber and rubber and collecting NTFPs. The only cost is *Social cost of carbon* which can be nevertheless very high. The thickness of arrows portrays well the dilemma of forest clearing. Timber exports are the main source of revenue but forest clearing is the main source of *Social cost of carbon.* Release of carbon from *Managed forest* is relatively small but so is the amount of *Wood product*. *Plantations* can provide both timber and rubber revenues but *Forest clearing* is necessary for their establishment.

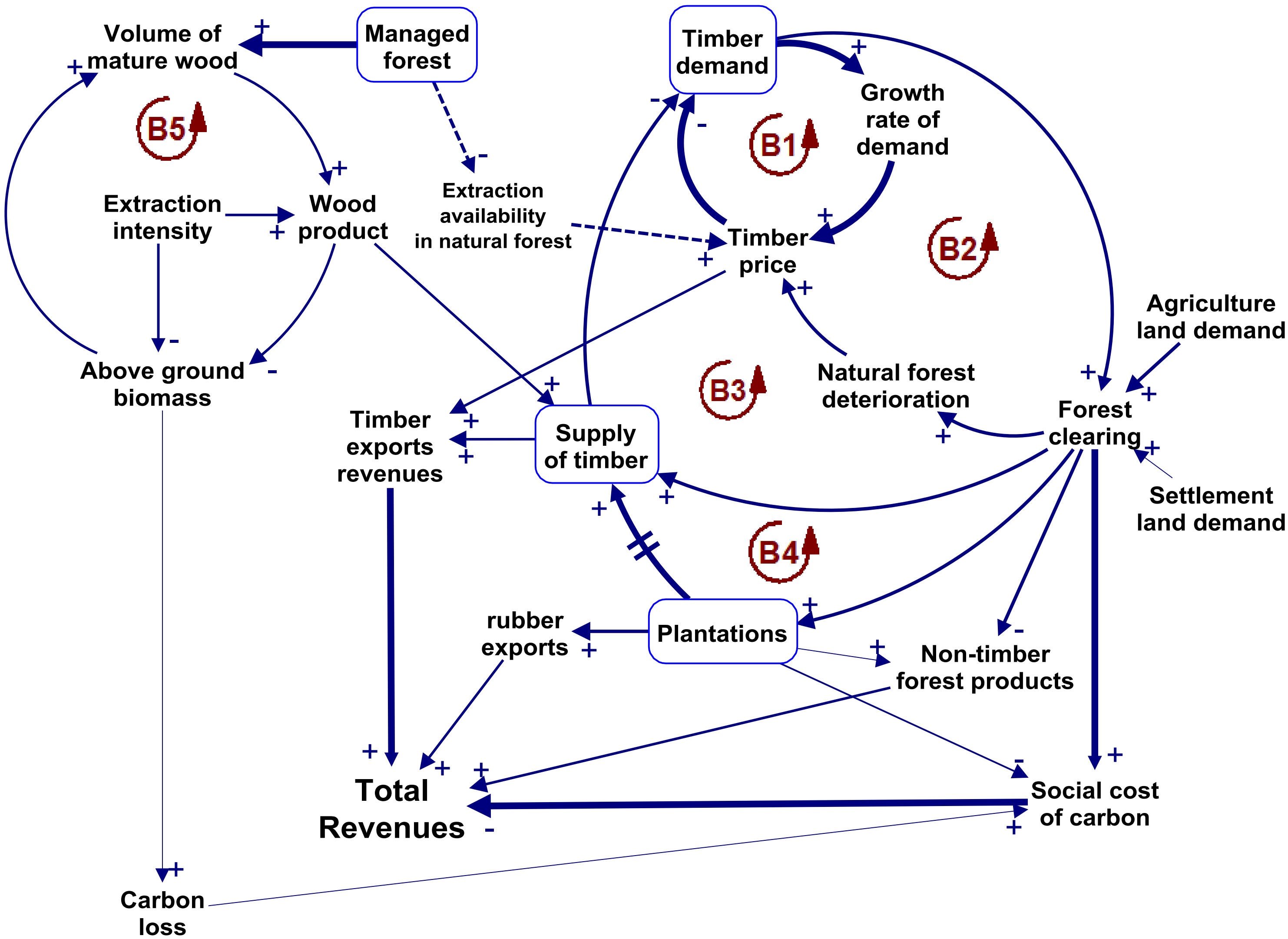

Figure 29. Model's CLD

CHAPTER 4. RESULTS

This section presents results of five different simulation runs. Section starts with description of scenarios succeed by summary of the simulations. Afterwards more in-depth report of individual scenarios results is provided. Each scenario is presented with graphs demonstrating the most important changes as well as table showing behavior of the most relevant indictors. Full table with recorded changes is provided in Appendix C.

4.1. Scenarios

A) **Business as usual (BAU):** This is a baseline simulation where the model is let to run its own course. It presents a situation where no changes are introduced.

B) **Low impact management (LIM):** Better logging practices in natural and managed forest are introduced. Parameters *logging waste* and *logging damage* are decreased which leads to higher amount of timber product per hectare of forest. *Cutting cycle time* in managed forest is increased to 40 years to secure longevity of the forest.

C) **Maximum plantations (MPL):** Plantations development is increased to its maximal potential within the existing structure. Plantations development is still dependent forest clearing but size of its inflow is now equal to the size of *fallow to forest* outflow.

D) **Maximum protection (MPR):** Size of the managed forest area is increased to the size of forest stock. No more forest land is available for clearing as well as no new plantations development.

E) **Ideal run (IR):** Changes are optimized for the best possible results. Low impact management is introduced and managed forest area is expanded. Plantations development is increased to the maximum extent within the new condition.

4.2. Overview of simulation runs

In this overview, I will present results of the scenarios in comparative graphs and data table. In Figure 30 are probably the most important results concerning total government revenues deducted by social cost of carbon. As you can see, in all scenarios total government revenues area decreasing until year 2020. That is caused because until year 2020 most of the sold timber comes from deforestation not plantation as you can compare in Figure 31. Clearing forest area rises the social cost of carbon which is particularly costly in the first years of simulation when price of timber is low (Figure 32). After year 2020 the differences in total government revenues starts to express themselves among the scenarios:

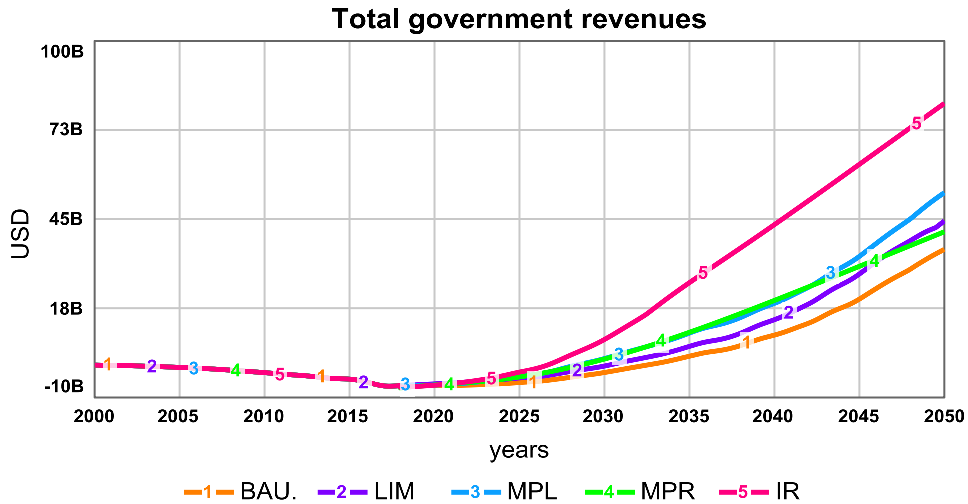

Figure 30. Results: government revenues - SCC

Ideal run (IR) generates the highest revenues due to the combination of many factors. Firstly, increase of the size of protected forest gives a fast rise to the timber price because it makes timber extraction more limited hence timber product more valuable. Similarly, sharp increase in timber price is observable in MPR scenario where protected forest is increased to its maximal potential (Figure 32). Secondly, plantation development is increased. Timber flow from plantations is preferable because it is not causing deforestation and increase in SCC. The more timber is coming

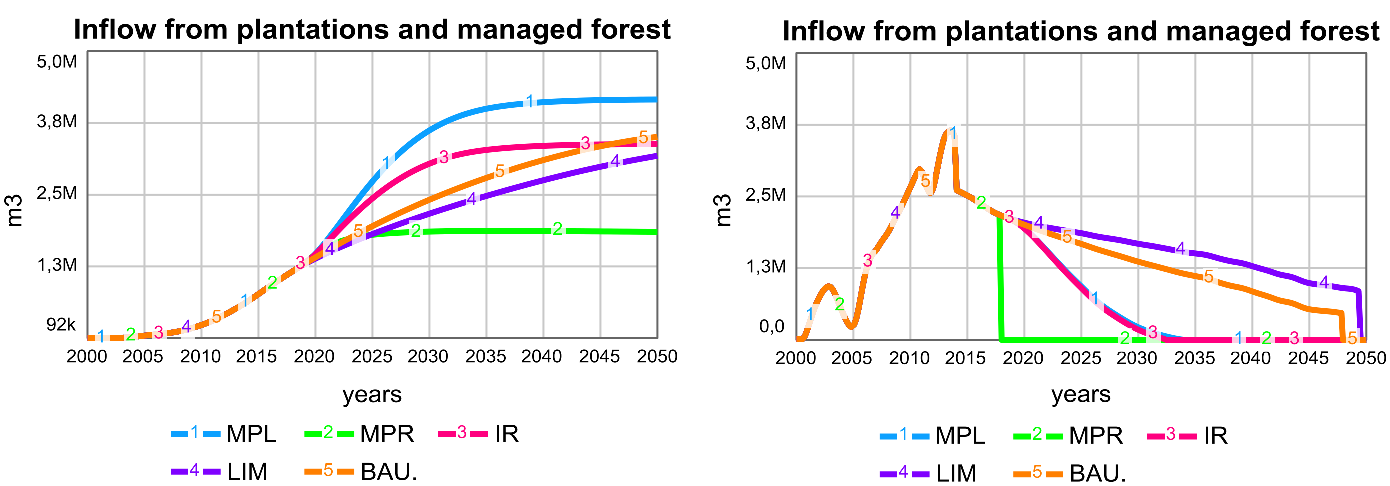

Figure 31. Results: inflows of timber

from plantations and managed forest, the less timber is necessary to extract from natural forest (Figure 31). Lastly, implementation of low impact extraction practices increases the amount of timber possible to extract from one hectare of forest so the same timber demand can be satisfied by clearing smaller forest area (Figures 32, 33).

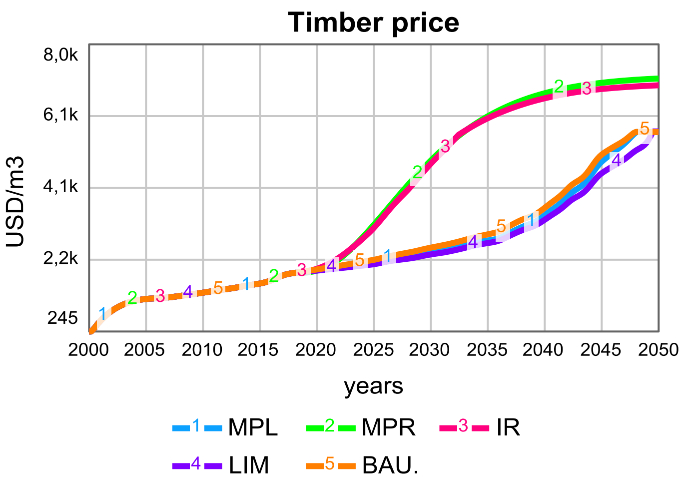

Figure 33. Results: timber price

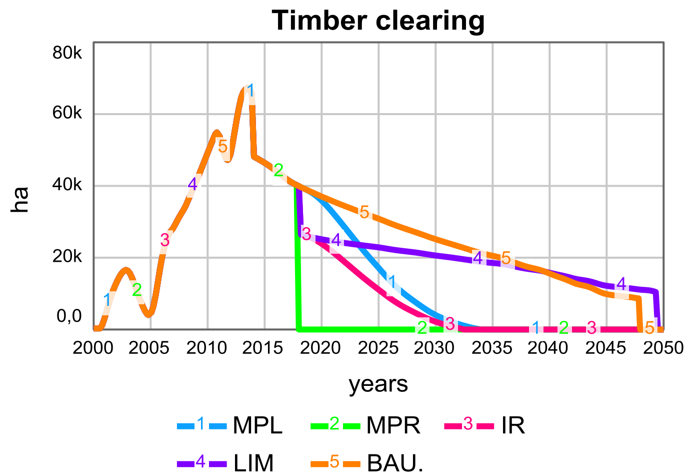

Figure 32. Results: timber clearing

The only downside of *Ideal run* is that it leads to increase of average price of food. Calculation of average food price happens within the original MFF model structure hence it wasn't presented in this thesis. Nevertheless, it sufficient to know that food price is causally linked to size of agriculture land. More agriculture land leads to more food production and lower prices. Ideal as well as maximum protection scenarios limits available forest to cut. This constrain decreases the rate of agriculture land development which limits food production and gives rise to food prices (Figure 34).

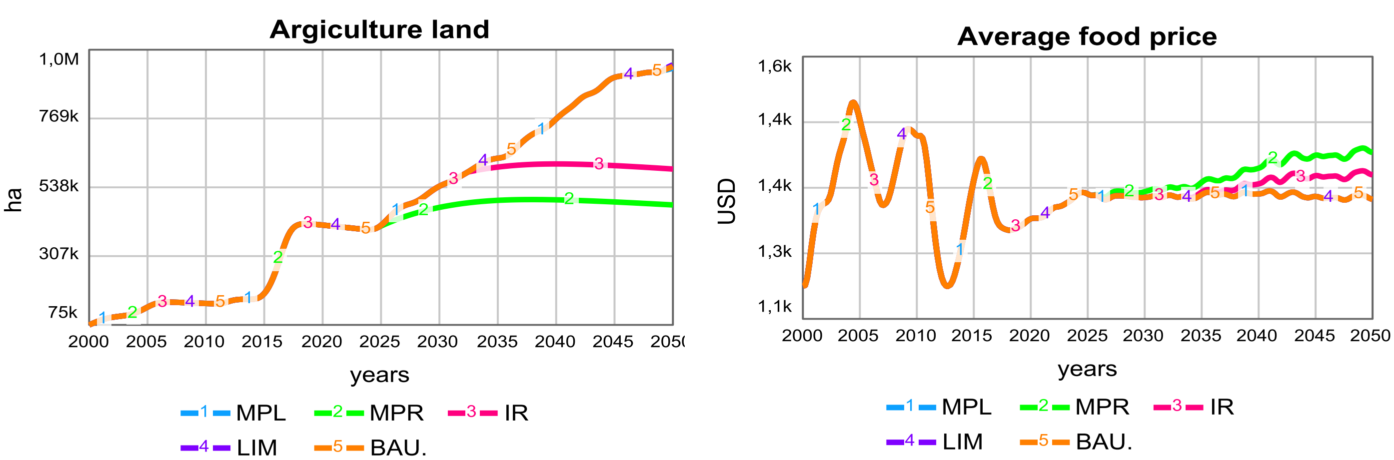

Figure 34. Results: agriculture land and food price

Second most profitable is *Maximum plantations* (MPL) scenario. In all scenario runs the tax income from plantations generates the largest portion of government's revenue. Figure 35 shows that maximal increase in plantations development creates almost as much tax revenue as is in case of *Ideal run*:

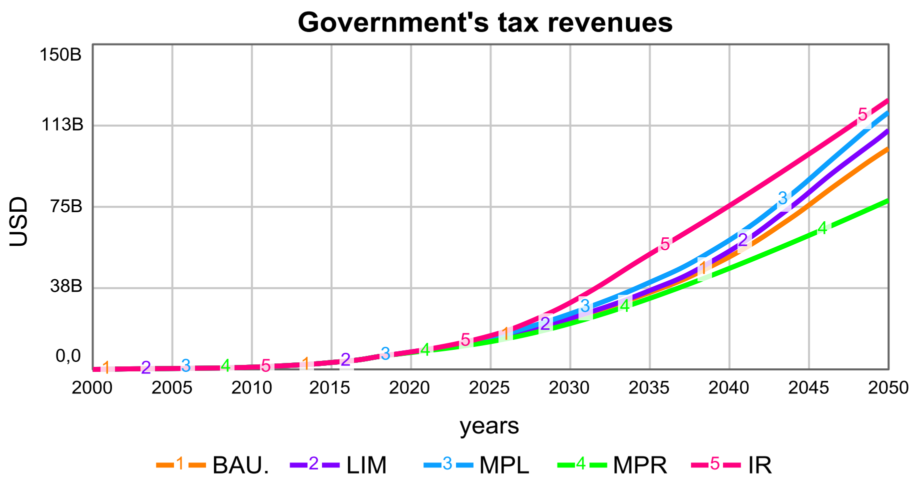

Figure 35. Results: government's tax revenues

The reason why total government revenues (Figure 30) can be so different from tax revenues (Figure 35) is explained by the variations in social cost of carbon release. The lack of forest protection will always lead to forest depletion caused mostly by timber and agriculture land demand. Decreasing forest area is the main cause of social cost of carbon increase (Figures 36, 37).

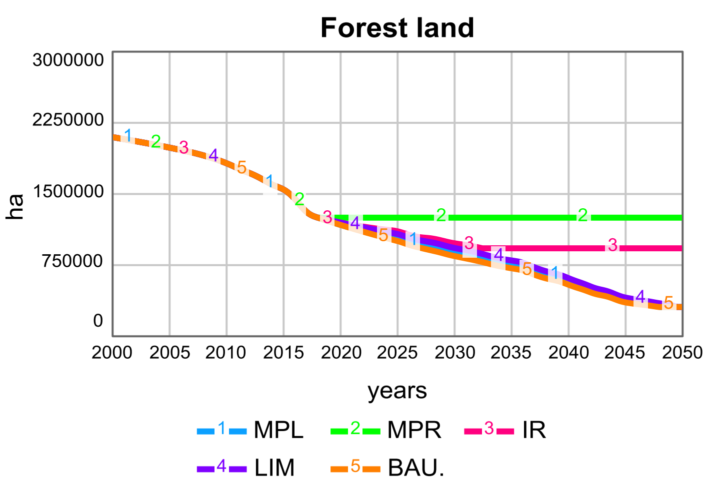

Figure 37. Results: Forest land

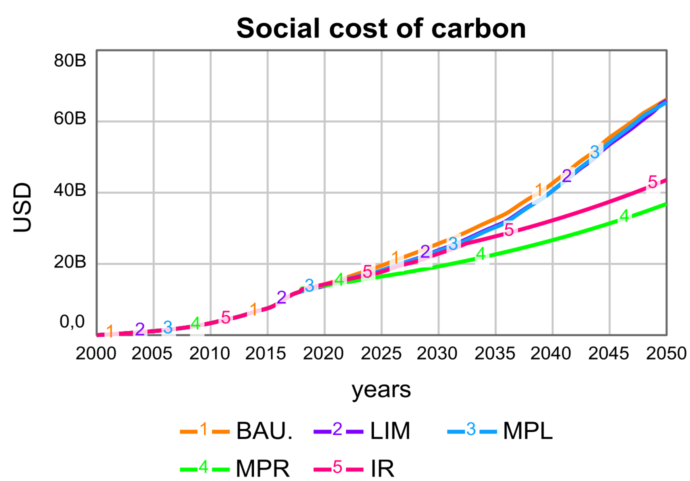

Figure 36. Results: SCC

Although MPL scenario leads to largest expansion of plantations it surprisingly does not lead to the highest profits for plantations owners (Figures 38,39). Higher profits in IR are caused by higher prices of timber product which generates more profits even with lower volumes. Values on profits from plantations are necessary to take with reservation because the plantations' running costs are not adjusted for inflation. The point of the Figure 39 is to provide general comparison of scenarios among each other more than provide exact values on future profits.

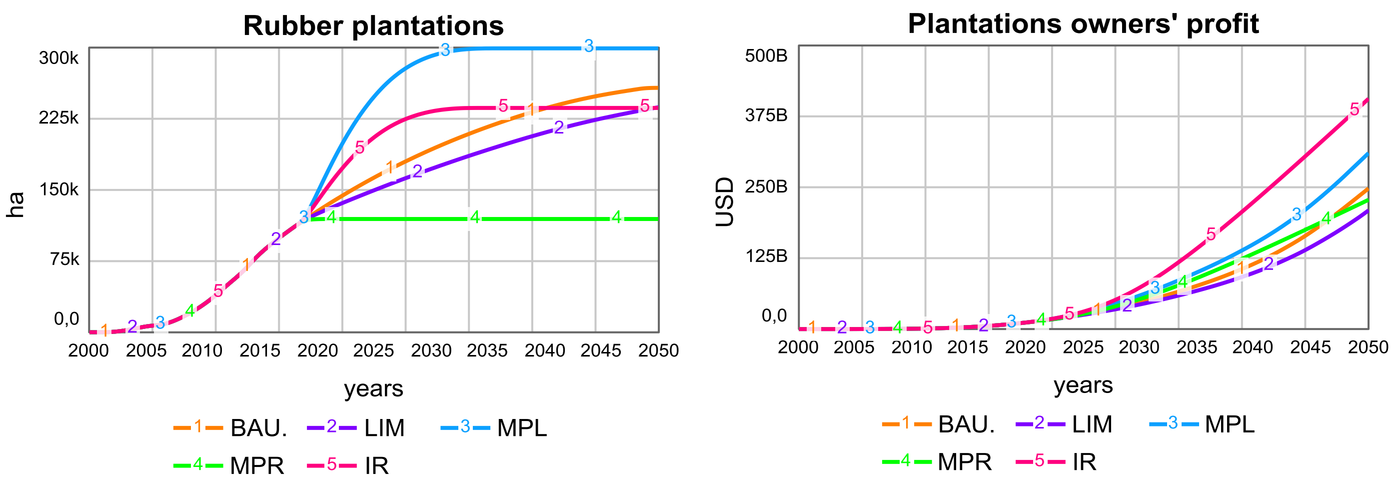

Figure 38. Results: Rubber plantations size and profit

Total government revenues in scenarios *Low impact management* (LIM) and *Maximum protection* (MPR) reach similar values of 44B and 41B USD in the year 2050 (Figure 30). In LIM scenario, more plantations are going to be developed which in turn accumulates more tax revenue over time. The downside is that without increased effort of plantations development most timber demand will be satisfied by inflow of wood product from forest clearing (Figure 31) which will deplete the available natural forest even with more cost-effective practice of timber extraction (Figure 37). Implementing low impact practices alone actually hinders plantation development because it makes clearing more efficient (Figure 38).

MPR scenario on the other hand creates the lowest amount of tax revenue (Figure 35) but it safes the largest possible forest area from degradation (Figure 37). That leads to lowest social cost of carbon so even with small tax revenue the total government's revenue is comparable with MPR scenario. Keeping large portion of forest protected will also generate the most ecosystem services connected to forest land as is shown in Figure 40 of net value of collected non-timber forest products.

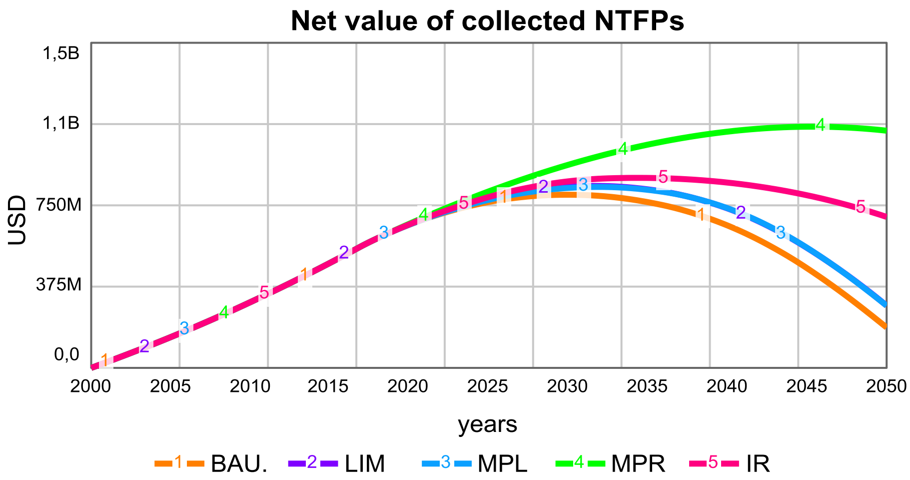

Figure 39. Results: NTFPs

The downside of MPR is similar to downside of *Ideal run* in a sense that more protected forest land constrains agriculture expansion which leads to higher food prices (Figure 34).

4.3. Business as usual (BAU)

In the BAU scenario no changes are introduced. Depreciation of forest will continue until it reaches its limit of 309 000 ha which is original size of protected area. Strong deforestation causes large increase of fallow land which enables very high expansion of agriculture and plantations reaching 944 000 ha and 382 000 ha respectively. Nevertheless, high increase of fallow land without stronger incentives for plantations development causes that fallow land is transformed slowly and 42 000 ha will stay unutilized in year 2050 (figure 41).

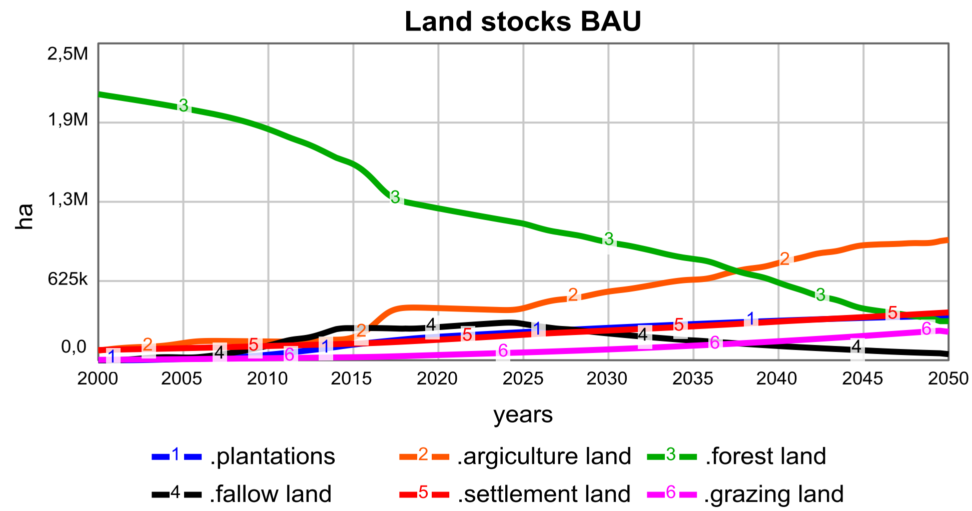

Figure 40. Results: Land stocks BAU

Most of government's revenues comes from as well as most timber products comes from plantations (Figures 42,43). By looking at the amount of timber produced by clearing higher revenues might be expectable but most of the wood from clearing is being sold during first half of

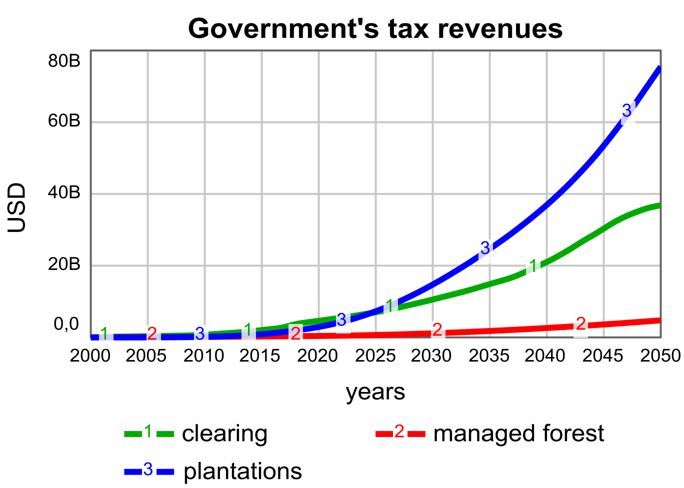

Figure 42. Results: Tax revenues BAU

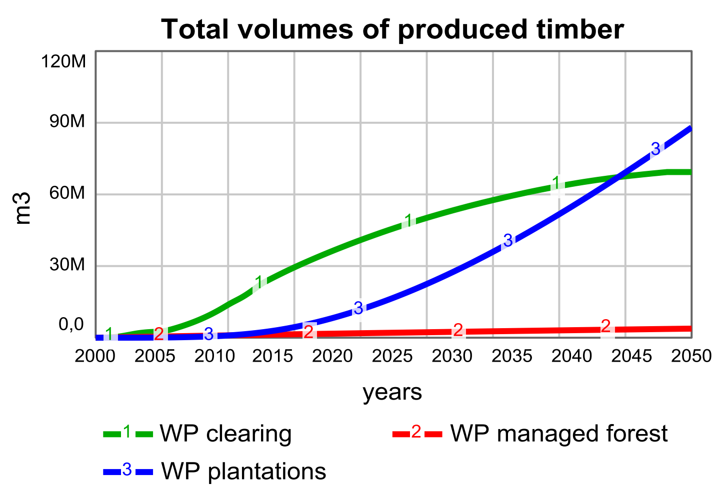

Figure 41. Results: Timber volumes BAU

simulation period when timber prices are lower. The absence of expansion protected forest area limits rise of timber price even further after year 2025 and makes inflow of wood from managed forest negligible.

Land type	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
Agriculture land	BAU	413 293	411 123	541 648	767 346	943 819
Forest land	BAU	1 250 475	1 173 457	845 297	543 373	308 696
Fallow land	BAU	249 560	282 114	266 375	143 359	42 105
Grazing land	BAU	33 109	413 91	85 553	149 909	205 414
Settlement land	BAU	147 451	161 753	234 550	305 201	377 047
Acacia	BAU	53 881	61 676	92 922	113 740	124 145
Rubber	BAU	111 064	127 320	192 488	235 906	257 607
Units: ha						
Tax revenues	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
Total	BAU	5 970	7 925	23 417	51 922	101 880
Clearing	BAU	3 693	4 619	10 563	21 021	36 807
managed forest	BAU	342	396	1 132	2 614	4 752
Plantations	BAU	1 933	2 909	11 721	28 286	60 319
Units: mill. USD						
NTFPs	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
Value collected	BAU	598	660	798	656	186
Units: mill. USD						
SCC	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
costs	BAU	12 324	14 248	25 705	42 677	66 202
Units: mill. USD						
Plantations	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
Owner's profit	BAU	12 324	14 248	25 705	42 677	66 202
Units: mill. USD						
Timber volumes	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
Total production	BAU	39,83	46,71	83,38	122,66	161,20
Clearing	BAU	32,43	36,60	53,36	64,44	69,36
Managed forest	BAU	1,54	1,70	2,45	3,15	3,80
Plantations	BAU	5,86	8,41	27,57	55,08	88,04
Units: mill. m^3						

Table 2. Results overview: BAU

4.4. Low impact management (LIM)

Changes introduced in 2018:

- Parameter *logging waste* decreased from 0.5 to 0.25
- Parameter *logging damage* decreased from 0.4 to 0.14
- Parameter *cutting cycle time* increased from 30 to 40

Direct impacts

In modules: *Government's revenues from managing forest, Government's revenues from clearing, Carbon in managed forest*

- Decrease in *logging waste*
  - In *Government's revenues from managing forest*
    - Increases outflow *final logging* from *volume of cut wood* stock
    - Decreases outflow *losses* from *volume of cut wood* stock
    - Increases *volume of timber per ha* variable
  - In *Government's revenues from clearing*
    - Increases outflow *final logging* from *volume of cut wood* stock
    - Decreases outflow *losses* from *volume of cut wood* stock
    - Increases *volume of timber per ha* variable
- Decrease in *logging damage*
  - In *Carbon in managed forest* (for all types of forests)
    - Increases *change in volume of mature trees* variable
    - Decreases *change in volume of rest of the trees* variable
    - Decreases *logging mortality* variable
- Increase in *cutting cycle time*
  - In *Government's revenues from managing forest*
    - Decreases inflow *cutting* into *volume of cut wood* stock
  - In *Carbon in managed forest* (for all types of forests)
    - Decreases *harvested carbon* variable

Introducing low impact management generally leads to more efficient timber extraction both from natural and managed forests because it reduces the amount of waste produced during wood processing.

In managed forest, decreasing *logging damage* limits the collateral damage of timber extraction. At the same time, increase of *cutting cycle time* decreases the overall amount of extracted wood which gives the forest better chance to regenerate. Combination of the two changes stops gradual degradation of managed forest which would otherwise happened in BAU scenario (Figure 44).

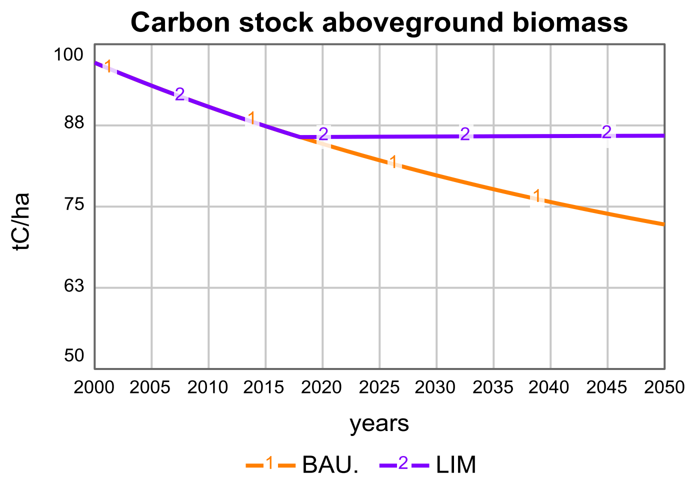

Figure 43. Results: CS biomass LIM

Changes in final sizes of land stocks are in this scenario minor (Table 3). The most important outcome of reduced impact management is increase in volumes of timber gained by clearing and decrease in amounts of timber from plantations which influence associated tax revenues (Figures 45.46). Forest clearing becomes more efficient which slows down the rate of clearing and therefore plantations development as well. The total amount of produced timber is higher in LIM scenario but decrease of inflow from plantations does make the total difference relatively small.

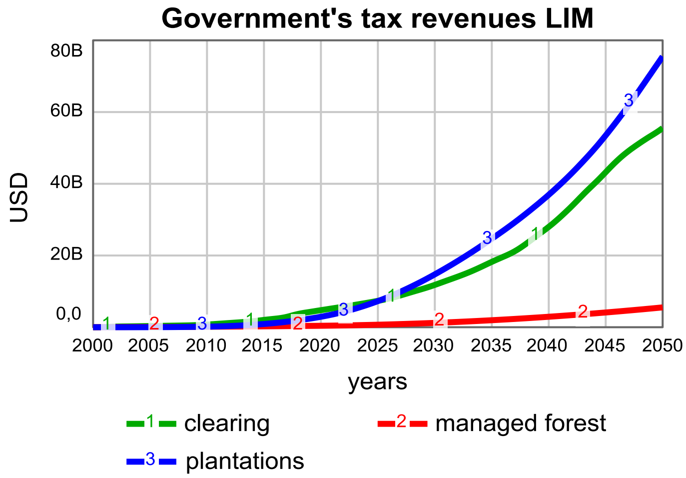

Figure 44. Results: Tax revenues LIM

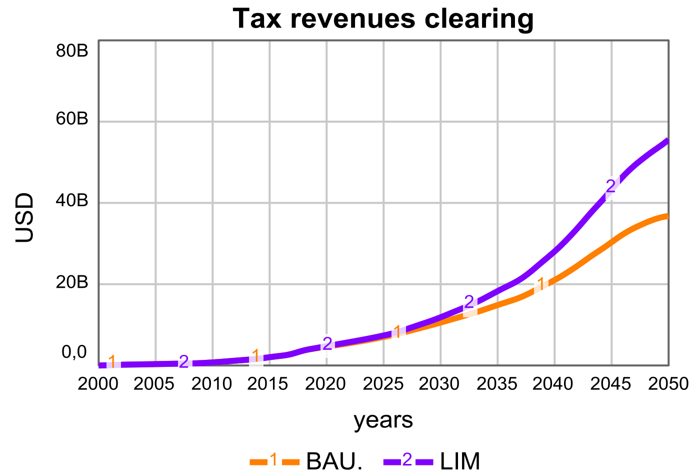

Figure 45. Results: Tax revenues clearing LIM

Although introducing low impact management practices reduces forest clearing in the beginning it also makes clearing more profitable which hampers plantations development. Slower plantations development leads to longer dependence on forest clearing. Deforestation then continues until it reaches its limits.

The results of LIM scenario are hence somewhat counter-intuitive. Applying more efficient timber extraction without increasing protected forest area or rate of plantations development causes forest clearing as more viable option. From the same size of natural forest more wood will be extracted which accumulates more total gov. revenues until year 2050 but the natural forest will still end up depleted and less plantations will be created.

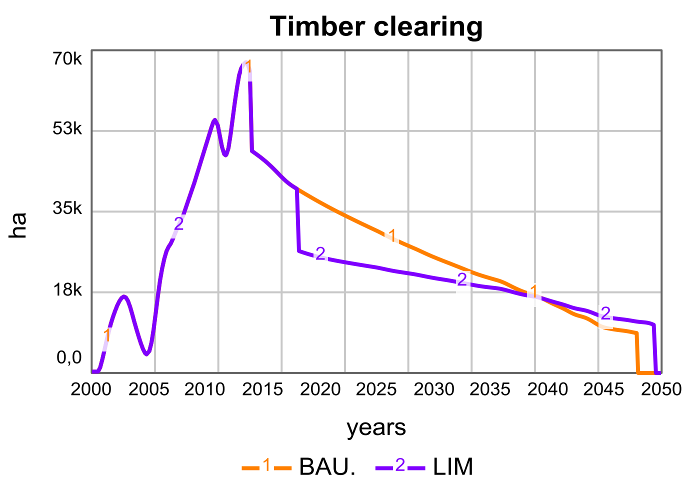

Figure 46. Results: Timber clearing LIM

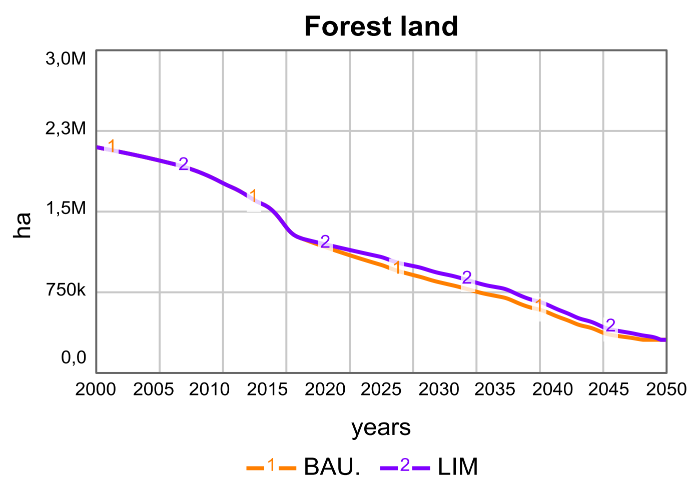

Figure 47. Results: Forest land LIM

Land type	Scenario	2018	2020	2030	2040	2050
Agriculture land	**BAU**	**413 293**	**411 123**	**541 648**	**767 346**	**943 819**
	LIM	413 293	411 123	541 648	767 346	949 461
	Δ LIM	0,00%	0,00%	0,00%	0,00%	0,60%
Forest land	**BAU**	**1 250 475**	**1 173 457**	**845 297**	**543 373**	**308 696**
	LIM	1 250 475	1 197 959	930 410	612 266	308 291
	Δ LIM	0,00%	2,09%	10,07%	12,68%	-0,13%
Fallow land	**BAU**	**249 560**	**282 114**	**266 375**	**143 359**	**42 105**
	LIM	249 560	261 331	211 380	112 170	48 045
	Δ LIM	0,00%	-7,37%	-20,65%	-21,76%	14,11%
Grazing land	**BAU**	**33 109**	**413 91**	**85 553**	**149 909**	**205 414**
	LIM	33 109	413 91	85 553	149 909	224 425
	Δ LIM	0,00%	0,00%	0,00%	0,00%	9,26%
Settlement land	**BAU**	**147 451**	**161 753**	**234 550**	**305 201**	**377 047**
	LIM	147 451	161 753	234 550	305 201	377 047
	Δ LIM	0,00%	0,00%	0,00%	0,00%	0,00%
Acacia	**BAU**	**53 881**	**61 676**	**92 922**	**113 740**	**124 145**
	LIM	53 881	60 470	83 161	101 521	114 362
	Δ LIM	0,00%	-1,95%	-10,50%	-10,74%	-7,88%
Rubber	**BAU**	**111 064**	**127 320**	**192 488**	**235 906**	**257 607**
	LIM	111 064	124 806	172 131	210 422	237 202
	Δ LIM	0,00%	-1,97%	-10,58%	-10,80%	-7,92%
Units: ha						
Tax revenues	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
Total	**BAU**	**5 970**	**7 925**	**23 417**	**51 922**	**101 880**
	LIM	5 970	80 47	23563	54 576	110 314
	Δ LIM	0,00%	1,54%	0,62%	5,11%	8,28%
Clearing	**BAU**	**3 693**	**4 619**	**10 563**	**21 021**	**36 807**
	LIM	3 693	4 754	11 862	28 068	55 559
	Δ LIM	0,00%	2,91%	12,29%	33,52%	50,95%
managed forest	**BAU**	**342**	**396**	**1 132**	**2 614**	**4 752**
	LIM	343	408	1 213	2 947	5 529
	Δ LIM	0,29%	3,03%	7,15%	12,73%	16,35%
Plantations	**BAU**	**1 933**	**2 909**	**11 721**	**28 286**	**60 319**
	LIM	1 933	2 900	10 767	24 436	50 944
	Δ LIM	0,00%	-0,30%	-8,14%	-13,61%	-15,54%
Units: mill. USD						
NTFPs	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
Value collected	**BAU**	**598**	**660**	**798**	**656**	**186**
	LIM	598	662	835	735	287
	Δ LIM	0,00%	0,20%	4,62%	11,98%	54,26%
Units: mill. USD						
SCC	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
costs	**BAU**	**12 324**	**14 248**	**25 705**	**42 677**	**66 202**
	LIM	12 324	13 844	23 860	40 575	65 847

	Δ LIM	0,00%	-2,84%	-7,18%	-4,92%	-0,54%
Units: mill. USD						
Plantations	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
Owner's profit	**BAU**	**12 324**	**14 248**	**25 705**	**42 677**	**66 202**
	LIM	5,86	8,40	26,44	51,08	80,71
	Δ LIM	0,00%	-0,04%	-0,04%	-7,26%	-8,33%
Units: mill. USD						
Timber volumes	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
Total production	**BAU**	**39,83**	**46,71**	**83,38**	**122,66**	**161,20**
	LIM	39,83	46,72	83,87	124,02	164,04
	Δ LIM	0,00%	0,03%	0,60%	1,10%	1,76%
Clearing	**BAU**	**32,43**	**36,60**	**53,36**	**64,44**	**69,36**
	LIM	32,43	36,81	55,32	70,90	80,21
	Δ LIM	0,00%	0,57%	3,67%	10,02%	15,64%
Managed forest	**BAU**	**1,54**	**1,70**	**2,45**	**3,15**	**3,80**
	LIM	1,54	1,69	2,24	2,78	3,31
	Δ LIM	0,00%	-0,63%	-8,42%	-11,74%	-12,95%
Plantations	**BAU**	**5,86**	**8,41**	**27,57**	**55,08**	**88,04**
	LIM	5,86	8,40	26,44	51,08	80,71
	Δ LIM	0,00%	-0,04%	-0,04%	-7,26%	-8,33%
Units: m^3						

Table 3. Results overview: LIM

4.5. Maximum plantations (MPL)

Changes introduced in 2018:

- Parameter *fraction of plantations* is increased from 0.3 to 1.0

Direct impact

In module: *Plantations*

- Increase in *fraction of plantations*
  - In *Plantations*
    - Increases inflow of *plantations development* based on *forest to fallow* outflow

From year 2018 plantations development is increased to be equal to the rate of timber clearing. Consequently, plantations stocks are 16% higher in year 2050 in comparison with BAU scenario (Figure 50). *Fallow land* is being utilized at faster rate and its size decreases to mere 1 116 ha instead of 42 105 ha in base run (Figure 49).

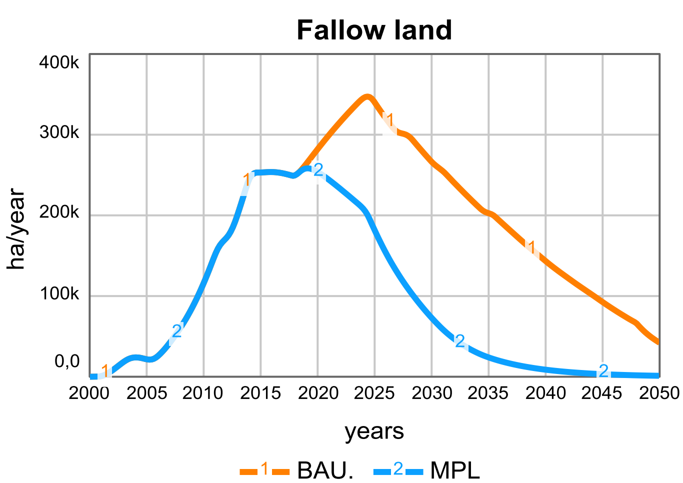

Figure 48. Results: Fallow land MPL

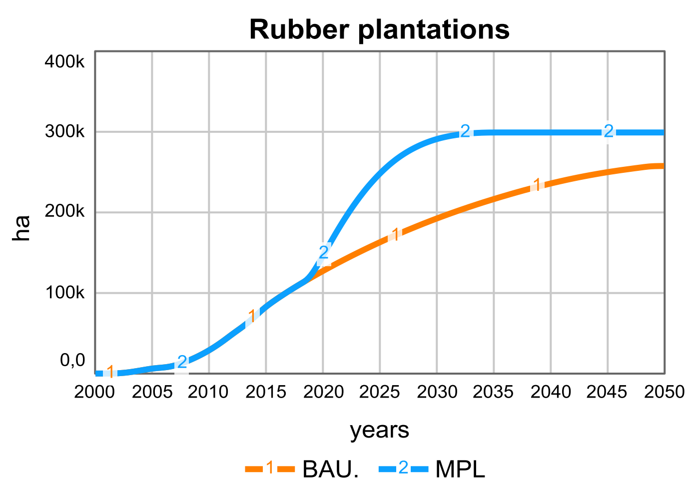

Figure 49. Results: Rubber plantations MPL

Plantations development stops around year 2033 because in the same year the flow of *timber clearing* stops as well (Figure 52). Cessation of *timber clearing* occurs at that time not because of forest depletion. Intensified plantations growth increases inflow of timber from plantations at very such a fast rate that all demand for timber can be satisfied already in year 2033 making forest clearing for timber unnecessary (Figure 51).

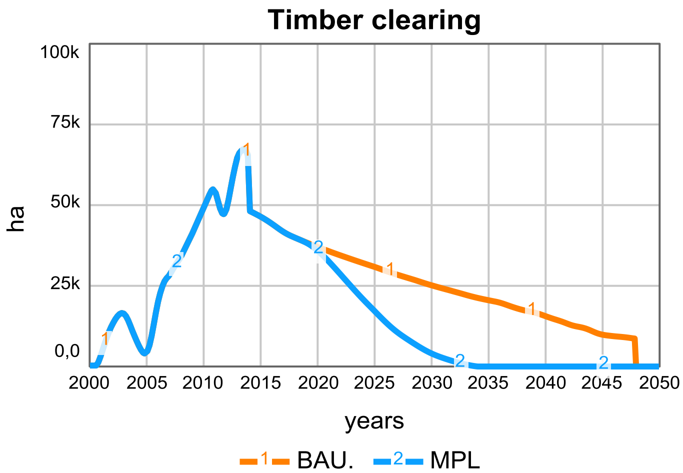

Figure 50. Results: Timber clearing MPL

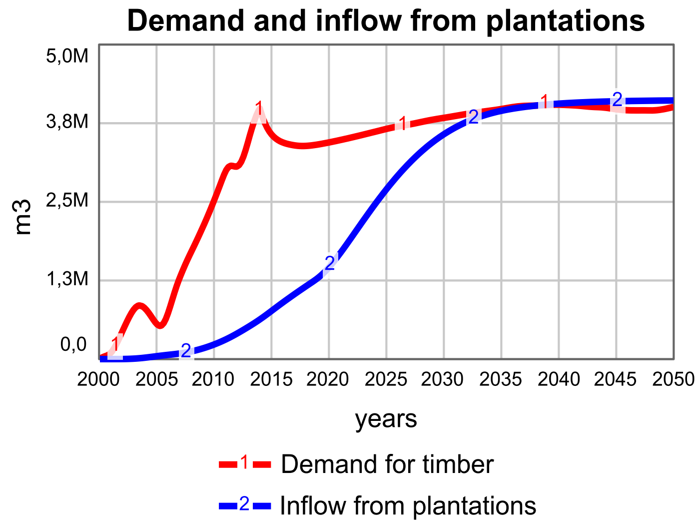

Figure 51. Results: Demand, pl. inflow MPL

Extending size of plantations has expectable effect of increase of volumes of timber from plantations (Figure 54) and decrease in volumes from clearing due to the sufficient stream from plantations (Figure 53).

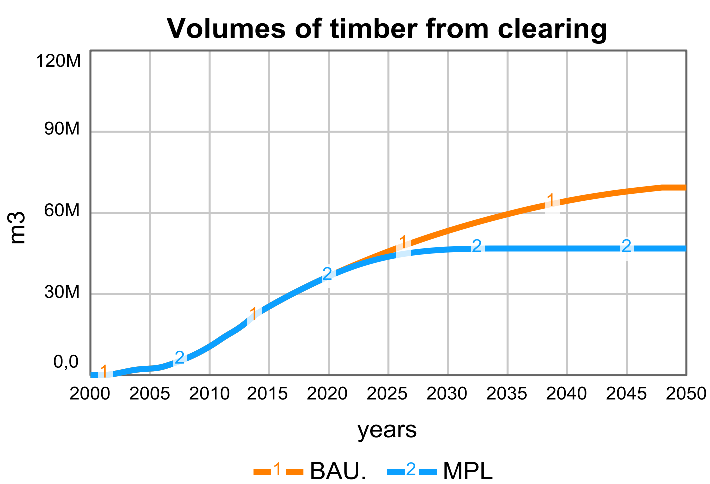

Figure 53. Results: Clearing WP volumes MPL

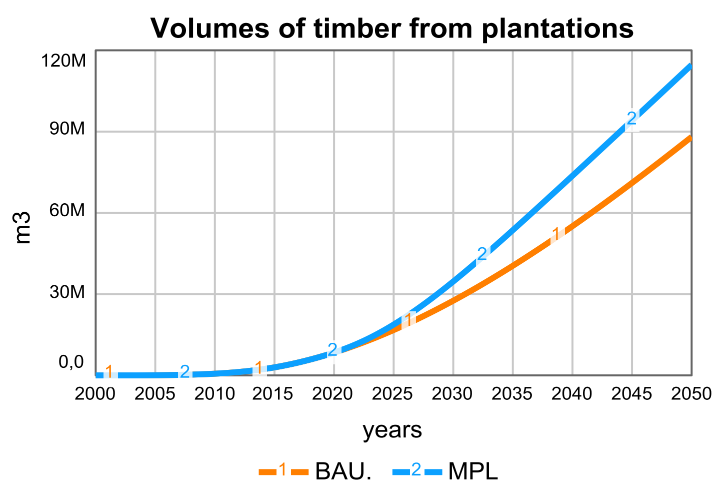

Figure 52. Results: Plantations WP volumes MPL

Increased plantations development generates more gov. revenues over time via larger streams of timber products and in case of rubber plantations also by higher latex production (Figures 55,56). More plantations also create more profit for plantations owners' (Figure 57). Slower pace of deforestation enables more non-timber forest products to be collected (Figure 58).

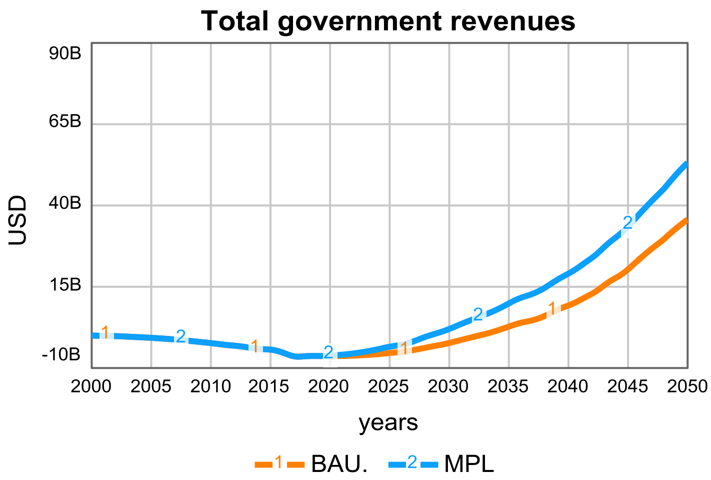

Figure 55. Results: Gov. revenues MPL

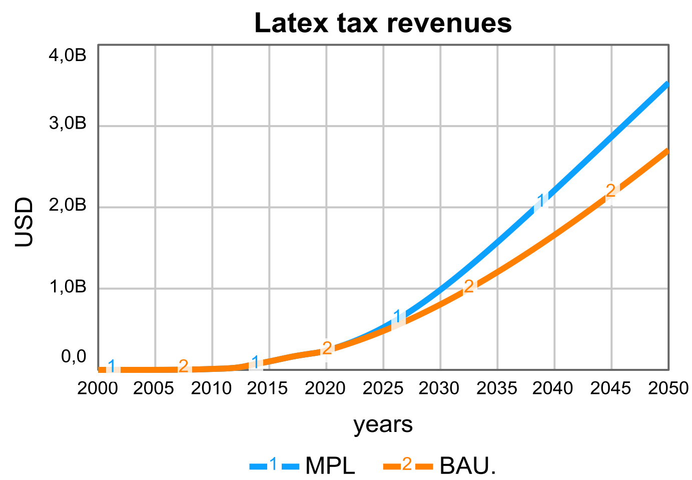

Figure 54. Results: Latex tax MPL

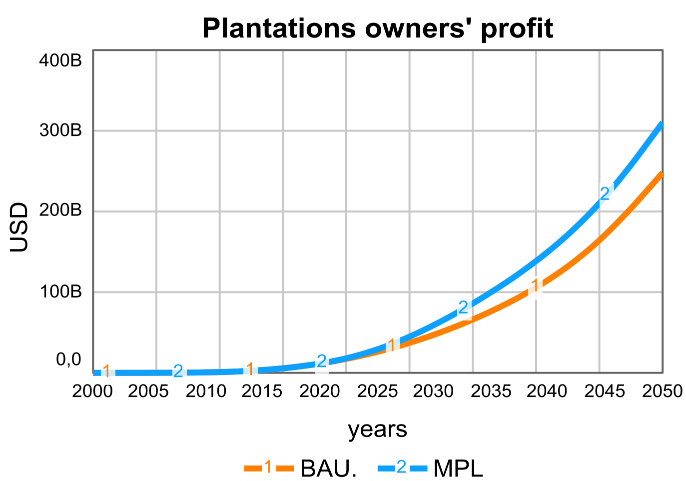

Figure 56. Results: Plantations profit MPL

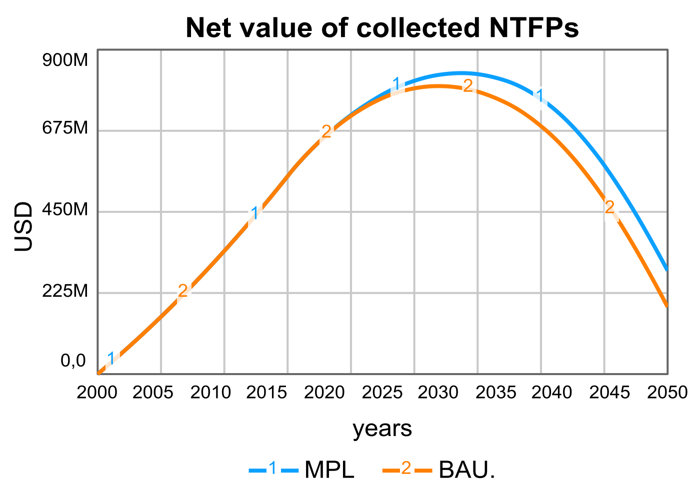

Figure 57. Results: Net value NTFPs MPL

Land type	Scenario	2018	2020	2030	2040	2050
Agriculture land	**BAU**	**413 293**	**411 123**	**541 648**	**767 346**	**943 819**
	MPL	413 293	411 123	541 648	767 346	937 861
	Δ MPL	0,00%	0,00%	0,00%	0,00%	-0,63%
Forest land	**BAU**	**1 250 475**	**1 173 457**	**845 297**	**543 373**	**308 696**
	MPL	1 250 475	1 173 949	892 927	584 367	308 835
	Δ MPL	0,00%	0,04%	5,63%	7,54%	0,04%
Fallow land	**BAU**	**249 560**	**282 114**	**266 375**	**143 359**	**42 105**
	MPL	249 560	253 807	72 996	8 728	1 166
	Δ MPL	0,00%	-10,03%	-72,60%	-93,91%	-97,23%
Grazing land	**BAU**	**33 109**	**413 91**	**85 553**	**149 909**	**205 414**
	MPL	33 109	41 391	85 553	149 909	190 641
	Δ MPL	0,00%	0,00%	0,00%	0,00%	-7,19%
Settlement land	**BAU**	**147 451**	**161 753**	**234 550**	**305 201**	**377 047**
	MPL	147 451	161 753	234 550	305 201	377 047
	Δ MPL	0,00%	0,00%	0,00%	0,00%	0,00%
Acacia	**BAU**	**53 881**	**61 676**	**92 922**	**113 740**	**124 145**
	MPL	53 881	70 690	140 157	144 087	144 087
	Δ MPL	0,00%	14,62%	50,83%	26,68%	16,06%
Rubber	**BAU**	**111 064**	**127 320**	**192 488**	**235 906**	**257 607**
	MPL	111 064	146 120	291 002	299 197	299 197
	Δ MPL	0,00%	14,77%	51,18%	26,83%	16,14%
Units: ha						
Tax revenues	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
Total	**BAU**	**5 970**	**7 925**	**23 417**	**51 922**	**101 880**
	MPL	5 970	7 935	25 667	59634	118 625
	Δ MPL	0,00%	0,13%	9,61%	14,85%	16,44%
Clearing	**BAU**	**3 693**	**4 619**	**10 563**	**21 021**	**36 807**
	MPL	3 693	4 619	9 793	20 092	38 380
	Δ MPL	0,00%	0,00%	-7,29%	-4,42%	4,27%
Managed forest	**BAU**	**342**	**396**	**1 132**	**2 614**	**4 752**
	MPL	342	396	1 132	2 614	4 752
	Δ MPL	0,00%	0,00%	0,00%	0,00%	0,00%
Plantations	**BAU**	**1 933**	**2 909**	**11 721**	**28 286**	**60 319**
	MPL	1 933	2 919	14 741	36 927	75 492
	Δ MPL	0,00%	0,35%	25,77%	30,55%	25,15%
Units: mill. USD						
NTFPs	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
Value collected	**BAU**	**598**	**660**	**798**	**656**	**186**
	MPL	598	661	830	736	287
	Δ MPL	0,00%	0,04%	3,94%	12,12%	54,13%
Units: mill. USD						
SCC	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
costs	**BAU**	**12 324**	**14 248**	**25 705**	**42 677**	**66 202**
	MPL	12 324	14 099	23 656	40 592	65 450

	Δ MPL	0,00%	-1,05%	-7,97%	-4,88%	-1,14%
Units: mill. USD						
Plantations	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
Owner's profit	**BAU**	**12 324**	**14 248**	**25 705**	**42 677**	**66 202**
	MPL	7 744	11 730	59 843	150 884	310 264
	Δ MPL	0,00%	0,32%	25,66%	30,49%	25,10%
Units: mill. USD						
Timber volumes	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
Total production	**BAU**	**39,83**	**46,71**	**83,38**	**122,66**	**161,20**
	MPL	39,83	46,71	83,58	123,67	165,27
	Δ MPL	0,00%	0,00%	0,24%	0,82%	2,53%
Clearing	**BAU**	**32,43**	**36,60**	**53,36**	**64,44**	**69,36**
	MPL	32,43	36,58	46,47	46,84	46,84
	Δ MPL	0,00%	-0,07%	-12,91%	-27,31%	-32,47%
Managed forest	**BAU**	**1,54**	**1,70**	**2,45**	**3,15**	**3,80**
	MPL	1,54	1,70	2,45	3,15	3,80
	Δ MPL	0,00%	0,00%	0,00%	0,00%	0,00%
Plantations	**BAU**	**5,86**	**8,41**	**27,57**	**55,08**	**88,04**
	MPL	5,86	8,43	34,66	73,69	114,63
	Δ MPL	0,00%	0,32%	25,70%	33,78%	30,20%
Units: m^3						

Table 4. Results overview: MPL

4.6. Maximum protection (MPR)

Changes introduced in 2018:

- Parameter *fractional change in size in 2018* is increased from 1 to 4

Direct impact

In module: *Government revenues in managed forest*

- Increase in *fractional change in size in 2018*
  - In *Government revenues in managed forest*
    - Increases sizes of *managed forest* variable from 309 000 ha to 1.25 mill ha which is a current size of *forest land* stock

Expanding protected area to the full extent of forest stock brings the largest changes out of all scenarios. Increase in plantations and agriculture, settlement and grazing lands is dependent on land clearing, i.e. decreasing forest land. With ceased deforestation, all the listed stocks will end up with smaller sizes. Plantations will reach only half of the baseline size as well as agriculture land. Forest land on the other hand will 4x larger (1 250 475 ha) than in BAU scenario.

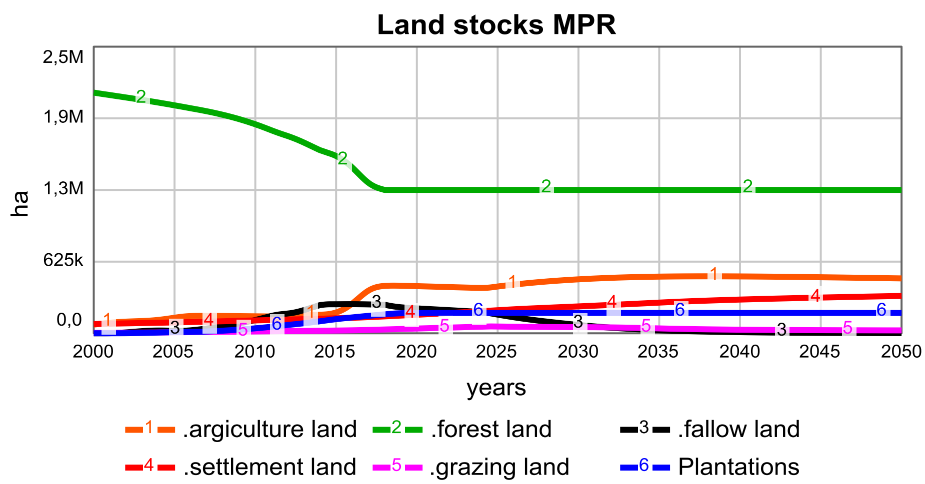

Figure 58. Results: Land stocks MPR

Lack of deforestation dramatically influences the total volumes of produced timber which ends up smaller by 40% (Table 5). Composition of sources of timber differs as well (Figure 60). Inflows from clearing and plantations are lower but as protected area becomes larger flow from managed forest rises. Nevertheless, even with maximal increase of managed forest the inflow from this source will constitute only 10% of all production.

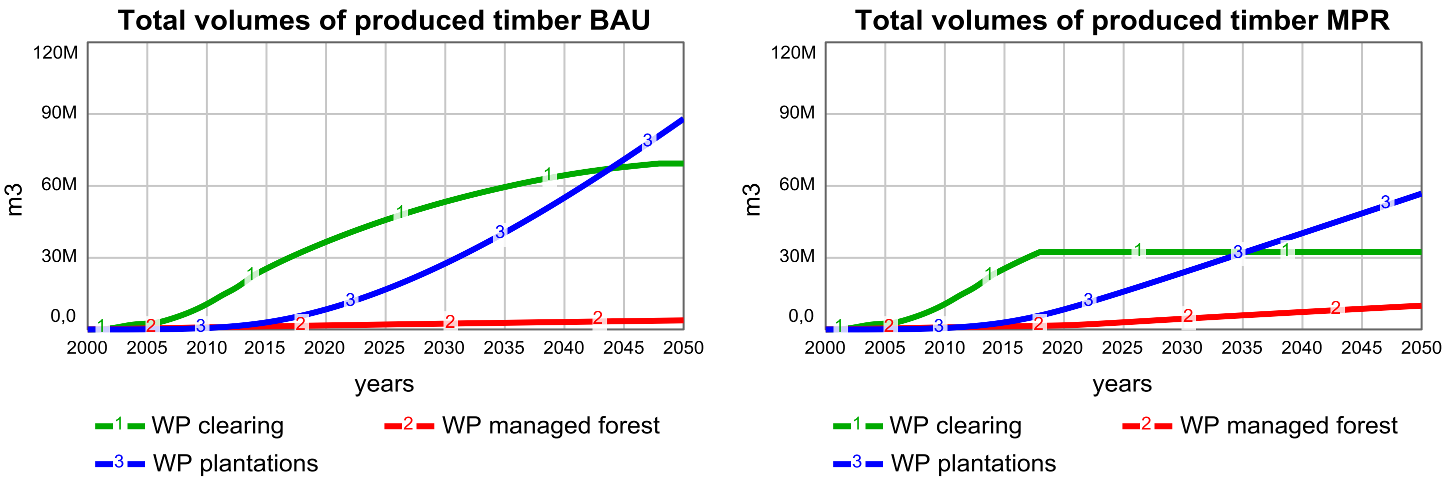

Figure 59. Results: WP volumes comparison LIM

Differences in timber production are also reflected in sources of government's tax revenues. Revenues from clearing decrease by 87% and revenues from managing forest increase by 276% making the MPR only scenario where revenues from protected forest grow higher than revenues from forest clearing (Figure 61).

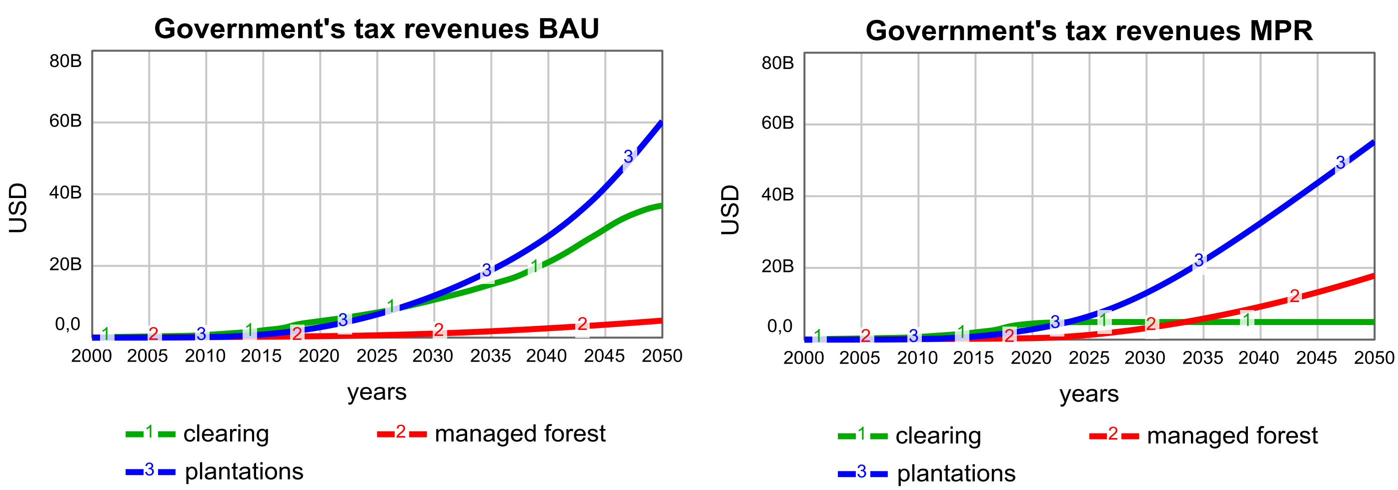

Figure 60. Results: Tax revenues comparison MPR

Interestingly, government tax revenues from plantations decreased only by 8.5% even though size of plantations decreased by 53% (Figure 63). That is explained by sharp increase in timber price (Figure 62). All forests are now protected so timber as an article becomes rarer. It is also reasonable to expect that forest under protection will be more patrolled thus making illegal logging more difficult making timber prices even higher.

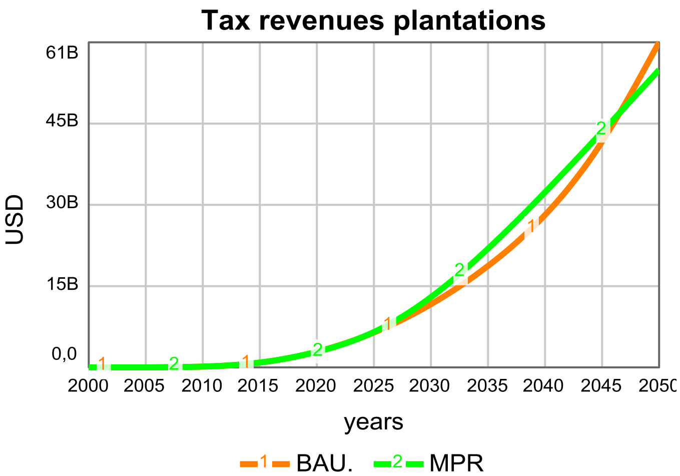

Figure 61. Results: Tax revenues plantations MPR

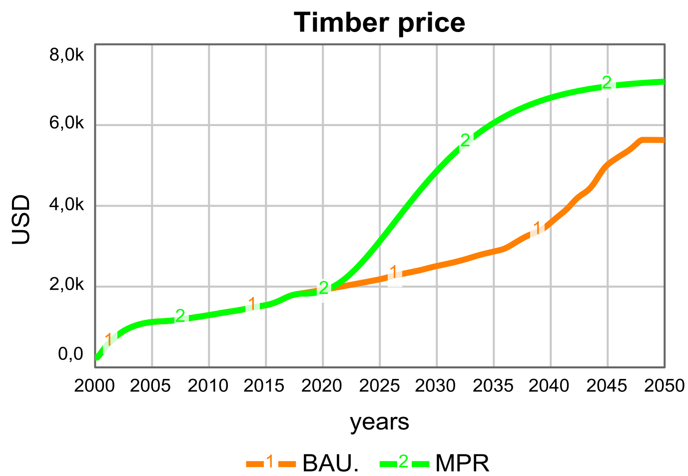

Figure 62. Results: Timber price MPR

Because tax revenues from plantations and clearing are decreased (in the case of latter substantially) the final sum of collected taxes is smaller by 23% counting 78B USD (Figure 65). But as Figure 64 portrays the total government revenues end up being higher reaching 41B instead of 36B USD in BAU scenario.

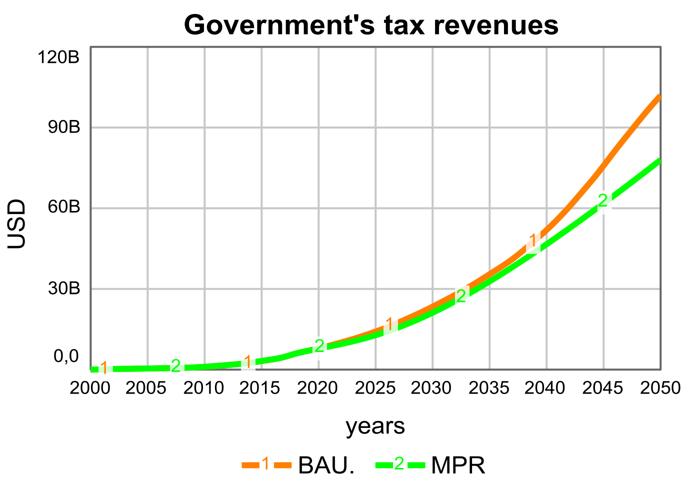

Figure 63. Results: Tax revenues MPR

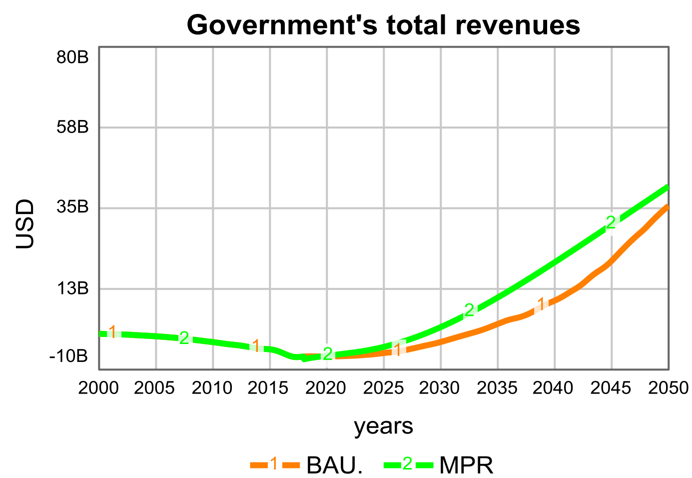

Figure 62. Results: Total gov. revenues MPR

Higher total revenues are result of halted deforestation making social cost of carbon nearly half smaller (Figure 67). Making whole forest area protected also maximizes potential of non-timber forest products collection for local population. The net value of extracted NTFPs will reach over 1B USD which is increase by 488% from the baseline scenario (Figure 66).

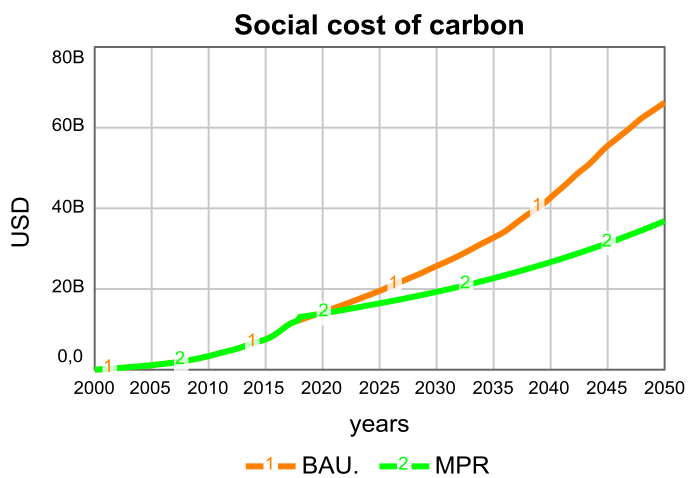

Figure 65. Results: SCC MPR

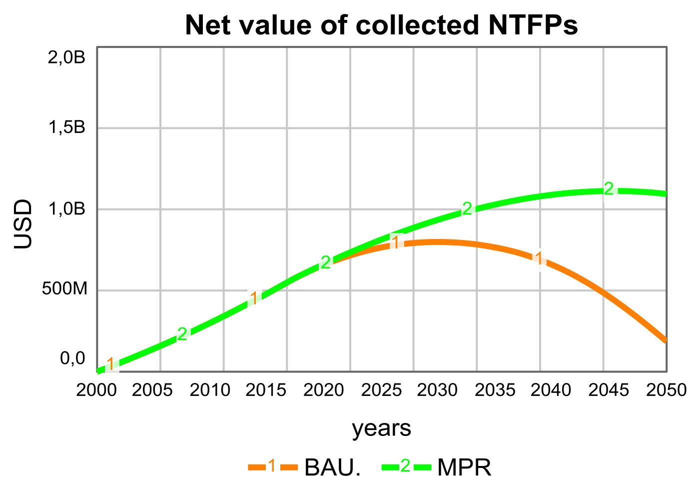

Figure 64. Results: NTFPs MPR

Land type	Scenario	2018	2020	2030	2040	2050
Agriculture land	**BAU**	**413 293**	**411 123**	**541 648**	**767 346**	**943 819**
	MPR	413 293	411 123	470 559	495 923	478 768
	Δ MPR	0,00%	0,00%	-13,12%	-35,37%	-49,27%
Forest land	**BAU**	**1 250 475**	**1 173 457**	**845 297**	**543 373**	**308 696**
	MPR	1 250 475	1 250 475	1 250 475	1 250 475	1 250 475
	Δ MPR	0,00%	6,56%	47,93%	130,13%	305,08%
Fallow land	**BAU**	**249 560**	**282 114**	**266 375**	**143 359**	**42 105**
	MPR	249 560	217 040	72 687	9 771	1 305
	Δ MPR	0,00%	-23,07%	-72,71%	-93,18%	-96,90%
Grazing land	**BAU**	**33 109**	**413 91**	**85 553**	**149 909**	**205 414**
	MPR	33 109	41 391	53 278	31 280	25 214
	Δ MPR	0,00%	0,00%	-37,73%	-79,13%	-87,73%
Settlement land	**BAU**	**147 451**	**161 753**	**234 550**	**305 201**	**377 047**
	MPR	147 451	161 753	234 550	294 100	325 786
	Δ MPR	0,00%	0,00%	0,00%	-3,64	-13,60%
Acacia	**BAU**	**53 881**	**61 676**	**92 922**	**113 740**	**124 145**
	MPR	53 881	57 805	57 880	57 880	57 880
	Δ MPR	0,00%	-6,28%	-37,71%	-49,11%	-53,38%
Rubber	**BAU**	**111 064**	**127 320**	**192 488**	**235 906**	**257 607**
	MPR	111 064	119 247	119 405	119 405	119 405
	Δ MPR	0,00%	-6,34%	-37,97%	-49,38%	-53,65%

Units: ha						
Tax revenues	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
Total	**BAU**	**5 970**	**7 925**	**23 417**	**51 922**	**101 880**
	MPR	5 970	7 792	21 165	46 624	77 977
	Δ MPR	0,00%	-1,69%	-9,62%	-10,20%	-23,46%
Clearing	**BAU**	**3 693**	**4 619**	**10 563**	**21 021**	**36 807**
	MPR	3 693	4 488	4 906	4 906	4 906
	Δ MPR	0,00%	-2,85%	-53,55%	-76,66%	-86,67%
Managed forest	**BAU**	**342**	**396**	**1 132**	**2 614**	**4 752**
	MPR	342	430	3 306	9 303	17 852
	Δ MPR	0,00%	8,85%	192,55%	255,66%	275,67%
Plantations	**BAU**	**1 933**	**2 909**	**11 721**	**28 286**	**60 319**
	MPR	1 933	2 890	13 038	32 506	55 217
	Δ MPR	0,00%	-0,66%	11,24%	14,92%	-8,46%
Units: mill. USD						
NTFPs	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
Value collected	**BAU**	**598**	**660**	**798**	**656**	**186**
	MPR	598	665	937	1090	1 094
	Δ MPR	0,00%	0,65%	17,33%	65,93%	487,61%
Units: mill. USD						
SCC	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
costs	**BAU**	**12 324**	**14 248**	**25 705**	**42 677**	**66 202**
	MPR	13 083	13 932	19 301	26 682	36 861
	Δ MPR	6,16%	-2,22%	-24,91%	-37,48%	-44,32%
Units: mill. USD						
Plantations	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
Owner's profit	**BAU**	**12 324**	**14 248**	**25 705**	**42 677**	**66 202**
	MPR	7 744	11 615	53 302	133 822	227 923
	Δ MPR	0,00%	-0,67%	11,92%	15,73%	-8,10%
Units: mill. USD						
Timber volumes	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
Total production	**BAU**	**39,83**	**46,71**	**83,38**	**122,66**	**161,20**
	MPR	39,83	42,57	60,74	79,98	99,17
	Δ MPR	0,00%	-8,86%	-27,14%	-34,79%	-38,48%
Clearing	**BAU**	**32,43**	**36,60**	**53,36**	**64,44**	**69,36**
	MPR	32,43	32,43	32,43	32,43	32,43
	Δ MPR	0,00%	-11,40%	-39,22%	-49,67%	-53,24%
Managed forest	**BAU**	**1,54**	**1,70**	**2,45**	**3,15**	**3,80**
	MPR	1,54	1,75	4,48	7,30	9,95
	Δ MPR	0,00%	2,74%	83,14%	132,14%	161,79%
Plantations	**BAU**	**5,86**	**8,41**	**27,57**	**55,08**	**88,04**
	MPR	5,86	8,39	23,83	40,25	56,79
	Δ MPR	0,00%	-0,14%	-13,57%	-26,92%	-35,50
Units: m^3						

Table 5. Results overview: MPR

4.7. Ideal run (IR)

Changes introduced in 2018:

- Parameter *fractional change in size in 2018* is increased from 1 to 3
- Parameter *logging waste* decreased from 0.5 to 0.25
- Parameter *logging damage* decreased from 0.4 to 0.14
- Parameter *cutting cycle time* increased from 30 to 40
- Parameter *fraction of plantations* is increased from 0.3 to 1.0

Direct impacts

In modules: *Government revenues in managed forest, Plantations, Government's revenues from clearing, Carbon in managed forest*

- Increase in *fractional change in size in 2018*
  - In *Government revenues in managed forest*
    - Increases sizes of *managed forest* variable from 309 000 ha to 927 778 ha which is a 74% of current *forest land* stock size
- Decrease in *logging waste*
  - Same change as in LIM scenario
- Decrease in *logging damage*
  - Same change as in LIM scenario
- Increase in *cutting cycle time*
  - Same change as in LIM scenario
- Increase in *fraction of plantations*
  - Same change as in MPL scenario

In the ideal scenario, managed forest is expanded, better management practices are implemented and plantations development is intensified. Changes introduced in LIM and MPL are exactly same in this simulation. Change presented in MPR is here implemented only partially because only ¾ of forest becomes protected instead of its full size. Detailed description of effects of listed changes is already provided in previous scenarios so here is focus concentrated on results comparison.

In terms of land stocks, the overall result is reminiscent to MPR scenario (Figure 68). Stock of forest land stabilizes at 927 425 ha which is 200% increase from BAU scenario and reminds the largest land stock. Extended forest protection constrains development of plantations, settlement and agriculture land. Settlement land and plantations are not hindered severely the difference in end values is within 10% range in comparison with BAU scenario. Agriculture development is suppressed to larger extent and reaches only 63% of baseline value. Relatively small size of agriculture land could be explained not only by suppression of deforestation but also by higher rate of plantations expansion. Increased plantation development is instigating faster depletion of fallow land stock leaving less fallow land to be transformed into agriculture land. Without the faster rate of plantation development, the agriculture stock would reach 71% of BAU value.

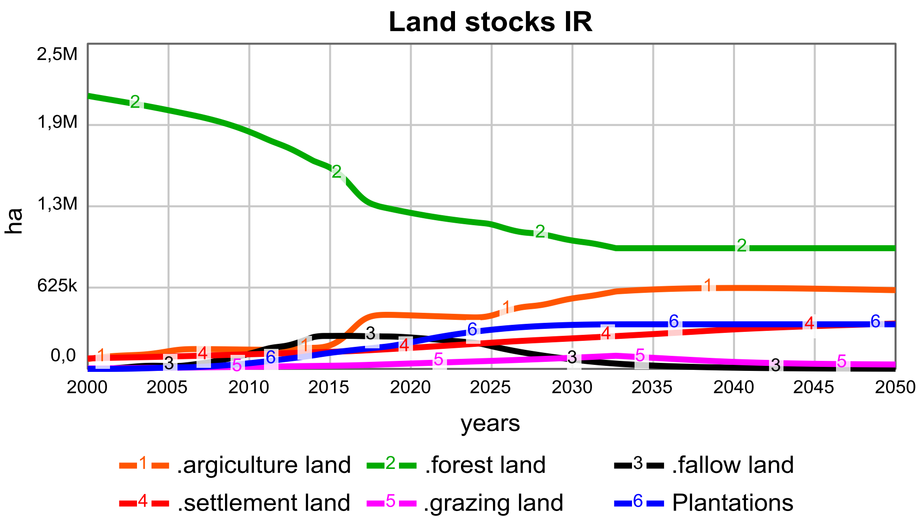

Figure 66. Results: Land stock IR

Similarly like in MPR scenario, expanding protected area increases the price of timber. That together with more efficient extraction practices and intensified plantations development generates the highest tax revenue (Figure 70). Majority of taxes comes from plantations reaching up to 100B USD (Figure 69). That is even more than in MPL scenario where plantations development is maximized. In ideal run the total size of plantations is lower but the timber is sold for higher prices.

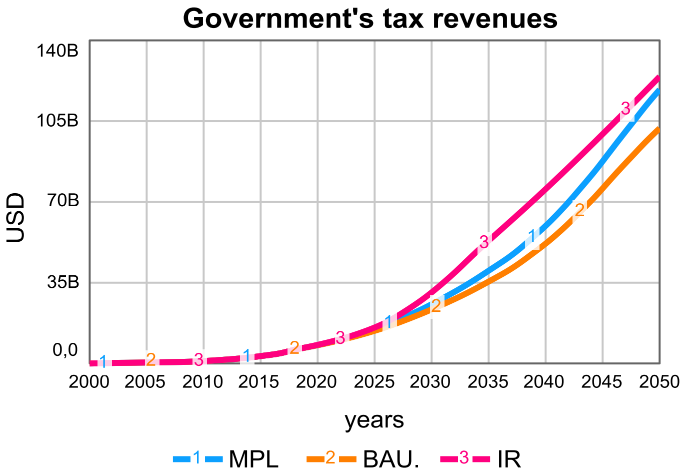

Figure 68. Results: Tax revenues IR

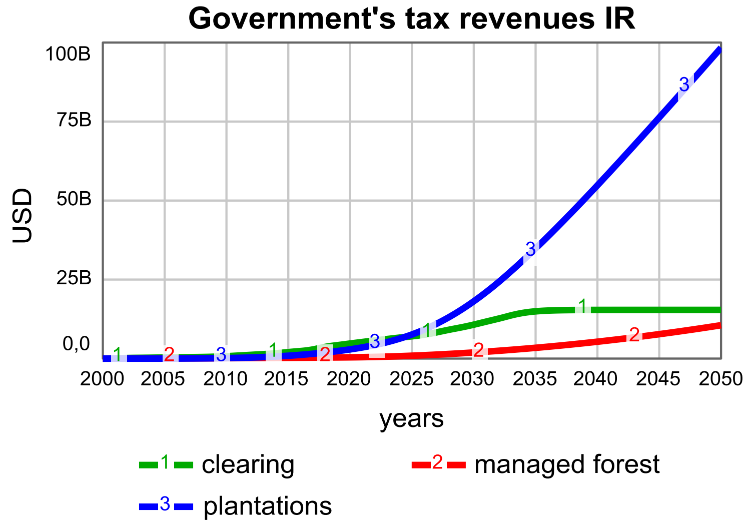

Figure 67. Results: Tax revenues sources IR

Although government's tax revenues are not much higher than in MPL scenario the total revenues will be larger (Figure 71). The reason for that is lower rates of deforestation accumulating lower costs of carbon release. As you can see in Figure 74 the total cost of carbon is almost as low as in MPR simulation where forest protection is maximized. Net value of non-timber forest collection is also substantial second only to MPR (Figure 73).

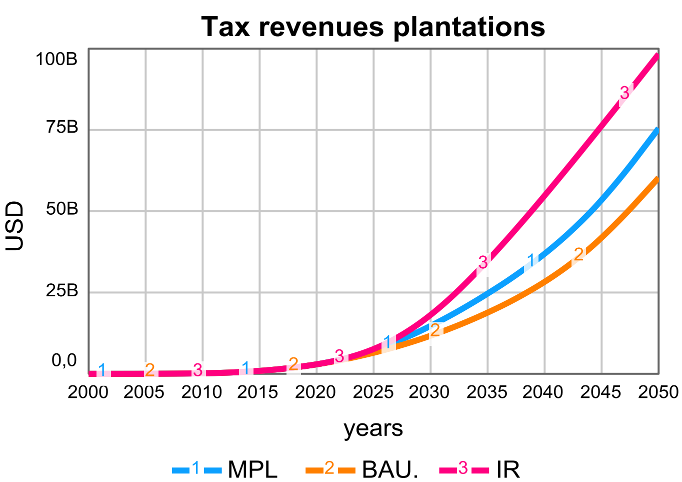

Figure 70. Results: Plantations taxes IR

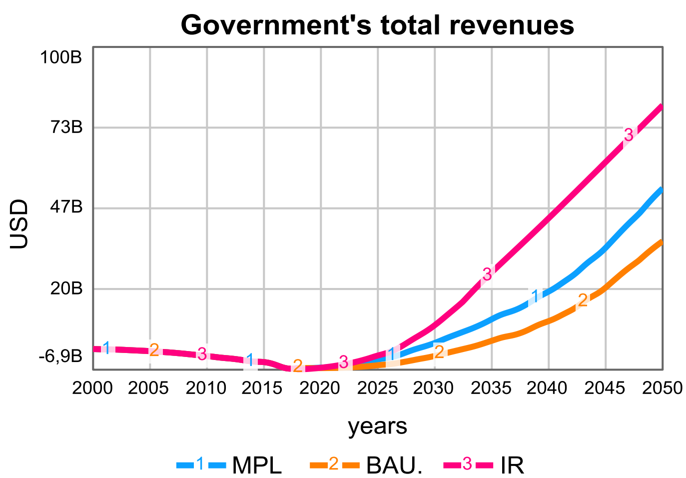

Figure 69. Results: Gov. total revenue IR

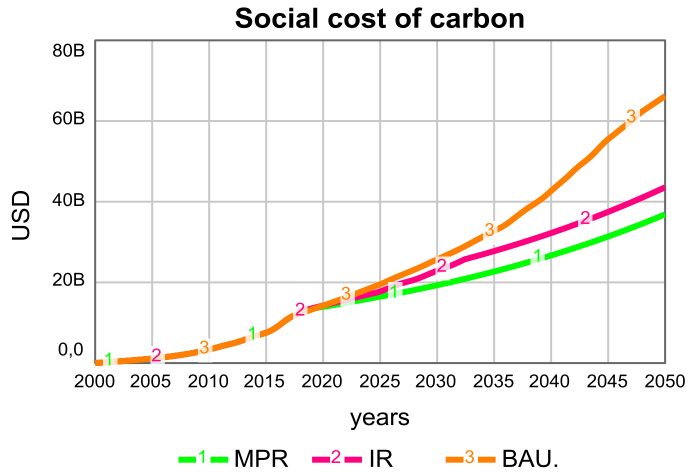

Figure 72. Results: SCC IR

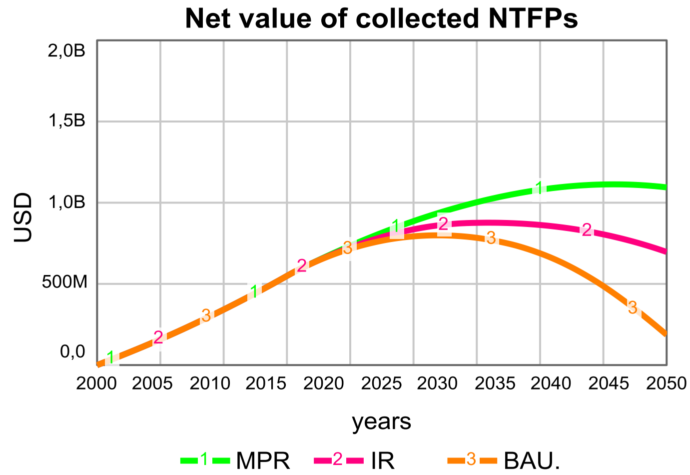

Figure 71. Results: NTFPs IR

Land type	Scenario	2018	2020	2030	2040	2050
Agriculture land	**BAU**	**413 293**	**411 123**	**541 648**	**767 346**	**943 819**
	IR	413 293	411 123	541 648	616 450	599 348
	Δ IR	0,00%	0,00%	0,00%	-19,66%	-36,50%
Forest land	**BAU**	**1 250 475**	**1 173 457**	**845 297**	**543 373**	**308 696**
	IR	1 250 475	1 198 598	979 743	927 425	927 425
	Δ IR	0,00%	2,14%	15,91%	70,68%	200,43%
Fallow land	**BAU**	**249 560**	**282 114**	**266 375**	**143 359**	**42 105**
	IR	249 560	241 596	72 550	9 191	1 228
	Δ IR	0,00%	-14,36%	-72,76%	-93,59%	-97,08%
Grazing land	**BAU**	**33 109**	**413 91**	**85 553**	**149 909**	**205 414**
	IR	33 109	41 391	85 553	52 076	33 252
	Δ IR	0,00%	0,00%	0,00%	-65,26%	-83,81%
Settlement land	**BAU**	**147 451**	**161 753**	**234 550**	**305 201**	**377 047**
	IR	147 451	161 753	234 550	303 287	347 176
	Δ IR	0,00%	0,00%	0,00%	-0,63%	-7,92%
Acacia	**BAU**	**53 881**	**61 676**	**92 922**	**113 740**	**124 145**
	IR	53 881	66 659	112 166	113 986	113 986
	Δ IR	0,00%	8,08%	20,71%	0,22%	-8,18%
Rubber	**BAU**	**111 064**	**127 320**	**192 488**	**235 906**	**257 607**
	IR	111 064	137 714	232 622	236 419	236 419
	Δ IR	0,00%	8,16%	20,85%	0,22%	-8,23%
Units: ha						
Tax revenues	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
Total	**BAU**	**5 970**	**7 925**	**23 417**	**51 922**	**101 880**
	IR	5 970	80 68	30 787	75 548	124 285
	Δ IR	-0,02%	1,79%	31,47%	45,50%	21,99%

Clearing	**BAU**	**3 693**	**4 619**	**10 563**	**21 021**	**36 807**
	IR	3 693	4 753	10 734	15 388	15 395
	Δ IR	-0,03	2,88	1,61	-26,80	-58,17
Managed forest	**BAU**	**342**	**396**	**1 132**	**2 614**	**4 752**
	IR	342	400	1 928	5 341	10 556
	Δ IR	-0,29%	0,78%	70,09%	104,21%	122,09%
Plantations	**BAU**	**1 933**	**2 909**	**11 721**	**28 286**	**60 319**
	IR	1 933	2 914	18 125	54 818	98 333
	Δ IR	-0,05%	0,14%	54,62%	93,79%	63,02%
Units: mill. USD						
NTFPs	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
Value collected	**BAU**	**598**	**660**	**798**	**656**	**186**
	IR	598	662	860	854	696
	Δ IR	-0,17%	0,08%	7,61%	29,94%	272,04%
Units: mill. USD						
SCC	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
costs	**BAU**	**12 324**	**14 248**	**25 705**	**42 677**	**66 202**
	IR	12 823	14 268	22 892	32 232	43 582
	Δ IR	4,04%	0,14%	-10,94%	-24,48%	-34,17%
Units: mill. USD						
Plantations	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
Owner's profit	**BAU**	**12 324**	**14 248**	**25 705**	**42 677**	**66 202**
	IR	7 744	11 711	74 108	225 829	406 100
	Δ IR	0,00%	0,14%	55,61%	95,30%	63,74%
Units: mill. USD						
Timber volumes	**Scenario**	**2018**	**2020**	**2030**	**2040**	**2050**
Total production	**BAU**	**39,83**	**46,71**	**83,38**	**122,66**	**161,20**
	IR	39,83	46,71	80,50	113,55	147,58
	Δ IR	0.00%	-2,09%	-4,60%	-8,18%	-9,01%
Clearing	**BAU**	**32,43**	**36,60**	**53,36**	**64,44**	**69,36**
	IR	32,43	36,58	46,22	46,43	46,43
	Δ IR	0,00%	-2,72%	-14,97%	-29,05%	-34,01%
Managed forest	**BAU**	**1,54**	**1,70**	**2,45**	**3,15**	**3,80**
	IR	1,54	1,71	3,21	4,81	6,40
	Δ IR	-39,30%	-36,62%	-6,99%	15,99%	33,40%
Plantations	**BAU**	**5,86**	**8,41**	**27,57**	**55,08**	**88,04**
	IR	5,86	8,42	31,07	62,32	94,75
	Δ IR	0,00%	0.14%	8,75%	11,12%	6,41%
Units: m^3						

Table 6. Results overview IR

CHAPTER 5. VALIDATION

System dynamics models falls into category causal-descriptive models which can be characterized as having internal structure in accordance with reality. It means that the models should not only provide correct outputs or results but also show clearly how the calculation is made. Structure of the model can be understood as simplified theory of how the system works in reality. To gain confidence about the structure a set of different validation tests has been conducted.

5.1. Reproduction of historical behavior

One of the ways of model validation is to compare historic data with simulation results. Simulation runs start at year 2000 and end it year 2050. That offers an opportunity to compare results generated endogenously with existing historical records.

Two different indicators have been chosen for comparison: *Size of rubber plantations* and *timber price*. Unfortunately, in case of rubber, lack of historic data is making the comparison less comprehensive than optimal because there are existing records for only few years. That is not a problem with *timber price* where the comparison of simulation and historic data can be observed for each year within a period 2000 – 2014. As an addition going beyond the frame of historic comparison a graph with simulated and projected timber price is also provided.

5.1.1. Size of rubber plantations

Rubber plantations has been chosen because there are no specific historic data on sizes of acacia plantations. The data on historic sizes are based on report *Rubber Sector Profile* issued by Cambodian government (Ministry of Commerce, 2012).

Figure 75 shows that the accuracy of reproduction of historic behavior is moderate. The inflow rubber plantations is a delayed function of *plantations development* flow multiplied by *rubber to acacia* fraction:

DELAY3 (*plantations development**rubber to acacia ratio*, *1*, *plantations development**rubber to acacia ratio*)

The reason for delay in formulation is to achieve higher degree of realism. The *plantations development* flow is a fraction of *timber clearing* flow. It is reasonable to assume that there should be a time delay between a moment when a hectare of land is cleared and when a rubber or acacia is being planted. The ratio between rubber and acacia is stable and its calculation is described in section 3.5.1. Because the ratio between rubber and acacia is constant, change in size of *fraction of plantations* has been used for rubber calibration. Originally, fraction 0.4 was being used as a result of comparison of sizes of agriculture and rubber in 2013. Nevertheless, value of this fraction was calibrated to 0.3 because fitting a longer historic period seems more valid for model accuracy then fitting calculated ratio between agriculture and rubber especially if there is historic data for only one year.

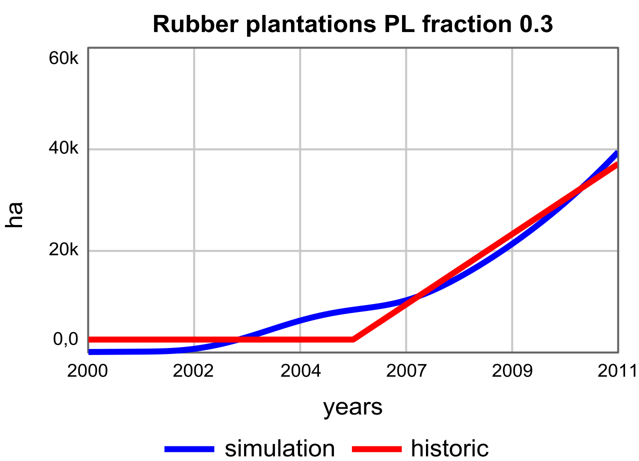

Figure 74. Rubber development original

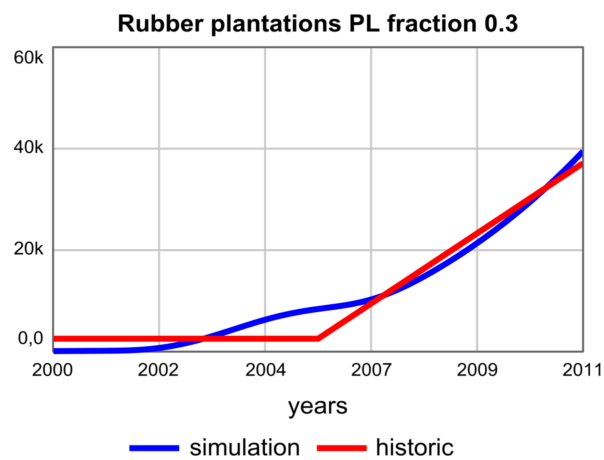

Figure 73. Rubber after calibration

5.1.2. Timber price

Calculation of timber price is affected by three effects: *growth rate of demand*, *forest deterioration* and *extraction availability*:

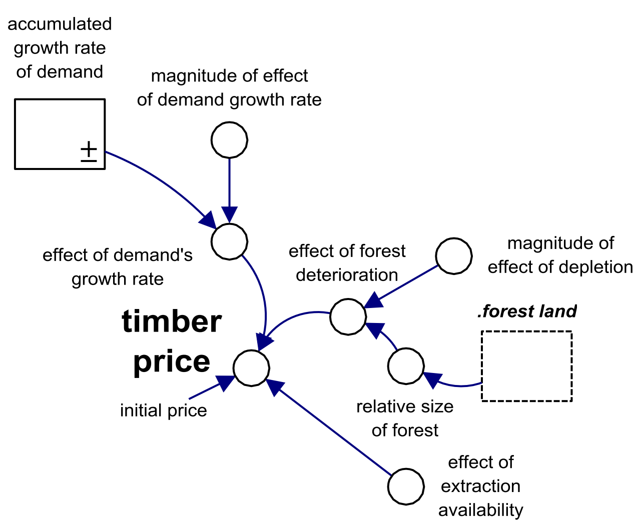

Figure 75. Timber price structure

Two parameters, *magnitude of effect of depletion* and *magnitude of effect of demand growth rate* were created specifically for timber price calibration in accordance with historic data. The timber price is formulated as follows:

((*initial price/effect of forest deterioration*)* *effect of demand's growth rate*)* *effect of extraction availability*

Increase in *magnitude of effect of depletion* will decrease the denominator in formulation which will increase the timber price hence making the price more sensitive to deforestation. At the same time increase in *magnitude of effect of demand growth* will increase multiplier *effect of demand's growth rate* causing timber price to be more sensitive to demand's growth.

Having two different parameters regulating the strength of effects proved to be very useful for *timber price* calibration. Because growth rate of demand is especially high in the beginning and extent of deforestation is logically largest towards the end, first of the effects is having stronger influence on price at early period and second on late period. That creates an opportunity to try different combinations of parameter values and find the one that will generate the most accurate price development. After series of tests the values for *magnitude of effect of depletion* and *magnitude of effect of demand growth rate* were set to be 0.80 and 0.65 respectively. The result can be seen in Figure 78:

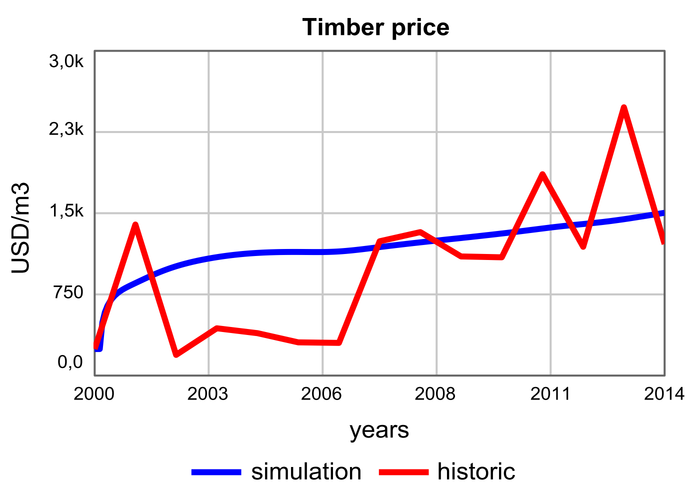

Figure 76. Timber price calibrated

The result can be judge as moderate or low accuracy. Simulated price does not produce erratic behavior but it follows the overall trend. Also, calibration was conducted not to factor only shape of historic price development but to consider accumulated value of price in the observed period as well. In this aspect, the simulated price exhibits moderate accuracy. The deviation of simulated price from its historical equivalent is 18.03%.[10] Lastly, during calibration a minor respect was also given to timber price forecast. Timber price in for year 2020 is estimated to be 2000 USD/m^3 (FIM, 2015). In BAU scenario the price of timber in year 2020 is 1920 USD/m^3 which is only -4% less than forecast hence very accurate result.

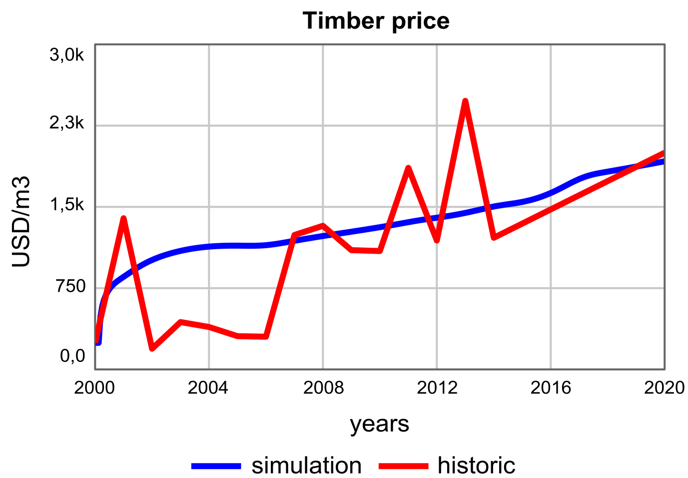

Figure 77. Timber price forecast comparison

5.2. Structure validity tests

Based on (Barlas, 1996) a structure and structure behavior was tested in a series of different validation tests.

5.2.1. Structure confirmation test

Structure confirmation tests were applied in modules *Government revenues from clearing, Government revenues from managed forest, Carbon in managed forest* and *Plantations.*

Modules *Government revenues from clearing* and *Government revenues from managed forest* are based on (Kim et al., 2006). In this source the authors were calculating government revenues based on taxation of produced timber, veneer sheets and sawn wood. For the purpose of this thesis the model was simplified to account timber as the only product. But for gaining validation of the module the structure was first build completely in accordance with the source

[10] Accumulated historic price is 14 012 USD/m3 and accumulated simulated price is 16 539 USD/m3.

material. In the article were tables with precise values of initial size of forest, production of veneer sheets and sawn wood as well as amount of accumulated taxes. When the structure presented in Appendix D was fed with data on initial size of forest it generated results on amounts of different products and collected taxes were in full accordance with original study. After this confirmation, I had full confidence in model's structure and then proceed to its simplification.

Exactly same process was applied in module *Plantations* for calculation of the amount of wood product. This structure was based on (Shigematsu et al., 2010). Authors of this article were calculating amounts of wood product, sawn timber and primary and secondary residuals based on size of rubber plantation. My original model was able to reproduce all the outputs when provided initial values from the article and is presented in Appendix E. After structure confirmation, it was simplified into present form.

Described way of initial model construction was used for model in *Carbon in managed forest* module as well. The source was article *Managing production forests for timber production and carbon emission reductions under the REDD+ scheme* (Sasaki et al., 2012). In this case I ran into series of problems because the outputs of my model were showing opposite behavior than described in the article. After going over every equation many times I came to conclusion that authors had a mistake in one of their equation, specifically formulation for *changes in the aboveground carbon stocks*:

$$\frac{dCS_i(t)}{dt} = \mathrm{MAI} - [\mathrm{LM}_i(t) - \mathrm{H}_i(t)] \times \mathrm{BEF}$$

Figure 78. Carbon stock changes formulation (Sasaki, Chheng, & Ty, 2012)

Problem is in the sum LM+H which implies that carbon lost due to logging-induced mortality should be subtracted by the amount of harvested carbon to calculate the change in carbon stock. The more logical way seems to be to have a sum of harvested and damaged wood when figuring out the amount of carbon change in the carbon stock. After making this change the the model started to show more logical behavior (less logging damage and longer cutting cycle times lead to increase in carbon stocks of aboveground biomass). Nevertheless, even the new results were not in full accordance with the results in the article but their direction was correct and the absolute values weren´t far off. The original structure is presented in Appendix F.

5.2.2. Parameters confirmation test

Vast majority of parameters used in the models are directly derived from existing literature. Each parameter obtained this way is provided with the source upon which is its value based. This type of parameters can be find in every module, for example: *tax on export* in *Government revenues from managing forest, license export fee* in *Government revenues from clearing, BEF biomass expansion factor* in *Carbon in managed forest, average household size* in *Non-timber forest products, domestic timber demand in 2010* in *Timber demand and price, volume of acacia wood per ha* in *Plantations* or *social cost of carbon initial 2015* in *C and CO_2* module.

Few of the parameters have been created to support model calibration. Four different magnitudes of effects in *Timber price and price* are good example. Another set of parameters with a tag SWITCH were created to change some variables as result of policy choice like a parameter *SWITCH only above and below ground (1) or all (0)* in *C and CO_2* module.

5.2.3. Extreme condition test

This test evaluates if reaction of variables to extreme conditions are plausible and logical. A suitable candidate for extreme condition test is *timber demand.* This stock variable should drive *clearing for timber* and *timber price*. Without demand no supply should be theoretically provided.

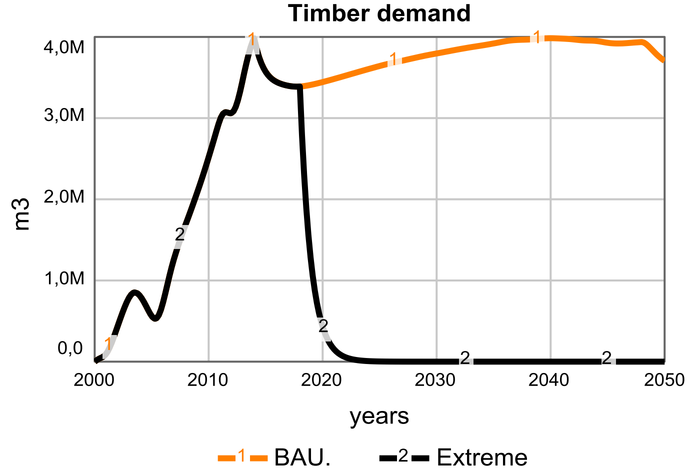

Figure 79. Timber demand extreme condition

Figure 81 represents shock to the system when in year 2018 inflow of demand becomes zero. The stock of demand is being depleted soon after. Direct impact is observable in the effect on *clearing for timber* variable (Figure 83). The response happens even before the stock of demand

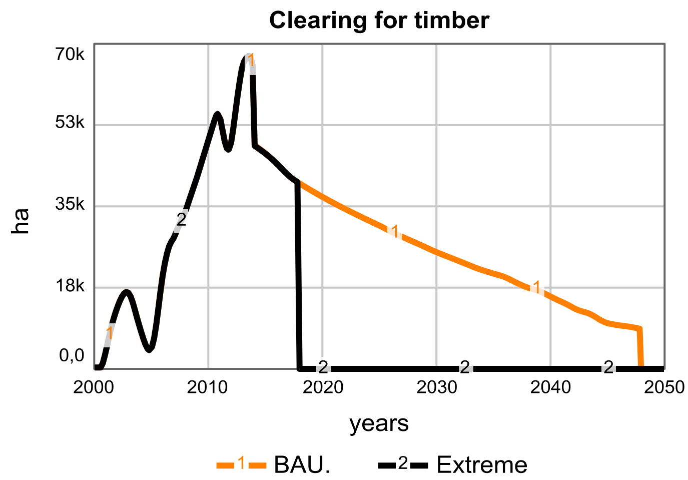

Figure 81. Clearing for timber extreme test

is depleted because clearing is halted when supply is higher than demand not only when demand is zero. *Timber price* is affected indirectly through declining *accumulated growth rate of demand* which pushes the price down (Figure 82).

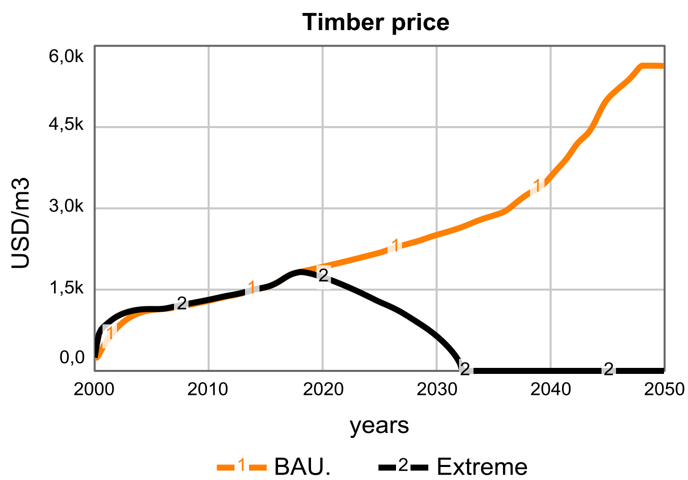

Figure 80. Timber price extreme test

What would be an expected effect on timber production in plantations is its plunge because timber product has no value anymore. In this case the test proved inconsistency with reality because inflow of timber counties onwards (Figure 84).

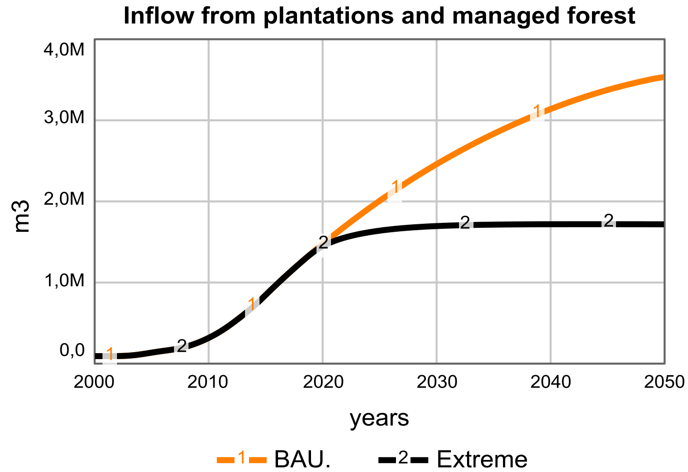

Figure 82. Plantations production extreme test

Stream of timber from plantations is modeled to be existing and is dependent only on the size of plantations. A feedback loop between demand and production seemed unnecessary because it is expected that demand will be always present. Extreme condition test therefore demonstrates a robust and realistic direct effect on clearing and indirect on price but unrealistic effect on plantations production showing there some limitations of the model.

5.2.4. Dimensional consistency test

Dimensional consistency test is performed to make sure that all units in the model are consistent. This test is conducted automatically by modeling software. According to test results all units which are not part of the original MFF model structure are consistent.

5.2.5. Sensitivity analysis

Sensitivity analysis was conducted when estimating parameters with values not based on literature to decrease the level of uncertainty. This test was applied for example during the calibration of parameter *fraction of plantations* used for estimation of *plantations development* flow (Figure 85).

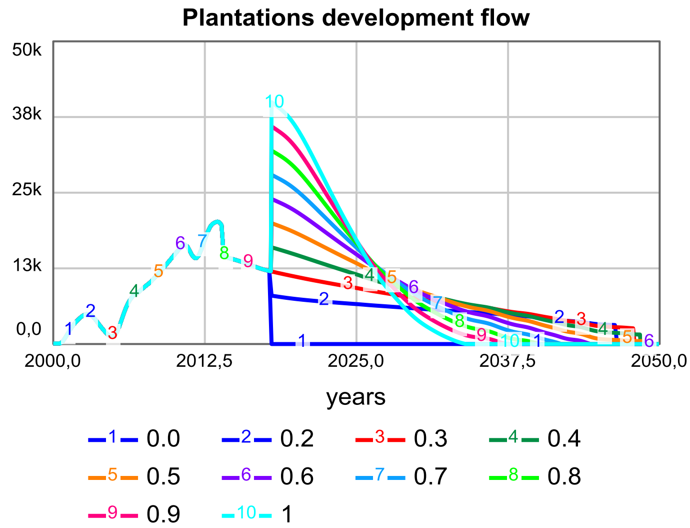

Figure 83. Plantations development sensitivity

Over the series of 10 simulations a *fraction of plantations* was gradually increased from 0 to 1.0. The tests proved that when *plantations development* is highly sensitive to a to the parameter. The knowledge of high sensitivity was helpful as a lead on how to calibrate the inflow into rubber plantations described in section 5.1.1.

Similar test was conducted during formulation of policies for *Maximum plantations* (MPL) scenario. Goal of this scenario was to create an increase of plantations development by speeding up transformation of *fallow land.* Originally the policy was set up to simply create outflow from *fallow land* into stock of acacia and rubber plantations limited only by *max fallow to ag conversion*. After observing the effect, I came to conclusion that this policy formulation is too strong because the inflow increases too sharply (Figure 86). Based on this policy sensitivity analysis I determine that it would be preferable to keep plantation development based on rate of timber clearing and only increase *fraction of plantations* parameter from 0.3 to 1.0.

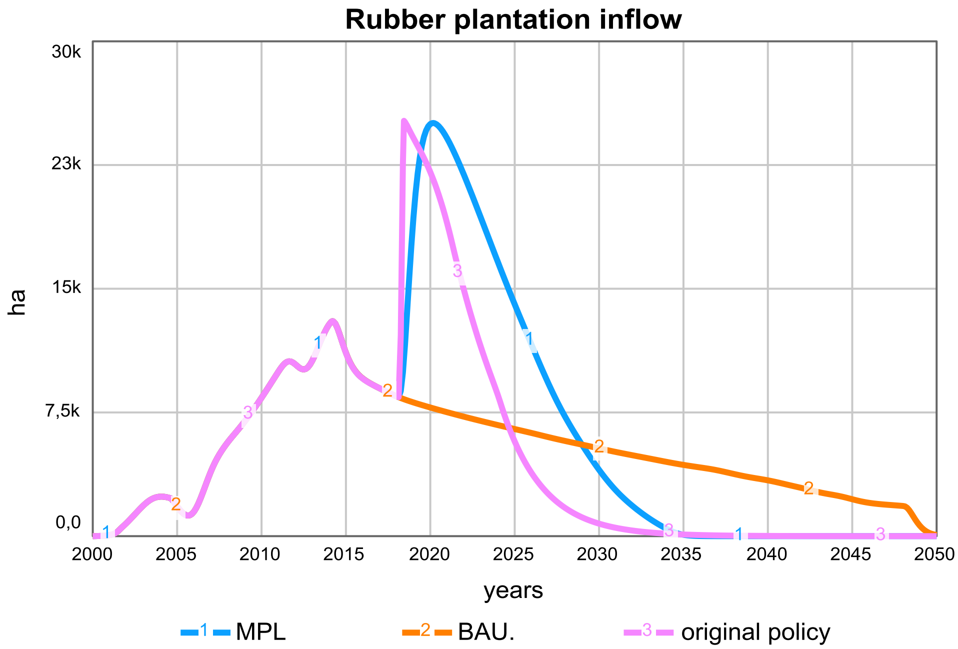

Figure 84. Rubber inflow policy sensitivity

CHAPTER 6. CONCLUSION

6.1. Limitations

Main limitation of the system lies with its assumption that only timber is being sold as wood product. At first this assumption did not seem as oversimplification because it can be expected that rise or fall of veneer sheets, sawn wood or other wood products would follow price development of timber as timber is the source material. But after examination of historic development of prices it showed to be wrong assumption (Figure 87).

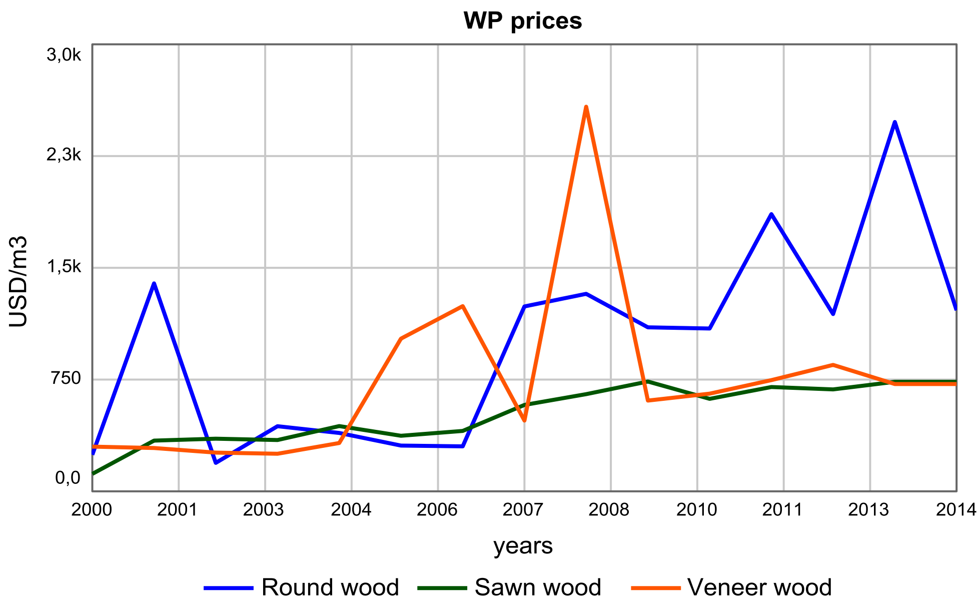

Figure 85. Wood products historic prices

As you can see, prices of sawn and veneer wood do not strictly follow price of round wood. Even more surprisingly, round wood tends to be more expensive than products made from it. This could be explained by high quality of timber in Cambodia and low degree of wood processing efficiency which could force external buyer to prefer importing unprocessed material and processing it somewhere else with higher efficiency and better yield on cubic meter of raw wood. Another explanation might be incorrect statistical data which is common occurrence in Cambodia. Nevertheless, it is obvious that for better estimation of demand and government revenues another module should be create where the demand and price of other wood products would be calculated.

Another limiting factor might be assumption that all timber is sold for the same price, i.e. all wood product is the same quality. This is problematic when considering inflow of wood from plantations as substitution for inflow from forest clearing. In reality, rubber plantations produce medium quality softwood which might be less desirable. Acacia and eucalyptus are hardwoods but the overall profitability of these plantations is lower due to absence of latex collection. Teak seems to provide good hardwood as well as profit in the long run but the long life cycle of 40 to 60 years this tree is species makes it not very spread in Cambodia (Ra & Kimsun, 2012). At any cost the best wood from plantations cannot compete in quality with the best wood from natural forest.

6.2. Answering the research questions

Following questions were raised in the introduction of the thesis:

6. What are the key ecosystem services provided by the forest land?
7. What are the main drivers for deforestation?
8. How is the forest land used after clearing?
9. How does deforestation affect government's and individual's income?
10. What policies would generate the best possible outcome?

This study examined monetary evaluation of forest ecosystem services to increase understanding of consequences of deforestation in two rural tropical regions of Cambodia from multilayered perspective of individual and governmental level. A comprehensive SD model was created to portray simplified version of reality and offer experimental tool for policy analysis.

Over the course of research, provision of timber, provision of non-timber forest products and carbon sequestration were identified as three crucial ecosystem services generated by forests. Global demand for timber and local pressure for agriculture expansion have been shown as main drivers for land clearing. Fast rate of deforestation is leading to creation of large areas of fallow lands providing no benefits to either individuals or government. Without introducing changes to the system, a continual degradation of forest land is to be expected because of ever present timber demand and rising price of timber product.

Such development is anticipated to produce a lot of government revenue which would be countered by high social cost of carbon release and intensification of public pressures and conflicts fueled by distress of low income population which is heavily dependent on non-timber forest products collection.

Based on different scenarios analysis, an expansion of protected forest land is proved to be a key factor preventing undesirable development. Securing large portion of a forest would guarantee steady inflow of ecosystem services supporting local population. It is also expected that limiting forest clearing would increase a price of timber product making managing forest or building plantations more profitable. In such scenario introducing low impact management practices would further increase the profitably of managed forest areas. On the other hand, without increased forest protection the same practices could have strong contradictory effect of making the system even more dependent on deforestation by creating wood extraction and processing more cost-effective and lucrative.

Increased plantations development should be part of the solution. As it was presented in ideal scenario, plantations can be expanded even without increasing land clearing because over the historic period a vast fallow land was accumulated.

It is disputable if plantations development itself can create enough employment opportunities for population to compensate NTFPs collection loss but it is clear it can generate enough wood product to satisfy timber demand constituting further deforestation unnecessary. This finding is in line with conclusion presented by (Shigematsu et al., 2010). Rubber plantations are perceived to be a preferable choice since they provide both timber and natural latex making this source of revenue more diversified (Ra & Kimsun, 2012).

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APPENDIX A. CARBON POOLS

Land cover	Ground level	Carbon pool in ton/ha	Source
Acacia***	Above and below ground + litters	28	(Zhang, Guan, & Song, 2012)
Cassava	Above ground	3	(Puig, 2005)
Deciduous forest	Above and below ground + litters	150	(Sasaki, Chheng, Mizoue, Abe, & Lowe, 2016)
Deciduous forest	Above ground	95	(Sasaki et al., 2016)
Deciduous forest	Below ground	29	(Sasaki et al., 2016)
Dense forest	Above ground	97	(Sasaki et al., 2016)
Dense forest	Below ground	29	(Sasaki et al., 2016)
Dense forest*	Above and below ground + litters	160	(Sasaki et al., 2016)
Mixed forest	Above ground	88	(Sasaki et al., 2016)
Mixed forest	Below ground	27	(Sasaki et al., 2016)
Mixed forest **	Above and below ground + litters	138	(Sasaki et al., 2016)
Rice	Above ground	17	(Puig, 2005)
Rubber	Above and below ground	43.2	(Blagodatsky, Xu, & Cadisch, 2016)

Table 7. Carbon pools

* Dense forest is calculated as average value of evergreen and semi-evergreen forest.

** Mixed forest is in the source named *Other forest*.

*** The value for acacia used in model is based on average value from multiple study sites.

APPENDIX B. NTFPS COLLECTION AREAS

Village	Population	Collection area (ha)	Collection area per person	Forest type
Chramas	783	1200	1.5	Deciduous
Doung	413	2600	6.3	Semi-evergreen
Kang Kdar	2086	7544	3.6	Semi-evergreen
Kol Totueng	1371	3099	2.3	Deciduous
Ksetr Bourei	1920	9700	5.1	Evergreen
Mil	779	4700	6.0	Semi-evergreen
Ou Am	2165	6400	3.0	Evergreen
Ou Rona	545	1000	1.8	Evergreen
Ronteah	385	3630	9.4	Evergreen
Samrang	667	1132	1.7	Deciduous
Samret	579	1200	2.1	Deciduous
Srae Popeay	608	1200	2.0	Deciduous
Srae Roneam	1102	1500	1.4	Deciduous
Tum Ar	766	4863	6.3	Evergreen
Veal	557	3562	6.4	Evergreen
Veal Vong	1113	4036	3.6	Semi-evergreen

Table 8. NTFPs collection areas based on survey (Hansen & Top, 2006)

APPENDIX C. RESULTS TABLES

In the tables are presented absolute values of scenario simulations and percental change in comparison with BAU base run.

a) Land stocks:

Land type	Scenario	2018	2020	2030	2040	2050
Agriculture land	**BAU**	**413 293**	**411 123**	**541 648**	**767 346**	**943 819**
in ha	LIM	413 293	411 123	541 648	767 346	949 461
	Δ LIM	0,00%	0,00%	0,00%	0,00%	0,60%
	MPL	413 293	411 123	541 648	767 346	937 861
	Δ MPL	0,00%	0,00%	0,00%	0,00%	-0,63%
	MPR	413 293	411 123	470 559	495 923	478 768
	Δ MPR	0,00%	0,00%	-13,12%	-35,37%	-49,27%
	IR	413 293	411 123	541 648	616 450	599 348
	Δ IR	0,00%	0,00%	0,00%	-19,66%	-36,50%
Forest land	**BAU**	**1 250 475**	**1 173 457**	**845 297**	**543 373**	**308 696**
in ha	LIM	1 250 475	1 197 959	930 410	612 266	308 291
	Δ LIM	0,00%	2,09%	10,07%	12,68%	-0,13%
	MPL	1 250 475	1 173 949	892 927	584 367	308 835
	Δ MPL	0,00%	0,04%	5,63%	7,54%	0,04%
	MPR	1 250 475	1 250 475	1 250 475	1 250 475	1 250 475
	Δ MPR	0,00%	6,56%	47,93%	130,13%	305,08%
	IR	1 250 475	1 198 598	979 743	927 425	927 425
	Δ IR	0,00%	2,14%	15,91%	70,68%	200,43%
Fallow land	**BAU**	**249 560**	**282 114**	**266 375**	**143 359**	**42 105**
in ha	LIM	249 560	261 331	211 380	112 170	48 045
	Δ LIM	0,00%	-7,37%	-20,65%	-21,76%	14,11%
	MPL	249 560	253 807	72 996	8 728	1166
	Δ MPL	0,00%	-10,03%	-72,60%	-93,91%	-97,23%
	MPR	249 560	217 040	72 687	9 771	1 305
	Δ MPR	0,00%	-23,07%	-72,71%	-93,18%	-96,90%
	IR	249 560	241 596	72550,56	9 191	1 228
	Δ IR	0,00%	-14,36%	-72,76%	-93,59%	-97,08%
Grazing land	**BAU**	**33 109**	**413 91**	**85 553**	**149 909**	**205 414**
in ha	LIM	33 109	413 91	85 553	149 909	224 425
	Δ LIM	0,00%	0,00%	0,00%	0,00%	9,26%
	MPL	33 109	41 391	85 553	149 909	190 641

	Δ MPL	0,00%	0,00%	0,00%	0,00%	-7,19%
	MPR	33 109	41 391	53 278	31 280	25 214
	Δ MPR	0,00%	0,00%	-37,73%	-79,13%	-87,73%
	IR	33 109	41 391	85 553	52 076	33 252
	Δ IR	0,00%	0,00%	0,00%	-65,26%	-83,81%
Settlement land	**BAU**	**147 451**	**161 753**	**234 550**	**305 201**	**377 047**
in ha	LIM	147 451	161 753	234 550	305 201	377 047
	Δ LIM	0,00%	0,00%	0,00%	0,00%	0,00%
	MPL	147 451	161 753	234 550	305 201	377 047
	Δ MPL	0,00%	0,00%	0,00%	0,00%	0,00%
	MPR	147 451	161 753	234 550	294 100	325 786
	Δ MPR	0,00%	0,00%	0,00%	-3,64	-13,60%
	IR	147 451	161 753	234 550	303 287	347 176
	Δ IR	0,00%	0,00%	0,00%	-0,63%	-7,92%
Acacia	**BAU**	**53 881**	**61 676**	**92 922**	**113 740**	**124 145**
in ha	LIM	53 881	60 470	83 161	101 521	114 362
	Δ LIM	0,00%	-1,95%	-10,50%	-10,74%	-7,88%
	MPL	53 881	70 690	140 157	144 087	144 087
	Δ MPL	0,00%	14,62%	50,83%	26,68%	16,06%
	MPR	53 881	57 805	57 880	57 880	57 880
	Δ MPR	0,00%	-6,28%	-37,71%	-49,11%	-53,38%
	IR	53 881	66 659	112 166	113 986	113 986
	Δ IR	0,00%	8,08%	20,71%	0,22%	-8,18%
Rubber	**BAU**	**111 064**	**127 320**	**192 488**	**235 906**	**257 607**
in ha	LIM	111 064	124 806	172 131	210 422	237 202
	Δ LIM	0,00%	-1,97%	-10,58%	-10,80%	-7,92%
	MPL	111 064	146 120	291 002	299 197	299 197
	Δ MPL	0,00%	14,77%	51,18%	26,83%	16,14%
	MPR	111 064	119 247	119 405	119 405	119 405
	Δ MPR	0,00%	-6,34%	-37,97%	-49,38%	-53,65%
	IR	111 064	137 714	232 622	236 419	236 419
	Δ IR	0,00%	8,16%	20,85%	0,22%	-8,23%

Table 9. Results: land changes

b) Government revenues:

Revenues	Scenario	2018	2020	2030	2040	2050
Total	**BAU**	**5 970**	**7 925**	**23 417**	**51 922**	**101 880**
in mill. USD	LIM	5 970	80 47	23563	54 576	110 314
	Δ LIM	0,00%	1,54%	0,62%	5,11%	8,28%
	MPL	5 970	7 935	25 667	59634	118 625
	Δ MPL	0,00%	0,13%	9,61%	14,85%	16,44%
	MPR	5 970	7 792	21 165	46 624	77 977
	Δ MPR	0,00%	-1,69%	-9,62%	-10,20%	-23,46%
	IR	5 970	80 68	30 787	75 548	124 285
	Δ IR	-0,02%	1,79%	31,47%	45,50%	21,99%
Clearing	**BAU**	**3 693**	**4 619**	**10 563**	**21 021**	**36 807**
in mill. USD	LIM	3 693	4 754	11 862	28 068	55 559
	Δ LIM	0,00%	2,91%	12,29%	33,52%	50,95%
	MPL	3 693	4 619	9 793	20 092	38 380
	Δ MPL	0,00%	0,00%	-7,29%	-4,42%	4,27%
	MPR	3 693	4 488	4 906	4 906	4 906
	Δ MPR	0,00%	-2,85%	-53,55%	-76,66%	-86,67%
	IR	3 693	4 753	10 734	15 388	15 395
	Δ IR	-0,03	2,88	1,61	-26,80	-58,17
Managed forest	**BAU**	**342**	**396**	**1 132**	**2 614**	**4 752**
in mill. USD	LIM	342	396	1 132	2 614	4 752
	Δ LIM	0,00%	0,00%	0,00%	0,00%	0,00%
	MPL	342	396	1 132	2 614	4 752
	Δ MPL	0,00%	0,00%	0,00%	0,00%	0,00%
	MPR	3 693	4 488	4 906	4 906	4 906
	Δ MPR	0,00%	-2,85%	-53,55%	-76,66%	-86,67%
	IR	342	400	1 928	5 341	10 556
	Δ IR	-0,29%	0,78%	70,09%	104,21%	122,09%
Plantations	**BAU**	**1 933**	**2 909**	**11 721**	**28 286**	**60 319**
in mill. USD	LIM	1 933	2 900	10 767	24 436	50 944
	Δ LIM	0,00%	-0,30%	-8,14%	-13,61%	-15,54%
	MPL	1 933	2 919	14 741	36 927	75 492
	Δ MPL	0,00%	0,35%	25,77%	30,55%	25,15%
	MPR	1 933	2 890	13 038	32 506	55 217
	Δ MPR	0,00%	-0,66%	11,24%	14,92%	-8,46%
	IR	1 933	2 914	18 125	54 818	98 333

	Δ IR	-0,05%	0,14%	54,62%	93,79%	63,02%

Table 10. Results: Government revenues

c) Net value of collected non-timber forest products:

	Scenario	2018	2020	2030	2040	2050
NTFPs collection	**BAU**	**598**	**660**	**798**	**656**	**186**
in mill. USD	LIM	598	662	835	735	287
	Δ LIM	0,00%	0,20%	4,62%	11,98%	54,26%
	MPL	598	661	830	736	287
	Δ MPL	0,00%	0,04%	3,94%	12,12%	54,13%
	MPR	598	665	937	1090	1 094
	Δ MPR	0,00%	0,65%	17,33%	65,93%	487,61%
	IR	598	662	860	854	696
	Δ IR	-0,17%	0,08%	7,61%	29,94%	272,04%

Table 11. Results: NTFPs

d) Social cost of carbon:

	Scenario	2018	2020	2030	2040	2050
SCC	**BAU**	**12 324**	**14 248**	**25 705**	**42 677**	**66 202**
in mill. USD	LIM	12 324	13 844	23 860	40 575	65 847
	Δ LIM	0,00%	-2,84%	-7,18%	-4,92%	-0,54%
	MPL	12 324	14 099	23 656	40 592	65 450
	Δ MPL	0,00%	-1,05%	-7,97%	-4,88%	-1,14%
	MPR	13 083	13 932	19 301	26 682	36 861
	Δ MPR	6,16%	-2,22%	-24,91%	-37,48%	-44,32%
	IR	12 823	14 268	22 892	32 232	43 582
	Δ IR	4,04%	0,14%	-10,94%	-24,48%	-34,17%

Table 12. Results: SCC

e) Revenues of plantations owners':

	Scenario	2018	2020	2030	2040	2050
Revenues	**BAU**	**7 744**	**11 693**	**47 624**	**115 631**	**248 010,07**
in mill. USD*	LIM	7 744	11 658	43 713	99 764	209 227
	Δ LIM	0,00%	-0,30%	-8,21%	-13,72%	-15,64%
	MPL	7 744	11 730	59 843	150 884	310 264
	Δ MPL	0,00%	0,32%	25,66%	30,49%	25,10%
	MPR	7 744	11 615	53 302	133 822	227 923
	Δ MPR	0,00%	-0,67%	11,92%	15,73%	-8,10%
	IR	7 744	11 711	74 108	225 829	406 100
	Δ IR	0,00%	0,14%	55,61%	95,30%	63,74%

Table 13. Results: Revenues of plantations owners'

* Presented revenues are necessary to take with reservation because the plantations' running costs are not adjusted for inflation.

f) Timber production volumes:

	Scenario	2018	2020	2030	2040	2050
Total production	**BAU**	**39,83**	**46,71**	**83,38**	**122,66**	**161,20**
in mill. m^3	LIM	39,83	46,72	83,87	124,02	164,04
	Δ LIM	0,00%	0,03%	0,60%	1,10%	1,76%
	MPL	39,83	46,71	83,58	123,67	165,27
	Δ MPL	0,00%	0,00%	0,24%	0,82%	2,53%
	MPR	39,83	42,57	60,74	79,98	99,17
	Δ MPR	0,00%	-8,86%	-27,14%	-34,79%	-38,48%
	IR	39,83	46,71	80,50	113,55	147,58
	Δ IR	0.00%	-2,09%	-4,60%	-8,18%	-9,01%
Clearing	BAU	32,43	36,60	53,36	64,44	69,36
in mill. m^3	LIM	32,43	36,81	55,32	70,90	80,21
	Δ LIM	0,00%	0,57%	3,67%	10,02%	15,64%
	MPL	32,43	36,58	46,47	46,84	46,84
	Δ MPL	0,00%	-0,07%	-12,91%	-27,31%	-32,47%
	MPR	32,43	32,43	32,43	32,43	32,43
	Δ MPR	0,00%	-11,40%	-39,22%	-49,67%	-53,24%
	IR	32,43	36,58	46,22	46,43	46,43
	Δ IR	0,00%	-2,72%	-14,97%	-29,05%	-34,01%

Managed forest	**BAU**	**1,54**	**1,70**	**2,45**	**3,15**	**3,80**
in mill. m³	LIM	1,54	1,69	2,24	2,78	3,31
	Δ LIM	0,00%	-0,63%	-8,42%	-11,74%	-12,95%
	MPL	1,54	1,70	2,45	3,15	3,80
	Δ MPL	0,00%	0,00%	0,00%	0,00%	0,00%
	MPR	1,54	1,75	4,48	7,30	9,95
	Δ MPR	0,00%	2,74%	83,14%	132,14%	161,79%
	IR	1,54	1,71	3,21	4,81	6,40
	Δ IR	-39,30%	-36,62%	-6,99%	15,99%	33,40%
Plantations	**BAU**	**5,86**	**8,41**	**27,57**	**55,08**	**88,04**
in mill. m³	LIM	5,86	8,40	26,44	51,08	80,71
	Δ LIM	0,00%	-0,04%	-0,04%	-7,26%	-8,33%
	MPL	5,86	8,43	34,66	73,69	114,63
	Δ MPL	0,00%	0,32%	25,70%	33,78%	30,20%
	MPR	5,86	8,39	23,83	40,25	56,79
	Δ MPR	0,00%	-0,14%	-13,57%	-26,92%	-35,50
	IR	5,86	8,42	31,07	62,32	94,75
	Δ IR	0,00%	0.14%	8,75%	11,12%	6,41%

Table 14. Results: timber production

APPENDIX D. STRUCTURE OF GOV. REVENUES BASED ON (KIM ET AL., 2006)

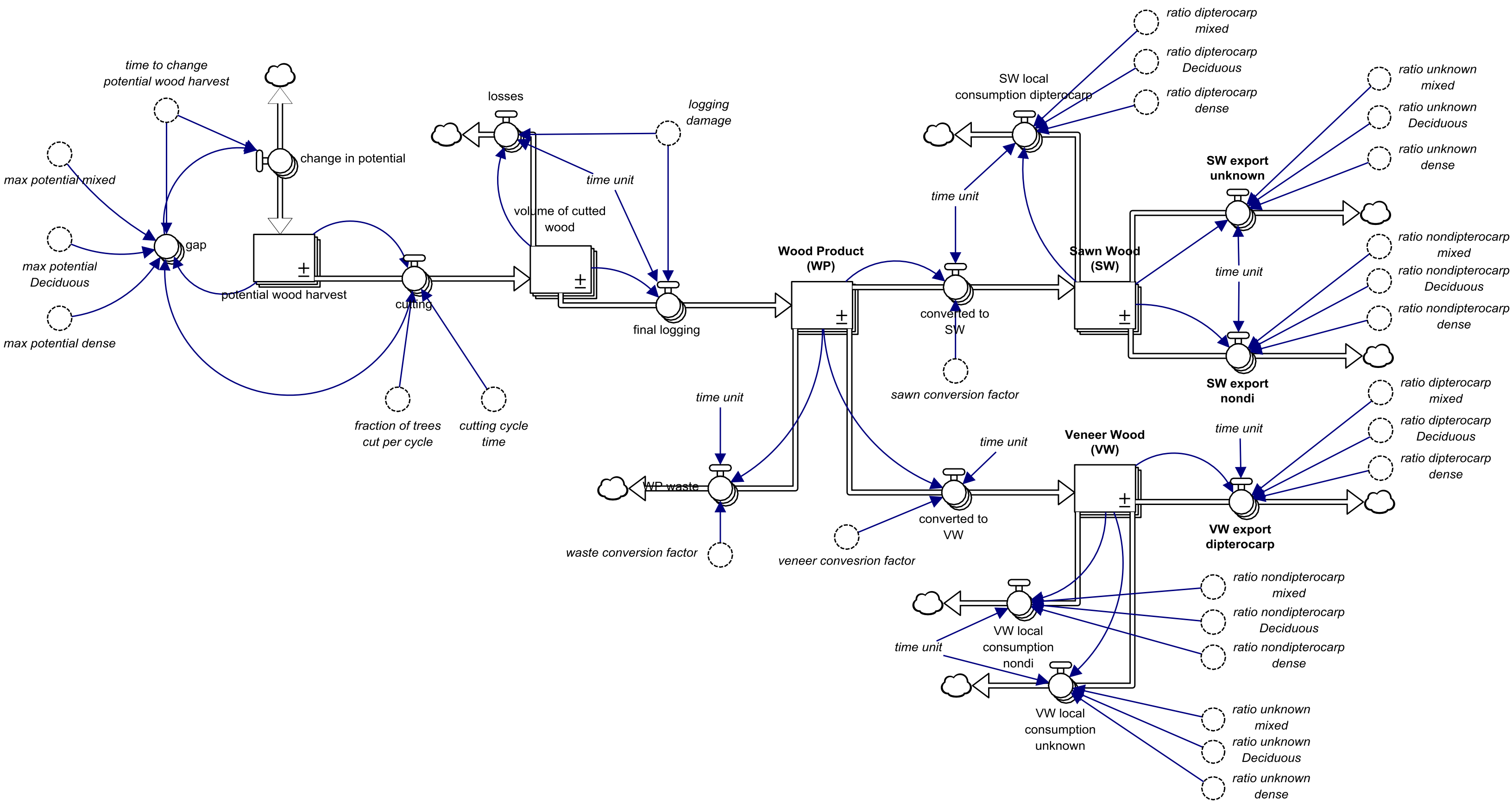

Figure 86. Gov. revenues original

APPENDIX E. RUBBERWOOD PRODUCTION BASED ON (SHIGEMATSU ET AL., 2010)

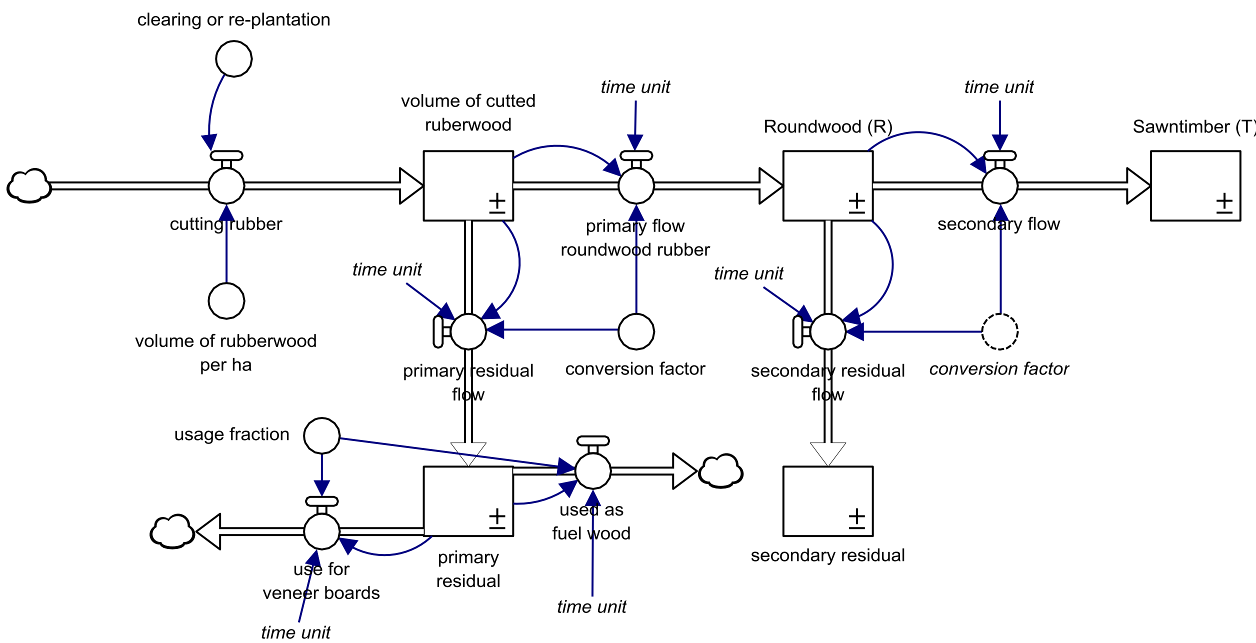

Figure 87. Rubberwood production original

APPENDIX F. CARBON STOCK MODEL BASED ON (SASAKI ET AL., 2012)

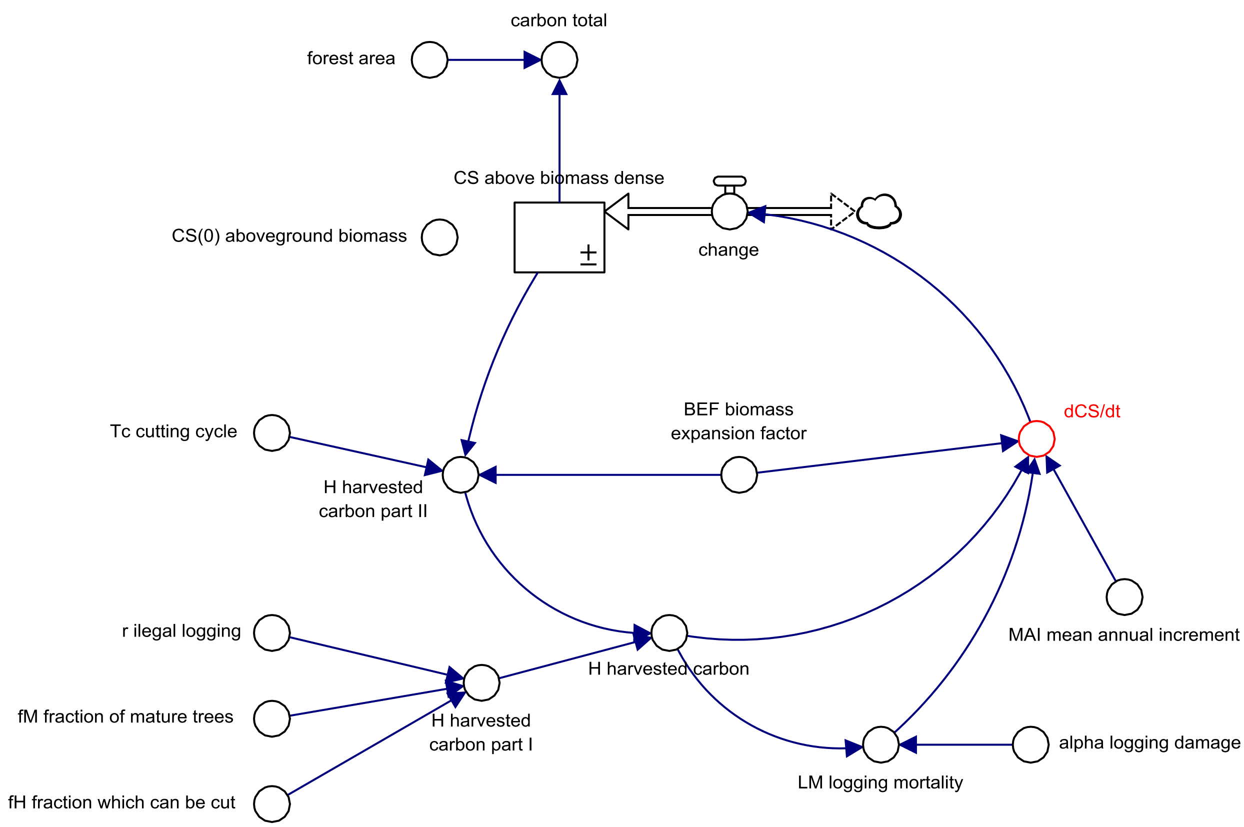

Figure 88. Carbon in managed forest original

APPENDIX G. DOCUMENTATION OF VARIABLES

Top-Level Model:
acacia_plantation(t) = acacia_plantation(t - dt) + (acacia_plantation_development) * dt
INIT acacia_plantation = 4
UNITS: ha
INFLOWS:
acacia_plantation_development = MIN(wood_plantations.planting_acacia, fallow_land/max_fallow_to_ag_conversion)
UNITS: ha/year
additional_share_of_crop_production_for_exports(t) = additional_share_of_crop_production_for_exports(t - dt) + (change_in_the_share_of_crop_production_for_export) * dt
INIT additional_share_of_crop_production_for_exports = 1
UNITS: Dimensionless
INFLOWS:
change_in_the_share_of_crop_production_for_export = additional_share_of_crop_production_for_exports*crop_production_for_export_growth_rate
UNITS: 1/year
argiculture_land(t) = argiculture_land(t - dt) + (grazing_to_agriculture + forest_to_agriculture + fallow_to_agr - agriculture_to_grazing) * dt
INIT argiculture_land = 55437+20469
UNITS: ha
DOCUMENT: Agricultural land and cultivated area: 49,924 ha by 2010 (guess). If the land expanded as it is in model the initial value should be 20 469. In document Stung Treng Province http://www.cambodiainvestment.gov.kh/content/uploads/2014/03/Stung-Treng-Province_eng.pdf.
INFLOWS:
grazing_to_agriculture = MIN((agriculture_land_gap/minimum_land_conversion_time)-forest_to_agriculture-fallow_to_agr, grazing_land/max_fallow_to_ag_conversion)
UNITS: ha/year
forest_to_agriculture = IF forest_land>protected_area THEN MIN((agriculture_land_gap/minimum_land_conversion_time)-fallow_to_agr ,forest_land/max_fallow_to_ag_conversion) ELSE 0
UNITS: ha/year
fallow_to_agr = MIN(agriculture_land_gap/minimum_land_conversion_time ,fallow_land/max_fallow_to_ag_conversion)
UNITS: ha/year
OUTFLOWS:
agriculture_to_grazing = argiculture_land/agriculture_land_lifetime
UNITS: ha/year
"bedload_(sand_and_gravel)"(t) = "bedload_(sand_and_gravel)"(t - dt) + (- construction_materials_extraction) * dt
INIT "bedload_(sand_and_gravel)" = 1000000000
UNITS: ton
OUTFLOWS:
construction_materials_extraction = construction_materials_extraction_for_local_use+construction_material_extraction_for_exports
UNITS: Ton/year
dolphin_population(t) = dolphin_population(t - dt) + (dolphin_fertility - dolphin_mortality) * dt
INIT dolphin_population = 109

UNITS: dolphin
INFLOWS:
dolphin_fertility = dolphin_birth_rate*dolphin_population
UNITS: dolphin/years
OUTFLOWS:
dolphin_mortality =
(dolphin_death_rate*dolphin_population/relative_fish_stock)*(1+(effect_of_hydropower_dam_on_dolphin_mortality)-1)/environmenta_l_flow_requirement
UNITS: dolphin/years

fallow_land(t) = fallow_land(t - dt) + (forest_to_fallow - rubber_plantation_development - acacia_plantation_development - fallow_to_agr - fallow_to_settlement) * dt
INIT fallow_land = 0
UNITS: ha
INFLOWS:
forest_to_fallow = IF forest_land>protected_area THEN timber_clearing ELSE 0
UNITS: ha/year
OUTFLOWS:
rubber_plantation_development = MIN(wood_plantations.planting_rubber, fallow_land/max_fallow_to_ag_conversion)
UNITS: ha/year
acacia_plantation_development = MIN(wood_plantations.planting_acacia, fallow_land/max_fallow_to_ag_conversion)
UNITS: ha/year
fallow_to_agr = MIN(agriculture_land_gap/minimum_land_conversion_time ,fallow_land/max_fallow_to_ag_conversion)
UNITS: ha/year
fallow_to_settlement = MIN((settlement_land_gap/minimum_land_conversion_time) , fallow_land/max_fallow_to_ag_conversion)
UNITS: ha/year

fish_stock(t) = fish_stock(t - dt) + (fish_breeding + fish_migration - fish_catch - fish_mortality) * dt
INIT fish_stock = 120000
UNITS: ton
INFLOWS:
fish_breeding = fish_stock*fish_birth_rate
UNITS: Ton/year
fish_migration = baseline_migration*(1+(effect_of_dam_construction_on_fish)-1)/(environmenta_l_flow_requirement*2)
UNITS: Ton/year
OUTFLOWS:
fish_catch = MIN(desired_fish_consumption_from_local_production,maximum_fish_catch)
UNITS: Ton/year
fish_mortality = fish_death_rate*fish_stock
UNITS: Ton/year

forest_land(t) = forest_land(t - dt) + (- forest_to_agriculture - forest_to_settlement - forest_to_fallow) * dt
INIT forest_land = 1087709+1011774
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/ Based on this site in the year 2000 there were 1087709 ha of forest in Stung Treng and 1011774 ha in Kratie.
OUTFLOWS:

forest_to_agriculture = IF forest_land>protected_area THEN MIN((agriculture_land_gap/minimum_land_conversion_time)-fallow_to_agr ,forest_land/max_fallow_to_ag_conversion) ELSE 0
UNITS: ha/year
forest_to_settlement = IF forest_land>protected_area THEN MIN((settlement_land_gap/minimum_land_conversion_time)-fallow_to_settlement , forest_land/max_fallow_to_ag_conversion) ELSE 0
UNITS: ha/year
forest_to_fallow = IF forest_land>protected_area THEN timber_clearing ELSE 0
UNITS: ha/year
grazing_land(t) = grazing_land(t - dt) + (agriculture_to_grazing - grazing_to_agriculture - grazing_to_settlement) * dt
INIT grazing_land = 2500+840
UNITS: ha
DOCUMENT: Addition calculated as 4.5% of initial value of agriculture land in Stung Treng in 2000 which I calculated as 20 469.
INFLOWS:
agriculture_to_grazing = argiculture_land/agriculture_land_lifetime
UNITS: ha/year
OUTFLOWS:
grazing_to_agriculture = MIN((agriculture_land_gap/minimum_land_conversion_time)-forest_to_agriculture-fallow_to_agr, grazing_land/max_fallow_to_ag_conversion)
UNITS: ha/year
grazing_to_settlement = MIN((settlement_land_gap/minimum_land_conversion_time)-forest_to_settlement-fallow_to_settlement,grazing_land/max_fallow_to_ag_conversion)
UNITS: ha/year
DOCUMENT: Addition calculated as 4.5% of agriculture land
Hydropower_Dam_Capacity(t) = Hydropower_Dam_Capacity(t - dt) + (dam_construction) * dt
INIT Hydropower_Dam_Capacity = 0
UNITS: Mw
INFLOWS:
dam_construction = Hydropower_investment/hydropower_cost_per_mw
UNITS: Mw/years
Hydropower_dam_capital(t) = Hydropower_dam_capital(t - dt) + (inflow_2 - hydropower_capital_discard) * dt
INIT Hydropower_dam_capital = 0
UNITS: usd
INFLOWS:
inflow_2 = Hydropower_investment
UNITS: usd/years
OUTFLOWS:
hydropower_capital_discard = Hydropower_dam_capital/hydropower_dam_useful_lifetime
UNITS: usd/years
hydropower_dam_costs(t) = hydropower_dam_costs(t - dt) + (inflow + actual_O&M_cost) * dt
INIT hydropower_dam_costs = 0
UNITS: usd
INFLOWS:
inflow = Hydropower_investment
UNITS: usd/years
actual_O&M_cost = required_O&M_cost*share_of_O&M_cost_implemented
UNITS: usd/years

hydropower_dam_revenues(t) = hydropower_dam_revenues(t - dt) + (revenues_from_hydropower_generation) * dt
INIT hydropower_dam_revenues = 0
UNITS: usd
INFLOWS:
revenues_from_hydropower_generation = hydropower_price_per_mwh*electricity_generation/4160
UNITS: usd/years
indicated_relative_GDP(t) = indicated_relative_GDP(t - dt) + (gdp_growth) * dt
INIT indicated_relative_GDP = 1
UNITS: Dimensionless
INFLOWS:
gdp_growth = gdp_growth_rate*indicated_relative_GDP
UNITS: dmnl/year
Population(t) = Population(t - dt) + (births + net_migration - deaths) * dt
INIT Population = 363482
UNITS: People
INFLOWS:
births = Population*birth_rate
UNITS: People/years
net_migration = IF Population>maximum_population THEN -(Population-maximum_population)/environmental_quality/migration_time ELSE effect_of_dam_construction_on_immigration
UNITS: People/years
OUTFLOWS:
deaths = death_rate*Population
UNITS: People/years
road_length(t) = road_length(t - dt) + (road_construction - road_decommissioning) * dt
INIT road_length = 1900+660
UNITS: km
DOCUMENT: Original value was 1900 but I believe that this value was just for Kratie province. In document Stung Treng Province http://www.cambodiainvestment.gov.kh/content/uploads/2014/03/Stung-Treng-Province_eng.pdf. I find out that length of roads is 733 km. In the document it is not mentioned for what year are the data valid. Based on the population number 117,490 I am guessing that these date can be valid for year 2010. In the model the road lenght increased by around 10% between 2000 and 2010. On the assumption of the same development in Stung Treng province I estimated the lenght of road as 660 in the year 2000 for Strung Treng.
INFLOWS:
road_construction = (road_infrastructure_investment+"hydropower-related_infrastructure_and_social_investments"*3914)/road_cost_per_km
UNITS: km/years
OUTFLOWS:
road_decommissioning = road_length/road_lifetime
UNITS: km/years
rubber_plantation(t) = rubber_plantation(t - dt) + (rubber_plantation_development) * dt
INIT rubber_plantation = wood_plantations.rubber_plantations_total
UNITS: ha
INFLOWS:
rubber_plantation_development = MIN(wood_plantations.planting_rubber, fallow_land/max_fallow_to_ag_conversion)
UNITS: ha/year

settlement_land(t) = settlement_land(t - dt) + (forest_to_settlement + grazing_to_settlement + fallow_to_settlement) * dt
INIT settlement_land = 80000+000000
UNITS: ha
DOCUMENT: The Provincial Department of Planning (2003) reports that the Stung Treng province has Residential land 103,217 ha in 2003. If I increase the initial value a lot there are no new settlement lands for quite some time. Is the settlement land per capita value correct?
INFLOWS:
forest_to_settlement = IF forest_land>protected_area THEN MIN((settlement_land_gap/minimum_land_conversion_time)-fallow_to_settlement , forest_land/max_fallow_to_ag_conversion) ELSE 0
UNITS: ha/year
grazing_to_settlement = MIN((settlement_land_gap/minimum_land_conversion_time)-forest_to_settlement-fallow_to_settlement,grazing_land/max_fallow_to_ag_conversion)
UNITS: ha/year
DOCUMENT: Addition calculated as 4.5% of argiculture land
fallow_to_settlement = MIN((settlement_land_gap/minimum_land_conversion_time) , fallow_land/max_fallow_to_ag_conversion)
UNITS: ha/year
stock(t) = stock(t - dt) + (sediment - effect_of_sedminet_budget_on_ag_productivity_2) * dt
INIT stock = 1*delay_duration
UNITS: dmnl
INFLOWS:
sediment = "relative_fine_sediment_(suspension)"
UNITS: dmnl/year
OUTFLOWS:
effect_of_sedminet_budget_on_ag_productivity_2 = stock/delay_duration
UNITS: dmnl/year
ag_water_use_efficiency = (argiculture_water_consumption/argiculture_land)/1000
UNITS: m3/ha/Year
agriculture_land_gap = SMTH3(MAX(0, desired_agriculture_land-argiculture_land), averaging_time, MAX(0, desired_agriculture_land-argiculture_land))
UNITS: ha
agriculture_land_lifetime = 100
UNITS: year
agriculture_productivity = reference_crop_yield*precipitation_trend*rainfall_variability/relative_temperature*effect_of_sedminet_budget_on_ag_productivity_2*effect_of_fertilizer_used_on_yield
UNITS: ton/ha/years
argiculture_water_consumption = initial_ag_water_consumption*relative_ag_yield^0.499999999999*relative_agriculture_land^0.45
UNITS: m3/year
average_electricity_price = local_hydro_electricity_supply/(local_hydro_electricity_supply+other_power_supply_table)*hydropower_price_per_mwh+other_power_supply_table/(local_hydro_electricity_supply+other_power_supply_table)*other_power_price_per_mwh
UNITS: KHR/Mw*hour
average_food_price = DELAYN(crop_price*share_of_crops_in_local_diet+fish_price*share_of_fish_in_local_diet+meat_price*share_of_meat_in_local_diet, 1,3, 1200)
UNITS: KHR/Ton

average_salary_per_worker = 200*12
UNITS: usd/people
averaging_time = 1
UNITS: Dimensionless
DOCUMENT: This variable was added to deal with erraticity of agriculture productivity cost by rainfall variability
baseline_migration = 2000
UNITS: ton/year
baseline_O&M_cost = GRAPH(TIME)
(2012,00, 101000), (2023,50, 82000), (2035,00, 70000)
UNITS: usd
birth_rate = GRAPH(TIME)
(2000,00, 0,025), (2001,00, 0,025), (2002,00, 0,025), (2003,00, 0,033), (2004,00, 0,033), (2005,00, 0,033), (2006,00, 0,034), (2007,00, 0,034), (2008,00, 0,034), (2009,00, 0,026), (2010,00, 0,026), (2011,00, 0,026), (2012,00, 0,026), (2013,00, 0,026), (2014,00, 0,026), (2015,00, 0,026), (2016,00, 0,026), (2017,00, 0,026), (2018,00, 0,026), (2019,00, 0,026), (2020,00, 0,026), (2021,00, 0,026), (2022,00, 0,026), (2023,00, 0,026), (2024,00, 0,026), (2025,00, 0,026), (2026,00, 0,026), (2027,00, 0,026), (2028,00, 0,026), (2029,00, 0,026), (2030,00, 0,026), (2031,00, 0,026), (2032,00, 0,026), (2033,00, 0,026), (2034,00, 0,026), (2035,00, 0,026), (2036,00, 0,026), (2037,00, 0,026), (2038,00, 0,026), (2039,00, 0,026), (2040,00, 0,026)
UNITS: Dimensionless/year
construction_employment_per_MW_of_capacity = GRAPH(TIME)
(2010,00, 10,80), (2011,00, 10,86), (2012,00, 10,93), (2013,00, 11,00), (2014,00, 11,06), (2015,00, 11,13), (2016,00, 11,19), (2017,00, 11,26), (2018,00, 11,33), (2019,00, 11,40), (2020,00, 11,47), (2021,00, 11,52), (2022,00, 11,58), (2023,00, 11,64), (2024,00, 11,70), (2025,00, 11,76), (2026,00, 11,81), (2027,00, 11,87), (2028,00, 11,93), (2029,00, 11,99), (2030,00, 12,05)
UNITS: People
construction_material_extraction_for_exports = 1000000
UNITS: Ton/year
construction_material_extraction_per_person = 3
UNITS: Ton/person
DOCUMENT: 7 ton per person in the UK: http://www.hertslink.org/buildingfutures/materials/matfacts/
construction_materials_extraction_for_local_use = MAX(0, (net_migration+births-deaths)*construction_material_extraction_per_person)
UNITS: Ton/Year
construction_materials_extraction_gdp = value_added_per_ton_of_construction_materials_extraction*construction_materials_extraction
UNITS: KHR/Year
crop_calories = crop_production*crop_calories_per_ton
UNITS: calories/year
crop_calories_per_ton = 1300*1000
UNITS: calories/ton
crop_price = DELAYN(crop_self_sufficiency*"crop_price_(local)"+(1-crop_self_sufficiency)*"crop_price_(import)", 1, 3, 750)
UNITS: KHR/ton
"crop_price_(import)" = GRAPH(TIME)
(2000,00, 730), (2001,00, 780), (2002,00, 780), (2003,00, 830), (2004,00, 830), (2005,00, 850), (2006,00, 900), (2007,00, 1050), (2008,00, 1100), (2009,00, 950), (2010,00, 920), (2011,00, 950), (2012,00, 950), (2013,00, 1100), (2014,00, 1100), (2015,00, 1100), (2016,00, 1100), (2017,00, 1100), (2018,00, 1100), (2019,00, 1100), (2020,00, 1100), (2021,00, 1100), (2022,00, 1100), (2023,00, 1100), (2024,00, 1100), (2025,00, 1100), (2026,00, 1100), (2027,00, 1100), (2028,00, 1100), (2029,00, 1100), (2030,00, 1100),

(2031,00, 1100), (2032,00, 1100), (2033,00, 1100), (2034,00, 1100), (2035,00, 1100), (2036,00, 1100), (2037,00, 1100), (2038,00, 1100), (2039,00, 1100), (2040,00, 1100)
UNITS: KHR/ton
"crop_price_(local)" = GRAPH(TIME)
(2000,00, 750), (2001,00, 800), (2002,00, 800), (2003,00, 850), (2004,00, 850), (2005,00, 900), (2006,00, 1000), (2007,00, 1100), (2008,00, 1200), (2009,00, 1000), (2010,00, 950), (2011,00, 1000), (2012,00, 1100), (2013,00, 1200), (2014,00, 1200), (2015,00, 1200), (2016,00, 1200), (2017,00, 1200), (2018,00, 1200), (2019,00, 1200), (2020,00, 1200), (2021,00, 1200), (2022,00, 1200), (2023,00, 1200), (2024,00, 1200), (2025,00, 1200), (2026,00, 1200), (2027,00, 1200), (2028,00, 1200), (2029,00, 1200), (2030,00, 1200), (2031,00, 1200), (2032,00, 1200), (2033,00, 1200), (2034,00, 1200), (2035,00, 1200), (2036,00, 1200), (2037,00, 1200), (2038,00, 1200), (2039,00, 1200), (2040,00, 1200)
UNITS: KHR/ton
crop_production = argiculture_land*agriculture_productivity
UNITS: ton/year
crop_production_for_export =
additional_share_of_crop_production_for_exports*initial_crop_production_for_export
UNITS: Dimensionless
crop_production_for_export_growth_rate = GRAPH(TIME)
(2000,00, 0,010), (2001,00, 0,010), (2002,00, 0,010), (2003,00, 0,010), (2004,00, 0,010), (2005,00, 0,010), (2006,00, 0,450), (2007,00, 0,450), (2008,00, 0,450), (2009,00, 0,450), (2010,00, 0,450), (2011,00, 0,450), (2012,00, 0,450), (2013,00, 0,450), (2014,00, 0,032), (2015,00, 0,032), (2016,00, 0,032), (2017,00, 0,032), (2018,00, 0,032), (2019,00, 0,032), (2020,00, 0,032), (2021,00, 0,032), (2022,00, 0,032), (2023,00, 0,032), (2024,00, 0,032), (2025,00, 0,032), (2026,00, 0,032), (2027,00, 0,032), (2028,00, 0,032), (2029,00, 0,037), (2030,00, 0,032), (2031,00, 0,032), (2032,00, 0,032), (2033,00, 0,032), (2034,00, 0,032), (2035,00, 0,032), (2036,00, 0,032), (2037,00, 0,032), (2038,00, 0,032), (2039,00, 0,032), (2040,00, 0,032)
UNITS: Dimensionless/year
crop_self_sufficiency = MIN(1, crop_production/desired_crop_consumption_from_local_production)
UNITS: dmnl
dam_construction_employment = dam_construction*construction_employment_per_MW_of_capacity
UNITS: Mw*People/Years
dam_O&M_employment = O&M_employment_per_MW_of_capacity*Hydropower_Dam_Capacity
UNITS: Mw
days_per_year = 365
UNITS: day/Year
death_rate = GRAPH(TIME)
(2000,00, 0,007), (2001,00, 0,007), (2002,00, 0,007), (2003,00, 0,007), (2004,00, 0,007), (2005,00, 0,007), (2006,00, 0,007), (2007,00, 0,007), (2008,00, 0,007), (2009,00, 0,004), (2010,00, 0,004), (2011,00, 0,004), (2012,00, 0,004), (2013,00, 0,004), (2014,00, 0,004), (2015,00, 0,004), (2016,00, 0,004), (2017,00, 0,004), (2018,00, 0,004), (2019,00, 0,004), (2020,00, 0,004), (2021,00, 0,004), (2022,00, 0,004), (2023,00, 0,004), (2024,00, 0,004), (2025,00, 0,004), (2026,00, 0,004), (2027,00, 0,004), (2028,00, 0,004), (2029,00, 0,004), (2030,00, 0,004), (2031,00, 0,004), (2032,00, 0,004), (2033,00, 0,004), (2034,00, 0,004), (2035,00, 0,004), (2036,00, 0,004), (2037,00, 0,004), (2038,00, 0,004), (2039,00, 0,004), (2040,00, 0,004)
UNITS: dmnl/year
delay_duration = 3
UNITS: dmnl
desired_agriculture_land =
SMTH3(desired_crop_consumption_from_local_production/agriculture_productivity, averaging_time, desired_crop_consumption_from_local_production/agriculture_productivity)
UNITS: ha

desired_crop_consumption_from_local_production =
((total_food_demand*initial_share_of_crops_in_local_diet)/crop_calories_per_ton*effect_of_crop_price_on_crop_consumption+(unmet_fish_calories/fish_calories_per_ton*share_of_unmet_fish_consumption_to_ag))+crop_production_for_export
UNITS: Ton/Year
desired_fish_consumption_from_local_production =
(total_food_demand*initial_share_of_fish_in_local_diet)/fish_calories_per_ton*effect_of_fish_price_on_fish_consumption
UNITS: ton/year
desired_meat_consumption_from_local_production =
(total_food_demand*initial_share_of_meat_in_local_diet)/meat_calories_per_ton*effect_of_meat_price_on_meat_consumption+(unmet_fish_calories/fish_calories_per_ton*(1-share_of_unmet_fish_consumption_to_ag))
UNITS: ton/year
desired_settlement_land = (Population*settlement_land_per_capita*1.1 +
Hydropower_Dam_Capacity*ha_cleared_per_mw)*extra_growth*effect_of_road_lenght_on_desired_settlement_land
UNITS: ha
dolphin_birth_rate = 0.02
UNITS: Dimensionless/year
dolphin_death_rate = GRAPH(TIME)
(2007,00, 0,042), (2018,50, 0,024), (2030,00, 0,02)
UNITS: 1/years
effect = effect_of_sedminet_budget_on_ag_productivity_2*time_unit
UNITS: dmnl
effect_of_crop_price_on_crop_consumption = GRAPH(relative_crop_price)
(0,000, 1,3000), (0,333333333333, 1,2000), (0,666666666667, 1,1100), (1,000, 1,0000), (1,33333333333, 0,9200), (1,66666666667, 0,9000), (2,000, 0,8900)
UNITS: dmnl
effect_of_dam_construction_on_fish = GRAPH(Hydropower_Dam_Capacity)
(0,0, 1,000), (83,3333333333, 0,900), (166,666666667, 0,750), (250,0, 0,500), (333,333333333, 0,300), (416,666666667, 0,200), (500,0, 0,100)
UNITS: dmnl
effect_of_dam_construction_on_immigration = share_of_local_jobs*total_dam_employment
UNITS: People/year
effect_of_fertilizer_used_on_yield = 1/effect^0.499999999
UNITS: dmnl
effect_of_fish_price_on_fish_consumption = GRAPH(relative_fish_price)
(0,000, 1,300), (0,333333333333, 1,200), (0,666666666667, 1,110), (1,000, 1,000), (1,33333333333, 0,920), (1,66666666667, 0,900), (2,000, 0,890)
UNITS: Dimensionless
"effect_of_gdp/income_on_energy_demand" = 0.5
UNITS: Dimensionless
"effect_of_gdp/income_on_food_demand" = 0.1
UNITS: Dimensionless
effect_of_hydropower_dam_on_dolphin_mortality = GRAPH(Hydropower_Dam_Capacity)
(0, 1,000), (500, 1,500), (1000, 3,000)
UNITS: dmnl
effect_of_meat_price_on_meat_consumption = GRAPH(relative_meat_price)
(0,000, 1,3000), (0,333333333333, 1,2500), (0,666666666667, 1,1500), (1,000, 1,0000), (1,33333333333, 0,8500), (1,66666666667, 0,7800), (2,000, 0,7500)

UNITS: dmnl
effect_of_O&M_expenditure_of_lifetime = GRAPH(share_of_O&M_cost_implemented)
(0,5000, 0,200), (1,0000, 1,000)
UNITS: Dimensionless
effect_of_road_lenght_on_desired_settlement_land = GRAPH(relative_road_length)
(-4,000, 0,750), (-2,000, 0,900), (0,000, 1,000), (2,000, 1,100), (4,000, 1,150)
UNITS: Dimensionless
DOCUMENT: In Cambodia, road development and past policies aimed at in-migration (in particular, offering secure land) have increased demand for land and resources. As immigrants arrive rapidly and often occupy land illegally, existing land-use plans are destabilized and land tenure conflicts become more prevalent. Although migration rates have been falling since 2008, new road developments have opened up previously inaccessible forests, increasing deforestation and degradation in these areas. The situationis exacerbated by lack of state land registration and forest estate demarcation. Protected areas adjacent to development zones are especially threatened by forest encroachment. From: Drivers of Forest Change in the Greater Mekong Subregion, Regional Report
http://www.climatefocus.com/sites/default/files/Drivers%20of%20Forest%20Change%20in%20the%20Greater%20Mekong%20Subregion%20Regional%20Report.pdf pg. 15(9)
electricity_demand_per_capita = GRAPH(TIME)
(2011,000, 1,195), (2013,000, 1,230), (2015,000, 1,500)
UNITS: Dimensionless
electricity_generation = hydro_load_factor*hours_per_year*Hydropower_Dam_Capacity
UNITS: Mw*hour/Year
electricity_supply_per_capita = ((local_hydro_electricity_supply+other_power_supply_table)/Population)
UNITS: Mw*hour/person/Year
eletricity_demand =
electricity_demand_per_capita*Population*"relative_gdp/income"^"effect_of_gdp/income_on_energy_demand"*extra_growth
UNITS: Dimensionless
environmenta_l_flow_requirement = IF(Hydropower_Dam_Capacity=0)THEN 1 ELSE 1
UNITS: dmnl
environmental_quality = 1/effect_of_fertilizer_used_on_yield
UNITS: dmnl
extra_growth = GRAPH(TIME)
(2000,00, 1,000), (2040,00, 1,300)
UNITS: Dimensionless
fish_birth_rate = 0.16
UNITS: dmnl
fish_calories = fish_calories_per_ton*fish_catch
UNITS: calories/Year
fish_calories_per_ton = 2000*1000
UNITS: calories/Ton
fish_death_rate = 0.13
UNITS: Dimensionless/year
fish_price = DELAYN(fish_self_sufficiency*"fish_price_(local)"+(1-fish_self_sufficiency)*"fish_price_(import)", 1, 3, 6000)
UNITS: KHR/ton
"fish_price_(import)" = GRAPH(TIME)
(2000,00, 9000), (2001,00, 9000), (2002,00, 9000), (2003,00, 9000), (2004,00, 10000), (2005,00, 10000), (2006,00, 10000), (2007,00, 10000), (2008,00, 10000), (2009,00, 10000), (2010,00, 10000), (2011,00, 10000), (2012,00, 12000), (2013,00, 12000), (2014,00, 12000)
UNITS: KHR/Ton

"fish_price_(local)" = GRAPH(TIME)
(2000,00, 6000), (2001,00, 6000), (2002,00, 6000), (2003,00, 6000), (2004,00, 7000), (2005,00, 7000), (2006,00, 7000), (2007,00, 7000), (2008,00, 7000), (2009,00, 7000), (2010,00, 7000), (2011,00, 7000), (2012,00, 8000), (2013,00, 8000), (2014,00, 8000)
UNITS: KHR/Ton
fish_self_sufficiency = MIN(1,fish_catch/desired_fish_consumption_from_local_production)
UNITS: dmnl
food_self_sufficiency = total_food_production/total_food_demand
UNITS: dmnl
"forest/protected_forest_ratio" = forest_land/protected_area
UNITS: Dimensionless
gdp_growth_rate = 0.03
UNITS: 1/years
"GDP/income" = (((initial_gdp_per_capita*Population)*indicated_relative_GDP*productivity)+tourism_gdp+construction_materials_extraction_gdp +"hydropower_dam_local_wages_(khr)")
UNITS: KHR/Year
"gdp/income_growth_rate" = TREND("GDP/income", time_for_growth_estimation,"initial_gdp/income_growth_rate")
UNITS: dmnl/year
"gdp/income_per_capita" = "GDP/income"/Population
UNITS: KHR/Year
"gdp/income_per_capita_per_month" = "gdp/income_per_capita"/12
UNITS: KHR/month
ha_cleared_per_mw = 21.53
UNITS: ha/Mw
hours_per_year = 8760
UNITS: Hours/years
hydro_load_factor = IF Hydropower_Dam_Capacity<980 THEN 0.71/(relative_sedimentation^0.2) ELSE 0.71/(relative_sedimentation^0.2)/environmenta_l_flow_requirement^0.3
UNITS: Dimensionless
hydropower_cost_per_mw = 1000000
UNITS: usd/mw
"hydropower_dam_local_wages_(khr)" = hydropower_dam_wages*4160*share_of_local_jobs
UNITS: usd/years
hydropower_dam_useful_lifetime = effect_of_O&M_expenditure_of_lifetime*20
UNITS: Dimensionless
hydropower_dam_wages = total_dam_employment*average_salary_per_worker
UNITS: usd/years
Hydropower_investment = GRAPH(TIME)
(2000,00, 0,0), (2001,00, 0,0), (2002,00, 0,0), (2003,00, 0,0), (2004,00, 0,0), (2005,00, 0,0), (2006,00, 0,0), (2007,00, 0,0), (2008,00, 0,0), (2009,00, 0,0), (2010,00, 0,0), (2011,00, 0,0), (2012,00, 0,0), (2013,00, 0,0), (2014,00, 0,0), (2015,00, 0,0), (2016,00, 98000000,0), (2017,00, 98000000,0), (2018,00, 98000000,0), (2019,00, 98000000,0), (2020,00, 98000000,0), (2021,00, 98000000,0), (2022,00, 98000000,0), (2023,00, 98000000,0), (2024,00, 98000000,0), (2025,00, 98000000,0), (2026,00, 0,0), (2027,00, 0,0), (2028,00, 0,0), (2029,00, 0,0), (2030,00, 0,0), (2031,00, 0,0), (2032,00, 0,0), (2033,00, 0,0), (2034,00, 0,0), (2035,00, 0,0), (2036,00, 0,0), (2037,00, 0,0), (2038,00, 0,0), (2039,00, 0,0), (2040,00, 0,0)
UNITS: usd/years
hydropower_price_per_mwh = 346000
UNITS: KHR/Mw*hour

"hydropower-related_infrastructure_and_social_investments" =
share_of_infrastructure_and_social_investments*Hydropower_investment
UNITS: usd/years
initial_ag_water_consumption = 45000000000
UNITS: m3/year
initial_crop_production_for_export = 50000
UNITS: Dimensionless
initial_crop_yield = 2.5
UNITS: ton/hectare
initial_food_demand_per_capita = 2000*365
UNITS: calories/people
initial_gdp_per_capita = 1000000
UNITS: KHR/people/years
DOCUMENT: See table 3: http://www.adb.org/sites/default/files/institutional-document/151706/cambodia-country-poverty-analysis-2014.pdf (2.1e+006 khr in recent years)
"initial_gdp/income_growth_rate" = 0.06
UNITS: dmnl/year
initial_rainfall = 2012.4
UNITS: Dimensionless
initial_share_of_crops_in_local_diet = 0.9
UNITS: Dimensionless
initial_share_of_fish_in_local_diet = 1-initial_share_of_crops_in_local_diet-initial_share_of_meat_in_local_diet
UNITS: dmnl
initial_share_of_meat_in_local_diet = 0.06
UNITS: dmnl
initial_water_demand = 60000000
UNITS: m3/Year
land_clearing = (forest_to_agriculture+forest_to_settlement+0.000000000001+forest_to_fallow)
UNITS: ha/year
local_hydro_electricity_supply =
share_of_local_electricity_supply*hydro_load_factor*Hydropower_Dam_Capacity*hours_per_year
UNITS: Mw*hour/Year
loss_of_forest = INIT(forest_land)-forest_land
UNITS: ha
max_fallow_to_ag_conversion = 10
UNITS: Years
max_water_consumption = 173200000
UNITS: m3/year
max_water_consumption_for_ag = max_water_consumption-(residential_water_consumption/1000)
UNITS: m3/year
maximum_fish_catch = fish_stock/time_to_catch
UNITS: ton/year
maximum_population = settlement_land/settlement_land_per_capita
UNITS: person
meat_calories = meat_calories_per_ton*meat_production
UNITS: calories/Year
meat_calories_per_ton = 3000*1000
UNITS: calories/Ton
meat_price = DELAYN(meat_self_sufficiency*"meat_price_(local)"+(1-meat_self_sufficiency)*"meat_price_(import)", 1, 3, 18000)

UNITS: KHR/Ton
"meat_price_(import)" = GRAPH(TIME)
(2000,00, 17000), (2001,00, 17000), (2002,00, 17000), (2003,00, 18000), (2004,00, 18000), (2005,00, 19000), (2006,00, 20000), (2007,00, 20000), (2008,00, 21000), (2009,00, 21000), (2010,00, 22000), (2011,00, 22000), (2012,00, 23000), (2013,00, 23000), (2014,00, 24000)
UNITS: KHR/Ton
"meat_price_(local)" = GRAPH(TIME)
(2000,00, 18000), (2001,00, 18000), (2002,00, 18000), (2003,00, 19000), (2004,00, 19000), (2005,00, 20000), (2006,00, 21000), (2007,00, 21000), (2008,00, 22000), (2009,00, 22000), (2010,00, 23000), (2011,00, 23000), (2012,00, 24000), (2013,00, 24000), (2014,00, 25000)
UNITS: KHR/ton
meat_production = MIN(desired_meat_consumption_from_local_production, grazing_land*meat_production_per_ha)
UNITS: Ton/Year
meat_production_per_ha = 2
UNITS: Ton/ha/Year
meat_self_sufficiency = MIN(1, meat_production/desired_meat_consumption_from_local_production)
UNITS: dmnl
migration_time = 1
UNITS: Years
minimum_land_conversion_time = 1
UNITS: Years
O&M_cost_per_MW = baseline_O&M_cost*relative_sedimentation
UNITS: usd
O&M_employment_per_MW_of_capacity = GRAPH(TIME)
(2010,00, 0,22), (2011,00, 0,22), (2012,00, 0,22), (2013,00, 0,22), (2014,00, 0,23), (2015,00, 0,23), (2016,00, 0,23), (2017,00, 0,23), (2018,00, 0,23), (2019,00, 0,23), (2020,00, 0,23), (2021,00, 0,23), (2022,00, 0,24), (2023,00, 0,24), (2024,00, 0,24), (2025,00, 0,24), (2026,00, 0,24), (2027,00, 0,24), (2028,00, 0,24), (2029,00, 0,24), (2030,00, 0,25)
UNITS: dmnl
other_power_price_per_mwh = 470000
UNITS: KHR/Mw*hour
other_power_supply_table = GRAPH(TIME)
(2000,00, 434500), (2002,35294118, 428100), (2004,70588235, 456100), (2007,05882353, 497100), (2009,41176471, 528500), (2011,76470588, 575900), (2014,11764706, 633500), (2016,47058824, 704100), (2018,82352941, 737300), (2021,17647059, 764200), (2023,52941176, 815700), (2025,88235294, 913100), (2028,23529412, 1065000), (2030,58823529, 1183000), (2032,94117647, 1410000), (2035,29411765, 1634000), (2037,64705882, 1750000), (2040,00, 2550000)
UNITS: Mw*hour/Year
"per_capita_food_availability_(day)" = "per_capita_food_availability_(year)"/days_per_year
UNITS: calories/(day*person)
"per_capita_food_availability_(year)" = total_food_production/Population
UNITS: calories/(Year*person)
"per_capita_food_demand_(day)" = "per_capita_food_demand_(year)"/days_per_year
UNITS: calories/(day*person)
"per_capita_food_demand_(year)" = total_food_demand/Population
UNITS: calories/(Year*person)
per_capita_water_consumption = 22550
UNITS: m3/year/person
potential_ag_land = max_water_consumption_for_ag/ag_water_use_efficiency
UNITS: ha

precipitation_trend = rainfall/initial_rainfall
UNITS: Dimensionless
productivity =
relative_electricity_supply_per_capita/relative_average_food_price/relative_average_electricity_price
UNITS: dmnl
protected_area = government_revenues_from_managed_forest.area_which_cannot_be_cleared
UNITS: ha
rainfall = GRAPH(TIME)
(2000,00, 2212), (2001,00, 1964), (2002,00, 1847), (2003,00, 1666), (2004,00, 1752), (2005,00, 1431), (2006,00, 1718), (2007,00, 1911), (2008,00, 1706), (2009,00, 2011), (2010,00, 1342), (2011,00, 1990), (2012,00, 2224), (2013,00, 1992), (2014,00, 1735), (2015,00, 1209), (2016,00, 1830), (2017,00, 1830), (2018,00, 1820), (2019,00, 1820), (2020,00, 1800), (2021,00, 1800), (2022,00, 1800), (2023,00, 1800), (2024,00, 1800), (2025,00, 1800), (2026,00, 1800), (2027,00, 1800), (2028,00, 1800), (2029,00, 1800), (2030,00, 1800), (2031,00, 1800), (2032,00, 1800), (2033,00, 1800), (2034,00, 1800), (2035,00, 1800), (2036,00, 1800), (2037,00, 1790), (2038,00, 1780), (2039,00, 1780), (2040,00, 1766)
UNITS: Dimensionless
rainfall_variability = IF TIME <2017 THEN SMTH3(UNIFORM(0.75 , 1.25 , 0), 0.5, UNIFORM(0.75 , 1.25 , 0)) ELSE SMTH3(UNIFORM(0.75 , 1.25 , 0), 0.5, UNIFORM(0.75 , 1.25 , 0))
UNITS: Dimensionless
reference_crop_yield = GRAPH(TIME)
(2000,00, 2,46), (2001,25, 2,19), (2002,50, 2,11), (2003,75, 1,75), (2005,00, 2,63), (2006,25, 3,16), (2007,50, 3,51), (2008,75, 4,21), (2010,00, 4,91), (2011,25, 6,84), (2012,50, 9,21), (2013,75, 10,53), (2015,00, 10,53), (2016,25, 10,79), (2017,50, 11,05), (2018,75, 11,05), (2020,00, 11,14), (2021,25, 11,23), (2022,50, 11,32), (2023,75, 11,40), (2025,00, 11,49), (2026,25, 11,67), (2027,50, 11,75), (2028,75, 11,84), (2030,00, 11,93), (2031,25, 12,02), (2032,50, 12,11), (2033,75, 12,28), (2035,00, 12,37), (2036,25, 12,46), (2037,50, 12,63), (2038,75, 12,89), (2040,00, 13,07), (2041,25, 13,33), (2042,50, 13,60), (2043,75, 13,68), (2045,00, 13,95), (2046,25, 14,12), (2047,50, 14,30), (2048,75, 14,47), (2050,00, 14,56)
UNITS: ton/ha
reference_tourist_arrivals = GRAPH(TIME)
(2003,00, 8985), (2004,00, 9067), (2005,00, 11080), (2006,00, 16330), (2007,00, 46240), (2008,00, 230200), (2009,00, 223900), (2010,00, 243800), (2011,00, 275600), (2012,00, 332600), (2013,00, 429100), (2014,00, 414300)
UNITS: tourist/Year
relative_ag_yield = agriculture_productivity/initial_crop_yield
UNITS: Dimensionless
relative_agriculture_land = argiculture_land/INIT(argiculture_land)
UNITS: Dimensionless
relative_average_electricity_price = average_electricity_price/INIT(average_electricity_price)
UNITS: dmnl
relative_average_food_price = average_food_price/INIT(average_food_price)
UNITS: Dimensionless
relative_crop_price = crop_price/INIT(crop_price)
UNITS: Dimensionless
relative_electricity_supply_per_capita =
electricity_supply_per_capita/INIT(electricity_supply_per_capita)
UNITS: dmnl
"relative_fine_sediment_(suspension)" = IF TIME<2022 THEN
1/(water_diversion/initial_water_demand)^0.5*0.7^(Hydropower_Dam_Capacity/target_hydro_capacity)
ELSE
MAX(1/(water_diversion/initial_water_demand)^0.5*0.7^(Hydropower_Dam_Capacity/target_hydro_cap

acity),
1/(water_diversion/initial_water_demand^0.5*0.7^(Hydropower_Dam_Capacity/target_hydro_capacity)*environmenta_l_flow_requirement))
UNITS: Dimensionless
relative_fish_price = fish_price/INIT(fish_price)
UNITS: Dimensionless
relative_fish_stock = fish_stock/INIT(fish_stock)
UNITS: Dimensionless
"relative_gdp/income" = "GDP/income"/INIT("GDP/income")
UNITS: KHR/years
"relative_gdp/income^effect_of_gdp/income_on_food_demand" =
"relative_gdp/income"^"effect_of_gdp/income_on_food_demand"
UNITS: Dimensionless
relative_meat_price = meat_price/INIT(meat_price)
UNITS: dmnl
relative_population = Population/INIT(Population)
UNITS: Dimensionless
relative_road_length = road_length/INIT(road_length)
UNITS: Dimensionless
relative_sedimentation = 1/"relative_fine_sediment_(suspension)"
UNITS: Dimensionless
relative_temperature = GRAPH(TIME)
(2000,00, 1,0046), (2001,00, 1,0082), (2002,00, 1,0100), (2003,00, 1,0128), (2004,00, 1,0146), (2005,00, 1,0174), (2006,00, 1,0201), (2007,00, 1,0210), (2008,00, 1,0237), (2009,00, 1,0265), (2010,00, 1,0292), (2011,00, 1,0320), (2012,00, 1,0329), (2013,00, 1,0365), (2014,00, 1,0384), (2015,00, 1,0411), (2016,00, 1,0429), (2017,00, 1,0457), (2018,00, 1,0484), (2019,00, 1,0502), (2020,00, 1,0530), (2021,00, 1,0557), (2022,00, 1,0594), (2023,00, 1,0621), (2024,00, 1,0648), (2025,00, 1,0685), (2026,00, 1,0712), (2027,00, 1,0740), (2028,00, 1,0776), (2029,00, 1,0813), (2030,00, 1,0840), (2031,00, 1,0868), (2032,00, 1,0895), (2033,00, 1,0913), (2034,00, 1,0941), (2035,00, 1,0977), (2036,00, 1,1005), (2037,00, 1,1032), (2038,00, 1,1059), (2039,00, 1,1096), (2040,00, 1,1114)
UNITS: Dimensionless
required_O&M_cost = Hydropower_Dam_Capacity*O&M_cost_per_MW
UNITS: Mw*USD
residential_water_consumption = per_capita_water_consumption*extra_growth*Population
UNITS: m3/year
road_cost_per_km = GRAPH(TIME)
(2002,00, 1219000000), (2003,00, 1,36e+009), (2004,00, 1304000000), (2005,00, 891100000), (2006,00, 711300000), (2007,00, 718100000), (2008,00, 893900000), (2009,00, 1532000000), (2010,00, 1594000000), (2011,00, 1615000000), (2012,00, 1521000000), (2013,00, 1196000000), (2014,00, 1104000000)
UNITS: KHR/km
road_infrastructure_investment = GRAPH(TIME)
(2000,00, 110500000000), (2001,07142857, 52770000000), (2002,14285714, 54400000000), (2003,21428571, 50840000000), (2004,28571429, 60390000000), (2005,35714286, 58640000000), (2006,42857143, 73270000000), (2007,50, 115200000000), (2008,57142857, 274900000000), (2009,64285714, 287200000000), (2010,71428571, 3,03e+011), (2011,78571429, 251400000000), (2012,85714286, 92840000000), (2013,92857143, 297400000000), (2015,00, 2e+011)
UNITS: KHR/km
road_lifetime = 30
UNITS: year
settlement_land_gap = MAX(0, desired_settlement_land-settlement_land)

UNITS: ha
settlement_land_per_capita = 0.202
UNITS: ha/person
share_of_crops_in_local_diet = crop_production/"total_food_production_(tons)"
UNITS: dmnl
share_of_fish_in_local_diet = 1-share_of_crops_in_local_diet-share_of_meat_in_local_diet
UNITS: dmnl
share_of_infrastructure_and_social_investments = 0.1
UNITS: Dimensionless
share_of_local_electricity_supply = 0.15
UNITS: Dimensionless
share_of_local_jobs = 0.4
UNITS: Dimensionless
share_of_meat_in_local_diet = meat_production/"total_food_production_(tons)"
UNITS: dmnl
share_of_O&M_cost_implemented = 1
UNITS: Dimensionless
share_of_unmet_fish_consumption_to_ag = 0.5
UNITS: dmnl
target_hydro_capacity = 900
UNITS: Dimensionless
timber_clearing = timber_demand_and_price.clearing_for_timber
UNITS: ha/year
time_for_growth_estimation = 1
UNITS: year
time_to_catch = 20
UNITS: Year
time_unit = 1
UNITS: year
total_dam_employment = dam_O&M_employment+dam_construction_employment
UNITS: People/year
total_food_demand =
initial_food_demand_per_capita*Population*"relative_gdp/income"^"effect_of_gdp/income_on_food_demand"*extra_growth
UNITS: calories/Year
total_food_production = crop_calories+meat_calories+fish_calories
UNITS: calories/Year
"total_food_production_(tons)" = fish_catch+meat_production+crop_production
UNITS: Ton/Year
total_value_of_food_production =
value_of_crop_production+value_of_meat_production+value_of_fish_catch
UNITS: KHR/Year
tourism_arrivals = IF dolphin_population>0 THEN reference_tourist_arrivals*0.8*relative_road_length ELSE 0
UNITS: tourist/year
tourism_gdp = tourism_arrivals*value_added_per_tourism_visit
UNITS: KHR/Year
unmet_fish_calories = (desired_fish_consumption_from_local_production-fish_catch)*fish_calories_per_ton
UNITS: Ton/Year
value_added_per_ton_of_construction_materials_extraction = 40000

UNITS: KHR/Ton
value_added_per_tourism_visit = 170000*environmental_quality
UNITS: KHR/tourist
value_of_crop_production = "crop_price_(local)"*crop_production
UNITS: KHR/Year
value_of_fish_catch = "fish_price_(local)"*fish_catch
UNITS: KHR/Year
value_of_meat_production = "meat_price_(local)"*meat_production
UNITS: KHR/Year
water_diversion = (agriculture_water_consumption+residential_water_consumption)/1000
UNITS: M3/Years

rabbit_hole:

C_and_CO2:
Cost_per_ton(t) = Cost_per_ton(t - dt) + (change_in_value) * dt
INIT Cost_per_ton = social_cost_of_carbon_initial_2000
UNITS: USD/tCO2
INFLOWS:
change_in_value = annual_increase*Cost_per_ton
UNITS: usd/tCO2/years
above_and_below_C_managed_deciduous_per_ha =
Carbon_in_managed_forest.CS_above_biomass_per_ha_deciduous+Deciduous_forest_C_below_ground_per_ha
UNITS: tC/ha
above_and_below_C_managed_dense_per_ha =
Carbon_in_managed_forest.CS_above_biomass_per_ha_dense+Dense_forest_C_below_ground_per_ha
UNITS: tC/ha
above_and_below_C_managed_mixed_per_ha =
Carbon_in_managed_forest.CS_above_biomass_per_ha_mixed+mixed_forest_C_below_ground_per_ha
UNITS: tC/ha
acacia_plot_1 = 10980
UNITS: ha
DOCUMENT: CAR 5 Biomass and carbon storage of Eucalyptus and Acacia plantations in the Pearl River Delta, South China 2012 http://www.sciencedirect.com/science/article/pii/S0378112712002241 Pg. 6 (95), Table 4
acacia_plot_2 = 17470
UNITS: ha
DOCUMENT: CAR 5 Biomass and carbon storage of Eucalyptus and Acacia plantations in the Pearl River Delta, South China 2012 http://www.sciencedirect.com/science/article/pii/S0378112712002241 Pg. 6 (95), Table 4
acacia_plot_3 = 15690
UNITS: ha
DOCUMENT: CAR 5 Biomass and carbon storage of Eucalyptus and Acacia plantations in the Pearl River Delta, South China 2012 http://www.sciencedirect.com/science/article/pii/S0378112712002241 Pg. 6 (95), Table 4
annual_increase = 0.03
UNITS: dmnl/year
"average_MgC/ha_acacia" = ("MtC/ha_1"+"MtC/ha_2"+"MtC/ha_3")/3
UNITS: tC/ha

average_percentage_dense_forest =
(dense_forest_Stung_Treng_percentage+dense_forest_kratie_percentage)/2
UNITS: dmnl
DOCUMENT: Areas classified as dense forest in these maps include “evergreen forest” and “semi-evergreen forest” as defined in the Forestry Administration’s Cambodia Forest Cover publication dated June 2010. Dense forest is mostly located at elevations higher than 500 meters, although Cambodia has also had large areas of lowland evergreen forests in the past. Dense forest may also be called old-growth forest. As part of their independent analysis of ODC’s 2014 data, Global Forest Watch approximated that the dense forest classification equated to tree canopy cover greater than 60 percent.
https://opendevelopmentcambodia.net/profiles/forest-cover
average_percentage_mixed_forest =
(mixed_forest_kratie_percentage+mixed_forest_Stung_Treng_percentage)/2
UNITS: dmnl
C_per_ha_cassava = (3.4+2.6)/2
UNITS: tC/ha
DOCUMENT:
http://www.zef.de/fileadmin/webfiles/downloads/zefc_ecology_development/ecol_dev_33_text.pdf 106
3.4 2.6
C_per_ha_rice = 16.8
UNITS: tC/ha
DOCUMENT:
http://www.zef.de/fileadmin/webfiles/downloads/zefc_ecology_development/ecol_dev_33_text.pdf 106
C_plot_1 = 285000
UNITS: tC
DOCUMENT: CAR 5 Biomass and carbon storage of Eucalyptus and Acacia plantations in the Pearl River Delta, South China 2012 http://www.sciencedirect.com/science/article/pii/S0378112712002241 Pg. 6 (95), Table 4
C_plot_2 = 449000
UNITS: tC
DOCUMENT: CAR 5 Biomass and carbon storage of Eucalyptus and Acacia plantations in the Pearl River Delta, South China 2012 http://www.sciencedirect.com/science/article/pii/S0378112712002241 Pg. 6 (95), Table 4
C_plot_3 = 506000
UNITS: tC
DOCUMENT: CAR 5 Biomass and carbon storage of Eucalyptus and Acacia plantations in the Pearl River Delta, South China 2012 http://www.sciencedirect.com/science/article/pii/S0378112712002241 Pg. 6 (95), Table 4
C_pool_acacia = "average_MgC/ha_acacia"*wood_plantations.acacia_plantation
UNITS: tC
C_pool_of_cassava = C_per_ha_cassava*size_of_cassava_fields
UNITS: tC
C_pool_of_rice = C_per_ha_rice*size_of_rice_fields
UNITS: tC
"C_rice_+_cassava" = C_pool_of_cassava + C_pool_of_rice
UNITS: tC
"C_rice_+_cassava_per_ha" = "C_rice_+_cassava"/.argiculture_land
UNITS: tC/ha
C_to_CO2 = 44/12
UNITS: tCO2/tC
C_to_CO2_multiplier = 44/12
UNITS: tCO2/ha

cassava_production = GRAPH(TIME)
(2000,00, 14056,0), (2001,00, 1964,0), (2002,00, 4518,0), (2003,00, 832,0), (2004,00, 1040,0), (2005,00, 7184,0), (2006,00, 40756,0), (2007,00, 46631,0), (2008,00, 93306,0), (2009,00, 176029,0), (2010,00, 341995,0), (2011,00, 975352,0), (2012,00, 737625,0), (2013,00, 1416767,0)
UNITS: t
DOCUMENT: Master>WWF file MFF-data-list
Cassava_yield = GRAPH(TIME)
(2000,00, 9,607), (2001,00, 10,46), (2002,00, 6,32), (2003,00, 13,2), (2004,00, 16,08), (2005,00, 17,86), (2006,00, 22,65), (2007,00, 20,5), (2008,00, 20,42), (2009,00, 21,81), (2010,00, 20,99), (2011,00, 21,74), (2012,00, 22,58), (2013,00, 22,85)
UNITS: t/ha
DOCUMENT: https://knoema.com/FAOPRDSC2015Feb/production-statistics-crops-crops-processed-february-2015?country=1000310-cambodia&item=1000260-cassava
change_in_above_and_below_C_managed_deciduous =
change_in_above_and_below_C_managed_deciduous_per_ha*government_revenues_from_managed_forest.Deciduous_forest
UNITS: tC
change_in_above_and_below_C_managed_deciduous_per_ha =
above_and_below_C_managed_deciduous_per_ha-INIT(above_and_below_C_managed_deciduous_per_ha)
UNITS: tC/ha
change_in_above_and_below_C_managed_dense =
change_in_above_and_below_C_managed_dense_per_ha*government_revenues_from_managed_forest.dense_forest
UNITS: tC
change_in_above_and_below_C_managed_dense_per_ha =
above_and_below_C_managed_dense_per_ha-INIT(above_and_below_C_managed_dense_per_ha)
UNITS: tC/ha
change_in_above_and_below_C_managed_mixed =
change_in_above_and_below_C_managed_mixed_per_ha*(government_revenues_from_managed_forest.mixed_forest)
UNITS: tC
change_in_above_and_below_C_managed_mixed_per_ha =
above_and_below_C_managed_mixed_per_ha-INIT(above_and_below_C_managed_mixed_per_ha)
UNITS: tC/ha
change_in_C_acacia = C_pool_acacia-INIT(C_pool_acacia)
UNITS: tC
change_in_C_agriculture = "C_rice_+_cassava"-INIT("C_rice_+_cassava")
UNITS: tC
change_in_C_rubber = Rubber_plantations_C_total- INIT(Rubber_plantations_C_total)
UNITS: tC
change_in_CO2_acacia = change_in_C_acacia*C_to_CO2
UNITS: tCO2
change_in_CO2_agriculture = CO2_agriculture-INIT(CO2_agriculture)
UNITS: tCO2
change_in_CO2_rubber = change_in_C_rubber*C_to_CO2
UNITS: tCO2
CO2_agriculture = C_to_CO2*"C_rice_+_cassava"
UNITS: tCO2
Deciduous_forest = ("mixed_+_Deciduous_forest"/6)*4.5
UNITS: ha

DOCUMENT: My estiamtion for the ratio between mixed forest and deciduos forest is 6:4.5. Based on data here: http://www.fao.org/docrep/013/al470E/al470E.pdf GLOBAL FOREST RESOURCES ASSESSMENT 2010 COUNTRY REPORT CAMBODIA and map of forest cover types here: http://theredddesk.org/sites/default/files/resources/pdf/2013/assessment_of_land_use_forest_policy_and_governance_in_cambodia_1.pdf Assessment of land use, forest policy and governance in Cambodia Working paper Jeremy Broadhead and Rebeca Izquierdo page 13
Deciduous_forest_C = Deciduous_forest*(IF SWITCH=1 THEN Deciduous_forest_C_above_and_below_ground_per_ha ELSE Deciduous_forest_C_all_per_ha)
UNITS: tC
Deciduous_forest_C_above_and_below_ground_per_ha = Deciduous_forest_C_above_ground_per_ha+Deciduous_forest_C_below_ground_per_ha
UNITS: tC/ha
Deciduous_forest_C_above_ground_per_ha = 95.1
UNITS: tC/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
Deciduous_forest_C_all_per_ha = 150
UNITS: tC/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
Deciduous_forest_C_below_ground_per_ha = 28.9
UNITS: tC/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
Deciduous_forest_C_change = Deciduous_forest_C-INIT(Deciduous_forest_C)
UNITS: tC
Deciduous_forest_CO2 = Deciduous_forest*(IF SWITCH=1 THEN Deciduous_forest_CO2_above_and_below_ground_per_ha ELSE Deciduous_forest_CO2_all_per_ha)
UNITS: tCO2
Deciduous_forest_CO2_above_and_below_ground_per_ha = 124*C_to_CO2_multiplier
UNITS: tCO2/ha
Deciduous_forest_CO2_above_ground_per_ha = 95.1*C_to_CO2_multiplier
UNITS: tCO2/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
Deciduous_forest_CO2_all_per_ha = 550.2
UNITS: tCO2/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
Deciduous_forest_CO2_below_ground_per_ha = 28.9*C_to_CO2_multiplier
UNITS: tCO2/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
Deciduous_forest_CO2_change = Deciduous_forest_CO2-INIT(Deciduous_forest_CO2)
UNITS: tCO2
dense_forest = (average_percentage_dense_forest/100)*.forest_land
UNITS: ha
DOCUMENT: Dense forest Areas classified as dense forest in these maps include “evergreen forest” and “semi-evergreen forest” as defined in the Forestry Administration’s Cambodia Forest Cover publication dated June 2010. Dense forest is mostly located at elevations higher than 500 meters, although Cambodia has also had large areas of lowland evergreen forests in the past. Dense forest may also be

called old-growth forest. As part of their independent analysis of ODC's 2014 data, Global Forest Watch approximated that the dense forest classification equated to tree canopy cover greater than 60 percent. https://opendevelopmentcambodia.net/profiles/forest-cover
dense_forest_C = dense_forest*(IF SWITCH=1 THEN Dense_forest_C_above_and_below_ground_per_ha ELSE Dense_forest_C_all_per_ha)
UNITS: tC
Dense_forest_C_above_and_below_ground_per_ha = Dense_forest_C_above_ground_per_ha+Dense_forest_C_below_ground_per_ha
UNITS: tC/ha
Dense_forest_C_above_ground_per_ha = ("Semi-evergreen_C_above_ground_per_ha"+Evergreen_forest_C_above_ground_per_ha)/2
UNITS: tC/ha
DOCUMENT: Dense forest is consists of evergreen and semi-evergreen forest
Dense_forest_C_all_per_ha = ("Semi-evergreen_C_all_per_ha"+Evergreen_forest_C_all_per_ha)/2
UNITS: tC/ha
DOCUMENT: Dense forest is consists of evergreen and semi-evergreen forest
Dense_forest_C_below_ground_per_ha = ("Semi-evergreen_C_below_ground_per_ha"+Evergreen_forest_C_below_ground_per_ha)/2
UNITS: tC/ha
DOCUMENT: Dense forest is consists of evergreen and semi-evergreen forest
dense_forest_C_change = dense_forest_C-INIT(dense_forest_C)
UNITS: tC
dense_forest_CO2 = dense_forest*(IF SWITCH=1 THEN Dense_forest_CO2_above_and_below_ground_per_ha ELSE Dense_forest_CO2_all_per_ha)
UNITS: tCO2
Dense_forest_CO2_above_and_below_ground_per_ha = 126*C_to_CO2_multiplier
UNITS: tCO2/ha
Dense_forest_CO2_above_ground_per_ha = ("Semi-evergreen_CO2_above_ground_per_ha"+Evergreen_forest_CO2_above_ground_per_ha)/2
UNITS: tCO2/ha
DOCUMENT: Dense forest is consists of evergreen and semi-evergreen forest
Dense_forest_CO2_all_per_ha = ("Semi-evergreen_CO2_all_per_ha"+Evergreen_forest_CO2_all_per_ha)/2
UNITS: tCO2/ha
DOCUMENT: Dense forest is consists of evergreen and semi-evergreen forest
Dense_forest_CO2_below_ground_per_ha = ("Semi-evergreen_CO2_below_ground_per_ha"+Evergreen_forest_CO2_below_ground_per_ha)/2
UNITS: tCO2/ha
DOCUMENT: Dense forest is consists of evergreen and semi-evergreen forest
dense_forest_CO2_change = dense_forest_CO2-INIT(dense_forest_CO2)
UNITS: tCO2
dense_forest_kratie = GRAPH(TIME)
(2000,00, 452833), (2004,66666667, 394540), (2009,33333333, 277029), (2014,00, 117104)
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/ Areas classified as dense forest in ODC's maps include evergreen forest and semi-evergreen forest as defined in the Forestry Administration's Cambodia Forest Cover publication (June 2010). Dense forest is mostly located higher than 500 meters. Dense forest may also be called old-growth forest. The definition allows for limited signs of human occupation, such as small settlements of indigenous people in the forest (which the 'primary forest' definition does not). As part of their independent analysis of ODC's

2014 forest cover data, Global Forest Watch stated that dense forest has tree canopy cover greater than 60 percent.
dense_forest_kratie_percentage = (dense_forest_kratie*100)/total_kratie
UNITS: dmnl
dense_forest_Stung_Treng = GRAPH(TIME)
(2000,00, 590502), (2004,66666667, 566443), (2009,33333333, 277029), (2014,00, 439225)
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/
dense_forest_Stung_Treng_percentage = (dense_forest_Stung_Treng*100)/total_Stung_Treng
UNITS: dmnl
Evergreen_forest_C_above_ground_per_ha = 96.2
UNITS: tC/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
Evergreen_forest_C_all_per_ha = 164.8
UNITS: tC/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
Evergreen_forest_C_below_ground_per_ha = 27.8
UNITS: tC/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
Evergreen_forest_CO2_above_ground_per_ha = 96.2*C_to_CO2_multiplier
UNITS: tCO2/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
Evergreen_forest_CO2_all_per_ha = 604.3
UNITS: tCO2/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
Evergreen_forest_CO2_below_ground_per_ha = 27.8*C_to_CO2_multiplier
UNITS: tCO2/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
fraction_of_cassava = size_of_cassava_field/(size_of_cassava_field+size_of_rice_field)
UNITS: Dimensionless
fraction_of_rice = 1-fraction_of_cassava
UNITS: Dimensionless
"mixed_+_Deciduous_forest" = ((100-average_percentage_dense_forest)/100)*(.forest_land)
UNITS: ha
DOCUMENT: Mixed forest Primarily regarded as dry mixed deciduous forest (deciduous trees drop and regrow their leaves seasonally.) Mixed forest may also include regrowth forest, stunted forest, mangroves, inundated or “flooded” forest, and bamboo, as well as forest plantations growing rubber, acacia, and eucalyptus or other tree crops. Areas classified as mixed forest in these maps include “deciduous forest” and “other forest” as defined in the Forestry Administration’s Cambodia Forest Cover 2010. It also includes “grass land” and “wood shrub land evergreen and wood shrub land dry” included in the “non forest” classification of the same publication. This is due to the limitation of color differentiation on the available satellite images. https://opendevelopmentcambodia.net/profiles/forest-cover
mixed_forest = ("mixed_+_Deciduous_forest"/6)*1.5
UNITS: ha

DOCUMENT: My estiamtion for the ratio between mixed forest and deciduos forest is 6:4.5. Based on data here: http://www.fao.org/docrep/013/al470E/al470E.pdf GLOBAL FOREST RESOURCES ASSESSMENT 2010 COUNTRY REPORT CAMBODIA and map of forest cover types here: http://theredddesk.org/sites/default/files/resources/pdf/2013/assessment_of_land_use_forest_policy_and_governance_in_cambodia_1.pdf Assessment of land use, forest policy and governance in Cambodia Working paper Jeremy Broadhead and Rebeca Izquierdo page 13
mixed_forest_C = mixed_forest*(IF SWITCH=1 THEN mixed_forest_C_above_and_below_ground_per_ha ELSE mixed_forest_C_all_per_ha)
UNITS: tC
mixed_forest_C_above_and_below_ground_per_ha = mixed_forest_C_above_ground_per_ha+mixed_forest_C_below_ground_per_ha
UNITS: tC/ha
mixed_forest_C_above_ground_per_ha = Other_forest_C_above_ground_per_ha
UNITS: tC/ha
mixed_forest_C_all_per_ha = Other_forest_C_all_per_ha
UNITS: tC/ha
mixed_forest_C_below_ground_per_ha = Other_forest_C_below_ground_per_ha
UNITS: tC/ha
mixed_forest_C_change = mixed_forest_C-INIT(mixed_forest_C)
UNITS: tC
mixed_forest_CO2 = mixed_forest*(IF SWITCH=1 THEN mixed_forest_CO2_above_and_below_ground_per_ha ELSE mixed_forest_CO2_all_per_ha)
UNITS: tCO2
mixed_forest_CO2_above_and_below_ground_per_ha = 114*C_to_CO2_multiplier
UNITS: tCO2/ha
mixed_forest_CO2_above_ground_per_ha = Other_forest_CO2_above_ground_per_ha
UNITS: tCO2/ha
mixed_forest_CO2_all_per_ha = Other_forest_CO2_all_per_ha
UNITS: tCO2/ha
mixed_forest_CO2_below_ground_per_ha = Other_forest_CO2_below_ground_per_ha
UNITS: tCO2/ha
mixed_forest_CO2_change = mixed_forest_CO2-INIT(mixed_forest_CO2)
UNITS: tCO2
mixed_forest_kratie = GRAPH(TIME)
(2000,00, 558941), (2004,66666667, 584032), (2009,33333333, 592369), (2014,00, 495363)
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/ Primarily regarded as dry mixed deciduous forest (deciduous trees drop and regrow their leaves seasonally.) Mixed forest may also include regrowth forest, stunted forest, mangroves, inundated or “flooded” forest, and bamboo, as well as forest plantations growing rubber, acacia, and eucalyptus or other tree crops. Areas classified as mixed forest in these maps include “deciduous forest” and “other forest” as defined in the Forestry Administration’s Cambodia Forest Cover 2010. It also includes “grass land” and “wood shrub land evergreen and wood shrub land dry” included in the “non forest” classification of the same publication. This is due to the limitation of color differentiation on the available satellite images.
mixed_forest_kratie_percentage = 100-dense_forest_kratie_percentage
UNITS: dmnl
mixed_forest_Stung_Treng = GRAPH(TIME)
(2000,00, 497206), (2004,66666667, 519130), (2009,33333333, 592369), (2014,00, 514610)
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/

mixed_forest_Stung_Treng_percentage = 100-dense_forest_Stung_Treng_percentage
UNITS: dmnl
"MtC/ha_1" = C_plot_1/acacia_plot_1
UNITS: tC/ha
"MtC/ha_2" = C_plot_2/acacia_plot_2
UNITS: tC/ha
"MtC/ha_3" = C_plot_3/acacia_plot_3
UNITS: tC/ha
Other_forest_C_above_ground_per_ha = 87.6
UNITS: tC/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
Other_forest_C_all_per_ha = 138.2
UNITS: tC/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
Other_forest_C_below_ground_per_ha = 26.6
UNITS: tC/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
Other_forest_CO2_above_ground_per_ha = 87.6*C_to_CO2_multiplier
UNITS: tCO2/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
Other_forest_CO2_all_per_ha = 506.9
UNITS: tCO2/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
Other_forest_CO2_below_ground_per_ha = 26.6*C_to_CO2_multiplier
UNITS: tCO2/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
rice_production = GRAPH(TIME)
(2000,00, 62837,0), (2001,00, 71787,0), (2002,00, 107023,0), (2003,00, 124044,0), (2004,00, 81788,0), (2005,00, 98200,0), (2006,00, 164655,0), (2007,00, 184246,0), (2008,00, 169665,0), (2009,00, 173778,0), (2010,00, 193314,0), (2011,00, 212262,0), (2012,00, 155235,0), (2013,00, 214444,0)
UNITS: t
DOCUMENT: Master>WWF file MFF-data-list
rice_yield = GRAPH(TIME)
(2000,00, 2,11), (2001,00, 2,69), (2002,00, 1,91), (2003,00, 2,1), (2004,00, 1,97), (2005,00, 2,49), (2006,00, 2,621), (2007,00, 2,745), (2008,00, 2,836), (2009,00, 2,836), (2010,00, 2,969), (2011,00, 2,957), (2012,00, 3,09), (2013,00, 3,03)
UNITS: t/ha
DOCUMENT: https://knoema.com/FAOPRDSC2015Feb/production-statistics-crops-crops-processed-february-2015?country=1000310-cambodia&item=1000260-cassava
rubber_plantation_C_per_ha = 43.2
UNITS: tC/ha
DOCUMENT: CAR 4 Carbon balance of rubber (Hevea brasiliensis) plantations A review of uncertainties at plot, landscape and production level 2016 http://www.sciencedirect.com/science/article/pii/S0167880916300378 Pg. 3 (10), Table 1 There are many different values in the table coming from many different studies. I have choose to use value for Sri Lanka,

intermediate zone, because it accounts both above and below ground C and has similar rotation period of 30 years.
Rubber_plantations_C_total = wood_plantations.rubber_plantations_total*rubber_plantation_C_per_ha
UNITS: tC
"Semi-evergreen_C_above_ground_per_ha" = 98.1
UNITS: tC/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
"Semi-evergreen_C_all_per_ha" = 154.9
UNITS: tC/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
"Semi-evergreen_C_below_ground_per_ha" = 29.8
UNITS: tC/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
"Semi-evergreen_CO2_above_ground_per_ha" = 98.1*C_to_CO2_multiplier
UNITS: tCO2/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
"Semi-evergreen_CO2_all_per_ha" = 567.9
UNITS: tCO2/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
"Semi-evergreen_CO2_below_ground_per_ha" = 29.8*C_to_CO2_multiplier
UNITS: tCO2/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
size_of_agriculture_land_without_rubber = .argiculture_land
UNITS: ha
size_of_cassava_field = cassava_production/Cassava_yield
UNITS: ha
size_of_cassava_fields = size_of_agriculture_land_without_rubber*fraction_of_cassava
UNITS: ha
size_of_rice_field = rice_production/rice_yield
UNITS: ha
size_of_rice_fields = size_of_agriculture_land_without_rubber*fraction_of_rice
UNITS: ha
social_cost_of_carbon_initial_2000 = 19.88
UNITS: USD/tCO2
social_cost_of_carbon_initial_2015 = 31.2
UNITS: USD/tCO2
DOCUMENT: http://www.pnas.org/content/114/7/1518.full
SWITCH = "SWITCH_only_above_and_below_ground_(1)_or_all_(0)"
UNITS: Dimensionless
"SWITCH_only_above_and_below_ground_(1)_or_all_(0)" = 1
UNITS: Dimensionless
total_change_in_C_managed_forest = change_in_above_and_below_C_managed_deciduous + change_in_above_and_below_C_managed_dense + change_in_above_and_below_C_managed_mixed
UNITS: tC
total_change_in_CO2_managed_forest = C_to_CO2*total_change_in_C_managed_forest

UNITS: tCO2
total_cost_of_carbon_acacia = change_in_CO2_acacia*Cost_per_ton*-1
UNITS: usd
total_cost_of_carbon_agriculture = change_in_CO2_agriculture*Cost_per_ton*-1
UNITS: usd
total_cost_of_carbon_managed_forest = Cost_per_ton*total_change_in_CO2_managed_forest*-1
UNITS: usd
total_cost_of_carbon_plantations = total_cost_of_carbon_acacia + total_cost_of_carbon_rubber
UNITS: usd
total_cost_of_carbon_rubber = change_in_CO2_rubber*Cost_per_ton*-1
UNITS: usd
total_cost_of_carbon_secondary_forest = total_forest_CO2_change*Cost_per_ton*-1
UNITS: USD
total_forest_C = Deciduous_forest_C + dense_forest_C + mixed_forest_C
UNITS: tC
total_forest_C_change = Deciduous_forest_C_change + dense_forest_C_change + mixed_forest_C_change
UNITS: tC
total_forest_CO2 = Deciduous_forest_CO2 + dense_forest_CO2 + mixed_forest_CO2
UNITS: tCO2
total_forest_CO2_change = Deciduous_forest_CO2_change + dense_forest_CO2_change + mixed_forest_CO2_change
UNITS: tCO2
total_kratie = GRAPH(TIME)
(2000,00, 1011774), (2004,66666667, 978575), (2009,33333333, 869399), (2014,00, 612467)
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/
Total_social_cost_of_carbon = total_cost_of_carbon_acacia + total_cost_of_carbon_agriculture + total_cost_of_carbon_managed_forest + total_cost_of_carbon_rubber + total_cost_of_carbon_secondary_forest
UNITS: usd
total_Stung_Treng = GRAPH(TIME)
(2000,00, 1087709), (2004,66666667, 1085574), (2009,33333333, 869399), (2014,00, 953835)
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/

Carbon_in_managed_forest:
CS_above_biomass_per_ha_deciduous(t) = CS_above_biomass_per_ha_deciduous(t - dt) + (change_in_above_CS_deciduous) * dt
INIT CS_above_biomass_per_ha_deciduous = initial_CS_deciduous
UNITS: tC/ha
INFLOWS:
change_in_above_CS_deciduous = "dCS/dt_3"
UNITS: tC/ha/year
CS_above_biomass_per_ha_dense(t) = CS_above_biomass_per_ha_dense(t - dt) + (inflow_of_change_in_above_CS_dense) * dt
INIT CS_above_biomass_per_ha_dense = initial_CS_dense
UNITS: tC/ha
INFLOWS:

inflow_of_change_in_above_CS_dense = change_in_above_CS_dense
UNITS: tC/ha/year
CS_above_biomass_per_ha_mixed(t) = CS_above_biomass_per_ha_mixed(t - dt) + (change_in_above_CS_mixed) * dt
INIT CS_above_biomass_per_ha_mixed = initial_CS_mixed
UNITS: tC/ha
INFLOWS:
change_in_above_CS_mixed = "dCS/dt_2"
UNITS: tC/ha/year
BEF_biomass_expansion_factor = 1.74
UNITS: Dimensionless
DOCUMENT: CAR 7 Managing production forests for timber production and carbon emission reductions under the REDD+ scheme 2012 pg. 2
change_in_above_CS_dense = MAI_mean_annual_increment-(LM_logging_mortality_dense+H_harvested_carbon_complete_dense)*BEF_biomass_expansion_factor
UNITS: tC/ha/year
change_in_volume_of_all_trees_deciduous = volume_of_all_trees_deciduous-initial_volume_of_all_trees_deciduous
UNITS: m3/ha
change_in_volume_of_all_trees_dense = volume_of_all_trees_dense-initial_volume_of_all_trees_dense
UNITS: m3/ha
change_in_volume_of_all_trees_mixed = volume_of_all_trees_mixed-initial_volume_of_all_trees_mixed
UNITS: m3/ha
change_in_volume_of_mature_trees_deciduous = (1-"revenues,_costs,_benefits".logging_damage)*change_in_volume_of_all_trees_deciduous
UNITS: m3/ha
change_in_volume_of_mature_trees_dense = (1-"revenues,_costs,_benefits".logging_damage)*change_in_volume_of_all_trees_dense
UNITS: m3/ha
change_in_volume_of_mature_trees_mixed = (1-"revenues,_costs,_benefits".logging_damage)*change_in_volume_of_all_trees_mixed
UNITS: m3/ha
change_in_volume_of_rest_of_the_trees_deciduous = "revenues,_costs,_benefits".logging_damage*change_in_volume_of_all_trees_deciduous
UNITS: m3/ha
change_in_volume_of_rest_of_the_trees_dense = "revenues,_costs,_benefits".logging_damage*change_in_volume_of_all_trees_dense
UNITS: m3/ha
change_in_volume_of_rest_of_the_trees_mixed = "revenues,_costs,_benefits".logging_damage*change_in_volume_of_all_trees_mixed
UNITS: m3/ha
"dCS/dt_2" = MAI_mean_annual_increment-(LM_logging_mortality_mixed+H_harvested_carbon_complete_dense_1)*BEF_biomass_expansion_factor
UNITS: tC/ha/year
"dCS/dt_3" = MAI_mean_annual_increment-(LM_logging_mortality_deciduous+H_harvested_carbon_complete_deciduous)*BEF_biomass_expansion_factor
UNITS: tC/ha/year
deciduous_forest_C_above_ground_per_ha = 95.1
UNITS: tC/ha

DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
Dense_forest_C_above_ground_per_ha = ("Semi-evergreen_C_above_ground_per_ha"+Evergreen_forest_C_above_ground_per_ha)/2
UNITS: tC/ha
DOCUMENT: Dense forest is consists of evergreen and semi-evergreen forest
Evergreen_forest_C_above_ground_per_ha = 96.2
UNITS: tC/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
fM_fraction_of_mature_trees_deciduous = volume_of_mature_trees_per_ha_deciduous/(volume_of_mature_trees_per_ha_deciduous+volume_of_rest_of_trees_deciduous)
UNITS: Dimensionless
fM_fraction_of_mature_trees_dense = volume_of_mature_trees_per_ha_dense/(volume_of_mature_trees_per_ha_dense+volume_of_rest_of_trees_dense)
UNITS: Dimensionless
fM_fraction_of_mature_trees_mixed = volume_of_mature_trees_per_ha_mixed/(volume_of_mature_trees_per_ha_mixed+volume_of_rest_of_trees_mixed)
UNITS: Dimensionless
H_harvested_carbon_complete_deciduous = H_harvested_carbon_part_II_deciduous*H_harvested_carbon_part_I_deciduous
UNITS: tC/ha/year
H_harvested_carbon_complete_dense = H_harvested_carbon_part_II_dense*H_harvested_carbon_part_I_dense
UNITS: tC/ha/year
H_harvested_carbon_complete_dense_1 = H_harvested_carbon_part_II_mixed*H_harvested_carbon_part_I_dense_1
UNITS: tC/ha/year
H_harvested_carbon_part_I_deciduous = CS_above_biomass_per_ha_deciduous/("revenues,_costs,_benefits".cutting_cycle_time*BEF_biomass_expansion_factor)
UNITS: tC/ha/year
H_harvested_carbon_part_I_dense = CS_above_biomass_per_ha_dense/("revenues,_costs,_benefits".cutting_cycle_time*BEF_biomass_expansion_factor)
UNITS: tC/ha/year
H_harvested_carbon_part_I_dense_1 = CS_above_biomass_per_ha_mixed/("revenues,_costs,_benefits".cutting_cycle_time*BEF_biomass_expansion_factor)
UNITS: tC/ha/year
H_harvested_carbon_part_II_deciduous = fM_fraction_of_mature_trees_deciduous*"revenues,_costs,_benefits".fraction_of_trees_cut_per_cycle/(1-"revenues,_costs,_benefits".illegal_logging_rate)
UNITS: Dimensionless
H_harvested_carbon_part_II_dense = fM_fraction_of_mature_trees_dense*"revenues,_costs,_benefits".fraction_of_trees_cut_per_cycle/(1-"revenues,_costs,_benefits".illegal_logging_rate)
UNITS: Dimensionless

H_harvested_carbon_part_II_mixed =
fM_fraction_of_mature_trees_mixed*"revenues,_costs,_benefits".fraction_of_trees_cut_per_cycle/(1-"revenues,_costs,_benefits".illegal_logging_rate)
UNITS: Dimensionless
initial_CS_deciduous = deciduous_forest_C_above_ground_per_ha
UNITS: tC/ha
initial_CS_dense = Dense_forest_C_above_ground_per_ha
UNITS: tC/ha
initial_CS_mixed = mixed_forest_C_above_ground_per_ha
UNITS: tC/ha
initial_volume_of_all_trees_deciduous = 178.1
UNITS: m3/ha
initial_volume_of_all_trees_dense = 235.2
UNITS: m3/ha
initial_volume_of_all_trees_mixed = 167.9
UNITS: m3/ha
initial_volume_of_mature_trees_deciduous = 117.1
UNITS: m3/ha
DOCUMENT: Estimating actual and potential government revenues from timber harvesting in Cambodia http://www.sciencedirect.com/science/article/pii/S1389934104001509 table 1, pg. 3 DBH of mature trees is
initial_volume_of_mature_trees_dense = 128
UNITS: m3/ha
DOCUMENT: Estimating actual and potential government revenues from timber harvesting in Cambodia http://www.sciencedirect.com/science/article/pii/S1389934104001509 table 1, pg. 3 DBH of mature trees is
initial_volume_of_mature_trees_mixed = 92.7
UNITS: m3/ha
DOCUMENT: Estimating actual and potential government revenues from timber harvesting in Cambodia http://www.sciencedirect.com/science/article/pii/S1389934104001509 table 1, pg. 3 DBH of mature trees is
initial_volume_of_rest_of_the_trees_deciduous = initial_volume_of_all_trees_deciduous-initial_volume_of_mature_trees_deciduous
UNITS: m3/ha
initial_volume_of_rest_of_the_trees_dense = initial_volume_of_all_trees_dense-initial_volume_of_mature_trees_dense
UNITS: m3/ha
initial_volume_of_rest_of_the_trees_mixed = initial_volume_of_all_trees_mixed-initial_volume_of_mature_trees_mixed
UNITS: m3/ha
LM_logging_mortality_deciduous =
H_harvested_carbon_complete_deciduous*"revenues,_costs,_benefits".logging_damage
UNITS: tC/ha/year
LM_logging_mortality_dense =
H_harvested_carbon_complete_dense*"revenues,_costs,_benefits".logging_damage
UNITS: tC/ha/year
LM_logging_mortality_mixed =
H_harvested_carbon_complete_dense_1*"revenues,_costs,_benefits".logging_damage
UNITS: tC/ha/year
MAI_mean_annual_increment = 0.744
UNITS: tC/ha/year

mixed_forest_C_above_ground_per_ha = Other_forest_C_above_ground_per_ha
UNITS: tC/ha
Other_forest_C_above_ground_per_ha = 87.6
UNITS: tC/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
relative_change_biomass_deciduous = CS_above_biomass_per_ha_deciduous/INIT(CS_above_biomass_per_ha_deciduous)
UNITS: Dimensionless
relative_change_biomass_dense = CS_above_biomass_per_ha_dense/INIT(CS_above_biomass_per_ha_dense)
UNITS: Dimensionless
relative_change_biomass_mixed = CS_above_biomass_per_ha_mixed/INIT(CS_above_biomass_per_ha_mixed)
UNITS: Dimensionless
relative_change_in_above_biomass_all_deciduous = (CS_above_biomass_per_ha_deciduous)/INIT(CS_above_biomass_per_ha_deciduous)
UNITS: Dimensionless
relative_change_in_above_biomass_all_dense = (CS_above_biomass_per_ha_dense)/INIT(CS_above_biomass_per_ha_dense)
UNITS: Dimensionless
relative_change_in_above_biomass_all_mixed = (CS_above_biomass_per_ha_mixed)/INIT(CS_above_biomass_per_ha_mixed)
UNITS: Dimensionless
relative_change_mature_deciduous = volume_of_mature_trees_per_ha_deciduous/INIT(volume_of_mature_trees_per_ha_deciduous)
UNITS: Dimensionless
relative_change_mature_dense = volume_of_mature_trees_per_ha_dense/INIT(volume_of_mature_trees_per_ha_dense)
UNITS: Dimensionless
relative_change_mature_mixed = volume_of_mature_trees_per_ha_mixed/INIT(volume_of_mature_trees_per_ha_mixed)
UNITS: Dimensionless
"Semi-evergreen_C_above_ground_per_ha" = 98.1
UNITS: tC/ha
DOCUMENT: Forest Reference Emission Level and Carbon Sequestration in Cambodia 2016 http://www.sciencedirect.com/science/article/pii/S2351989416300063 Pg. 7 (88), Table 1
volume_of_all_trees_deciduous = relative_change_in_above_biomass_all_deciduous*initial_volume_of_all_trees_deciduous
UNITS: m3/ha
volume_of_all_trees_dense = relative_change_in_above_biomass_all_dense*initial_volume_of_all_trees_dense
UNITS: m3/ha
volume_of_all_trees_mixed = relative_change_in_above_biomass_all_mixed*initial_volume_of_all_trees_mixed
UNITS: m3/ha
volume_of_mature_trees_per_ha_deciduous = initial_volume_of_mature_trees_deciduous+change_in_volume_of_mature_trees_deciduous
UNITS: m3/ha

DOCUMENT: Estimating actual and potential government revenues from timber harvesting in Cambodia http://www.sciencedirect.com/science/article/pii/S1389934104001509 table 1, pg. 3 DBH of mature trees is
volume_of_mature_trees_per_ha_dense = initial_volume_of_mature_trees_dense+change_in_volume_of_mature_trees_dense
UNITS: m3/ha
DOCUMENT: Estimating actual and potential government revenues from timber harvesting in Cambodia http://www.sciencedirect.com/science/article/pii/S1389934104001509 table 1, pg. 3 DBH of mature trees is
volume_of_mature_trees_per_ha_mixed = initial_volume_of_mature_trees_mixed+change_in_volume_of_mature_trees_mixed
UNITS: m3/ha
DOCUMENT: Estimating actual and potential government revenues from timber harvesting in Cambodia http://www.sciencedirect.com/science/article/pii/S1389934104001509 table 1, pg. 3 DBH of mature trees is
volume_of_rest_of_trees_deciduous = initial_volume_of_rest_of_the_trees_deciduous+change_in_volume_of_rest_of_the_trees_deciduous
UNITS: m3/ha
volume_of_rest_of_trees_dense = initial_volume_of_rest_of_the_trees_dense+change_in_volume_of_rest_of_the_trees_dense
UNITS: m3/ha
volume_of_rest_of_trees_mixed = initial_volume_of_rest_of_the_trees_mixed+change_in_volume_of_rest_of_the_trees_mixed
UNITS: m3/ha

government_revenues_from_clearing:
accumulated_revenue_from_land_clearing(t) = accumulated_revenue_from_land_clearing(t - dt) + (revenue_flow) * dt
INIT accumulated_revenue_from_land_clearing = 0
UNITS: usd
INFLOWS:
revenue_flow = Total_revenue_from_clearing
UNITS: usd/years
volume_of_cut_wood[mixed](t) = volume_of_cut_wood[mixed](t - dt) + (cutting[mixed] - losses[mixed] - processing[mixed]) * dt
INIT volume_of_cut_wood[mixed] = init_VCW[mixed]
UNITS: m3
volume_of_cut_wood[Deciduous](t) = volume_of_cut_wood[Deciduous](t - dt) + (cutting[Deciduous] - losses[Deciduous] - processing[Deciduous]) * dt
INIT volume_of_cut_wood[Deciduous] = init_VCW[Deciduous]
UNITS: m3
volume_of_cut_wood[dense](t) = volume_of_cut_wood[dense](t - dt) + (cutting[dense] - losses[dense] - processing[dense]) * dt
INIT volume_of_cut_wood[dense] = init_VCW[dense]
UNITS: m3
UNITS: m3
INFLOWS:
cutting[mixed] = max_potential_mixed/time_unit
UNITS: M3/year
cutting[Deciduous] = max_potential_Deciduous/time_unit
UNITS: M3/year

cutting[dense] = max_potential_dense/time_unit
UNITS: M3/year
UNITS: M3/year
OUTFLOWS:
losses[mixed] =
(volume_of_cut_wood[mixed]*("revenues,_costs,_benefits".logging_waste))/time_unit
UNITS: M3/year
losses[Deciduous] =
(volume_of_cut_wood[Deciduous]*("revenues,_costs,_benefits".logging_waste))/time_unit
UNITS: M3/year
losses[dense] = (volume_of_cut_wood[dense]*"revenues,_costs,_benefits".logging_waste)/time_unit
UNITS: M3/year
UNITS: M3/year
processing[mixed] = (volume_of_cut_wood[mixed]*(1-
"revenues,_costs,_benefits".logging_waste))/time_unit
UNITS: M3/year
processing[Deciduous] = (volume_of_cut_wood[Deciduous]*(1-
"revenues,_costs,_benefits".logging_waste))/time_unit
UNITS: M3/year
processing[dense] = (volume_of_cut_wood[dense]*(1-
"revenues,_costs,_benefits".logging_waste))/time_unit
UNITS: M3/year
UNITS: M3/year
"Wood_Product_(WP)"[mixed](t) = "Wood_Product_(WP)"[mixed](t - dt) + (processing[mixed] -
selling_WP[mixed]) * dt
INIT "Wood_Product_(WP)"[mixed] = init_WP[mixed]
UNITS: m3
"Wood_Product_(WP)"[Deciduous](t) = "Wood_Product_(WP)"[Deciduous](t - dt) +
(processing[Deciduous] - selling_WP[Deciduous]) * dt
INIT "Wood_Product_(WP)"[Deciduous] = init_WP[Deciduous]
UNITS: m3
"Wood_Product_(WP)"[dense](t) = "Wood_Product_(WP)"[dense](t - dt) + (processing[dense] -
selling_WP[dense]) * dt
INIT "Wood_Product_(WP)"[dense] = init_WP[dense]
UNITS: m3
UNITS: m3
INFLOWS:
processing[mixed] = (volume_of_cut_wood[mixed]*(1-
"revenues,_costs,_benefits".logging_waste))/time_unit
UNITS: M3/year
processing[Deciduous] = (volume_of_cut_wood[Deciduous]*(1-
"revenues,_costs,_benefits".logging_waste))/time_unit
UNITS: M3/year
processing[dense] = (volume_of_cut_wood[dense]*(1-
"revenues,_costs,_benefits".logging_waste))/time_unit
UNITS: M3/year
UNITS: M3/year
OUTFLOWS:
selling_WP[mixed] = "Wood_Product_(WP)"[mixed]/time_unit
UNITS: M3/year
selling_WP[Deciduous] = "Wood_Product_(WP)"[Deciduous]/time_unit

UNITS: M3/year
selling_WP[dense] = "Wood_Product_(WP)"[dense]/time_unit
UNITS: M3/year
UNITS: M3/year
annual_operable_area = 1-"revenues,_costs,_benefits".illegal_logging_rate
UNITS: Dimensionless
DOCUMENT: Total annual operable area (FoA) in all forest concessions can be estimated by: FoA ¼ RRFaoAjk ð9Þ where FaoAjk is the sum of annual operable areas of j forest (i.e., evergreen, mixed, or deciduous forests) in k forest concession. In 1997 there were 44 forest concessions covering a total area of 5.3 million ha, or about 50% of the country's forest area (DFW, 1998). The area of forest concessions changes frequently because of the government's policy reform. For simplicity, however, the above area is assumed to be constant.
average_percentage_dense_forest = (dense_forest_Stung_Treng_percentage+dense_forest_kratie_percentage)/2
UNITS: Dimensionless
DOCUMENT: Areas classified as dense forest in these maps include "evergreen forest" and "semi-evergreen forest" as defined in the Forestry Administration's Cambodia Forest Cover publication dated June 2010. Dense forest is mostly located at elevations higher than 500 meters, although Cambodia has also had large areas of lowland evergreen forests in the past. Dense forest may also be called old-growth forest. As part of their independent analysis of ODC's 2014 data, Global Forest Watch approximated that the dense forest classification equated to tree canopy cover greater than 60 percent. https://opendevelopmentcambodia.net/profiles/forest-cover
average_percentage_mixed_forest = (mixed_forest_kratie_percentage+mixed_forest_Stung_Treng_percentage)/2
UNITS: dmnl
custom_charge_total = customs_charge*timber_price*exporting_WP
UNITS: usd/years
customs_charge = 0.00085
UNITS: Dimensionless
DOCUMENT: Estimating actual and potential government revenues from timber harvesting in Cambodia http://www.sciencedirect.com/science/article/pii/S1389934104001509
Deciduous_forest = (("mixed_+_Deciduous_forest"/6)*4.5)*annual_operable_area
UNITS: ha
DOCUMENT: My estiamtion for the ratio between mixed forest and deciduos forest is 6:4.5. Based on data here: http://www.fao.org/docrep/013/al470E/al470E.pdf GLOBAL FOREST RESOURCES ASSESSMENT 2010 COUNTRY REPORT CAMBODIA and map of forest cover types here: http://theredddesk.org/sites/default/files/resources/pdf/2013/assessment_of_land_use_forest_policy_and_governance_in_cambodia_1.pdf Assessment of land use, forest policy and governance in Cambodia Working paper Jeremy Broadhead and Rebeca Izquierdo page 13
Deciduous_volume_of_mature_trees = 117.1
UNITS: m3/ha
DOCUMENT: Estimating actual and potential government revenues from timber harvesting in Cambodia http://www.sciencedirect.com/science/article/pii/S1389934104001509 table 1, pg. 3 (627) Value represents volume of mature trees
dense_forest = (((average_percentage_dense_forest/100)*.land_clearing)*time_unit)*annual_operable_area
UNITS: ha
DOCUMENT: Dense forest Areas classified as dense forest in these maps include "evergreen forest" and "semi-evergreen forest" as defined in the Forestry Administration's Cambodia Forest Cover publication dated June 2010. Dense forest is mostly located at elevations higher than 500 meters, although Cambodia has also had large areas of lowland evergreen forests in the past. Dense forest may also be

called old-growth forest. As part of their independent analysis of ODC's 2014 data, Global Forest Watch approximated that the dense forest classification equated to tree canopy cover greater than 60 percent. https://opendevelopmentcambodia.net/profiles/forest-cover
dense_forest_kratie = GRAPH(TIME)
(2000,00, 452833), (2004,66666667, 394540), (2009,33333333, 277029), (2014,00, 117104)
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/ Areas classified as dense forest in ODC's maps include evergreen forest and semi-evergreen forest as defined in the Forestry Administration's Cambodia Forest Cover publication (June 2010). Dense forest is mostly located higher than 500 meters. Dense forest may also be called old-growth forest. The definition allows for limited signs of human occupation, such as small settlements of indigenous people in the forest (which the 'primary forest' definition does not). As part of their independent analysis of ODC's 2014 forest cover data, Global Forest Watch stated that dense forest has tree canopy cover greater than 60 percent.
dense_forest_kratie_percentage = (dense_forest_kratie*100)/total_kratie
UNITS: dmnl
dense_forest_Stung_Treng = GRAPH(TIME)
(2000,00, 590502), (2004,66666667, 566443), (2009,33333333, 277029), (2014,00, 439225)
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/
dense_forest_Stung_Treng_percentage = (dense_forest_Stung_Treng*100)/total_Stung_Treng
UNITS: dmnl
dense_volume_of_mature_trees = 128.1
UNITS: m3/ha
DOCUMENT: Estimating actual and potential government revenues from timber harvesting in Cambodia http://www.sciencedirect.com/science/article/pii/S1389934104001509 table 1, pg. 3 (627) Value represents mature trees
export_tax_total = exporting_WP*timber_price*tax_on_export
UNITS: usd/years
exporting_WP = timber_demand_and_price.exports_fraction*(selling_WP[mixed]+selling_WP[Deciduous]+selling_WP[dense])
UNITS: m3/year
init_VCW[potential_wood_harverst] = cutting
UNITS: m3/year
init_WP[potential_wood_harverst] = processing*time_unit
UNITS: m3
licence_fee_total = license_export_fee*timber_price*exporting_WP
UNITS: usd/years
license_export_fee = 0.01
UNITS: Dimensionless
DOCUMENT: Estimating actual and potential government revenues from timber harvesting in Cambodia http://www.sciencedirect.com/science/article/pii/S1389934104001509
max_potential_Deciduous = Deciduous_volume_of_mature_trees*Deciduous_forest
UNITS: m3
max_potential_dense = dense_volume_of_mature_trees*dense_forest
UNITS: M3
max_potential_mixed = mixed_volume_of_mature_trees*mixed_forest
UNITS: m3
"mixed_+_Deciduous_forest" = (((100-average_percentage_dense_forest)/100)*.land_clearing)*time_unit

UNITS: ha
DOCUMENT: Mixed forest Primarily regarded as dry mixed deciduous forest (deciduous trees drop and regrow their leaves seasonally.) Mixed forest may also include regrowth forest, stunted forest, mangroves, inundated or "flooded" forest, and bamboo, as well as forest plantations growing rubber, acacia, and eucalyptus or other tree crops. Areas classified as mixed forest in these maps include "deciduous forest" and "other forest" as defined in the Forestry Administration's Cambodia Forest Cover 2010. It also includes "grass land" and "wood shrub land evergreen and wood shrub land dry" included in the "non forest" classification of the same publication. This is due to the limitation of color differentiation on the available satellite images. https://opendevelopmentcambodia.net/profiles/forest-cover
"mixed_+_Deciduous_forest_percentage" = ((100-average_percentage_dense_forest)/100)
UNITS: Dimensionless
mixed_forest = (("mixed_+_Deciduous_forest"/6)*1.5)*annual_operable_area
UNITS: ha
DOCUMENT: My estiamtion for the ratio between mixed forest and deciduos forest is 6:4.5. Based on data here: http://www.fao.org/docrep/013/al470E/al470E.pdf GLOBAL FOREST RESOURCES ASSESSMENT 2010 COUNTRY REPORT CAMBODIA and map of forest cover types here: http://theredddesk.org/sites/default/files/resources/pdf/2013/assessment_of_land_use_forest_policy_and_governance_in_cambodia_1.pdf Assessment of land use, forest policy and governance in Cambodia Working paper Jeremy Broadhead and Rebeca Izquierdo page 13
mixed_forest_kratie = GRAPH(TIME)
(2000,00, 558941), (2004,66666667, 584032), (2009,33333333, 592369), (2014,00, 495363)
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/ Primarily regarded as dry mixed deciduous forest (deciduous trees drop and regrow their leaves seasonally.) Mixed forest may also include regrowth forest, stunted forest, mangroves, inundated or "flooded" forest, and bamboo, as well as forest plantations growing rubber, acacia, and eucalyptus or other tree crops. Areas classified as mixed forest in these maps include "deciduous forest" and "other forest" as defined in the Forestry Administration's Cambodia Forest Cover 2010. It also includes "grass land" and "wood shrub land evergreen and wood shrub land dry" included in the "non forest" classification of the same publication. This is due to the limitation of color differentiation on the available satellite images.
mixed_forest_kratie_percentage = 100-dense_forest_kratie_percentage
UNITS: dmnl
mixed_forest_Stung_Treng = GRAPH(TIME)
(2000,00, 497206), (2004,66666667, 519130), (2009,33333333, 592369), (2014,00, 514610)
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/
mixed_forest_Stung_Treng_percentage = 100-dense_forest_Stung_Treng_percentage
UNITS: dmnl
mixed_volume_of_mature_trees = 92.7
UNITS: m3/ha
DOCUMENT: Estimating actual and potential government revenues from timber harvesting in Cambodia http://www.sciencedirect.com/science/article/pii/S1389934104001509 table 1, pg. 3
ratio_dipterocarp_Deciduous = 0.084
UNITS: Dimensionless
DOCUMENT: All dipterocarp WP
ratio_dipterocarp_dense = 0.657
UNITS: Dimensionless
DOCUMENT: All dipterocarp WP
ratio_dipterocarp_mixed = 0.492
UNITS: Dimensionless

DOCUMENT: All dipterocarp WP
ratio_nondipterocarp_Deciduous = 0.804
UNITS: Dimensionless
DOCUMENT: All nondipterocarp WP
ratio_nondipterocarp_dense = 0.146
UNITS: Dimensionless
DOCUMENT: All nondipterocarp WP
ratio_nondipterocarp_mixed = 0.293
UNITS: Dimensionless
DOCUMENT: All nondipterocarp WP
ratio_unknown_Deciduous = 0.112
UNITS: Dimensionless
DOCUMENT: All unknown WP
ratio_unknown_dense = 0.196
UNITS: Dimensionless
DOCUMENT: All unknown WP
ratio_unknown_mixed = 0.215
UNITS: Dimensionless
DOCUMENT: All unknown WP
reforestation_tax_dipterocarp_WP_Deciduous =
ratio_dipterocarp_Deciduous*reforestation_tax_rate*"Wood_Product_(WP)"[Deciduous]
UNITS: usd
reforestation_tax_dipterocarp_WP_dense =
reforestation_tax_rate*"Wood_Product_(WP)"[dense]*ratio_dipterocarp_dense
UNITS: usd
reforestation_tax_dipterocarp_WP_mixed =
"Wood_Product_(WP)"[mixed]*ratio_dipterocarp_mixed*reforestation_tax_rate
UNITS: USD
reforestation_tax_for_nondipterocarp_WP_Deciduous =
ratio_nondipterocarp_Deciduous*reforestation_tax_rate*"Wood_Product_(WP)"[Deciduous]
UNITS: usd
reforestation_tax_for_nondipterocarp_WP_dense =
reforestation_tax_rate*"Wood_Product_(WP)"[dense]*ratio_nondipterocarp_dense
UNITS: usd
reforestation_tax_for_nondipterocarp_WP_mixed =
reforestation_tax_rate*ratio_nondipterocarp_mixed*"Wood_Product_(WP)"[mixed]
UNITS: usd
reforestation_tax_for_unknown_WP_Deciduous =
ratio_unknown_Deciduous*reforestation_tax_rate*"Wood_Product_(WP)"[Deciduous]
UNITS: usd
reforestation_tax_for_unknown_WP_dense =
reforestation_tax_rate*"Wood_Product_(WP)"[dense]*ratio_unknown_dense
UNITS: usd
reforestation_tax_for_unknown_WP_mixed =
reforestation_tax_rate*ratio_unknown_mixed*"Wood_Product_(WP)"[mixed]
UNITS: usd
reforestation_tax_rate = 2.3
UNITS: USD/m3
Royalty_for_dipterocarp_WP_Deciduous =
"Wood_Product_(WP)"[Deciduous]*Royalty_rates_for_dipterocarp_WP*ratio_dipterocarp_Deciduous
UNITS: usd

Royalty_for_dipterocarp_WP_dense =
"Wood_Product_(WP)"[dense]*Royalty_rates_for_dipterocarp_WP*ratio_dipterocarp_dense
UNITS: usd
Royalty_for_dipterocarp_WP_mixed =
Royalty_rates_for_dipterocarp_WP*ratio_dipterocarp_mixed*"Wood_Product_(WP)"[mixed]
UNITS: usd
Royalty_for_nondipterocarp_WP_Deciduous =
"Wood_Product_(WP)"[Deciduous]*Royalty_rates_for_nondipterocarp_WP*ratio_nondipterocarp_Deciduous
UNITS: usd
Royalty_for_nondipterocarp_WP_dense =
"Wood_Product_(WP)"[dense]*Royalty_rates_for_nondipterocarp_WP*ratio_nondipterocarp_dense
UNITS: usd
Royalty_for_nondipterocarp_WP_mixed =
Royalty_rates_for_nondipterocarp_WP*ratio_nondipterocarp_mixed*"Wood_Product_(WP)"[mixed]
UNITS: usd
Royalty_for_unknown_WP_Deciduous =
"Wood_Product_(WP)"[Deciduous]*Royalty_rates_for_unknown_WP*ratio_unknown_Deciduous
UNITS: usd
Royalty_for_unknown_WP_dense =
Royalty_rates_for_unknown_WP*"Wood_Product_(WP)"[dense]*ratio_unknown_dense
UNITS: usd
Royalty_for_unknown_WP_mixed =
Royalty_rates_for_unknown_WP*ratio_unknown_mixed*"Wood_Product_(WP)"[mixed]
UNITS: usd
Royalty_rates_for_dipterocarp_WP = 40
UNITS: USD/m3
Royalty_rates_for_nondipterocarp_WP = 38
UNITS: USD/m3
Royalty_rates_for_unknown_WP = 20
UNITS: USD/m3
royalty_total_deciduous = Royalty_for_dipterocarp_WP_Deciduous +
Royalty_for_nondipterocarp_WP_Deciduous + Royalty_for_unknown_WP_Deciduous +
reforestation_tax_dipterocarp_WP_Deciduous + reforestation_tax_for_nondipterocarp_WP_Deciduous +
reforestation_tax_for_unknown_WP_Deciduous
UNITS: USD
royalty_total_dense = Royalty_for_dipterocarp_WP_dense + Royalty_for_nondipterocarp_WP_dense +
Royalty_for_unknown_WP_dense + reforestation_tax_dipterocarp_WP_dense +
reforestation_tax_for_nondipterocarp_WP_dense + reforestation_tax_for_unknown_WP_dense
UNITS: USD
royalty_total_mixed = Royalty_for_dipterocarp_WP_mixed + Royalty_for_nondipterocarp_WP_mixed +
Royalty_for_unknown_WP_mixed + reforestation_tax_dipterocarp_WP_mixed +
reforestation_tax_for_nondipterocarp_WP_mixed + reforestation_tax_for_unknown_WP_mixed
UNITS: USD
tax_on_export = 0.1
UNITS: Dimensionless
DOCUMENT: Estimating actual and potential government revenues from timber harvesting in Cambodia http://www.sciencedirect.com/science/article/pii/S1389934104001509
timber_price = timber_demand_and_price.timber_price
UNITS: USD/m3
time_unit = 1

UNITS: year
total_kratie = GRAPH(TIME)
(2000,00, 1011774), (2004,66666667, 978575), (2009,33333333, 869399), (2014,00, 612467)
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/
Total_revenue_from_clearing =
(royalty_total_mixed+royalty_total_dense+royalty_total_deciduous)/time_unit+custom_charge_total+licence_fee_total+export_tax_total
UNITS: usd/years
total_Stung_Treng = GRAPH(TIME)
(2000,00, 1087709), (2004,66666667, 1085574), (2009,33333333, 869399), (2014,00, 953835)
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/
Total_WP_from_clearing = SUM("Wood_Product_(WP)"[*])
UNITS: m3
volume_of_mature_trees_per_ha = volume_of_trees_for_Decidous + volume_of_trees_for_dense + volume_of_trees_for_mixed
UNITS: m3/ha
volume_of_timber_per_ha = volume_of_mature_trees_per_ha*(1-"revenues,_costs,_benefits".logging_waste)
UNITS: m3/ha
volume_of_trees_for_Decidous =
("mixed_+_Deciduous_forest_percentage"/6)*1.5*Deciduous_volume_of_mature_trees
UNITS: m3/ha
volume_of_trees_for_dense = (average_percentage_dense_forest/100)*dense_volume_of_mature_trees
UNITS: m3/ha
volume_of_trees_for_mixed =
("mixed_+_Deciduous_forest_percentage"/6)*4.5*mixed_volume_of_mature_trees
UNITS: m3/ha

government_revenues_from_managed_forest:
accumulated_revenue_from_managed_forest(t) = accumulated_revenue_from_managed_forest(t - dt) + (revenue_inflow) * dt
INIT accumulated_revenue_from_managed_forest = 0
UNITS: USD
INFLOWS:
revenue_inflow = total_revenue
UNITS: usd/years
potential_wood_harvest[mixed](t) = potential_wood_harvest[mixed](t - dt) + (change_in_potential[mixed]) * dt
INIT potential_wood_harvest[mixed] = INIT(max_potential_mixed)
UNITS: m3
potential_wood_harvest[Deciduous](t) = potential_wood_harvest[Deciduous](t - dt) + (change_in_potential[Deciduous]) * dt
INIT potential_wood_harvest[Deciduous] = INIT(max_potential_deciduous)
UNITS: m3
potential_wood_harvest[dense](t) = potential_wood_harvest[dense](t - dt) + (change_in_potential[dense]) * dt
INIT potential_wood_harvest[dense] = INIT(max_potential_dense)

UNITS: m3
UNITS: m3
INFLOWS:
change_in_potential[mixed] = gap_in_potential[mixed]/time_unit
UNITS: M3/year
change_in_potential[Deciduous] = gap_in_potential[Deciduous]/time_unit
UNITS: M3/year
change_in_potential[dense] = gap_in_potential[dense]/time_unit
UNITS: M3/year
UNITS: M3/year
volume_of_cut_wood[mixed](t) = volume_of_cut_wood[mixed](t - dt) + (cutting[mixed] - losses[mixed] - final_logging[mixed]) * dt
INIT volume_of_cut_wood[mixed] = init_VCW[mixed]
UNITS: m3
volume_of_cut_wood[Deciduous](t) = volume_of_cut_wood[Deciduous](t - dt) + (cutting[Deciduous] - losses[Deciduous] - final_logging[Deciduous]) * dt
INIT volume_of_cut_wood[Deciduous] = init_VCW[Deciduous]
UNITS: m3
volume_of_cut_wood[dense](t) = volume_of_cut_wood[dense](t - dt) + (cutting[dense] - losses[dense] - final_logging[dense]) * dt
INIT volume_of_cut_wood[dense] = init_VCW[dense]
UNITS: m3
UNITS: m3
INFLOWS:
cutting[mixed] = ("revenues,_costs,_benefits".fraction_of_trees_cut_per_cycle*potential_wood_harvest[mixed])/"revenues,_costs,_benefits".cutting_cycle_time
UNITS: M3/year
cutting[Deciduous] = ("revenues,_costs,_benefits".fraction_of_trees_cut_per_cycle*potential_wood_harvest[Deciduous])/"revenues,_costs,_benefits".cutting_cycle_time
UNITS: M3/year
cutting[dense] = ("revenues,_costs,_benefits".fraction_of_trees_cut_per_cycle*potential_wood_harvest[dense])/"revenues,_costs,_benefits".cutting_cycle_time
UNITS: M3/year
UNITS: M3/year
OUTFLOWS:
losses[mixed] = (volume_of_cut_wood[mixed]*("revenues,_costs,_benefits".logging_waste))/time_unit
UNITS: M3/year
losses[Deciduous] = (volume_of_cut_wood[Deciduous]*("revenues,_costs,_benefits".logging_waste))/time_unit
UNITS: M3/year
losses[dense] = (volume_of_cut_wood[dense]*("revenues,_costs,_benefits".logging_waste))/time_unit
UNITS: M3/year
UNITS: M3/year
final_logging[mixed] = (volume_of_cut_wood[mixed]*(1-"revenues,_costs,_benefits".logging_waste))/time_unit
UNITS: M3/year

final_logging[Deciduous] = (volume_of_cut_wood[Deciduous]*(1-"revenues,_costs,_benefits".logging_waste))/time_unit
UNITS: M3/year
final_logging[dense] = (volume_of_cut_wood[dense]*(1-"revenues,_costs,_benefits".logging_waste))/time_unit
UNITS: M3/year
UNITS: M3/year
"Wood_Product_(WP)"[mixed](t) = "Wood_Product_(WP)"[mixed](t - dt) + (final_logging[mixed] - selling_WP[mixed]) * dt
INIT "Wood_Product_(WP)"[mixed] = init_WP[mixed]
UNITS: m3
"Wood_Product_(WP)"[Deciduous](t) = "Wood_Product_(WP)"[Deciduous](t - dt) + (final_logging[Deciduous] - selling_WP[Deciduous]) * dt
INIT "Wood_Product_(WP)"[Deciduous] = init_WP[Deciduous]
UNITS: m3
"Wood_Product_(WP)"[dense](t) = "Wood_Product_(WP)"[dense](t - dt) + (final_logging[dense] - selling_WP[dense]) * dt
INIT "Wood_Product_(WP)"[dense] = init_WP[dense]
UNITS: m3
UNITS: m3
INFLOWS:
final_logging[mixed] = (volume_of_cut_wood[mixed]*(1-"revenues,_costs,_benefits".logging_waste))/time_unit
UNITS: M3/year
final_logging[Deciduous] = (volume_of_cut_wood[Deciduous]*(1-"revenues,_costs,_benefits".logging_waste))/time_unit
UNITS: M3/year
final_logging[dense] = (volume_of_cut_wood[dense]*(1-"revenues,_costs,_benefits".logging_waste))/time_unit
UNITS: M3/year
UNITS: M3/year
OUTFLOWS:
selling_WP[mixed] = ("Wood_Product_(WP)"[mixed]/time_unit)
UNITS: M3/year
selling_WP[Deciduous] = ("Wood_Product_(WP)"[Deciduous]/time_unit)
UNITS: M3/year
selling_WP[dense] = ("Wood_Product_(WP)"[dense]/time_unit)
UNITS: M3/year
UNITS: M3/year
annual_operable_area = 1-"revenues,_costs,_benefits".illegal_logging_rate
UNITS: Dimensionless
DOCUMENT: Total annual operable area (FoA) in all forest concessions can be estimated by: FoA ¼ RRFaoAjk ð9Þ where FaoAjk is the sum of annual operable areas of j forest (i.e., evergreen, mixed, or deciduous forests) in k forest concession. In 1997 there were 44 forest concessions covering a total area of 5.3 million ha, or about 50% of the country’s forest area (DFW, 1998). The area of forest concessions changes frequently because of the government’s policy reform. For simplicity, however, the above area is assumed to be constant.
area_which_cannot_be_cleared = managed_forest
UNITS: ha
average_percentage_dense_forest = (dense_forest_Stung_Treng_percentage+dense_forest_kratie_percentage)/2

UNITS: dmnl
DOCUMENT: Areas classified as dense forest in these maps include “evergreen forest” and “semi-evergreen forest” as defined in the Forestry Administration’s Cambodia Forest Cover publication dated June 2010. Dense forest is mostly located at elevations higher than 500 meters, although Cambodia has also had large areas of lowland evergreen forests in the past. Dense forest may also be called old-growth forest. As part of their independent analysis of ODC’s 2014 data, Global Forest Watch approximated that the dense forest classification equated to tree canopy cover greater than 60 percent.
https://opendevelopmentcambodia.net/profiles/forest-cover
change_of_managed_forest = IF TIME=2018 OR(TIME>2018) AND(SWITCH_to_change_managed_forest_in_2018=1) THEN fractional_change_in_size_in_2018 ELSE 1
UNITS: dmnl
Community_forest = Community_forest_Stung_Treng+Community_forest_Kratie
UNITS: ha
DOCUMENT: TI 2 Understanding timber flows and control in Cambodia in the context of FLEGT 2014
http://www.euflegt.efi.int/documents/10180/211477/Understanding+timber+flows+and+control+in+Cambodia+in+the+context+of+FLEGTc/03c0c17a-5dd0-43d6-9ccc-b4f661ba7463 Pg. 33 Forest managed by community for timber and NFTPs "Based on the Community Forest Agreement, a Community Forest community has the right to plant, manage, harvest forest products and NTFPs and sell tree species as approved in a Community Forest management plan. Community Forest agreements are for a maximum of 15 years and are renewable for another 15 years based on article 27."
Community_forest_Kratie = 59042
UNITS: ha
DOCUMENT: TI 2 Understanding timber flows and control in Cambodia in the context of FLEGT 2014
http://www.euflegt.efi.int/documents/10180/211477/Understanding+timber+flows+and+control+in+Cambodia+in+the+context+of+FLEGTc/03c0c17a-5dd0-43d6-9ccc-b4f661ba7463 Pg. 34 Forest managed by community for timber and NFTPs "Based on the Community Forest Agreement, a Community Forest community has the right to plant, manage, harvest forest products and NTFPs and sell tree species as approved in a Community Forest management plan. Community Forest agreements are for a maximum of 15 years and are renewable for another 15 years based on article 27."
Community_forest_Stung_Treng = 16208
UNITS: ha
DOCUMENT: TI 2 Understanding timber flows and control in Cambodia in the context of FLEGT 2014
http://www.euflegt.efi.int/documents/10180/211477/Understanding+timber+flows+and+control+in+Cambodia+in+the+context+of+FLEGTc/03c0c17a-5dd0-43d6-9ccc-b4f661ba7463 Pg. 34 Forest managed by community for timber and NFTPs "Based on the Community Forest Agreement, a Community Forest community has the right to plant, manage, harvest forest products and NTFPs and sell tree species as approved in a Community Forest management plan. Community Forest agreements are for a maximum of 15 years and are renewable for another 15 years based on article 27."
custom_charge_total = customs_charge*timber_price*exporting_WP
UNITS: usd/years
customs_charge = 0.085
UNITS: Dimensionless
DOCUMENT: Estimating actual and potential government revenues from timber harvesting in Cambodia http://www.sciencedirect.com/science/article/pii/S1389934104001509
Deciduous_forest = ("mixed_+_Deciduous_forest"*0.67)*annual_operable_area
UNITS: ha

DOCUMENT: My estiamtion for the ratio between mixed forest and deciduos forest is 6:4.5. Based on data here: http://www.fao.org/docrep/013/al470E/al470E.pdf GLOBAL FOREST RESOURCES ASSESSMENT 2010 COUNTRY REPORT CAMBODIA and map of forest cover types here: http://theredddesk.org/sites/default/files/resources/pdf/2013/assessment_of_land_use_forest_policy_and_governance_in_cambodia_1.pdf Assessment of land use, forest policy and governance in Cambodia Working paper Jeremy Broadhead and Rebeca Izquierdo page 13
dense_forest = ((average_percentage_dense_forest/100)*managed_forest)*annual_operable_area
UNITS: ha
DOCUMENT: Dense forest Areas classified as dense forest in these maps include "evergreen forest" and "semi-evergreen forest" as defined in the Forestry Administration's Cambodia Forest Cover publication dated June 2010. Dense forest is mostly located at elevations higher than 500 meters, although Cambodia has also had large areas of lowland evergreen forests in the past. Dense forest may also be called old-growth forest. As part of their independent analysis of ODC's 2014 data, Global Forest Watch approximated that the dense forest classification equated to tree canopy cover greater than 60 percent. https://opendevelopmentcambodia.net/profiles/forest-cover
dense_forest_kratie = GRAPH(TIME)
(2000,00, 452833), (2004,66666667, 394540), (2009,33333333, 277029), (2014,00, 117104)
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/ Areas classified as dense forest in ODC's maps include evergreen forest and semi-evergreen forest as defined in the Forestry Administration's Cambodia Forest Cover publication (June 2010). Dense forest is mostly located higher than 500 meters. Dense forest may also be called old-growth forest. The definition allows for limited signs of human occupation, such as small settlements of indigenous people in the forest (which the 'primary forest' definition does not). As part of their independent analysis of ODC's 2014 forest cover data, Global Forest Watch stated that dense forest has tree canopy cover greater than 60 percent.
dense_forest_kratie_percentage = (dense_forest_kratie*100)/total_kratie
UNITS: dmnl
dense_forest_Stung_Treng = GRAPH(TIME)
(2000,00, 590502), (2004,66666667, 566443), (2009,33333333, 277029), (2014,00, 439225)
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/
dense_forest_Stung_Treng_percentage = (dense_forest_Stung_Treng*100)/total_Stung_Treng
UNITS: dmnl
export_tax_total = tax_on_export*timber_price*exporting_WP
UNITS: usd/years
exporting_WP = timber_demand_and_price.exports_fraction*(selling_WP[mixed]+selling_WP[Deciduous]+selling_WP[dense])
UNITS: m3/year
fraction_of_trees_cut_per_cycle = 0.3
UNITS: Dimensionless
fractional_change_in_size_in_2018 = 1
UNITS: dmnl
gap_in_potential[mixed] = max_potential_mixed-potential_wood_harvest[mixed]
UNITS: m3
gap_in_potential[Deciduous] = max_potential_deciduous-potential_wood_harvest[Deciduous]
UNITS: m3
gap_in_potential[dense] = max_potential_dense-potential_wood_harvest[dense]
UNITS: m3

UNITS: m3
init_VCW[potential_wood_harverst] = cutting*time_unit
UNITS: M3
init_WP[potential_wood_harverst] = time_unit*final_logging
UNITS: M3
Kratie_protected_area = 62000
UNITS: ha
DOCUMENT: Snoul Wildlife Sanctuary https://www.protectedplanet.net/68869
Kratie_protected_forest = 59640
UNITS: ha
DOCUMENT: Aproximatelly 1/5 of Seima protected forest https://www.protectedplanet.net/478398 TI 2 Understanding timber flows and control in Cambodia in the context of FLEGT 2014 http://www.euflegt.efi.int/documents/10180/211477/Understanding+timber+flows+and+control+in+Cambodia+in+the+context+of+FLEGTc/03c0c17a-5dd0-43d6-9ccc-b4f661ba7463 Pg. 27 Protection Forests under Forestry Law do not include Protected Areas under the jurisdiction of the Ministry of Environment pursuant to the environmental protection and natural resource management law. Local communities have customary user rights to collect Forest Products and NTFP within the Protection Forest with minimal impact on the forests.
licence_fee_total = license_export_fee*timber_price*exporting_WP
UNITS: usd/years
license_export_fee = 0.01
UNITS: Dimensionless
DOCUMENT: Estimating actual and potential government revenues from timber harvesting in Cambodia http://www.sciencedirect.com/science/article/pii/S1389934104001509
managed_forest = MIN((Community_forest+protected_land_total)*change_of_managed_forest, .forest_land)
UNITS: ha
max_potential_deciduous = Deciduous_forest*Carbon_in_managed_forest.volume_of_mature_trees_per_ha_deciduous
UNITS: m3
max_potential_dense = Carbon_in_managed_forest.volume_of_mature_trees_per_ha_dense*dense_forest
UNITS: m3
max_potential_mixed = Carbon_in_managed_forest.volume_of_mature_trees_per_ha_mixed*mixed_forest
UNITS: m3
"mixed_+_Deciduous_forest" = ((100-average_percentage_dense_forest)/100)*(managed_forest)
UNITS: ha
DOCUMENT: Mixed forest Primarily regarded as dry mixed deciduous forest (deciduous trees drop and regrow their leaves seasonally.) Mixed forest may also include regrowth forest, stunted forest, mangroves, inundated or “flooded” forest, and bamboo, as well as forest plantations growing rubber, acacia, and eucalyptus or other tree crops. Areas classified as mixed forest in these maps include “deciduous forest” and “other forest” as defined in the Forestry Administration’s Cambodia Forest Cover 2010. It also includes “grass land” and “wood shrub land evergreen and wood shrub land dry” included in the “non forest” classification of the same publication. This is due to the limitation of color differentiation on the available satellite images. https://opendevelopmentcambodia.net/profiles/forest-cover
"mixed_+_Deciduous_forest_percentage" = ((100-average_percentage_dense_forest)/100)
UNITS: Dimensionless
mixed_forest = ("mixed_+_Deciduous_forest"*0.33)*annual_operable_area
UNITS: ha

DOCUMENT: My estiamtion for the ratio between mixed forest and deciduos forest is 6:4.5. Based on data here: http://www.fao.org/docrep/013/al470E/al470E.pdf GLOBAL FOREST RESOURCES ASSESSMENT 2010 COUNTRY REPORT CAMBODIA
protected_land_total = Kratie_protected_forest+Stung_treng_protected_area+Kratie_protected_area
UNITS: ha
ratio_dipterocarp_Deciduous = 0.084
UNITS: Dimensionless
DOCUMENT: All dipterocarp WP
ratio_dipterocarp_dense = 0.657
UNITS: Dimensionless
DOCUMENT: All dipterocarp WP
ratio_dipterocarp_mixed = 0.492
UNITS: Dimensionless
DOCUMENT: All dipterocarp WP
ratio_nondipterocarp_Deciduous = 0.804
UNITS: Dimensionless
DOCUMENT: All nondipterocarp WP
ratio_nondipterocarp_dense = 0.146
UNITS: Dimensionless
DOCUMENT: All nondipterocarp WP
ratio_nondipterocarp_mixed = 0.293
UNITS: Dimensionless
DOCUMENT: All nondipterocarp WP
ratio_unknown_Deciduous = 0.112
UNITS: Dimensionless
DOCUMENT: All unknown WP
ratio_unknown_dense = 0.196
UNITS: Dimensionless
DOCUMENT: All unknown WP
ratio_unknown_mixed = 0.215
UNITS: Dimensionless
DOCUMENT: All unknown WP
reforestation_tax_dipterocarp_WP_Deciduous =
ratio_dipterocarp_Deciduous*reforestation_tax_rate*"Wood_Product_(WP)"[Deciduous]
UNITS: usd
reforestation_tax_dipterocarp_WP_dense =
reforestation_tax_rate*"Wood_Product_(WP)"[dense]*ratio_dipterocarp_dense
UNITS: usd
reforestation_tax_dipterocarp_WP_mixed =
"Wood_Product_(WP)"[mixed]*ratio_dipterocarp_mixed*reforestation_tax_rate
UNITS: USD
reforestation_tax_for_nondipterocarp_WP_Deciduous =
ratio_nondipterocarp_Deciduous*reforestation_tax_rate*"Wood_Product_(WP)"[Deciduous]
UNITS: usd
reforestation_tax_for_nondipterocarp_WP_dense =
reforestation_tax_rate*"Wood_Product_(WP)"[dense]*ratio_nondipterocarp_dense
UNITS: usd
reforestation_tax_for_nondipterocarp_WP_mixed =
reforestation_tax_rate*ratio_nondipterocarp_mixed*"Wood_Product_(WP)"[mixed]
UNITS: usd

reforestation_tax_for_unknown_WP_Deciduous =
ratio_unknown_Deciduous*reforestation_tax_rate*"Wood_Product_(WP)"[Deciduous]
UNITS: usd
reforestation_tax_for_unknown_WP_dense =
reforestation_tax_rate*"Wood_Product_(WP)"[dense]*ratio_unknown_dense
UNITS: usd
reforestation_tax_for_unknown_WP_mixed =
reforestation_tax_rate*ratio_unknown_mixed*"Wood_Product_(WP)"[mixed]
UNITS: usd
reforestation_tax_rate = 2.3
UNITS: USD/m3
Royalty_for_dipterocarp_WP_Deciduous =
"Wood_Product_(WP)"[Deciduous]*Royalty_rates_for_dipterocarp_WP*ratio_dipterocarp_Deciduous
UNITS: usd
Royalty_for_dipterocarp_WP_dense =
"Wood_Product_(WP)"[dense]*Royalty_rates_for_dipterocarp_WP*ratio_dipterocarp_dense
UNITS: usd
Royalty_for_dipterocarp_WP_mixed =
Royalty_rates_for_dipterocarp_WP*ratio_dipterocarp_mixed*"Wood_Product_(WP)"[mixed]
UNITS: usd
Royalty_for_nondipterocarp_WP_Deciduous =
"Wood_Product_(WP)"[Deciduous]*Royalty_rates_for_nondipterocarp_WP*ratio_nondipterocarp_Decid
uous
UNITS: usd
Royalty_for_nondipterocarp_WP_dense =
"Wood_Product_(WP)"[dense]*Royalty_rates_for_nondipterocarp_WP*ratio_nondipterocarp_dense
UNITS: usd
Royalty_for_nondipterocarp_WP_mixed =
Royalty_rates_for_nondipterocarp_WP*ratio_nondipterocarp_mixed*"Wood_Product_(WP)"[mixed]
UNITS: usd
Royalty_for_unknown_WP_Deciduous =
"Wood_Product_(WP)"[Deciduous]*Royalty_rates_for_unknown_WP*ratio_unknown_Deciduous
UNITS: usd
Royalty_for_unknown_WP_dense =
Royalty_rates_for_unknown_WP*"Wood_Product_(WP)"[dense]*ratio_unknown_dense
UNITS: usd
Royalty_for_unknown_WP_mixed =
Royalty_rates_for_unknown_WP*ratio_unknown_mixed*"Wood_Product_(WP)"[mixed]
UNITS: usd
Royalty_rates_for_dipterocarp_WP = 40
UNITS: USD/m3
Royalty_rates_for_nondipterocarp_WP = 38
UNITS: USD/m3
Royalty_rates_for_unknown_WP = 20
UNITS: USD/m3
royalty_total_deciduous = Royalty_for_dipterocarp_WP_Deciduous +
Royalty_for_nondipterocarp_WP_Deciduous + Royalty_for_unknown_WP_Deciduous +
reforestation_tax_dipterocarp_WP_Deciduous + reforestation_tax_for_nondipterocarp_WP_Deciduous +
reforestation_tax_for_unknown_WP_Deciduous
UNITS: USD

royalty_total_dense = Royalty_for_dipterocarp_WP_dense + Royalty_for_nondipterocarp_WP_dense + Royalty_for_unknown_WP_dense + reforestation_tax_dipterocarp_WP_dense + reforestation_tax_for_nondipterocarp_WP_dense + reforestation_tax_for_unknown_WP_dense
UNITS: USD
royalty_total_mixed = Royalty_for_dipterocarp_WP_mixed + Royalty_for_nondipterocarp_WP_mixed + Royalty_for_unknown_WP_mixed + reforestation_tax_dipterocarp_WP_mixed + reforestation_tax_for_nondipterocarp_WP_mixed + reforestation_tax_for_unknown_WP_mixed
UNITS: USD
Stung_treng_protected_area = 112500
UNITS: ha
DOCUMENT: Approximitely 1/3 of Virachey Nation Park https://www.protectedplanet.net/virachey-national-park-and-asean-heritage-park
SWITCH_to_change_managed_forest_in_2018 = 1
UNITS: dmnl
tax_on_export = 0.1
UNITS: Dimensionless
DOCUMENT: Estimating actual and potential government revenues from timber harvesting in Cambodia http://www.sciencedirect.com/science/article/pii/S1389934104001509 Pg. 4 (629) "where tEXPORT is tax on export of SW and VW (tEXPORT=0.1, 10% of reference price) for all species."
timber_price = timber_demand_and_price.timber_price
UNITS: USD/m3
time_unit = 1
UNITS: year
total_kratie = GRAPH(TIME)
(2000,00, 1011774), (2004,66666667, 978575), (2009,33333333, 869399), (2014,00, 612467)
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/
total_revenue = Total_revenue_dense
UNITS: usd/years
Total_revenue_dense =
(royalty_total_dense/time_unit)+export_tax_total+licence_fee_total+custom_charge_total+(royalty_total_mixed/time_unit)+(royalty_total_deciduous/time_unit)
UNITS: usd/years
total_Stung_Treng = GRAPH(TIME)
(2000,00, 1087709), (2004,66666667, 1085574), (2009,33333333, 869399), (2014,00, 953835)
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/
Total_WP = SUM("Wood_Product_(WP)"[*])
UNITS: m3
volume_of_mature_trees_in_deciduous_part =
("mixed_+_Deciduous_forest_percentage"/6)*1.5*Carbon_in_managed_forest.volume_of_mature_trees_per_ha_deciduous
UNITS: m3/ha
volume_of_mature_trees_in_dense_part =
(average_percentage_dense_forest/100)*Carbon_in_managed_forest.volume_of_mature_trees_per_ha_dense
UNITS: m3/ha

volume_of_mature_trees_in_mixed_part =
("mixed_+_Deciduous_forest_percentage"/6)*4.5*Carbon_in_managed_forest.volume_of_mature_trees_per_ha_mixed
UNITS: m3/ha
volume_of_timber_per_ha = volume_of_trees_per_ha*(1-"revenues,_costs,_benefits".logging_waste)
UNITS: m3/ha
volume_of_trees_per_ha = volume_of_mature_trees_in_deciduous_part +
volume_of_mature_trees_in_dense_part + volume_of_mature_trees_in_mixed_part
UNITS: m3/ha

NTFPs:
accumulated_loss_of_revenue_from_NTFPs(t) = accumulated_loss_of_revenue_from_NTFPs(t - dt) +
(loss_of_revenue_from_collecting_NTFPs) * dt
INIT accumulated_loss_of_revenue_from_NTFPs = 0
UNITS: USD
INFLOWS:
loss_of_revenue_from_collecting_NTFPs = (IF("supply/demand_ratio"<1) THEN
value_of_demanded_NTFPs*(1-"supply/demand_ratio") ELSE 0)/time_unit
UNITS: usd/years
accumulated_value_of_collected_NTFPs(t) = accumulated_value_of_collected_NTFPs(t - dt) +
(value_of_collected_NTFPs) * dt
INIT accumulated_value_of_collected_NTFPs = 0
UNITS: USD
INFLOWS:
value_of_collected_NTFPs = (IF("supply/demand_ratio">1) THEN value_of_demanded_NTFPs
ELSE "supply/demand_ratio"*value_of_demanded_NTFPs)/time_unit
UNITS: usd/years
accumulated_net_value_from_NTFPs = accumulated_value_of_collected_NTFPs-
accumulated_loss_of_revenue_from_NTFPs
UNITS: USD
available_forest_for_NTFPs_collection =
.forest_land+(0.25*(wood_plantations.acacia_plantation+wood_plantations.rubber_plantations_total))
UNITS: ha
DOCUMENT: Establishment of forest plantations has two negative effects: (1) the area of plantation does not provide same amount of NTFPs as secondary forest and (2) land owners of the plantations can restrict local population from collecting NTFPs in the area. (1): NT 4 Effects of industrial plantations on ecosystem services and livelihoods Perspectives of rural communities in China 2017 http://www.sciencedirect.com/science/article/pii/S026483771630388X Pg. 6 (271), Figure 2 (2): PL 3 Rubber Plantation Development in Cambodia at what cost 2011 https://surumer.uni-hohenheim.de/fileadmin/einrichtungen/surumer/Rubber_Plantation_Development_in_Cambodia.pdf Pg. 35 (29) PL 10 Fast-wood Plantations, Economic Concessions and Local Livelihoods in Cambodia 2006 http://wrm.org.uy/oldsite/countries/Cambodia/EFCT_Plantations_Report.pdf Pg. 13, 15, 20, 49, 77, 87, 101
average_collection_area_per_person_deciduous =
(Srae_Roneam_CA_per_person_D+Samrag_CA_per_person_D+Samret_CA_per_person_D+Kol_Totueng_CA_per_person_D+Chranas_CA_per_person_D+Srae_Popeay_CA_per_person_D)/6
UNITS: ha/person
average_collection_area_per_person_dense =
(average_collection_area_per_person_evergreen+"average_collection_area_per_person_semi-evergreen")/2
UNITS: ha/person

average_collection_area_per_person_evergreen =
(Veal_CA_per_person_E+Tum_Ar_CA_per_person_E+Ronteah_CA_per_person_E+Ou_Am_CA_per_person_E+Ou_Rona_CA_per_person_E+Ksetr_Bourei_CA_per_person_E)/6
UNITS: ha/person
average_collection_area_per_person_mixed =
(average_collection_area_per_person_dense+average_collection_area_per_person_deciduous)/2
UNITS: ha/person
"average_collection_area_per_person_semi-evergreen" =
(Veal_Vong_CA_per_person_SE+Kang_Kdar_CA_per_person_SE+Doung_CA_per_person_SE+Mil_CA_per_person_SE)/4
UNITS: ha/person
average_household_size = 5.7
UNITS: person/household
DOCUMENT: Impacts of Protected Areas on Local Livelihoods in Cambodia 2014 http://ac.els-cdn.com/S0305750X14000746/1-s2.0-S0305750X14000746-main.pdf?_tid=224362e4-0f15-11e7-82a9-00000aab0f6c&acdnat=1490197090_afa201cc18a8d7ac7d9929ddd49dd4af Pg. 5 (129), Table. 1
average_percentage_dense_forest =
(dense_forest_Stung_Treng_percentage+dense_forest_kratie_percentage)/2
UNITS: dmnl
DOCUMENT: Areas classified as dense forest in these maps include “evergreen forest” and “semi-evergreen forest” as defined in the Forestry Administration’s Cambodia Forest Cover publication dated June 2010. Dense forest is mostly located at elevations higher than 500 meters, although Cambodia has also had large areas of lowland evergreen forests in the past. Dense forest may also be called old-growth forest. As part of their independent analysis of ODC’s 2014 data, Global Forest Watch approximated that the dense forest classification equated to tree canopy cover greater than 60 percent. https://opendevelopmentcambodia.net/profiles/forest-cover
Chramas = 783
UNITS: People
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Chramas_CA_D = 1200
UNITS: ha
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Chranas_CA_per_person_D = Chramas_CA_D/Chramas
UNITS: ha/person
Deciduous_forest = ("mixed_+_Deciduous_forest"/6)*4.5
UNITS: ha
DOCUMENT: My estiamtion for the ratio between mixed forest and deciduos forest is 6:4.5. Based on data here: http://www.fao.org/docrep/013/al470E/al470E.pdf GLOBAL FOREST RESOURCES ASSESSMENT 2010 COUNTRY REPORT CAMBODIA and map of forest cover types here: http://theredddesk.org/sites/default/files/resources/pdf/2013/assessment_of_land_use_forest_policy_and_governance_in_cambodia_1.pdf Assessment of land use, forest policy and governance in Cambodia Working paper Jeremy Broadhead and Rebeca Izquierdo page 13
deciduous_NTFPs_capacity = Deciduous_forest/average_collection_area_per_person_deciduous
UNITS: People
dense_forest = (average_percentage_dense_forest/100)*available_forest_for_NTFPs_collection
UNITS: ha

DOCUMENT: Dense forest Areas classified as dense forest in these maps include "evergreen forest" and "semi-evergreen forest" as defined in the Forestry Administration's Cambodia Forest Cover publication dated June 2010. Dense forest is mostly located at elevations higher than 500 meters, although Cambodia has also had large areas of lowland evergreen forests in the past. Dense forest may also be called old-growth forest. As part of their independent analysis of ODC's 2014 data, Global Forest Watch approximated that the dense forest classification equated to tree canopy cover greater than 60 percent. https://opendevelopmentcambodia.net/profiles/forest-cover

dense_forest_kratie = GRAPH(TIME)
(2000,00, 452833), (2004,66666667, 394540), (2009,33333333, 277029), (2014,00, 117104)
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/ Areas classified as dense forest in ODC's maps include evergreen forest and semi-evergreen forest as defined in the Forestry Administration's Cambodia Forest Cover publication (June 2010). Dense forest is mostly located higher than 500 meters. Dense forest may also be called old-growth forest. The definition allows for limited signs of human occupation, such as small settlements of indigenous people in the forest (which the 'primary forest' definition does not). As part of their independent analysis of ODC's 2014 forest cover data, Global Forest Watch stated that dense forest has tree canopy cover greater than 60 percent.

dense_forest_kratie_percentage = (dense_forest_kratie*100)/total_kratie
UNITS: dmnl

dense_forest_Stung_Treng = GRAPH(TIME)
(2000,00, 590502), (2004,66666667, 566443), (2009,33333333, 277029), (2014,00, 439225)
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/

dense_forest_Stung_Treng_percentage = (dense_forest_Stung_Treng*100)/total_Stung_Treng
UNITS: dmnl

dense_NTFPs_capacity = dense_forest/average_collection_area_per_person_dense
UNITS: People

Doung = 413
UNITS: person
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2

Doung_CA_per_person_SE = Doung_CA_SE/Doung
UNITS: ha/person

Doung_CA_SE = 2600
UNITS: ha
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2

Kang_Kdar = 2086
UNITS: People
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2

Kang_Kdar_CA_per_person_SE = Kang_Kdar_CA_SE/Kang_Kdar
UNITS: ha/person

Kang_Kdar_CA_SE = 7544
UNITS: ha

DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Kol_Totueng = 1371
UNITS: People
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Kol_Totueng_CA_D = 3099
UNITS: ha
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Kol_Totueng_CA_per_person_D = Kol_Totueng_CA_D/Kol_Totueng
UNITS: ha/person
Ksetr_Bourei = 1920
UNITS: People
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Ksetr_Bourei_CA_E = 9700
UNITS: ha
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Ksetr_Bourei_CA_per_person_E = Ksetr_Bourei_CA_E/Ksetr_Bourei
UNITS: ha/person
livelihood_value_derived_from_NTFPs_per_person = livelihood_value_per_household/average_household_size
UNITS: USD/person
livelihood_value_per_household = 424
UNITS: USD/household
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf "The average values for households in the survey were: USD265/household in Kompong, USD424/household in Kratie...." Pg. 36 (38)
Mil = 779
UNITS: person
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Mil_CA_per_person_SE = Mil_CA_SE/Mil
UNITS: ha/person
Mil_CA_SE = 4700
UNITS: ha
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
"mixed_+_Deciduous_forest" = ((100-average_percentage_dense_forest)/100)*(available_forest_for_NTFPs_collection)
UNITS: ha

DOCUMENT: Mixed forest Primarily regarded as dry mixed deciduous forest (deciduous trees drop and regrow their leaves seasonally.) Mixed forest may also include regrowth forest, stunted forest, mangroves, inundated or "flooded" forest, and bamboo, as well as forest plantations growing rubber, acacia, and eucalyptus or other tree crops. Areas classified as mixed forest in these maps include "deciduous forest" and "other forest" as defined in the Forestry Administration's Cambodia Forest Cover 2010. It also includes "grass land" and "wood shrub land evergreen and wood shrub land dry" included in the "non forest" classification of the same publication. This is due to the limitation of color differentiation on the available satellite images. https://opendevelopmentcambodia.net/profiles/forest-cover
mixed_forest = ("mixed_+_Deciduous_forest"/6)*1.5
UNITS: ha
DOCUMENT: My estiamtion for the ratio between mixed forest and deciduos forest is 6:4.5. Based on data here: http://www.fao.org/docrep/013/al470E/al470E.pdf GLOBAL FOREST RESOURCES ASSESSMENT 2010 COUNTRY REPORT CAMBODIA and map of forest cover types here: http://theredddesk.org/sites/default/files/resources/pdf/2013/assessment_of_land_use_forest_policy_and_governance_in_cambodia_1.pdf Assessment of land use, forest policy and governance in Cambodia Working paper Jeremy Broadhead and Rebeca Izquierdo page 13
mixed_NTFPs_capacity = mixed_forest/average_collection_area_per_person_mixed
UNITS: People
net_flow_of_revenue_from_collecting_NTFPs = value_of_collected_NTFPs-loss_of_revenue_from_collecting_NTFPs
UNITS: usd/years
NFTPs_capacity_total = mixed_NTFPs_capacity+deciduous_NTFPs_capacity+dense_NTFPs_capacity
UNITS: People
Ou_Am = 2165
UNITS: People
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Ou_Am_CA_E = 6400
UNITS: ha
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Ou_Am_CA_per_person_E = Ou_Am_CA_E/Ou_Am
UNITS: ha/person
Ou_Rona = 545
UNITS: People
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Ou_Rona_CA_E = 1000
UNITS: ha
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Ou_Rona_CA_per_person_E = Ou_Rona_CA_E/Ou_Rona
UNITS: ha/person
Ronteah = 385
UNITS: People

DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Ronteah_CA_E = 3630
UNITS: ha
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Ronteah_CA_per_person_E = Ronteah_CA_E/Ronteah
UNITS: ha/person
Samrag_CA_per_person_D = Samrang_CA_D/Samrang
UNITS: ha/person
Samrang = 667
UNITS: People
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Samrang_CA_D = 1132
UNITS: ha
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Samret = 579
UNITS: People
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Samret_CA_D = 1200
UNITS: ha
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Samret_CA_per_person_D = Samret_CA_D/Samret
UNITS: ha/person
Srae_Popeay = 608
UNITS: People
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Srae_Popeay_CA_D = 1200
UNITS: ha
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Srae_Popeay_CA_per_person_D = Srae_Popeay_CA_D/Srae_Popeay
UNITS: ha/person
Srae_Roneam = 1102
UNITS: People
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2

Srae_Roneam_CA_D = 1500
UNITS: ha
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Srae_Roneam_CA_per_person_D = Srae_Roneam_CA_D/Srae_Roneam
UNITS: ha/person
"supply/demand_ratio" = value_of_supply_of_NTFPs/value_of_demanded_NTFPs
UNITS: dmnl
time_unit = 1
UNITS: year
total_kratie = GRAPH(TIME)
(2000,00, 1011774), (2004,66666667, 978575), (2009,33333333, 869399), (2014,00, 612467)
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/
total_Stung_Treng = GRAPH(TIME)
(2000,00, 1087709), (2004,66666667, 1085574), (2009,33333333, 869399), (2014,00, 953835)
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/
Tum_Ar = 766
UNITS: People
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Tum_Ar_CA_E = 4863
UNITS: ha
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Tum_Ar_CA_per_person_E = Tum_Ar_CA_E/Tum_Ar
UNITS: ha/person
value_of_demanded_NTFPs = (.Population*livelihood_value_derived_from_NTFPs_per_person)
UNITS: usd
value_of_supply_of_NTFPs = NFTPs_capacity_total*livelihood_value_derived_from_NTFPs_per_person
UNITS: USD
Veal = 557
UNITS: People
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Veal_CA_E = 3562
UNITS: ha
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Veal_CA_per_person_E = Veal_CA_E/Veal
UNITS: ha/person
Veal_Vong = 1113

UNITS: People
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2
Veal_Vong_CA_per_person_SE = Veal_Vong_CA_SE/Veal_Vong
UNITS: ha/person
Veal_Vong_CA_SE = 4036
UNITS: ha
DOCUMENT: NT 1 Natural Forest Benefits and Economic Analysis of Natural Forest Conversion in Cambodia 2006 https://www.cdri.org.kh/webdata/download/wp/wp33e.pdf Pg. 85 (87), Appendix 2, Table 9.2

"revenues,_costs,_benefits":
"plantations_g._revenues" =
wood_plantations.total_government_revenues_rubber+wood_plantations.government_revenues_acacia
UNITS: USD
change_illegal_logging = 0.5
UNITS: Dimensionless
change_in_CC_time = 30
UNITS: Years
change_in_fraction_of_pl = 0.3
UNITS: Dimensionless
cutting_cycle_time = IF TIME< 2018 THEN 30 ELSE change_in_CC_time
UNITS: years
fraction_of_trees_cut_per_cycle = 0.3
UNITS: dmnl
gov_revenues_total =
"plantations_g._revenues"+government_revenues_from_clearing.accumulated_revenue_from_land_clearing+government_revenues_from_managed_forest.accumulated_revenue_from_managed_forest
UNITS: USD
illegal_logging_rate = IF TIME< 2018 THEN 0.5 ELSE change_illegal_logging
UNITS: dmnl
"LIM_1=on_0=off" = 0
UNITS: Dimensionless
logging_damage = IF TIME=2018 OR(TIME>2018) AND("LIM_1=on_0=off"=1) THEN 0.14 ELSE 0.4
UNITS: dmnl
DOCUMENT: CAR 7 Managing production forests for timber production and carbon emission reductions under the REDD+ scheme 2012
http://www.sciencedirect.com/science/article/pii/S1462901112000895 Pg. 3 (37) "the proportion of trees killed by logging and log skidding"
logging_waste = IF (TIME>2018) AND("LIM_1=on_0=off"=1) THEN 0.25 ELSE 0.5
UNITS: dmnl
DOCUMENT: CAR 7 Managing production forests for timber production and carbon emission reductions under the REDD+ scheme 2012
http://www.sciencedirect.com/science/article/pii/S1462901112000895 Pg. 3 (37) "proportion of unusable wood after deducting losses due to logging, skidding, and damage during transportation"
sum_of_revenues_and_SCC = gov_revenues_total-C_and_CO2.Total_social_cost_of_carbon
UNITS: USD

timber_demand_and_price:
accumulated_calculated_price(t) = accumulated_calculated_price(t - dt) + (Flow_6) * dt

```
  INIT accumulated_calculated_price = 0
  UNITS: usd/m3
  INFLOWS:
    Flow_6 = timber_price/time_unit
      UNITS: usd/m3/years
accumulated_growth_rate_of_demand(t) = accumulated_growth_rate_of_demand(t - dt) +
(change_in_growth_rate) * dt
  INIT accumulated_growth_rate_of_demand = 1
  UNITS: Dimensionless
  INFLOWS:
    change_in_growth_rate = growth_rate_of_demand
      UNITS: 1/year
accumulated_historic_price(t) = accumulated_historic_price(t - dt) + (Flow_4) * dt
  INIT accumulated_historic_price = 0
  UNITS: usd/m3
  INFLOWS:
    Flow_4 = "historic_export_price_+_forecast"/time_unit
      UNITS: usd/m3/years
demand_for_timber(t) = demand_for_timber(t - dt) + (inflow_of_demand - fulfilled_demand) * dt
  INIT demand_for_timber = init_demand_for_timber
  UNITS: m3
  INFLOWS:
    inflow_of_demand = (IF(TIME<2014)THEN
local_timber_demand+"foreign_demand_(until_2014)"+inflow_from_plantations_and_managed_forest
ELSE local_timber_demand+"foreign_demand_(since_2014)")
      UNITS: M3/year
  OUTFLOWS:
    fulfilled_demand = outflow_of_supply
      UNITS: M3/year
projected_demand_from_rest_of_the_world(t) = projected_demand_from_rest_of_the_world(t - dt) +
(increase_of_demand) * dt
  INIT projected_demand_from_rest_of_the_world = 0
  UNITS: M3
  INFLOWS:
    increase_of_demand =
initial_pulse+(projected_demand_from_rest_of_the_world*Projection_of_annual_change_in_global_dem
and)/time_unit
      UNITS: M3/year
supply_of_timber(t) = supply_of_timber(t - dt) + (inflow_from_clearing +
inflow_from_plantations_and_managed_forest - outflow_of_supply) * dt
  INIT supply_of_timber = init_demand_for_timber
  UNITS: m3
  INFLOWS:
    inflow_from_clearing =
(clearing_for_timber*government_revenues_from_clearing.volume_of_timber_per_ha)
      UNITS: m3/year
    inflow_from_plantations_and_managed_forest =
(wood_plantations.primary_flow_wood_product_rubber+wood_plantations.primary_flow_wood_product
_acacia+timber_from_manged_forest)
      UNITS: m3/year
  OUTFLOWS:
```

outflow_of_supply = demand_for_timber/time_unit
UNITS: m3/year
clearing_for_timber =
((volume_to_clear/government_revenues_from_clearing.volume_of_timber_per_ha))*availabity_of_forest_for_clearing
UNITS: ha/year
availabity_of_forest_for_clearing = IF(."forest/protected_forest_ratio">1) THEN 1 ELSE 0
UNITS: Dimensionless
"average_loss_per_year_2000-2009" = "total_loss_between_2000-2009"/"number_of_years_(10)"
UNITS: ha/year
"average_loss_per_year_2009-2014" = "total_loss_between_2009-2014"/"number_of_years_(5)"
UNITS: ha/year
demand_to_clear_land_for_timber = MAX("historical_loss_aproximation_2000-2014"-non_timber_land_demand, 0)
UNITS: ha/year
domestic_timber_demand_in_2010 = 670000
UNITS: m3
DOCUMENT: It was reported that that national demand for timber was estimated at 400,000 ton/year (around 670,000m3) (RGC& UNDP. 2011). Forest-Land Conversion and Conversion Timber Estimates: Cambodia Case Study https://www.nepcon.org/sites/default/files/library/NEPCon-ForestTrends-Cambodia-conversion-2014-11.pdf Pg. 28 (27)
effect_of_demand's_growth_rate =
accumulated_growth_rate_of_demand^magnitude_of_effect_of_demand_growth_rate
UNITS: Dimensionless
effect_of_extraction_availability =
DELAY3(government_revenues_from_managed_forest.managed_forest/INIT(government_revenues_from_managed_forest.managed_forest), 12,
government_revenues_from_managed_forest.managed_forest/INIT(government_revenues_from_managed_forest.managed_forest))
UNITS: Dimensionless
effect_of_forest_deterioration = (relative_size_of_forest)^magnitude_of_effect_of_depletion
UNITS: Dimensionless
effect_of_price_increase = MAX(1, timber_price/price_in_2014)
UNITS: Dimensionless
effect_of_price_on_foreign_demand =
effect_of_price_increase^magnitude_of_effect_of_price_on_foreign_demand
UNITS: Dimensionless
effect_of_price_on_local_demand =
effect_of_price_increase^magnitude_of_effect_of_price_on_local_demand
UNITS: Dimensionless
exports_fraction = 1-SAFEDIV(local_timber_demand, inflow_of_demand, 0)
UNITS: Dimensionless
"foreign_demand_(since_2014)" =
(projected_demand_from_rest_of_the_world/effect_of_price_on_foreign_demand)/time_unit
UNITS: m3/year
"foreign_demand_(until_2014)" = MAX(0, (timber_equivalent-local_timber_demand))
UNITS: m3/year
growth_rate_of_demand = TREND(demand_for_timber, 1,1)
UNITS: Dimensionless/year
"historic_export_price_+_forecast" = GRAPH(TIME)

(2000,00, 245,19), (2001,00, 1395,58), (2002,00, 191,03), (2003,00, 437), (2004,00, 391,67), (2005,00, 307,05), (2006,00, 301,89), (2007,00, 1240,78), (2008,00, 1325,4), (2009,00, 1100,59), (2010,00, 1092,7), (2011,00, 1860,3), (2012,00, 1189,64), (2013,00, 2478,66), (2014,00, 1215), (2020,00, 2000)
UNITS: USD/m3
DOCUMENT:
https://darkroom.fimltd.co.uk/original/09fd8a5ed124902f8d87871096be5727:c1f739de890cc03662902a1e55b7b0fb
"historical_loss_aproximation_2000-2014" = GRAPH(TIME)
(2000,00, 20000), (2001,00, 21000), (2002,00, 22000), (2003,00, 24000), (2004,00, 26000), (2005,00, 27000), (2006,00, 28400), (2007,00, 29100), (2008,00, 34000), (2009,00, 41200), (2010,00, 49200), (2011,00, 57200), (2012,00, 62000), (2013,00, 68400), (2014,00, 68406), (2015,00, 68406)
UNITS: ha/year
init_demand_for_timber = ("foreign_demand_(until_2014)"+local_timber_demand-(non_timber_land_demand*government_revenues_from_clearing.volume_of_timber_per_ha))*time_unit
UNITS: m3
initial_price = 245
UNITS: USd/m3
DOCUMENT: I set up the local price to be little lower than smallest recorded export price
initial_pulse =
PULSE("foreign_demand_(until_2014)"+inflow_from_plantations_and_managed_forest*0, 2013.93, 0)*time_unit
UNITS: M3/year
Kratie_forest_land_in_2000 = 1011774
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/
Kratie_forest_land_in_2004 = 978575
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/
Kratie_forest_land_in_2009 = 869399
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/
Kratie_forest_land_in_2014 = 612467
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/
local_timber_demand =
((timber_demand_per_ca*.Population)/time_unit)/effect_of_price_on_local_demand
UNITS: m3/year
loss_of_forest = INIT(.forest_land)-.forest_land
UNITS: ha
magnitude_of_effect_of_demand_growth_rate = 0.65
UNITS: Dimensionless
magnitude_of_effect_of_depletion = 0.8
UNITS: Dimensionless
magnitude_of_effect_of_price_on_foreign_demand = 0.25
UNITS: Dimensionless
magnitude_of_effect_of_price_on_local_demand = 0.3
UNITS: Dimensionless

non_timber_land_demand = (.forest_to_settlement+.agriculture_land_gap/time_unit)
UNITS: ha/year
"number_of_years_(10)" = 10
UNITS: year
"number_of_years_(5)" = 5
UNITS: year
population_in_2010 = 14360000
UNITS: person
price_in_2014 = 1215
UNITS: usd/m3
Projection_of_annual_change_in_global_demand = GRAPH(TIME)
(2014,00, 0,018), (2022,00, 0,018), (2030,00, 0,013)
UNITS: Dimensionless
DOCUMENT: Global demand for wood products - FAO.org (PDF)
ftp://ftp.fao.org/docrep/fao/011/i0350e/i0350e02a.pdf pg. 67, Table 24 Information there coralates with information here: Global Timber Outlook - FIM (PDF)
http://darkroom.fimltd.co.uk/original/09fd8a5ed124902f8d87871096be5727:c1f739de890cc03662902a1e55b7b0fb pg. 20
relative_size_of_forest = .forest_land/INIT(.forest_land)
UNITS: Dimensionless
reserves_policy = (demand_for_timber/20)
UNITS: m3
Stung_Treng_forest_land_in_2000 = 1087709
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/
Stung_Treng_forest_land_in_2004 = 1085574
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/
Stung_Treng_forest_land_in_2009 = 1038935
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/
Stung_Treng_forest_land_in_2014 = 953835
UNITS: ha
DOCUMENT: https://opendevelopmentcambodia.net/profiles/forest-cover/forest-cover-analysis-1973-2014/
timber_demand_per_ca = domestic_timber_demand_in_2010/population_in_2010
UNITS: m3/person
timber_equivalent =
government_revenues_from_clearing.volume_of_timber_per_ha*demand_to_clear_land_for_timber
UNITS: m3/year
timber_from_manged_forest = SUM(government_revenues_from_managed_forest.selling_WP[*])
UNITS: m3/year
timber_price =
((initial_price/effect_of_forest_deterioration)*effect_of_demand's_growth_rate)*effect_of_extraction_availability
UNITS: usd/m3
time_unit = 1
UNITS: year

Total_2000 = Kratie_forest_land_in_2000 + Stung_Treng_forest_land_in_2000
UNITS: ha
total_2009 = Kratie_forest_land_in_2009 + Stung_Treng_forest_land_in_2009
UNITS: ha
total_2014 = Kratie_forest_land_in_2014 + Stung_Treng_forest_land_in_2014
UNITS: ha
"total_loss_between_2000-2009" = Total_2000-total_2009
UNITS: ha
"total_loss_between_2009-2014" = total_2009-total_2014
UNITS: ha
volume_to_clear = IF (demand_for_timber-supply_of_timber)<-reserves_policy THEN 0 ELSE inflow_of_demand-inflow_from_plantations_and_managed_forest
UNITS: M3/year

wood_plantations:
acacia_plantation(t) = acacia_plantation(t - dt) + (planting_acacia + "re-planting_acacia" - "re-planting_acacia") * dt
INIT acacia_plantation = 4
UNITS: ha
INFLOWS:
planting_acacia = DELAY3(plantations_development*acacia_plantations_ratio, 1, plantations_development*acacia_plantations_ratio)
UNITS: ha/year
"re-planting_acacia" = acacia_plantation/cutting_age_acacia
UNITS: ha/year
OUTFLOWS:
"re-planting_acacia" = acacia_plantation/cutting_age_acacia
UNITS: ha/year
accumulated_cost_acacia(t) = accumulated_cost_acacia(t - dt) + (inflow_of_cost_acacia) * dt
INIT accumulated_cost_acacia = 0
UNITS: usd
INFLOWS:
inflow_of_cost_acacia = (avg_cost_per_ha_per_year_acaica*acacia_plantation)/time_unit
UNITS: usd/years
accumulated_goverment_revenues_rubber_wood(t) = accumulated_goverment_revenues_rubber_wood(t - dt) + (rubber_wood_goverment_revenues) * dt
INIT accumulated_goverment_revenues_rubber_wood = 0
UNITS: usd
INFLOWS:
rubber_wood_goverment_revenues = (sales_revenue_flow_rubber_wood*(custom_charge+licence_export_fee+tax_on_export))*timber_demand_and_price.exports_fraction
UNITS: usd/years
accumulated_government_revenues_acacia(t) = accumulated_government_revenues_acacia(t - dt) + (government_revenues_flow_acacia) * dt
INIT accumulated_government_revenues_acacia = 0
UNITS: USD
INFLOWS:
government_revenues_flow_acacia = ((revenue_flow_acacia)*(custom_charge+licence_export_fee+tax_on_export))*timber_demand_and_price.exports_fraction

UNITS: usd/years
accumulated_government_revenues_latex(t) = accumulated_government_revenues_latex(t - dt) + (government_revenues_flow_rubber) * dt
INIT accumulated_government_revenues_latex = 0
UNITS: USD
INFLOWS:
government_revenues_flow_rubber = ((latex_sales_revenues_flow)*(custom_charge+licence_export_fee+tax_on_export))*timber_demand_and_price.exports_fraction
UNITS: usd/years
accumulated_latex(t) = accumulated_latex(t - dt) + (latex_inflow) * dt
INIT accumulated_latex = 0
UNITS: kg
INFLOWS:
latex_inflow = Rubber_yield*mature_trees_rubber
UNITS: kg/years
accumulated_latex_sales_revenues(t) = accumulated_latex_sales_revenues(t - dt) + (latex_sales_revenues_flow) * dt
INIT accumulated_latex_sales_revenues = 0
UNITS: usd
INFLOWS:
latex_sales_revenues_flow = latex_inflow*price_per_kg
UNITS: usd/years
accumulated_running_cost_rubber(t) = accumulated_running_cost_rubber(t - dt) + (inflow_of_running_cost_rubber) * dt
INIT accumulated_running_cost_rubber = 0
UNITS: usd
INFLOWS:
inflow_of_running_cost_rubber = (avg_cost_per_ha_per_year_rubber*rubber_plantations_total)/time_unit
UNITS: usd/years
accumulated_sales_revenue_acacia(t) = accumulated_sales_revenue_acacia(t - dt) + (revenue_flow_acacia) * dt
INIT accumulated_sales_revenue_acacia = 0
UNITS: USD
INFLOWS:
revenue_flow_acacia = (primary_flow_wood_product_acacia*timber_demand_and_price.timber_price)
UNITS: usd/years
accumulated_sales_revenue_rubber_wood(t) = accumulated_sales_revenue_rubber_wood(t - dt) + (sales_revenue_flow_rubber_wood) * dt
INIT accumulated_sales_revenue_rubber_wood = 0
UNITS: USD
INFLOWS:
sales_revenue_flow_rubber_wood = (primary_flow_wood_product_rubber*timber_demand_and_price.timber_price)
UNITS: usd/years
imature_trees_rubber(t) = imature_trees_rubber(t - dt) + ("re-planting_rubber" + planting_rubber - maturing_rubber) * dt
INIT imature_trees_rubber = 17
UNITS: ha

INFLOWS:
"re-planting_rubber" = mature_trees_rubber/cutting_age_rubber
UNITS: ha/year
planting_rubber = DELAY3(plantations_development*rubber_to_acaccia_ratio, 1, plantations_development*rubber_to_acaccia_ratio)
UNITS: ha/year
OUTFLOWS:
maturing_rubber = imature_trees_rubber/avg_maturing_age_rubber
UNITS: ha/year
mature_trees_rubber(t) = mature_trees_rubber(t - dt) + (maturing_rubber - "re-planting_rubber") * dt
INIT mature_trees_rubber = 87
UNITS: ha
INFLOWS:
maturing_rubber = imature_trees_rubber/avg_maturing_age_rubber
UNITS: ha/year
OUTFLOWS:
"re-planting_rubber" = mature_trees_rubber/cutting_age_rubber
UNITS: ha/year
primary_residual(t) = primary_residual(t - dt) + (primary_residual_flow - use_for_veneer_boards - used_as_fuel_wood_rubber) * dt
INIT primary_residual = 0
UNITS: m3
INFLOWS:
primary_residual_flow = (volume_of_cut_ruberwood*(1-conversion_factor))/time_unit
UNITS: m3/year
OUTFLOWS:
use_for_veneer_boards = (primary_residual*usage_fraction)/time_unit
UNITS: m3/year
used_as_fuel_wood_rubber = (primary_residual*usage_fraction)/time_unit
UNITS: m3/year
primary_residual_1(t) = primary_residual_1(t - dt) + (primary_residual_flow_acacia - use_for_veneer_boards_acacia - use_as_fuel_wood_acacia) * dt
INIT primary_residual_1 = 0
UNITS: m3
INFLOWS:
primary_residual_flow_acacia = (volume_of_cutted_acacia_wood*(1-conversion_factor_1))/time_unit
UNITS: m3/year
OUTFLOWS:
use_for_veneer_boards_acacia = (primary_residual_1*usage_fraction_acacia)/time_unit
UNITS: m3/year
use_as_fuel_wood_acacia = (primary_residual_1*usage_fraction_acacia)/time_unit
UNITS: m3/year
volume_of_cut_ruberwood(t) = volume_of_cut_ruberwood(t - dt) + (cutting_rubber - primary_flow_wood_product_rubber - primary_residual_flow) * dt
INIT volume_of_cut_ruberwood = 687
UNITS: m3
INFLOWS:
cutting_rubber = volume_of_rubberwood_per_ha*"re-planting_rubber"
UNITS: m3/year
OUTFLOWS:

primary_flow_wood_product_rubber = (volume_of_cut_ruberwood*conversion_factor)/time_unit
UNITS: M3/year
primary_residual_flow = (volume_of_cut_ruberwood*(1-conversion_factor))/time_unit
UNITS: m3/year
volume_of_cutted_acacia_wood(t) = volume_of_cutted_acacia_wood(t - dt) + (cutting_acacia - primary_flow_wood_product_acacia - primary_residual_flow_acacia) * dt
INIT volume_of_cutted_acacia_wood = 687
UNITS: m3
INFLOWS:
cutting_acacia = volume_of_acacia_wood_per_ha*"re-planting_acacia"
UNITS: m3/year
OUTFLOWS:
primary_flow_wood_product_acacia = (volume_of_cutted_acacia_wood*conversion_factor_1)/time_unit
UNITS: M3/year
primary_residual_flow_acacia = (volume_of_cutted_acacia_wood*(1-conversion_factor_1))/time_unit
UNITS: m3/year
plantations_development = (fraction_of_plantations*.forest_to_fallow)
UNITS: ha/year
acacia_plantations_ratio = 1-rubber_to_acaccia_ratio
UNITS: Dimensionless
acacia_to_agr_ratio = ratio_of_rubber_and_forest_plantations*rubber_to_agr_ratio
UNITS: Dimensionless
Agriculture_total = Stung_Treng_size_of_agriculture_2013+Kratie_size_of_agriculture_2013
UNITS: ha
assumption_of_forest_plantations_size = historical_data_rubber_total*ratio_of_rubber_and_forest_plantations
UNITS: ha
avg_cost_per_ha_per_year_acaica = 256
UNITS: USD/ha
DOCUMENT: PL 8 Financial viability of plantations of fastgrowing tree species in Cambodia http://twgfr.org/download/Study%20Reports(2)/13-Financial%20viability%20of%20plantation-fast-growing%20tree%20species%20in%20Cambodia-2012.pdf Pg. 12 (8) ..."an average cost of acacia and eucalyptus plantation is about USD 256 per ha for the period of 6 years"... BUT Therefore, the cost of land rental which commonly included in the cost estimation of acacia, eucalyptus, and teak plantation in other studies is excluded.
avg_cost_per_ha_per_year_rubber = 343
UNITS: USD/ha
DOCUMENT: PL 8 Financial viability of plantations of fastgrowing tree species in Cambodia http://twgfr.org/download/Study%20Reports(2)/13-Financial%20viability%20of%20plantation-fast-growing%20tree%20species%20in%20Cambodia-2012.pdf Pg. 13 (9) Taking land preparation which cost USD 1000 per ha in the first year into account, the expense of rubber plantation increases up to USD 343 per ha. BUT It is worth noting that our finding is extremely low compared to the study conducted by Yem et al. (2011) which argued that an average annual total cost for rubber plantations is USD 628 per ha
avg_maturing_age_rubber = 6
UNITS: years
DOCUMENT: Rubber Sector Profile 2012 http://www.moc.gov.kh/tradeswap/userfiles/Media/file/Projects/TDSP/Top%20Ten%20Products/2012-07-26%20Rubber%20Sector%20profile.pdf "...it takes only about 5--7 years for the trees to mature..." PG. 11 (8) Hevea brasiliensis is non-dipterocapr species

conversion_factor = 0.67
UNITS: Dimensionless
conversion_factor_1 = 0.67
UNITS: Dimensionless
custom_charge = 0.085
UNITS: Dimensionless
DOCUMENT: Estimating actual and potential government revenues from timber harvesting in Cambodia http://www.sciencedirect.com/science/article/pii/S1389934104001509 Pg. 5 (630) "where cCUSTOM is the customs charge on SW and VW at the exporting point 8.5% of reference price.."
cutting_age_acacia = 6
UNITS: years
DOCUMENT: PL 8 Financial viability of plantations of fastgrowing tree species in Cambodia http://twgfr.org/download/Study%20Reports(2)/13-Financial%20viability%20of%20plantation-fast-growing%20tree%20species%20in%20Cambodia-2012.pdf Pg. 11 (7) "In general, the harvesting cycle of eucalyptus and acacia plantations in Cambodia for pulp production is 6 years." Acacia is non-dipterocapr species
cutting_age_rubber = 21
UNITS: year
DOCUMENT: PL 1 Rubber Sector Profile 2012 http://www.moc.gov.kh/tradeswap/userfiles/Media/file/Projects/TDSP/Top%20Ten%20Products/2012-07-26%20Rubber%20Sector%20profile.pdf "Tapping starts in the fifth to seventh year after planting and continues for 25 to 30 years." PG. 27 (24) PL 5 Estimation of rubberwood production in Cambodia 2010 http://search.proquest.com/docview/882114006?accountid=8579 "(1) yield of rubberwood per ha, (2) annual harvesting area and (3) recovery rate of processing activities. First, we found that the unit volume of rubberwood is 372.8 m3/ha Our estimation of the unit rubberwood yield is higher than the value adopted in Thailand case: 250 m3/ha (FAO 2009a). The difference is mainly because our study assumed harvesting old rubber trees aged over 40 years from large scaled estate plantations from 1996 to 2011, while common harvesting age is around 25–30 years old (FAO 2001)." Based on the information in the two sources I choose average value 27 years.
forest_plantations_in_2011_cambodia = 69064
UNITS: ha
DOCUMENT: PL 8 Financial viability of plantations of fastgrowing tree species in Cambodia 2012 http://twgfr.org/download/Study%20Reports(2)/13-Financial%20viability%20of%20plantation-fast-growing%20tree%20species%20in%20Cambodia-2012.pdf Pg. 23 (19)
fraction_of_plantations = IF TIME< 2018 THEN 0.4 ELSE "revenues,_costs,_benefits".change_in_fraction_of_pl
UNITS: Dimensionless
government_revenues_acacia = accumulated_government_revenues_acacia
UNITS: USD
historical_data_rubber_Cambodia = GRAPH(TIME)
(2000,00, 53722), (2001,00, 51458), (2002,00, 53527), (2003,00, 53527), (2004,00, 54209), (2005,00, 60406), (2006,00, 69994), (2007,00, 82059), (2008,00, 108510), (2009,00, 129920), (2010,00, 181433), (2011,00, 213104), (2012,00, 280350), (2013,00, 326000)
UNITS: ha
DOCUMENT: http://www.moc.gov.kh/Tradeswap/userfiles/Media/file/Projects/TDSP/Top%20Ten%20Products/2012-07-26%20Rubber%20Sector%20profile.pdf PL 1 Rubber Sector Profile 2012 pg. 60 (57) + PL 4 Forest-Land Conversion and Conversion Timber Estimates https://www.nepcon.org/sites/default/files/library/NEPCon-ForestTrends-Cambodia-conversion-2014-11.pdf PG. 16 "Rubber plantations increased from around 129,000 ha in 2009 to around 326,000 ha in

2013 (up 16 percent on the 2012 figure of 280,350 hectares). The Cambodian ministry of agriculture recently predicted that rubber plantations would reach 450,000 by 2020 (Xinhuanet News, 2014)."
historical_data_rubber_Kratie = GRAPH(TIME)
(2000,00, 2550), (2005,50, 2550), (2011,00, 27696)
UNITS: ha
DOCUMENT:
http://www.moc.gov.kh/Tradeswap/userfiles/Media/file/Projects/TDSP/Top%20Ten%20Products/2012-07-26%20Rubber%20Sector%20profile.pdf Rubber Sector Profile 2012 pg. 10 (13) In this document is exact value for mature (2 550 ha) and imature (25 146 ha) trees in the year 2011 in Kratie. Between the years 2000 - 2014 the size of rubber plantations in Cambodia increased four times. Under the assumption that this development was similar in Kratie region, I calculated the initial value for year 2000 to be 6924 ha in Kratie region.
historical_data_rubber_Stung_Treng = GRAPH(TIME)
(2000,00, 0), (2005,50, 0), (2011,00, 9453)
UNITS: ha
DOCUMENT:
http://www.moc.gov.kh/Tradeswap/userfiles/Media/file/Projects/TDSP/Top%20Ten%20Products/2012-07-26%20Rubber%20Sector%20profile.pdf Rubber Sector Profile 2012 pg. 10 (13) In this document is exact value for mature (0 ha) and imature (9 453 ha) trees in the year 2011 in Stung Treng. The rubber tree can be tapped on average after 6 years after its planted. That means that the earliest plantation in Stung Treng could not happen yearlier than in year 2005. Since I lack more detailed data I have simple linear increase from year 2005 to the 2011 value.
historical_data_rubber_total = historical_data_rubber_Stung_Treng+historical_data_rubber_Kratie
UNITS: ha
Kratie_size_of_agriculture_2013 = 83569
UNITS: ha
DOCUMENT: https://data.opendevelopmentmekong.net/dataset/b789b447-5fdc-4a9c-a1b4-c5969ad643fb/resource/9fec36bc-a47c-47c1-9d0b-e54d1483c7dd/download/KratieProvince09.06.2014.pdf
Kratie_size_of_rubber_2013 = 39125
UNITS: ha
licence_export_fee = 0.01
UNITS: Dimensionless
DOCUMENT: Estimating actual and potential government revenues from timber harvesting in Cambodia http://www.sciencedirect.com/science/article/pii/S1389934104001509 Pg. 5 (630) "where tEXPORTL is the tax on issuing the export license (tEXPORT=0.01, 1% of reference price)."
owner's_profit_acacia = accumulated_sales_revenue_acacia-accumulated_government_revenues_acacia-accumulated_cost_acacia
UNITS: USD
owner's_profit_plantations = owner's_profit_rubber+owner's_profit_acacia
UNITS: USD
owner's_profit_rubber = accumulated_latex_sales_revenues+accumulated_sales_revenue_rubber_wood-accumulated_running_cost_rubber-total_government_revenues_rubber
UNITS: USD
plantations_to_agr_ratio = acacia_to_agr_ratio+rubber_to_agr_ratio
UNITS: Dimensionless
price_per_kg = GRAPH(TIME)
(2000,00, 0,643970793), (2001,17647059, 0,601862467), (2002,35294118, 0,567249863), (2003,52941176, 0,906321099), (2004,70588235, 1,268099966), (2005,88235294, 1,195126898), (2007,05882353, 1,703292827), (2008,23529412, 1,747164853), (2009,41176471, 2,497839468), (2010,58823529, 1,250022046), (2011,76470588, 2,810389072), (2012,94117647, 5,519497698),

(2014,11764706, 3,38453941), (2015,29411765, 3,18590275), (2016,47058824, 2,557364327), (2017,64705882, 1,660082188), (2018,82352941, 1,219818692), (2020,00, 2,200)
UNITS: usd/kg
DOCUMENT: Historical data from here: https://ycharts.com/indicators/singapore_malaysia_rubber_price prognosis for year 2020: PL 1 Rubber Sector Profile 2012 http://www.moc.gov.kh/tradeswap/userfiles/Media/file/Projects/TDSP/Top%20Ten%20Products/2012-07-26%20Rubber%20Sector%20profile.pdf pg. 49 (46)
ratio_of_rubber_and_forest_plantations = forest_plantations_in_2011_cambodia/rubber_plantations_in_2011_cambodia
UNITS: dmnl
rubber_plantations_in_2011_cambodia = 213104
UNITS: ha
rubber_plantations_projection = GRAPH(TIME)
(2013,000, 326000), (2020,000, 450000)
UNITS: ha
DOCUMENT: PL 4 Forest-Land Conversion and Conversion Timber Estimates https://www.nepcon.org/sites/default/files/library/NEPCon-ForestTrends-Cambodia-conversion-2014-11.pdf PG. 16 "Rubber plantations increased from around 129,000 ha in 2009 to around 326,000 ha in 2013 (up 16 percent on the 2012 figure of 280,350 hectares). The Cambodian ministry of agriculture recently predicted that rubber plantations would reach 450,000 by 2020 (Xinhuanet News, 2014)."
rubber_plantations_total = mature_trees_rubber+imature_trees_rubber
UNITS: ha
rubber_to_acaccia_ratio = 1-ratio_of_rubber_and_forest_plantations
UNITS: Dimensionless
rubber_to_agr_ratio = rubber_total/Agriculture_total
UNITS: Dimensionless
rubber_total = Stung_Treng_size_of_rubber_2013+Kratie_size_of_rubber_2013
UNITS: ha
Rubber_yield = 1342
UNITS: kg/ha/year
DOCUMENT: PL 1 Rubber Sector Profile 2012 http://www.moc.gov.kh/tradeswap/userfiles/Media/file/Projects/TDSP/Top%20Ten%20Products/2012-07-26%20Rubber%20Sector%20profile.pdf bottom paragraph PG. 27 (24) PL 3 Rubber Plantation Development in Cambodia at what cost http://www.eepsea.org/pub/tr/Rubber%20Report-Cambodia-Yem%20Dararath-et-al-Technical-Report.pdf "Normally, the tree is cut down and re-planted when production decreases. On average, in Cambodia rubber trees produce 1100 kg/ha of latex per year, compared with about 1400kg/ha per year in Thailand, Indonesia, and Malaysia (Khun, 2006)." pg. 15 (9) Financial viability of plantations of fastgrowing tree species in Cambodia 2012 http://twgfr.org/download/Study%20Reports(2)/13-Financial%20viability%20of%20plantation-fast-growing%20tree%20species%20in%20Cambodia-2012.pdf "CRRI (2010) reported that yield of different rubber clone at 6 years of tapping varied from 1,293 to 1,861 kg/ha/year."... mean vlaue 1577 Pg. 7 In the first source the value is 1250 kg/ha and in the second 1200 kg/ha and in the third the average value is 1577 Kg/ha. Hence I mean value 1342 kg/ha.
Stung_Treng_size_of_agriculture_2013 = 49924
UNITS: ha
DOCUMENT: http://www.cambodiainvestment.gov.kh/content/uploads/2014/03/Stung-Treng-Province_eng.pdf
Stung_Treng_size_of_rubber_2013 = 1324
UNITS: ha

DOCUMENT: http://www.cambodiainvestment.gov.kh/content/uploads/2014/03/Stung-Treng-Province_eng.pdf
tax_on_export = 0.1
UNITS: Dimensionless
DOCUMENT: Estimating actual and potential government revenues from timber harvesting in Cambodia http://www.sciencedirect.com/science/article/pii/S1389934104001509 Pg. 4 (629) "where tEXPORT is tax on export of SW and VW (tEXPORT=0.1, 10% of reference price) for all species." AND http://www.phnompenhpost.com/national/rubbery-revenues "The government has awarded an export monopoly to the Mong Rithy company, but sells rubber to the company at just $900 per tonne. It has also exempted the company from the normal ten percent export tax," Rainsy said.
time_unit = 1
UNITS: year
total_government_revenues_rubber = accumulated_goverment_revenues_rubber_wood+accumulated_government_revenues_latex
UNITS: USD
usage_fraction = 0.5
UNITS: dmnl
DOCUMENT: Estimation of rubberwood production in Cambodia 2010 http://search.proquest.com/docview/882114006?accountid=8579 "The generation rate of primary processing residues (1-eprimary) is from 55.1 to 65.0%, and the residues are mainly sold to fuelwood producers and factories processing veneer and particle board." Pg. 7 (155)
usage_fraction_acacia = 0.5
UNITS: Dimensionless
volume_of_acacia_wood_per_ha = 140
UNITS: m3/ha
DOCUMENT: PL 8 Financial viability of plantations of fastgrowing tree species in Cambodia http://twgfr.org/download/Study%20Reports(2)/13-Financial%20viability%20of%20plantation-fast-growing%20tree%20species%20in%20Cambodia-2012.pdf Pg. 10 (6) table Based on the describtion in at the page 21 (25), the most common types of acacia tree in Cambodia are A. Mangium and A. Auriculiformis. These two types have different maturing age. Given the fact that in different part of the document (pg. 11 (7)) is mentioned that usual maturing age in Cambodian plantations is 6 years I chose Acacia Mangium to be represented here, because its maturing age is supposed to be 6 years.
volume_of_rubberwood_per_ha = 250
UNITS: m3/ha
DOCUMENT: Estimation of rubberwood production in Cambodia 2010 http://search.proquest.com/docview/882114006?accountid=8579 "(1) yield of rubberwood per ha, (2) annual harvesting area and (3) recovery rate of processing activities. First, we found that the unit volume of rubberwood is 372.8 m3/ha Our estimation of the unit rubberwood yield is higher than the value adopted in Thailand case: 250 m3/ha (FAO 2009a). The difference is mainly because our study assumed harvesting old rubber trees aged over 40 years from large scaled estate plantations from 1996 to 2011, while common harvesting age is around 25–30 years old (FAO 2001)." PG. 9 (157) I choose to use the value adopted for Thailand. That is because I am using the common harvesting age 30 years. I believe that the high harvesting age over 40 years is an subnormal harvesting pattern caused by deep political instability in the country over the period 1970-1990. Moving forward I assume similar harvesting patterns as are in the neigbouring countries. The Utilization, processing and demand for Rubberwood as a source of wood supply http://www.fao.org/docrep/003/Y0153E/Y0153E04.htm "The global rubberwood study carried out by Indufor under the auspices of the International Trade Centre estimated yield at 140 to 200 m3/ha, with the higher ranges observed in countries where plantations are carefully managed, i.e. Malaysia, Thailand, India and Sri Lanka (Indufor, 1993)." CAR 4 Carbon balance of rubber (Hevea brasiliensis) plantations A review of uncertainties at plot, landscape and production level 2016 http://www.sciencedirect.com/science/article/pii/S0167880916300378 "Presented figures are based on the

work of Khun et al. (2008), who estimated rubber wood volume as 240–270 m3 ha after 25–30 years" Pg. 10 (17)

wood_fuel_plantations = use_as_fuel_wood_acacia+used_as_fuel_wood_rubber
UNITS: M3/year

{ The model has 935 (975) variables (array expansion in parens).
In 10 Modules with 53 Sectors.
Stocks: 54 (64) Flows: 84 (102) Converters: 797 (809)
Constants: 233 (233) Equations: 648 (678) Graphicals: 62 (62)
There are also 129 expanded macro variables.
}