UNIVERSITY OF BERGEN

Sustainable development in the Lower Mekong Basin Cambodia

By Bjørn Christian Rødal

JUNE 1, 2017

Bergen, Norway

Supervisors:

Prof. Dr. Pål Davidsen (University of Bergen)

Assoc. Prof. Dr. Andrea Bassi (Stellenbosch University / CEO KnwolEdge Srl)

Acknowledgements

First off all, I want to thank my special someone who has been so supportive, patient and understanding for many months throughout the writing of this thesis. Providing food, council and encouragement. Never a word of complaint.

Then I want to give a special thanks to Andrea Bassi. He is the most excellent supervisor I have had. Knowledgeable, friendly, available and ALWAYS quick to answer. And the answers he provides are full of insight and exactly what I have needed at the right time, never too much, never too little.

Then I want to thank Paul Davidsen for inviting me onto this project in cooperation with WWF and the Luc Hoffmann Institute. He is an excellent teacher and has become a friend over the two years I have had him as my professor at the University of Bergen.

Then I want to give thanks and well done to my two fellow students Miroslav Stejskal and Rita Guillot, with whom I have cooperated with.

Sustainable development in the Lower Mekong Basin, Cambodia

Abstract

Across the entire globe energy demand is rising, and more specifically demand for electricity, as more and more developing countries are going through a process of modernization and industrialization. This is placing an increased pressure on our ecosystems and natural resources. If this development is not managed properly it can cause ecological collapse and inflict severe costs on both nature and society.

In the case of Cambodia, it is a country that is currently undergoing such a development. With regards to hydropower the Mekong-river still represents a largely untapped resource. Currently there are several hydropower dams under construction or undergoing plans for construction in Cambodia (Open Development 2016). With the construction of new electricity generating capacity comes both opportunities and challenges.

The Mekong-river basin is home to the largest inland fishery in the world and it supports about 10 million people in the region living of subsistence. The building of hydropower dams along the river represents a threat to the fish stock since it blocks fish migration. Dams along the river also slows down the sediment flow and contributes to land erosion. Crop yield will also be effected by the trapping of sediments since less nutrients will be carried to fields down-stream. However, increased supply of affordable electricity can also promote welfare and economic growth within the country. Access to electricity is beneficial to health and education, by providing a substitute to firewood, coal and kerosene for cocking and lighting. It also helps to improve the information flow, further supporting educational purposes.

There are several tradeoffs that must be considered. First is the tradeoff between the natural capital that is already there in force of the ecosystem, represented through the fish-stock, transportation along rivers and the forest, and the building up of physical capital such as dams and roads. Another tradeoff to consider is the tradeoff between different technologies for electricity generation, as they all come with different costs and benefits. Given this context I will build a model using system dynamics methodology to give a better understanding of the tradeoffs and how we can achieve sustainable growth and prevent ecological collapse.

Contents

List of figures

List of Tables

List of abbreviations

GDP : Gross domestic production

TFP : Total factor productivity

BAU : Business as usual

CLD : Causal loop diagram

MW : Megawatt

Mwh : Megawatt hour

Kwh : Kilowatt hour

Dmnl : Dimensionless

Ha : Hectare

1. Introduction

The purpose of this thesis is to investigate how we can engage in sustainable economic development in the Mekong -river basin in Cambodia. In order for long term economic development to be successful and sustainable it is essential that it includes the ecosystem and natural capital into its plans.

The thesis will focus on the production of electricity supply and the building of hydropower dams on the Mekong-river and compare this with other alternatives for electricity production such as coal and solar power. These alternatives of electricity production will be compared on the basis of their long-term effect on both the ecosystem, environment and the economy.

Only about 30% of the population in Cambodia has access to electricity (Worldbank 2016), and in rural areas the number is down to 13% access to electricity (Energypedia 2016). In other words there is a substantial potential for expansion of the electricity coverage. One of the challenges of the electricity supply side is that most of the electricity production in Cambodia comes from the use of diesel/HFO fuels. This makes the cost of electricity relatively expensive and unstable since it is tied to the global diesel price (Poch and Tuy 2012), (IED 2009). Another drawback from the use of diesel/HFO fuels is the Nitrogen Oxide (NOx) pollution as well as the CO2 emissions (Icopal 2016). Access to electricity is shown as a key element to improve both education and health. The use of coal and kerosene oil for cooking and lighting in households has detrimental health effects, especially with regards to lungs and lung related diseases (BBC 2012), (Leung 1977), (Liu, Sasco et al. 1993).

Given a goal of economic and social development physical capital is being built up in order to achieve this goal. However when physical capital is being built it is very often at the expense of natural capital.

This poses a problem in that 1) built-up physical capital is needed in order to promote economic and social development and 2) the other capitals are depending on input from natural capital in order to either develop or at least sustain themselves.

As built-up physical capital increases it diminishes and deteriorates the natural capital. However degradation of natural capital will eventually undermine both social and economic development. Natural capital forms the basic fundament on which human life and society rests upon (Hawken, Lovins et al. 1999). It serves both as a framework and as input into economic and social activity (Van Paddenburg, Bassi et al. 2012).

The effects of degradation of natural capital do not show itself immediately. However a degraded ecosystem can in turn lead to unrest, migration and loss of social capital as well as economic losses. Even worse a damaged ecosystem can threaten the existence of whole communities and species (Abel, Cumming et al. 2006). However development of infrastructure and industry is a necessity in order to fuel economic and technological development. A balance between the different types of capitals is needed to be found. In this model social and capital and migration is not expressively modeled, but the consequences can be inferred based on the outcomes of certain variables, such as if local fish stock should collapse.

Concretely the model shows tradeoffs between Natural capital and Built-up capital. *Natural capital* is represented in the model through *forest, fish-stock*, *sediment-flow* and *river transportation*. *Physical built-up capital* is represented in the model through *electricity generating capacity* and infrastructure such as *roads.*

The research questions are as follows:

1. "*What are the tradeoffs between Natural Capital and Built-up of capital?"*

2. *"Is there a way to compensate for these tradeoffs in order to ensure sustainable growth?"*

The research has been conducted through 4 stages:

1) The review of existing literature on the subject and conceptualization of system structure.
2) The building of the model itself and research into specific data needed for exogenous variables or structure-graphs.
3) Analysis of model scenarios with different policies and model validation.
4) Conclusions and recommendations based on analysis of the model simulations.

This model and research is meant to be a support for decisionmakers in Cambodia when they are making strategic decisions for their country and help them to find a long-term perspective.

1.1 Definitions

Before describing the model and going into the analysis we need to establish some definitions. Essential to this thesis is the definition of capital since we are looking at trade-offs between *physical built-up capital* and *natural capital.*

In economics, the definition of capital is *"factors of production that are used to create goods or services and are not themselves the product"*.

Physical built-up capital are all means of production constructed by humans. It includes machinery and power plants as well as infrastructure and roads built for facilitation of transportation.

In the model, *physical built-up capital* is represented by: 1) the length of roads measured in kilometers (km), 2) Electricity generating capacity measured in Megawatts (mw) and 3) a stock called *gross capital* measured in currency (usd). *Gross capital* is meant to represent all capital formation in the country other than electricity generating capacity and roads. *Gross capital formation* is an exogenous input into this model and is thus not influenced by any feedback loop in the model. The other two representations of *physical built-up capital* in the model, *electricity generating capacity* and *roads and infrastructure*, is the result of investment policies that can be endogenized.

Natural capital is both the stock of natural resources *and* the structures provided by an ecosystem as a whole. These structures can facilitate transportation along its rivers and provide pure drinking water, it forms the basis for growth, fertilization and food production. It is essential to all other production processes either as a facilitator or as an input. Ultimately it is the very foundation to support life itself.

Earlier natural capital has come under the definition of land, but this does not sufficiently capture what *natural capital* is. Rather one should say that land is a included into the broader definition of *natural capital*.

In this model *natural capital* is represented by: 1) *fish stock* (both local and national), 2) *forest* (both in forest land and in biomass), 3) *Sediment* (sediment as a natural fertilizer), 4) *River transportation factor* (rivers are used for transportation). Agricultural land is cultivated so it cannot really be considered as natural capital per se, but the natural conservation and natural fertilization of it can be. These are supporting structures that can fall away if we are not careful. This is represented through the *increase of land-erosion as* a side effect of building hydro dams for instance.

Sometimes *built-up capital* comes into conflict with *natural capital.* Firms and governments can enrich themselves by extracting or exploiting natural capital, but if the capital is not replenished then the nation is in fact depleting its wealth and can eventually lead to a collapse in the ecosystem that will drag everyone with it down. In my model, I am trying to evaluate the value of some of these natural capitals and how we can compensate for or avoid a collapse in the natural capital stock.

2. Literature review

This model and thesis draws a lot of form and inspiration from the MFF model developed by the Luc Hoffmann Institute (Luc Hoffmann Institute 2017) and from the T21 model from the Millennium Institute[1].

These two models touch on the same topic of sustainability, environment and economy. They are both very useful for each their scope and in this thesis, I have borrowed elements form both models. The MFF focuses on the food, water and energy nexus on a regional and local level whereas the T21 model, also known as Threshold 21, focuses on the national level. The T21 takes on an integrated approach between several sectors and show how they influence each other; including the environment, society and economy[2].

[1] http://www.millennium-institute.org/integrated_planning/tools/T21/
[2] http://www.millennium-institute.org/integrated_planning/tools/T21/T21_sf.html

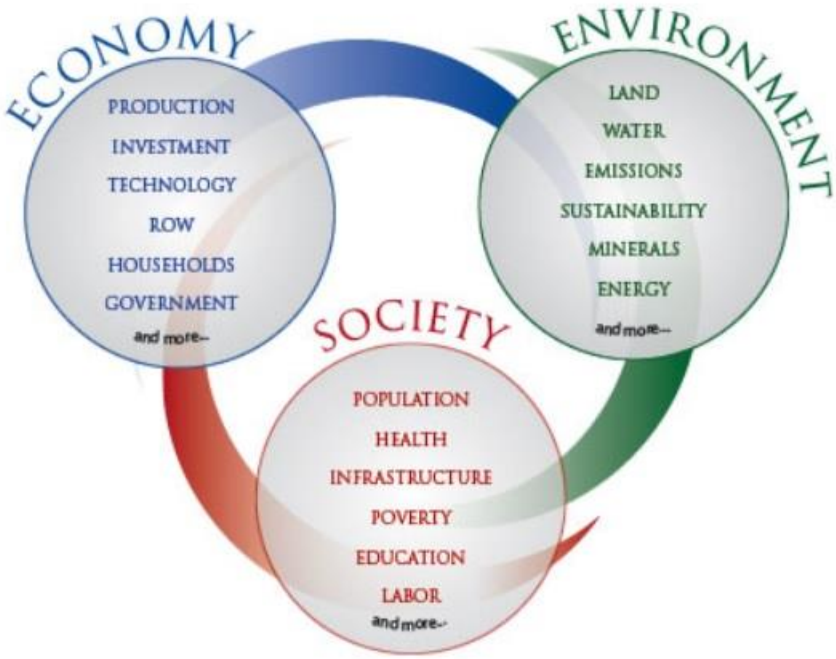


Figure 1: T21 model overview

This figure was taken from the webpage of the Millennium Institute[3]

National specific adaptations of the T21 model has been successfully made for several countries such as Malawi, China and Italy (Millennium Institute 2015). The type of integration between sectors done in the T21 model is especially useful for the topic of this thesis, since I am looking at the tradeoff between different types of capital. The different types of capital are found in the different model sectors of the T21 model. And these sectors influence each other. If for an example pollution from economic activity increases then this leads to adverse effects to health and life expectancy in another part of the model. This way you can measure gain in one sector or capital and a reduction of another type. This has been nicely captured by the Threshold 21 model.

Further the T21 model gives a template idea of how such a model with different sectors should be formed. I have taken inspiration from the architecture for the T21 in the formation of my own model for this thesis. Having clear sectors helps one to be specific about the effects coming from one sector, or type of capital, and how it influences the development of another.

[3] http://www.millennium-institute.org/integrated_planning/tools/T21/T21_sf.html

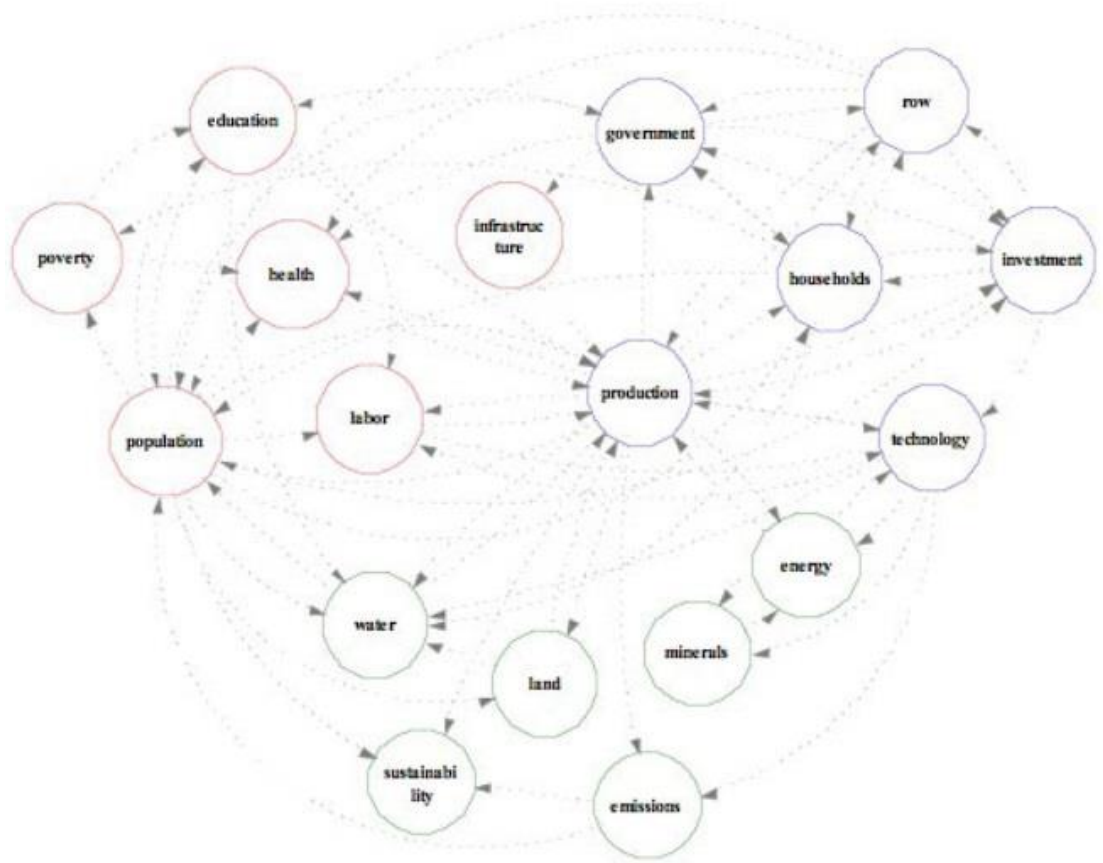


Figure 2: T21 model sectors

This figure gives the overview of the different model sectors in the T21 model. It shows the interconnection and integration of the different sectors found in a country.

The MFF model is location specific for the Kratie and Stung Treng provinces in Cambodia. It makes use of the "food-energy-water nexus" approach and incorporates relations that are specific to the landscape in the region. Similar to the T21 it also integrates factors coming from different sectors and types of capital, but gives region specific details with regards to fish stocks and food production. Sustainability and economic development are common aspects for both these two models.

Whereas the MFF model is focused on the local region, I am also looking at the whole country, while keeping an eye on the region where the hydropower dams are built. I am using the MMF model as a point of departure for this thesis as I am exploring options for how to balance between competing needs and desires.

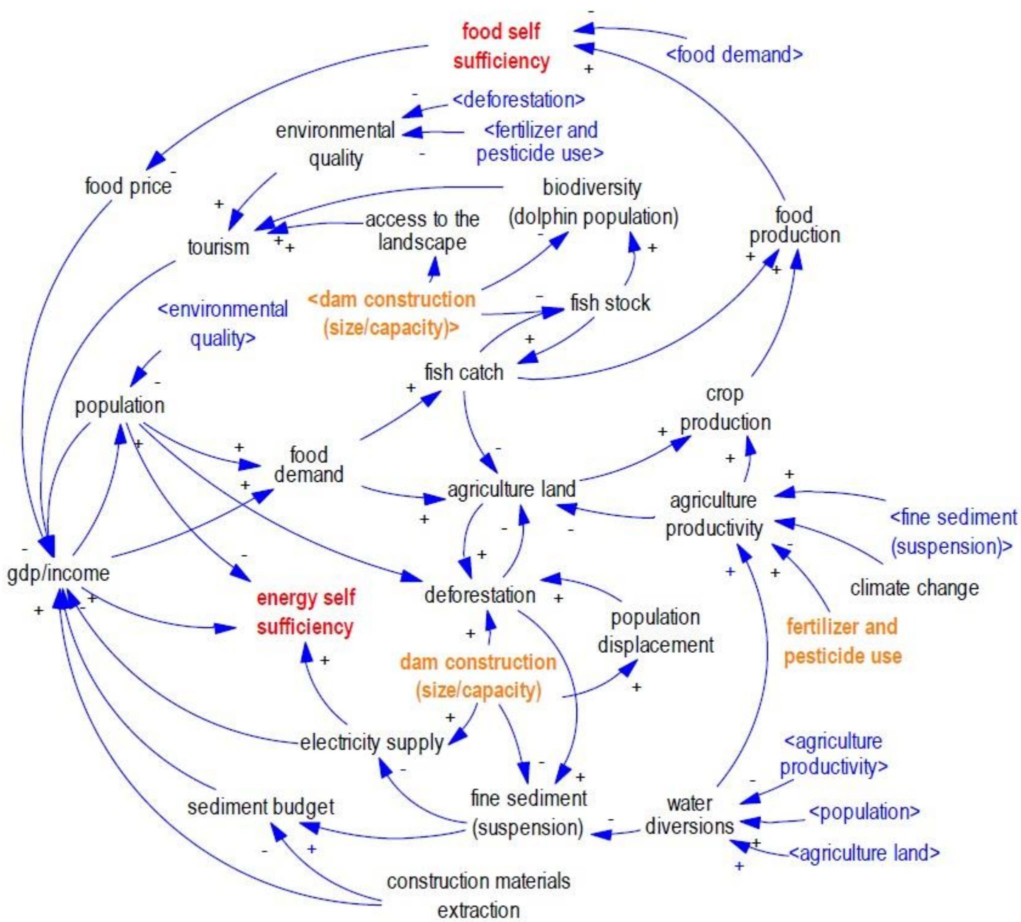


Figure 3: CLD of the MFF landscape

This figure represents the Causal loop diagram of the Food-Energy-Water Nexus in the MMF land scape.

There are several dams planned for construction on the Mekong River (Open Development 2016) and this has raised concerns about environmental issues as well as opportunities for economic advancement. Raising the issue of sustainability in the Lower Mekong Basin with regards to fisheries and hydropower development has been addressed several times before. A quite extensive report was made by the *International Center for Environmental Management (ICEM)* in 2010 for the Mekong River Commission on the subject of sustainability and economic development in the Mekong region (ICEM 2010). This report brings up the externalities and consequences of building hydropower dams on the Mekong river. And how this might be compensated for. Other papers and research has been made on this topic and concern for fish migration, agriculture and livelihoods are repeated topics in these papers (Ziv, Baran et al. 2012).

My thesis aims to incorporate these issues addressed in the literature in a model specific for Cambodia. My model lends elements from both the MFF model and the T21. It has a broader scope than the MFF with regards to looking at the whole country of Cambodia, but it is more specific and includes more details for local regional level than the generic T21 model does.

3. Method and modeling process

SD gives you the opportunity to model accumulation and feedback in a system. Accumulation and feedback give rise to dynamic, non-linear and often unexpected behavior. Ecosystems are complex and often vulnerable systems where change can have far reaching consequences. And the consequences are often not obvious or immediately evident. Accumulation and non-linear behavior with feedback is a key feature in an ecosystem. SD offers the tools and method to capture and model these aspects, and that is why SD is particularly well suited as a method for this subject.

Starting from the overarching problem formulated through the research question the problem is subdivided into concrete modeling tasks. These modeling tasks consist of breaking down the research question into concrete concepts and model structure. Often this process leads to the discovery of new questions and problems. Such problems and new questions are highlighted and researched as you will see in the model description below.

3.1 Model description

In this chapter, the model will be described and analyzed sector by sector. The model draws upon previous work and is to a large extent based on a customization of the Green Economy Model (GEM) called Mekong Flooded Forest (MFF). I have changed parts of the model and added new sectors and thus made it my own suiting the specific needs of this thesis. First I will present the core of the model pertaining to the GDP and the economic growth factors. This core sector is connected to all the other sectors and is a natural point of departure for exploring the rest of the model.

3.1.2 Model boundaries

This diagram gives a crude overview of the model boundaries. Although limited it gives a useful picture of the scope of the model.

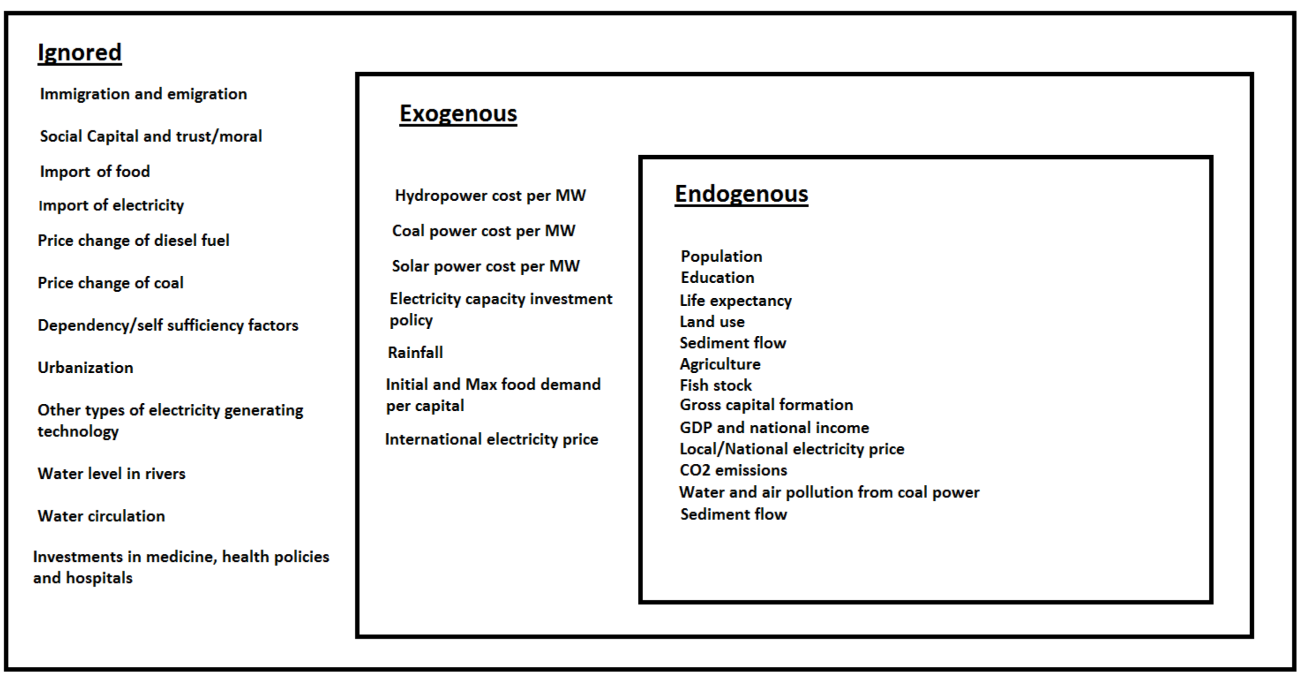


Figure 4: Model boundary diagram.

The model boundary diagram is divided into Endogenous variables that are determined by the model itself and Exogenous variables that are taken from datasets and fed into the model. Everything in the outer frame is ignored and has no impact on the model.

3.1.3 Causal Loop Diagram (CLD)

A CLD is a representation of a model intended to give a map over the causal relationships between different sectors and important variables. It is often simplified in order to give clarity or to enhance certain aspects of the model.

This CLD is meant to give a general overview of the layout of the model. The colors on the arrows are there to make it easier to follow the different causal lines going out from important variables and they do not represent closed loops. Many variables are left out of this CLD as it only is intended to show the most important elements of the model. CLDs coming later in this paper will be more sector specific than this CLD and use colored arrows to show feedback loops.

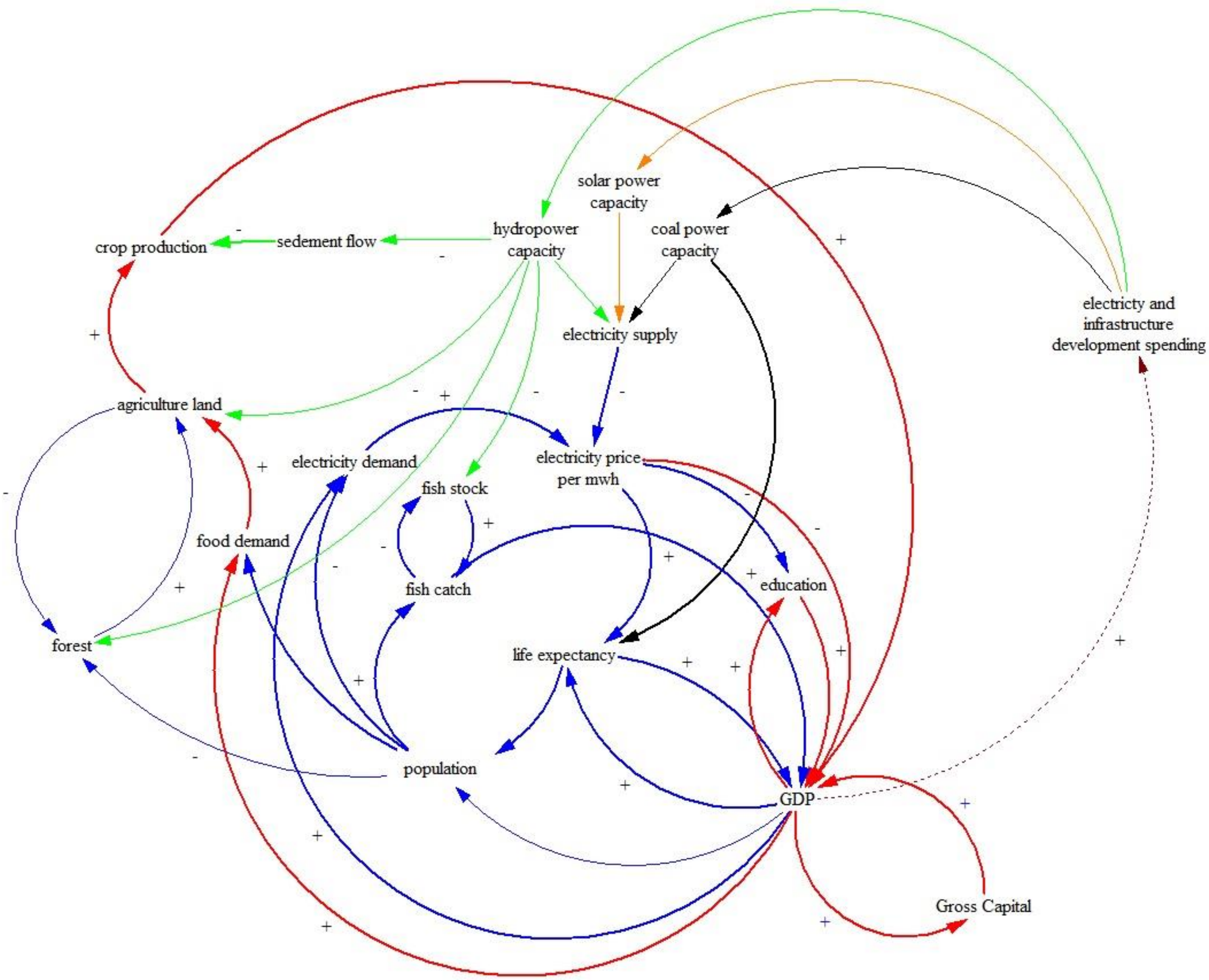


Figure 5: CLD

This CLD is showing the causal relationships between different sectors and important variables in the model. Here you can see the interaction between the electricity supply, education, population, GDP, agriculture, forest and fish stock on one and the same slide. Details are sacrificed in order to give some clarity. The red arrows show some of the most important loops connected to the GDP. The thin arrows show weaker relations and the thick arrows show stronger relations. The dotted arrow to the right represents a endogenous policy option that is optional for the model.

3.2 GDP sector

This sector calculates and show the behavior of the GDP and related variables. The GDP module has one stock*: gross capital.*

The *gross capital* grows from the *change in gross capital* inflow that goes into the stock. The inflow is governed by multiplying the stock value with a fractional growth rate.

The fractional growth rate and the initial stock level is estimated using the perpetual inventory method and is based of data taken from the World Bank[4] of year 2000. The initial value of the *gross capital* stock is found by multiplying the reference investment of the year 2000, with the value of *capital average lifetime*. The *capital average lifetime* is defined as the average time that capital stays productive once it has been invested.

Once the initial gross capital stock value is in place we can find the initial fractional growth rate for the capital stock. This is done by dividing the inflow of that year with the stock of the same year. An alternative way of doing this is to divide "1" with the *capital average lifetime.*

When implementing this initial fractional growth rate, we get yet another confirmation for its validity by comparing the initial value generated in the inflow with our historic reference data.

The fractional growth rate is multiplied with the current value of the capital stock giving rise to further growth. This is a reinforcing feedback loop driving the continued growth of the *gross capital* stock. We call this loop **R1** and you can find it indicated on the figure below. There are several loops, both reinforcing and balancing, with regards to the GDP sector. However, there are two interacting loops of particular interest in this sector, **R2** and **B2**. The **R2** loop is a reinforcing loop that drives up investment as the GDP and the capital stock increases. The other loop, called **B2**, balances out the effect of continued growth in the capital stock. This loop has a negative influence on the fractional growth rate as the capital stock increases. The actual investments may keep on increasing in monetary value despite of this, but the gross capital fractional growth rate will decline. The reasoning behind this concept is the following: As the capital stock grows larger it will become increasingly harder to keep the same level of fractional growth due to increasing externalities and the logic of diminishing return to scale, each added unit of additional capital provides slightly less growth than the previous.

This is supported by historical evidence from other economies around the world that has gone through similar transitional stages of development. The neighboring country Thailand is used an example of reference[5]. These two loops have an interaction that can be called a shift in dominance. To begin with the reinforcing loop **R2** dominates driving up investments and causing the fractional growth rate to increase, however as the capital stock becomes larger the balancing loop **B2** grows relatively stronger and reduces the fractional growth rate, putting a damper on further growth.

[4] http://data.worldbank.org/indicator/NE.GDI.TOTL.KD.ZG?end=2015&locations=KH-TH&start=2000

[5] http://data.worldbank.org/indicator/NE.GDI.TOTL.KD.ZG?end=2015&locations=KH-TH&start=2000

The *GDP* is estimated by finding a *relative production* level and then multiplied with a GDP reference value. The reference value is the value of the GDP in the year 2000 at the beginning of the simulation and is taken from the World Bank[6]. *Relative production* is found by a Cobb-Douglas function (Y=K*L*TFP) using input from *relative capital, relative labor* and the *Total factor productivity (TFP)*. From now on we will refer to *Total factor productivity* as *TFP*.

The driving factors of *TFP* comes from the effects of *education, life expectancy, roads, electricity price, crop production and fish catch.* The concept behind TFP is that these are all factors that either increase the effectiveness of the other inputs or the value output of the economy as a whole. For an example, cheaper electricity makes production and the use of capital and labor less costly. The same goes for improvements in health represented by *life expectancy* and a higher average level of education. Education and health are also effected by electricity price as we will see later in following sectors. These effects and their feedback loops are described in the section below.

The key feedback loops for the *GDP* sector are named R1, R2, R3, R4a, R4b, R5, R6 and R7 for the reinforcing feedback loops and B1, B2, B3, B4, B5, B6 for the balancing loops. They are depicted in the figure below.

Reinforcing feedback loops:

R1: As explained above, this reinforcing loop goes between *gross capital formation* and the inflow *change in gross capital formation.* The stock value is multiplied with a fractional growth rate and causes further inflow.

R2: This loop goes between *GDP* and *Gross capital formation*. The *Gross capital formation* gives rise to the *effect of capital on production* that is an input into *relative production* where it is multiplied with the other inputs. *Relative production* and by extension *Gross capital formation* has a positive relationship polarity with *GDP*, causing *GDP* to rise when it rises, and *GDP* to fall when it falls. The *GDP* in turn gives rise to *effect of gdp on capital investment* that has a positive relationship polarity with *Gross capital formation* further bolstering growth when *GDP* rises.

R3a: This reinforcing feedback loop goes between *GDP* and the Education sector. An increase in *GDP* causes an increase in *gdp per capita* that has a positive effect on the enrollment rates in the education sector leading to a larger body of students. A larger body of students increases the overall graduation rates that has a positive impact on *effect of education on tfp*. When *effect of education on tfp* increases then *total factor productivity* increases as well, leading to an increase in *GDP*, thus completing the loop.

R3b: This reinforcing feedback loop goes between *GDP* and the Education sector. This loop is similar to **R3a**, but with the difference that instead of effecting enrollment rates it decreases dropout rates from the student body. *GDP* has a negative polarity relationship with dropout rates in the education sector, dropout causes a decrease of the student body and thus have a negative polarity relationship with the body of students. This double negative gives GDP a positive polarity with the body of students, leading to a positive effect on graduation rates. Graduation rates in turn has positive polarity with GDP, causing increase when they increase and a decrease when they decrease. Thus, completing the loop through the same pathway as in **R3a**, through the *total factor productivity* going back to the *GDP*.

[6] http://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=KH

***R4:** This loop goes between the *GDP* and the and the life expectancy sector. **As an important side note to this loop: This loop is only active if the endogenous investment policy is turned on by activating the **Electricity investment endogenous switch**. This activates a policy that dedicates a fraction of the GDP to be invested in one or more of the electricity development options. Care should be taken when using this policy structure and deciding the fraction and time duration of this policy. A high fraction of GDP devoted only to electricity development is unrealistic and causes unrealistic outcomes*. * This limitation aside this loop gives a valuable insight into the positive and reinforcing effects that growth in GDP can have on electricity production. An increase in electricity production and supply causes a fall in electricity prices. The concept behind the relationship between electricity price and health comes from the idea that a fall in electricity price will cause people to start substituting the use of fossil fuels for cooking in their homes, such as kerosene, with clean electricity. The use of burning fossil fuels for cooking a lighting in homes gives off toxic fumes that can cause cancer and health issues. When people substitute this with electricity we assume an increase in the *average life expectancy*. Average life expectancy has a positive polarity with regards to *total factor productivity* and thus by extension also with GDP, completing the loop.

***R5:** This loop goes between *GDP* and electricity capacity and back to *GDP* through *average electricity price*. The same side note as in **R4** goes to this loop as well. An increase in *GDP* leads to an increase in electricity generating capacity and an increase in electricity supply, and this leads to a decrease in the electricity price. The electricity price has a negative polarity relationship with *total factor productivity*. This is a double negative and gives a positive relation between electricity supply and *TFP*. Thus a fall in electricity price leads to an increase in the TFP leading to an increase in GDP, and the loop is completed.

R6: This loop goes between *GDP* and *fish catch.* An increase in *GDP* gives an increase in food demand leading to increased fishing activity and *fish catch*. An increase in *fish catch* leads directly to an increase *TFP,* and thus also to an increase in GDP. The same would be true for a decrease in *fish catch* leading to a decrease in *TFP* and *GDP* due to the positive polarities.

R7: This loop goes between *GDP* and *crop production* via both the agriculture sector and the land sector. An increase in *GDP* leads to an increase in the demand for food. When the demand for food increases then *desired crop production* increases as well. This will eventually lead to an increase in *crop production* by increasing the amount of *agriculture land*. An increase in *crop production* has a positive effect on *TFP* that will lead to an increase in *GDP*, this completing the loop.

Balancing feedback loops:

B1: This is a simple feedback loop going between *Gross capital formation* and *capital depreciation.* As the capital stock increases the *capital depreciation* increases as well. However, an increase in the depreciation has a negative effect on the capital stock causing it to decrease, thus eventually leading to a decrease in the *capital depreciation*, completing the loop.

B2: This loop goes between the *gross capital* stock and the *gross capital fractional growth rate.* As the capital stock increases *relative capital* increases as well. The *relative capital* has a negative polarity with the *effect of capital stock on fractional growth rate,* causing the *effect of capital stock on fractional growth rate* to decrease when it increases. This leads to a fall in the *gross capital fractional growth rate* dampening further growth of the *gross capital* stock, thus completing the loop.

B3: This loop goes between *GDP* and the *labor force* via the population sector. *GDP* and *GDP per capita* has a negative polarity relation with the *fertility rate*, this causes a fall in *birth* slowing down in the population growth as the *GDP* increases. A fall in population growth will eventually cause the labor force to decline. The labor force in an input in the relative production function and has a positive polarity with GDP. This a fall in labor force will cause a fall in the GDP.

B4: This loop goes between *GDP* and the *average life expectancy* through the *average electricity price*. As the *GDP* increases demand for electricity increases driving electricity prices up. Electricity price has a negative polarity relation with *average life expectancy*. As the electricity price goes up the life expectancy is dampened. Life expectancy is an input with a positive polarity to the *TFP*. Thus, a slowing down in the life expectancy development leads to a dampening in the growth of the *GDP*, completing the loop.

B5: This loop goes between the *GDP* and the electricity price through the *effect of electricity price on tfp. GDP* has a negative polarity relation with the *effect of electricity price on tfp.* As the demand for electricity rises due to a rise in the GDP driving the electricity price up the *effect of electricity price on tfp* falls leading to a dampening effect on the *TFP* and the *GDP*, completing the loop.

B6: This loop goes between the *GDP* and the *fish stock* through the *fish catch* and back to the *GDP* through the *effect of fish catch on tfp.* When the *GDP* and the demand for food also increases, this leads to an increase in *fish catch* as we saw in the R6 loop. However, there is a shift in dominance in this structure as the balancing loop becomes stronger when the fish stock decreases. Increase in *fish catch* leads to a decrease in the *fish stock* eventually decreasing the *fish catch*. This decrease in *fish catch* leads back to the *GDP* through the *TFP* and put a dampening effect on further *GDP* growth.

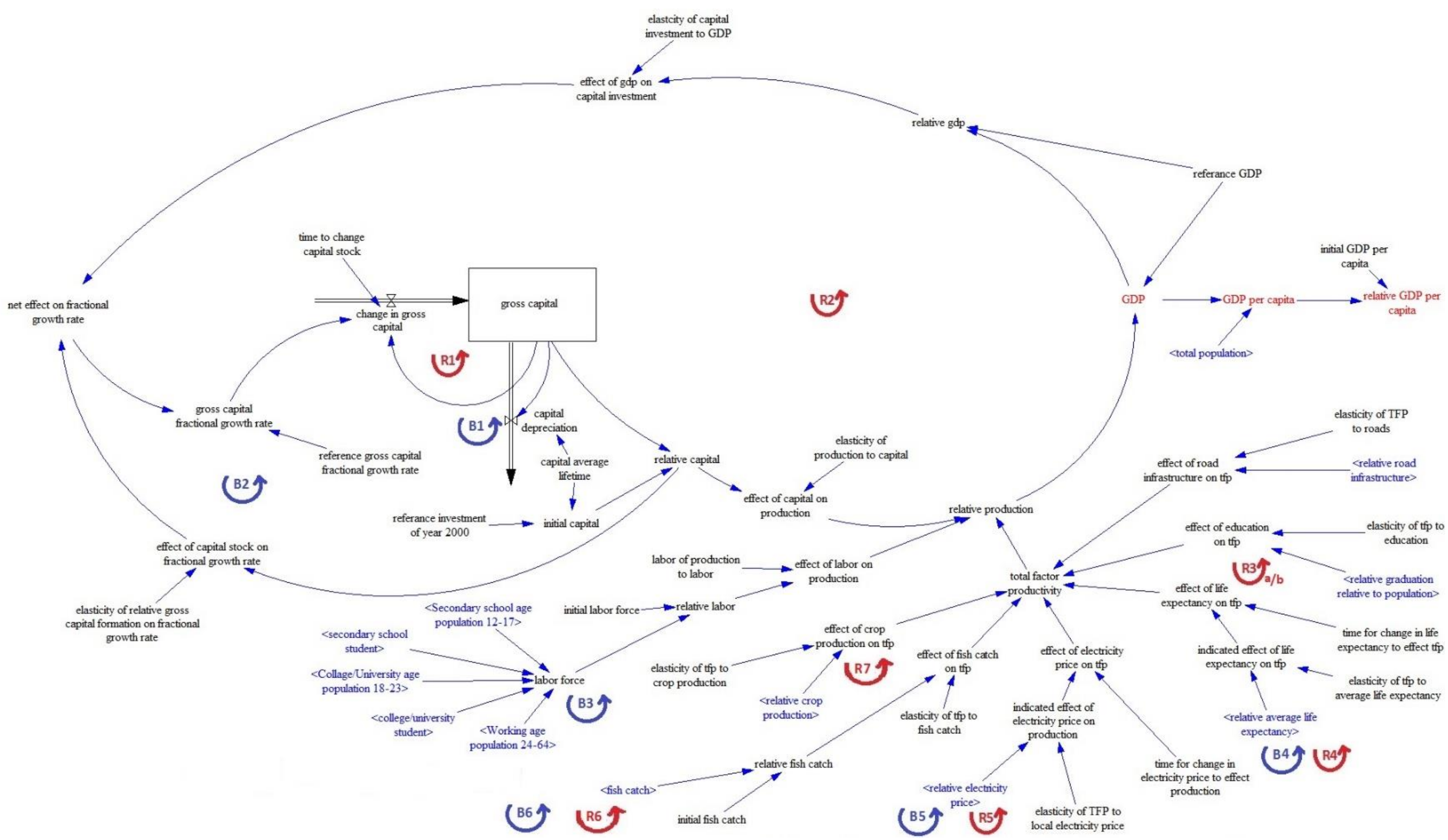


Figure 6: GDP sector overview

This is the model structure of the GDP sector. The red variables are *GDP*, *GDP per capita*, *and relative GDP per capita*. They are the output variables from this sector and feed in turn into other sectors creating a feedback-loop. The blue variables marked with < > around them are input variables from other sectors of the model. The reinforcing loops as described above are marked on this figure with the curved arrows around the name of the loops, such as R1,R2,B1,B2 etc. The reinforcing loops have the color red and the balancing loop have the color blue.

<table>
<tr><th>Name</th><th>Equation</th></tr>
<tr><td>GDP</td><td>referance GDP*relative production</td></tr>
<tr><td colspan="2">Unit: USD/Year
The gross domestic product (GDP) is meant to capture the total income/total production (Y) in a country in any given year. The reference GDP is the GDP of the year 2000 and the relative production is an estimate of the relative change in production from that reference year going forward. Relative production is multiplied with the reference GDP in order to estimate the GDP in the following years.</td></tr>
<tr><td>GDP per capita</td><td>if then else(total population<=0, 0, GDP/total population)</td></tr>
<tr><td colspan="2">Unit: USD/Year/person
GDP per capita tells us the average distribution of income per inhabitant. It is an indication of how wealthy a country is. This of course has its limitations and can give a skewed impression of how well the average citizen is doing. The wealth can be concentrated on relatively few hands. However, it gives a useful insight into how well a country is doing economically compared to its population size.

The logical function “if then else” is there to serve a formal function to avoid division by zero, if for example the value of the population is set arbitrarily to zero.</td></tr>
<tr><td>Relative GDP per capita</td><td>if then else(initial GDP per capita<=0, 1, GDP per capita/initial GDP per capita)</td></tr>
<tr><td colspan="2">Unit: Dimensionless
This show us how much the average income is relatively changing compared to itself. The advantage of looking at the relative change in GDP per capita is that it can make up for some of the skewed impression given by the “GDP per capita”. When we look the relative increase in income per person it does not give a monetary value of how much each can spend on average, but how much each now have compared to before. It is reasonable to assume that even if the wealth distribution is skewed in a country a general increase in income, for an example, will still increase the income across the social strata even if the income gap stays the same between upper and lower classes.

The “relative GDP per capita” is used as an input in other sectors of the model. It is used when we for an example want to estimate the development of demand for food and electricity, and it also influences the school enrolment and dropout rates, thus it is a key variable in the model.

The logical function “if then else” is there to serve a formal function to avoid division by zero, if for example the value of the population is set arbitrarily to zero.</td></tr>
<tr><td>Effect of GDP on capital investment</td><td>relative gdp^elastcity of capital investment to GDP</td></tr>
<tr><td colspan="2">Unit: Dimensionless
This effect completes the reinforcing loop between the GDP and the gross capital. This variable is meant to represent the effect that changes in the GDP will have on future capital investment. The concept behind this effect is that if the GDP increases people will both be able and encouraged to make further investments, thus this effect has a positive polarity between GDP and between gross capital.</td></tr>
<tr><td>Effect of capital stock on fractional growth rate</td><td>relative capital^elasticity of relative gross capital formation on fractional growth rate</td></tr>
<tr><td colspan="2">Unit: Dimensionless
The effect of capital stock on fractional growth rate is meant to represent the concept that as the capital stock increases it gets harder and harder to keep the same fractional growth rate and the fractional growth rate starts to decrease. This effect is modelled by using a negative polarity for the elasticity in the equation.
The evidence behind this concept is based on observation of other countries that has gone through the same process as Cambodia is going through right now. They show that eventually as the capital stock increases the fractional rate of capital formation decreases.</td></tr>
</table>

<table>
<tr><td>Net effect on fractional growth rate</td><td>effect of gdp on capital investment*effect of capital stock on fractional growth rate</td></tr>
<tr><td colspan="2"><u>Unit:</u> <u>Dimensionless</u>
This is where the effects coming from the loops R2 and B2 meets, and the result is the net effect that will influence the fractional growth rate. By observing this variable, we can observe the shift in relative strength between the two effects. As long as the effect keeps increasing the “effect from the gdp on capital investment” is dominating, but as soon as the net effect starts to decline the effect coming from the balancing loop is taking over the dominance.</td></tr>
<tr><td>Gross capital fractional growth rate</td><td>reference gross capital fractional growth rate*net effect on fractional growth rate</td></tr>
<tr><td colspan="2"><u>Unit:</u> <u>Dimensionless</u>
This fractional growth rate governs the rate at which new capital is formed. Its initial value is multiplied with the “net effect on fractional growth rate” to capture the effect coming from the shift in dominance of the two competing loops R2 and B2.</td></tr>
<tr><td>Change in gross capital</td><td>(gross capital*gross capital fractional growth rate)/time to change capital stock</td></tr>
<tr><td colspan="2"><u>Unit: USD/year</u>
This is the rate of capital investment going into the gross capital stock per year. It is determined by the level of the capital stock and the fractional growth rate. The R1 reinforcing feedback loop is the most closely related loop to the inflow driving the growth, however the R2 and B2 loops are also closely tied to the change in gross capital.</td></tr>
<tr><td>Relative production</td><td>total factor productivity*effect of capital on production*effect of labor on production</td></tr>
<tr><td colspan="2"><u>Unit:</u> <u>Dimensionless</u>
“Relative production” represents how much productivity is affected by changes is capital, labor and total factor productivity. The “relative production” is based on the Cobb-Douglas function Y=K*L*TFP, where Y is the “relative production” and K is capital and L is labor. The “relative production” an effect that is the product of three other effects.</td></tr>
<tr><td>Effect of capital on production</td><td>relative capital^capital elasticity on production</td></tr>
<tr><td colspan="2"><u>Unit: Dimensionless</u>
The concept behind this effect is to capture the logic of diminishing returns to scale as the capital stock increases. Therefore, the elasticity have a negative polarity. This causes an inverse relationship between the effect and the relative capital. When the relative capital increases the effect decreases. The elasticity is an assumption that should be used for sensitivity testing.</td></tr>
<tr><td>Effect of labor on production</td><td>relative labor^labor elasticity on production</td></tr>
<tr><td colspan="2"><u>Unit: Dimensionless</u>
The “effect of labor on production” is meant to capture the effect that changes in the labour stock has on relative production. If the labour stock grows then the production will increase as well. The elasticity represents how sensitive a change in the labour stock will be on the effect acting on the relative production. The elasticity is an assumption that should be used for sensitivity testing.</td></tr>
<tr><td>Total factor productivity</td><td>effect of crop production on tfp*effect of education on tfp*effect of electricity price on tfp*effect of fish catch on tfp*effect of life expectancy on tfp*effect of road infrastructure on tfp</td></tr>
<tr><td colspan="2"><u>Unit: Dimensionless</u>
The “total factor productivity” is meant to capture the factors that influences production in a country. These factors are often intangible and consist of either technology, method of organization or know-how. In the model the TFP is determined by the effects from education, road infrastructure, life expectancy ,electricity price, crop production* and fish catch*.</td></tr>
<tr><td>Effect of road infrastructure on tfp</td><td>relative road infrastructure^elasticity of roads on tfp</td></tr>
<tr><td colspan="2"><u>Unit: Dimensionless</u>
Effect of road infrastructure represents the density of roads. The concept is that roads facilitate transportation and is beneficial to economic growth and development. Thus, it has a positive relationship and effect on the TFP. The elasticity is an assumption that should be used for sensitivity testing.</td></tr>
<tr><td>Effect of education on tfp</td><td>relative graduation relative to population^elasticity of tfp to education</td></tr>
<tr><td colspan="2"><u>Unit: Dimensionless</u>
“Effect of education on tfp” is meant to capture the effect that the change in graduation has on the “total factor productivity” and subsequently on the GDP. This effect has its input from the education sector and is a product of the relative graduation rate. The “relative graduation relative to population” is meant to represent the average level of education in of the country.
The more people that graduate relative to before and relative to the growth of the population the higher the average level of education this in turn is thought to have a positive relationship on TFP. The elasticity is an assumption that should be used for sensitivity testing.</td></tr>
</table>

Effect of life expectancy on tfp	SMOOTH N(indicated effect of life expectancy on tfp, time for change in life expectancy to effect tfp, 1, 1)

Unit: Dimensionless

"Effect of life expectancy on tfp" is meant to capture the effect that change in life expectancy has on TFP. Life expectancy is thought of as a proxy for the general health condition of the country. The higher the average life expectancy the better the health condition in the country. The concept further assumes that the better the health the more productive the population becomes thus it has a positive relation to the TFP.

The equation has a SMOOTH N function in it, this is meant to represent the fact that it is a time delay before the change of life expectancy has its full effect on the TFP. The reason why it is thought that it will take some time before the full effect is realized is because people living under the previous health conditions for a long part of their life may still carry previous health conditions with them even if the environment influencing health conditions has changed. The time to effect this change is an assumption and should be tested for a sensitivity analysis.

Indicated effect of life expectancy on tfp	relative average life expectancy^elasticity of tfp to average life expectancy

Unit: Dimensionless

This variable is called "indicated effect of the life expectancy on tfp" is because it indicates what the effect eventually will be. When the life expectancy changes the indicated effect changes immediately also, however there is a time delay as mentioned earlier before this change will effect the TFP.

"The relative average life expectancy" is a proxy for the overall health condition of the country and the elasticity is an assumption that should be used for sensitivity testing.

Effect of electricity price on production	SMOOTH N(indicated effect of electricity price on production, time for change in electricity price to effect production, 1, 1)

Unit: Dimensionless

"Effect of electricity price on production" is meant to capture the effect that the change in electricity price has on the TFP. When the electricity price falls and becomes more affordable to use electricity as an input into production and this might encourage new business to start up or existing business to expand and increase their production.

The SMOOTH N function is meant to represent that there is a time delay before the market and the economy reacts to the change in electricity price.

Indicated effect of electricity price on production	relative local electricity price^elasticity of local electricity price on production

Unit: Dimensionless

This variable is called "Indicated effect of electricity price on production" is because it indicates what the effect eventually will be. When the electricity price changes the indicated effect changes immediately also, however there is a time delay as mentioned earlier before this change will effect the TFP. "The relative average life expectancy" is a proxy for the overall health condition of the country and the elasticity is an assumption that should be used for sensitivity testing.

Effect of fish catch on tfp	relative fish catch^elasticity of tfp to fish catch

Unit: Dimensionless

This effect represents the effect that fishing activities has on the economy of Cambodia. Fishing is one the of the key economic activities in the country and is therefore given such a role of relative importance with regards to the economic future of the country. Most people live of subsistence where fish is an important part of their diet and protein intake.

Effect of crop production on tfp	relative crop production^elasticity of tfp to crop production

Unit: Dimensionless

This effect represents the effect that agriculture has on the economy of Cambodia. Agriculture is of relative high importance in Cambodia since over 80% of its population live in rural villages and have their lives tied to agriculture in one way or another. Most people in the country live of subsistence and the production of their own rice is an important source of food and income.

The "elasticity of tfp to crop production" " is the parameter deciding the relative importance of this variable, as a high elasticity will increase the impact this variable has on the TFP.

Table 1: Equations of the GDP sector

3.3 Population sector

The population sector has six stocks, each of the stocks representing an age cohort, going from "*preschool age 0-5*" and until retirement age of "*elderly population65+".* The age cohorts are closely tied up to the school age cohorts in the *Education sector*. This is done to make the model coherent so that the sectors correspond to each other. The rate of *birth* is governed by the number of women in child bearing age represented through the variable "*childbearing women"* and the *"fertility rate".* This creates a reinforcing loop driving the population growth. The "*fertility rate*" is influenced by *relative GDP per capita* and the relative level of education. Both GDP and education has a negative relationship with the "*fertility rate"* , meaning that as GDP and education increases the fertility rate goes down. The elasticities corresponding to these relationships are assumptions and should be tested with sensitivity testing.

The rate of *death* is influenced by the "*relative average life expectancy".* As the life expectancy goes up the death rate goes down, each cohort having their own respective death rate and corresponding elasticity to the change in life expectancy. The elasticity values are estimated based on the historical development of death rates for each age group taken from the World Health Organization (WHO)[7] and compared to the corresponding average historical development of the life expectancy over the same period of time (year 2000-2015). Further confidence in these values have been established through sensitivity testing and comparison to reference mode.

The initial values for each of the population stocks are estimated based on the age distribution given in the CIA world factbook[8]. The demographical values from the CIA world factbook are from the year 2016. The estimation to find out the initial value for each age cohort in the year 2000 was broken down into several steps. First the accuracy of the whole estimation rests on the assumption that the demographical distribution across the age groups have remained unchanged from the year 2000 until the year 2016. This is a reasonable assumption, but opens up for a margin of error, however small, that can carry through the model. Second step is to find the amount of population within each cohort corresponding to the chosen cohorts in my model. The age groups in the CIA world factbook did not always correspond to the cohorts I had chosen for my model. To handle this I had to brake each age group given in the world factbook into smaller groups of 1 year, making a further assumption of equal weight distribution on each year of the respective age groups. Then rearrange the age groups by adding and subtracting population so that the new age groups would fit the cohorts in my model. Thirds step is to find the percentage of total population for each cohort. Then take the percentage of total population for each cohort and multiply it with the total population of the year 2000. Thus, you have a reasonable estimate for the initial values for each respective cohort at the starting time of the simulation and a correct total population.

[7] http://apps.who.int/gho/data/view.main.60270?lang=en
[8] https://www.cia.gov/library/publications/the-world-factbook/geos/cb.html

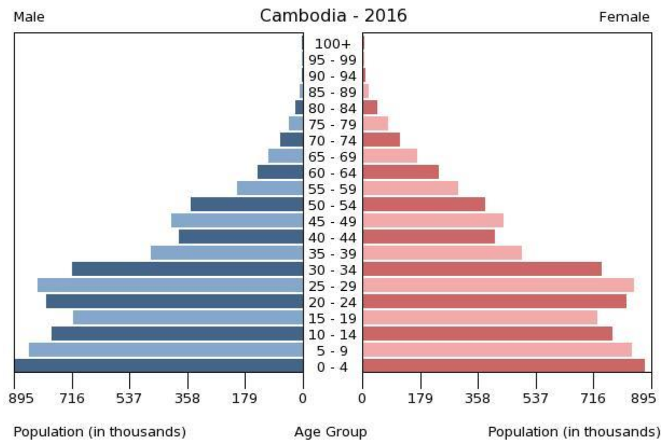


Figure 7: Age pyramid

This age pyramid is taken from the CIA World Factbook[9] and show the demographical distribution of Cambodia divided into age groups and gender for the year 2016.

The population sector is meant to capture and represent the demographical development of the country. The population sector provides important input that goes into other sectors of the model creating feedback loops.

Reinforcing feedback loops:

R8: This loop is going between the *birth* and *childbearing women*. It is the main reinforcing feedback loop of the population sector and is the driver behind all population growth. *Birth* has a positive polarity with the population stocks. As the population increases the number of *women in childbearing age* also increases. *Women in childbearing age* has a positive polarity relation with *birth*. The more women eligible to have children the more births, and in turn the more births the more women grow up to have new children. Thus, completing the loop.

Balancing feedback loops:

B7: These are loops going between deaths and the population stocks. They are all gathered together under the same name and called B7 because they all share the same underlying dynamic and belong to the same concept. These are balancing loops that go between deaths and the population stocks. Deaths and the population stocks have one positive polarity and one negative polarity connection. As the population rises so does the deaths, in turn when deaths rise the population decreases leading to a decrease in death. This is the main balancing feedback loop with regards to the population sector.

There are other feedback loops of a balancing character in this model structure as well governing the flows between the cohorts in the ageing chain. However, they are not key feedback loops that drive the development of the model structure such as the two that are described above.

[9] https://www.cia.gov/library/publications/the-world-factbook/geos/cb.html

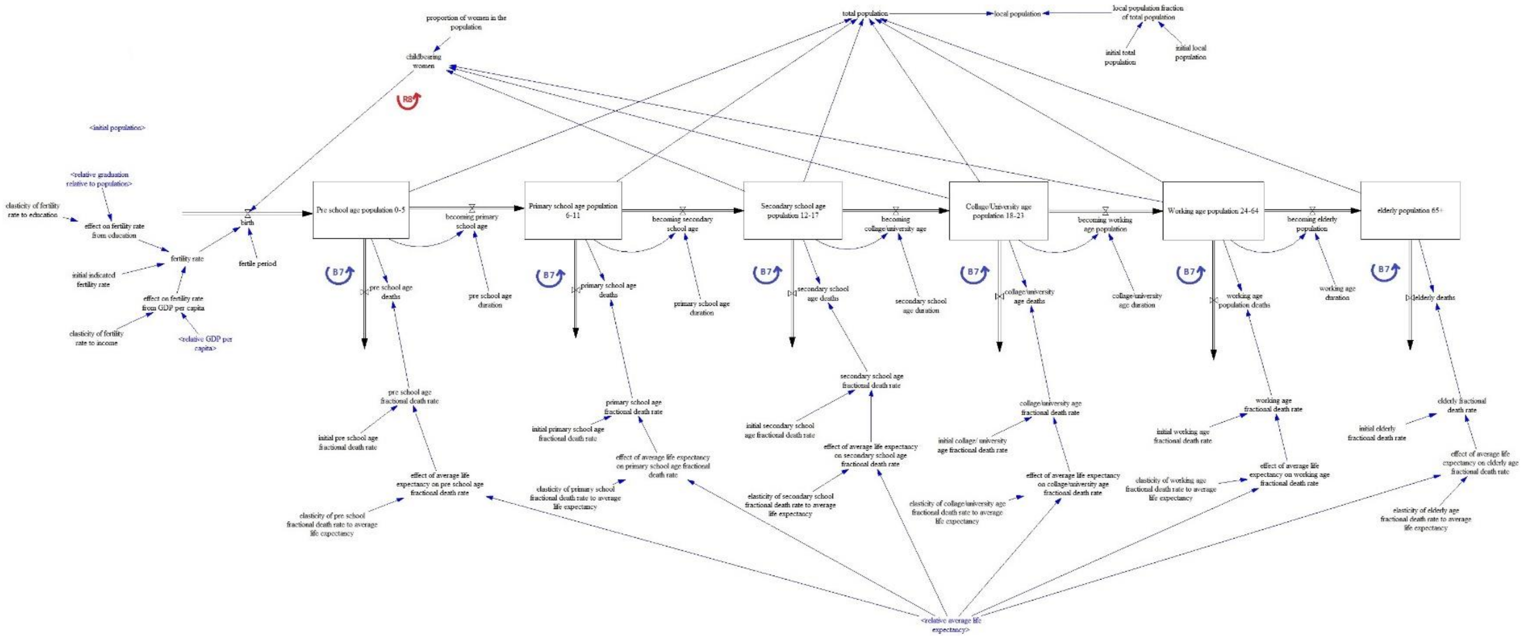


Figure 8: Population sector

This is the model structure for the population sector. Each of the stocks represents one age cohort that together comprise an ageing chain for the entire population. The feedback loops are represented by arrows that are curved around the letter R or B. The reinforcing feedback loops are marked with the color red and the letter R and the balancing loops are marked with the color blue and the letter B.

Name	**Equation**
Fertility rate	initial indicated fertility rate*effect on fertility rate from education*effect on fertility rate from GDP per capita
Unit: Dimensionless *The fertility rate represents the number of children that each woman would have if she were to live to the end of her childbearing age. The fertility rate is influenced by years of education and the level of GDP per capita.* *The structure of the equation has an initial value multiplied with two effects. The initial fertility rate is taken from the World Bank. Each of the effects will change the fertility rate relative to the initial starting value depending on the behavior of the model.* *The concept behind these effects are that the longer people stay in school the less likely they are to having children and women choose to put it off until they have finished their education. Also, increased years of education tend to increase the prevalence of contraceptives and reproductive control, this effect is not explicitly modelled in the model but is thought to be implicit in the effect of education on fertility.* *The concept behind the effect of GDP per capita on the fertility rate is that as income increases the fertility rate decreases. In societies and families with relatively low income having children is viewed as a source of cheap labor that can help out with manual tasks. It is also considered to be an insurance towards the future and old age. Another element why birthrates are high in developing countries is to compensate for correspondingly high child mortality rates. However, as income increases the need for having many children either as a source of manual labor or as an insurance for old age decreases. With more income more attention and resources can be devoted towards successfully raising a fewer number of children. And with higher income the parents are less dependent on having many offspring for their own survival and economic security.*	
Effect on fertility rate from education	relative graduation relative to population^elasticity of fertility rate to education
Unit: Dimensionless *The effect from the education sector depends on the relative rate of graduation relative to the change in the population. The elasticity of this effect is negative and thus ensures that if the relative level of education increases then the effect on education decreases and vice versa. The elasticity is an assumption and can be subject to sensitivity analysis. Further empirical research to further increase the confidence of the elasticity is recommended.*	

<table>
<tr><td>Effect on fertility rate from GDP per capita</td><td>relative GDP per capita^elasticity of fertility rate to income</td></tr>
<tr><td colspan="2"><u>Unit: Dimensionless</u>
The effect from the education sector depends on the development of the relative GDP per capita. The relative GDP per capita is raised to the power of an elasticity. This elasticity has a negative relationship to the “effect on fertility rate from GDP per capita”. The reason for this rests on the assumption that as GDP per capita increases the fertility rate will decrease. The exact negative value is estimated with the use of sensitivity testing and comparisons with historical data on how the fertility rate developed. Further empirical research to further increase the confidence of the elasticity is recommended.</td></tr>
<tr><td>Childbearing women</td><td>("Secondary school age population 12-17"+"Collage/University age population 18-23"+"Working age population 24-64")*proportion of women in the population</td></tr>
<tr><td colspan="2"><u>Unit: person</u>
This variable is a representation of all women of childbearing age in the country. It is based on adding the three age cohorts of the relevant age together and then multiplying it with the proportion of women in the population. The proportion of women in the population is taken from the CIA world factbook[10].

The number of childbearing women is essential to the growth of the population, and creates a reinforcing feedback loop between the births and the population stocks.</td></tr>
<tr><td>Total population</td><td>"Collage/University age population 18-23"+"elderly population 65+"+"Pre school age population 0-5"+"Primary school age population 6-11"+"Secondary school age population 12-17"+"Working age population 24-64"</td></tr>
<tr><td colspan="2"><u>Unit: person</u>
The total population is the sum of all the age cohorts put together. It is used as an input for GPD per capita, total food demand, electricity demand and other variables through the model.</td></tr>
<tr><td>Local population</td><td>total population*local population fraction of total population</td></tr>
<tr><td colspan="2"><u>Unit: person</u>
Local population is the estimation of the population in the local landscape of Stung Treng and Kratie. The reason for including a local estimate and level into the model is that the policies of hydropower development have different significance on the local and the national level.

This estimation is based on the assumption that the local population fraction of the total population stays the same over the duration of the model simulation.</td></tr>
<tr><td>Local population fraction of total population</td><td>initial local population/initial total population</td></tr>
<tr><td colspan="2"><u>Unit: Dimensionless</u>
The local population fraction of total population is arrived at by taking the initial local population and dividing it with the initial total population. The validity of this variable rests on the assumption that the fractional relationship between the local and the total population stays the same throughout.</td></tr>
<tr><td>Birth</td><td>childbearing women*fertility rate/fertile period</td></tr>
<tr><td colspan="2"><u>Unit: person/Year</u>
This is the governing flow of the population growth. The births directly go into the first age cohort "Pre school age population 0-5". The rate of birth is governed by the amount of childbearing women and the fertility rate divided by the fertile period.
The fertile period is the number of years that the average woman is eligible to get pregnant and give birth.</td></tr>
<tr><td>Becoming primary school age</td><td>"Pre school age population 0-5"/pre school age duration</td></tr>
<tr><td colspan="2"><u>Unit: person/Year</u>
This is the rate at which people mature from pre school age cohort to primary school age cohort. The “Pre school age duration” is the residency time for each individual in the “Pre school age population” cohort. The value of this residency time is based on a paper from UNESCO[11].</td></tr>
<tr><td>Becoming secondary school age</td><td>"Primary school age population 6-11"/primary school age duration</td></tr>
</table>

[10] https://www.cia.gov/library/publications/resources/the-world-factbook/geos/cb.html

[11] http://www.ibe.unesco.org/fileadmin/user_upload/Publications/WDE/2010/pdf-versions/Cambodia.pdf

Unit: person/Year *This is the rate at which people mature from primary school age cohort to secondary school age cohort. The "Primary school age duration" is the residency time for each individual in the "Primary school age population" cohort. The value of this residency time is based on a paper from UNESCO[12].*	
Becoming collage/university age	"Secondary school age population 12-17"/secondary school age duration
Unit: person/Year *This is the rate at which people mature from the Secondary school age cohort to Collage/university age cohort. The "Secondary school age duration" is the residency time for each individual in the "Secondary school age population" cohort. The value of this residency time is based on a paper from UNESCO[13].*	
Becoming working age population	"Collage/University age population 18-23"/"collage/university age duration"
Unit: person/Year *This is the rate at which people mature from the Collage/university age cohort to Working age cohort. The "Collage/university age duration" is the residency time for each individual in the "Collage/university age population" cohort. The value of this residency time is based on a paper from UNESCO[14].*	
Becoming elderly population	"Working age population 24-64"/working age duration
Unit: person/Year *This is the rate at which people mature from the Working age cohort to Elderly age cohort. The "Working age duration" is the residency time for each individual in the Working age population cohort. The value of this residency time is based on an estimation of the retirement age.*	
Pre school age deaths	"Pre school age population 0-5"*pre school age fractional death rate
Unit: person/Year *This in an outflow from the pre school age cohort and represents all the deaths taking place within this age group. The death rate is determined based on the size of the population stock multiplied with a fractional death rate.*	
Pre school age fractional death rate	initial pre school age fractional death rate*effect of average life expectancy on pre school age fractional death rate
Unit: 1/year *The fractional death rate determines the fraction of the stock that will die per time step. The fractional death rate is determined by changes in the average life expectancy. This is represented through multiplying an initial fractional death rate with an effect from life expectancy. The assumption is that if the life expectancy goes up then then the fractional death rate drops. This inverse relationship is determined through a negative polarity of the elasticity corresponding to the effect.* *The initial fractional death rate is taken from a paper from the WHO[15].The unit of this variable is 1/year. This means that the fractional rate of change is per year.*	
Effect of average life expectancy on pre school age fractional death rate	relative average life expectancy^elasticity of pre school fractional death rate to average life expectancy
Unit: Dimensionless *This effect is representing how change in the life expectancy influences the death rate. The effect is driven by the relative change in the life expectancy and the degree of change is determined by an elasticity. The elasticity has a negative polarity and ensures that there is an inverse relationship between the life expectancy and the death rate.* *As mentioned earlier in the introduction to the description of this sector the value of the elasticity is estimated based on the historical development of death rates[16] for each age group and compared to the corresponding average historical development of the life expectancy over the same period of time (year 2000-2015). Further confidence in these values have been established through sensitivity testing and comparison to reference mode.*	

[12] http://www.ibe.unesco.org/fileadmin/user_upload/Publications/WDE/2010/pdf-versions/Cambodia.pdf
[13] http://www.ibe.unesco.org/fileadmin/user_upload/Publications/WDE/2010/pdf-versions/Cambodia.pdf
[14] http://www.ibe.unesco.org/fileadmin/user_upload/Publications/WDE/2010/pdf-versions/Cambodia.pdf
[15] http://apps.who.int/gho/data/?theme=main&vid=60270
[16] http://apps.who.int/gho/data/?theme=main&vid=60270

Primary school age deaths	primary school age fractional death rate*"Primary school age population 6-11"
Unit: person/Year *This in an outflow from the primary school age cohort and represents all the deaths taking place within this age group. The death rate is determined based on the size of the population stock multiplied with a fractional death rate.*	
Primary school age fractional death rate	initial primary school age fractional death rate*effect of average life expectancy on primary school age fractional death rate
Unit: 1/year *The fractional death rate determines the fraction of the stock that will die per time step. The fractional death rate is determined by changes in the average life expectancy. This is represented through multiplying an initial fractional death rate with an effect from life expectancy. The assumption is that if the life expectancy goes up then then the fractional death rate drops. This inverse relationship is determined through a negative polarity of the elasticity corresponding to the effect.* *The initial fractional death rate is taken from a paper from the WHO[17].The unit of this variable is 1/year. This means that the fractional rate of change is per year.*	
Effect of average life expectancy on primary school age fractional death rate	relative average life expectancy^elasticity of primary school fractional death rate to average life expectancy
Unit: Dimensionless *This effect is representing how change in the life expectancy influences the death rate. The effect is driven by the relative change in the life expectancy and the degree of change is determined by an elasticity. The elasticity has a negative polarity and ensures that there is an inverse relationship between the life expectancy and the death rate.* *As mentioned earlier in the introduction to the description of this sector the value of the elasticity is estimated based on the historical development of death rates[18] for each age group and compared to the corresponding average historical development of the life expectancy over the same period of time (year 2000-2015). Further confidence in these values have been established through sensitivity testing and comparison to reference mode.*	
Secondary school age deaths	"Secondary school age population 12-17"*secondary school age fractional death rate
Unit: person/Year *This in an outflow from the secondary school age cohort and represents all the deaths taking place within this age group. The death rate is determined based on the size of the population stock multiplied with a fractional death rate.*	
Secondary school age fractional death rate	initial secondary school age fractional death rate*effect of average life expectancy on secondary school age fractional death rate
Unit: 1/year *The fractional death rate determines the fraction of the stock that will die per time step. The fractional death rate is determined by changes in the average life expectancy. This is represented through multiplying an initial fractional death rate with an effect from life expectancy. The assumption is that if the life expectancy goes up then then the fractional death rate drops. This inverse relationship is determined through a negative polarity of the elasticity corresponding to the effect.* *The initial fractional death rate is taken from a paper from the WHO[19]. The unit of this variable is 1/year. This means that the fractional rate of change is per year.*	
Effect of average life expectancy on secondary school age fractional death rate	relative average life expectancy^elasticity of secondary school fractional death rate to average life expectancy
Unit: Dimensionless *This effect is representing how change in the life expectancy influences the death rate. The effect is driven by the relative change in the life expectancy and the degree of change is determined by an elasticity. The elasticity has a negative polarity and ensures that there is an inverse relationship between the life expectancy and the death rate.*	

[17] http://apps.who.int/gho/data/?theme=main&vid=60270
[18] http://apps.who.int/gho/data/?theme=main&vid=60270
[19] http://apps.who.int/gho/data/?theme=main&vid=60270

As mentioned earlier in the introduction to the description of this sector the value of the elasticity is estimated based on the historical development of death rates[20] for each age group and compared to the corresponding average historical development of the life expectancy over the same period of time (year 2000-2015). Further confidence in these values have been established through sensitivity testing and comparison to reference mode.

Collage/university age deaths	Collage/University age population 18-23*collage/university age fractional death rate

Unit: person/Year

This in an outflow from the collage/university age cohort and represents all the deaths taking place within this age group. The death rate is determined based on the size of the population stock multiplied with a fractional death rate.

Collage/university age fractional death rate	initial collage/ university age fractional death rate*effect of average life expectancy on collage/university age fractional death rate

Unit: 1/year

The fractional death rate determines the fraction of the stock that will die per time step. The fractional death rate is determined by changes in the average life expectancy. This is represented through multiplying an initial fractional death rate with an effect from life expectancy. The assumption is that if the life expectancy goes up then then the fractional death rate drops. This inverse relationship is determined through a negative polarity of the elasticity corresponding to the effect.

The initial fractional death rate is taken from a paper from the WHO[21]. The unit of this variable is 1/year. This means that the fractional rate of change is per year.

Effect of average life expectancy on collage/university age fractional death rate	relative average life expectancy^elasticity of collage/university age fractional death rate to average life expectancy

Unit: Dimensionless

This effect is representing how change in the life expectancy influences the death rate. The effect is driven by the relative change in the life expectancy and the degree of change is determined by an elasticity. The elasticity has a negative polarity and ensures that there is an inverse relationship between the life expectancy and the death rate.

As mentioned earlier in the introduction to the description of this sector the value of the elasticity is estimated based on the historical development of death rates[22] for each age group and compared to the corresponding average historical development of the life expectancy over the same period of time (year 2000-2015). Further confidence in these values have been established through sensitivity testing and comparison to reference mode.

Working age population deaths	Working age population 24-64*working age fractional death rate

Unit: person/Year

This in an outflow from the working age cohort and represents all the deaths taking place within this age group. The death rate is determined based on the size of the population stock multiplied with a fractional death rate.

working age fractional death rate	initial working age fractional death rate*effect of average life expectancy on working age fractional death rate

Unit: 1/year

The fractional death rate determines the fraction of the stock that will die per time step. The fractional death rate is determined by changes in the average life expectancy. This is represented through multiplying an initial fractional death rate with an effect from life expectancy. The assumption is that if the life expectancy goes up then then the fractional death rate drops. This inverse relationship is determined through a negative polarity of the elasticity corresponding to the effect.

The initial fractional death rate is taken from a paper from the WHO[23]. The unit of this variable is 1/year. This means that the fractional rate of change is per year.

effect of average life expectancy on working	relative average life expectancy^elasticity of working age fractional death rate to average life expectancy

[20] http://apps.who.int/gho/data/?theme=main&vid=60270
[21] http://apps.who.int/gho/data/?theme=main&vid=60270
[22] http://apps.who.int/gho/data/?theme=main&vid=60270
[23] http://apps.who.int/gho/data/?theme=main&vid=60270

age fractional death rate	

Unit: Dimensionless
This effect is representing how change in the life expectancy influences the death rate.
The effect is driven by the relative change in the life expectancy and the degree of change is determined by an elasticity. The elasticity has a negative polarity and ensures that there is an inverse relationship between the life expectancy and the death rate.

As mentioned earlier in the introduction to the description of this sector the value of the elasticity is estimated based on the historical development of death rates[24] for each age group and compared to the corresponding average historical development of the life expectancy over the same period of time (year 2000-2015). Further confidence in these values have been established through sensitivity testing and comparison to reference mode.

Elderly deaths	"elderly population 65+"*elderly fractional death rate

Unit: person/Year
This in an outflow from the elderly age cohort and represents all the deaths taking place within this age group. The death rate is determined based on the size of the population stock multiplied with a fractional death rate.

Elderly fractional death rate	initial elderly fractional death rate*effect of average life expectancy on elderly age fractional death rate

Unit: 1/year
The fractional death rate determines the fraction of the stock that will die per time step. The fractional death rate is determined by changes in the average life expectancy. This is represented through multiplying an initial fractional death rate with an effect from life expectancy. The assumption is that if the life expectancy goes up then then the fractional death rate drops. This inverse relationship is determined through a negative polarity of the elasticity corresponding to the effect.

The initial fractional death rate is taken from a paper from the WHO[25]. The unit of this variable is 1/year. This means that the fractional rate of change is per year.

Effect of average life expectancy on elderly age fractional death rate	relative average life expectancy^elasticity of elderly age fractional death rate to average life expectancy

Unit: Dimensionless
This effect is representing how change in the life expectancy influences the death rate. The effect is driven by the relative change in the life expectancy and the degree of change is determined by an elasticity. The elasticity has a negative polarity and ensures that there is an inverse relationship between the life expectancy and the death rate.

As mentioned earlier in the introduction to the description of this sector the value of the elasticity is estimated based on the historical development of death rates[26] for each age group and compared to the corresponding average historical development of the life expectancy over the same period of time (year 2000-2015). Further confidence in these values have been established through sensitivity testing and comparison to reference mode.

Table 2: Equations of the Population sector

3.4 Education sector

The education sector has three stocks; all of them pertain to the body of students: "Primary school student", "Secondary school student" and "College/University student". The initial values for the three stocks comprising the body of students were taken from reference data[27]. The enrolment into the school levels are based on the corresponding age cohort and the fractional enrolment rate. The number of potential students is the size of the corresponding population stock minus the number of students already enrolled. The fractional enrolment rate is the fraction of people that enroll per year from the relevant age group.

[24] http://apps.who.int/gho/data/?theme=main&vid=60270
[25] http://apps.who.int/gho/data/?theme=main&vid=60270
[26] http://apps.who.int/gho/data/?theme=main&vid=60270
[27] http://www.nationmaster.com/country-info/profiles/Cambodia/Education/Elementary-school#2000

The fractional enrolment rate in Cambodia into the primary school has improved significantly over the last few decades and is therefore assumed to be 100%. The problem however is the dropout rate. Research show that the difficulty is to keep the children in school long enough until they graduate. The main reasons why children drop out of school were 1) parents needed their children at home to help with farming and fishing, and 2) the children had problems keeping up with the lessons[28].

The fractional dropout rates are influenced by two effects, the first coming from *relative GDP per capita* and the other one from *relative local electricity price*. These two effects are meant to represent each of the two key issues given as a reason for why someone dropped out. The *relative GDP per capita* influences the first issue of income and if the parents can afford to have them in school. The logic is that if the per capita income goes up less children will drop out. The concept behind the second effect is that if people have access to electricity and can afford it, it becomes easier for the student to keep up with his lessons due to artificial light in the evenings and the use of computers etc. The elasticities related to these effects are estimated based on the same survey that outlined the initial fractional dropout rates[29]. The same goes for enrollment into the secondary school level and college/university. The GDP per capita has a huge influence determining if people enroll or not.

The variable *relative graduation relative to population* is meant to represent the overall level of education in the country. This variable is the most important output from this sector and is used as the basis for important effects in the population sector, influencing the fertility rate, and in the GDP sector influencing the *total factor productivity*.

Reinforcing feedback loops:

Loop **R9a** and loop **R9b** is the as what is described in the **R3a** loop and **R10,a,b,c** are the same effects as is described in **R3b**, only in more detail. The reason why it is done this way is to give more relevant and detailed information relating to the sector that is described.

R9a: This loop goes between *secondary school enrolment* and *GDP* through *relative graduation relative to population*. The *GDP* has a positive polarity relation with *secondary school enrolment.* As *GDP* increases the *effect of gdp on secondary school enrolment* causes the enrolment into the secondary school to increase. An increase in enrolment causes an increase in secondary school students that will eventually cause the rate of graduation to go up. Graduation has a positive polarity relation with *GDP*, and an increase in the rate of graduation causes an increase in the *GDP*, thus completing the loop.

R9b: This loop follows the same logic as the R8b loop, only that the effect is going through *college/university enrolment.* As *GDP* increases the *effect of gdp on collage/university enrolment* causes the enrolment into the secondary school to increase. An increase in enrolment causes an increase in college/university students that will eventually cause the rate of graduation to go up. Graduation has a positive polarity relation with *GDP*, and an increase in the rate of graduation causes an increase in the *GDP*, thus completing the loop.

R10a,b,c: These are three loops that follow the same underlying logic reducing the school dropout rates as *GDP* increases. The **a**, **b** and **c** loops go to each their school level; **a** goes to primary school student, **b** to secondary school student and **c** to collage/university student. The logic for the loops are the following: An increase in *GDP*

[28] http://schooldropoutprevention.com/country-data-activities/cambodia/
[29] http://schooldropoutprevention.com/country-data-activities/cambodia/

causes the *effect of gdp on dropout fraction* to decrease, leading the dropout to decrease. The dropout rate and the body of students have a negative polarity relation, thus when the dropout rate decreases the student body increases. When the number of students increase graduation goes up. Graduation has a positive polarity relation with *GDP*, and an increase in the rate of graduation causes an increase in the *GDP*, thus completing the loop.

R11:** This reinforcing feedback loop goes between *GDP* and graduation through the supply of electricity and the electricity price. **As an important side note to this loop: This loop is only active if the endogenous investment policy is turned on by activating the* ***Electricity investment endogenous switch*. This activates a policy that dedicates a fraction of the GDP to be invested in one or more of the electricity development options. Care should be taken when using this policy structure and deciding the fraction and time duration of this policy. A high fraction of GDP devoted only to electricity development is unrealistic and causes unrealistic outcomes*. * Electricity capacity investment leads to the increase of electricity generating capacity increasing the electricity supply. An increase in the electricity supply causes the electricity price to fall. Through the *effect of electricity supply on primary and secondary dropout rate* the fall in electricity price causes the dropout rate to fall as well. When the dropout rate falls the stock of students increases and thus the graduation goes up as well. An increased graduation leads to an increase in the *GDP* through the effect coming from the *TFP*.

Balancing feedback loops:

B8a,b,c: These are three loops that follow the same underlying logic. Each of them corresponding to their own stock. Primary school student corresponds to **a**, secondary school student corresponds to **b,** and college/university student corresponds to **c**. These balancing loop goes between the stock of students and the dropout rates. As the body of students increase the dropout rates increase as well, however when the dropout rates increases the stocks of students decrease, this in turn decreasing the rate of dropout.

B9: This loop go between the body of students and the electricity price. As the number of students increase the graduation rate goes up and causes the *GDP* to increase. An increase in *GDP* causes an increase in the demand for electricity. Increased demand for electricity causes the electricity price to rise. When the electricity price increases the dropout rate increases as well due to *effect of electricity supply on primary and secondary dropout rate*. An increase in the dropout rate causes the body of students to decrease leading to a slowing down in the rate of graduation. This in turn slows down the growth of the *GDP*.

B10a,b,c: This balancing loop causes the enrolment to fall as the number of students in the stock increase. As the stock increases the remaining potential students falls and thus the rate of enrolment falls as well, slowing down the growth of the stock of students. The **a**, **b** and **c** correspond to each their school level.

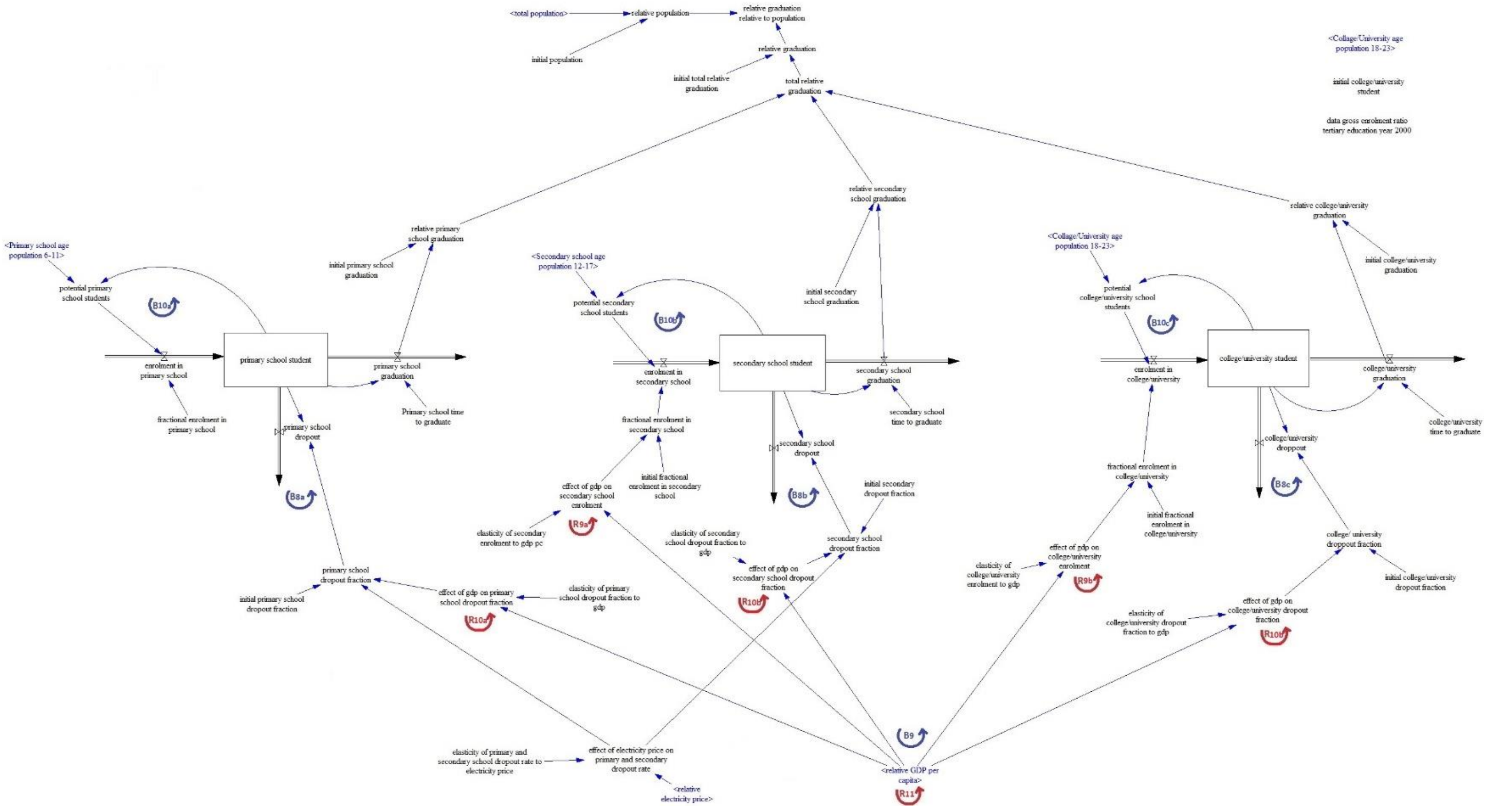


Figure 9: Education sector

This is the model structure for the education sector. The blue variables marked with < > around them are input variables from other sectors of the model. The reinforcing loops have the color red and the balancing loop have the color blue.

<u>**Name**</u>	<u>**Equation**</u>
Enrolment in secondary school	potential secondary school students*fractional enrolment in secondary school
<u>Unit: person/year</u> *This is the inflow into the primary student stock. It is the primary recruitment into the whole education system.*	
Potential primary school students	MAX("Primary school age population 6-11"-primary school student,0)
<u>Unit: person</u> *This is meant to represent the number of potential students available for enrolment into the primary school level. The concept behind this variable is that every person belonging to the relevant age cohort that is not already enrolled in school is a potential student. As the number of enrolled students increase the less potential students will remain. The reason why there is a MAX function is to ensure that the variable does not go negative. This is necessary at the beginning of the simulation as the initial stock value of the primary school student are greater than that of the corresponding population stock. The reason for this is that there is a significant number of "older" students that has also enrolled into primary school or they have not finished it in the required time. However the assumption is that going forward this is no longer a problem and students graduate on time and does not reenrol in the level below.*	
Primary school dropout	primary school student*primary school dropout fraction
<u>Unit: person/Year</u> *The primary school dropout is representing all the students that drop out of primary school before they graduate.*	

Primary school dropout fraction	initial primary school dropout fraction*effect of gdp on primary school dropout fraction*effect of electricity price on primary and secondary dropout rate
Unit: 1/Year *This is the fraction of primary school students that drop out per year. The fraction is determined by two effects, coming from GDP and the electricity price, multiplied with an initial value. The relative changes in both the GDP and the electricity price are the main determining factors for these effects. The initial value is taken from empirical reference data[30].*	
Effect of gdp on primary school dropout fraction	relative GDP per capita^elasticity of primary school dropout fraction to gdp
Unit: Dimensionless *This variable is meant to represent the effect that changes in income per capita has on the primary school dropout fraction. It has a negative polarity with GDP per capital, such as when the GDP per capita increases the effect causes the dropout rate to fall. This is due to the elasticity being negative.*	
Effect of electricity price on primary and secondary dropout rate	relative electricity price^elasticity of primary and secondary school dropout rate to electricity price
Unit: Dimensionless *This effect is affecting the primary school and the secondary school dropout rate. The reason why this effect is not also affecting the College/university dropout rate is based on the concept that the students that are enrolled in university already have sufficient access to electricity, since universities are located in cities and urban centres. It is the rural countryside that is lacking electricity and this is where the large majority of children live and go to school.* *This effect causes the dropout rates to decrease when the electricity price falls. The idea behind this is that the electricity supply to local households will help students keep up with their academic progression. One third (1/3) of dropouts report that they were unable to keep up with their lessons; thus the elasticity is set to 0.33[31].*	
Primary school graduation	primary school student/Primary school time to graduate
Unit: person/Year *This represents the number of students that graduate from primary school each year. Time to graduate is the number of years the average student stays in school. For primary school it is 6 years[32].*	
Potential secondary school students	MAX("Secondary school age population 12-17"-secondary school student,0)
Unit: person *This is meant to represent the number of potential students available for enrolment into secondary school level. The concept behind this variable is that every person belonging to the relevant age cohort that is not already enrolled in school is a potential student. As the number of enrolled students increase the less potential students will remain. The reason why there is a MAX function is to ensure that the variable does not go negative.*	
Enrolment in secondary school	"fractional enrolment in college/university"*"potential college/university school students"
Unit: person/Year *This is the inflow into the stock of secondary school students. It is meant to represent the number of new students entering the secondary school per year. They are recruited from the potential secondary students which is the difference between the corresponding age cohort and the current level of enrolled secondary students.*	
Fractional enrolment in secondary school	MIN(initial fractional enrolment in secondary school*effect of gdp on secondary school enrolment, 1)
Unit: 1/Year	

[30] http://schooldropoutprevention.com/country-data-activities/cambodia/

[31] http://schooldropoutprevention.com/country-data-activities/cambodia/

[32] http://www.ibe.unesco.org/fileadmin/user_upload/Publications/WDE/2010/pdf-versions/Cambodia.pdf

<table>
<tr><td colspan="2">This is the fractional rate that governs the proportion of potential students that will enrol per year. This variable is determined by an initial value multiplied by an effect coming from the GDP. As this fraction increases the rate of enrolment into the secondary school increases as well. The MIN function is there to ensure that the fractional rate does not exceed 100% enrolment since this would be conceptually wrong.</td></tr>
<tr><td>Effect of gdp on secondary school enrolment</td><td>relative GDP per capita^elasticity of secondary enrolment to gdp pc</td></tr>
<tr><td colspan="2"><u>Unit: Dimensionless</u>
The concept behind this effect is that as the GDP per capita increases the fractional enrolment rate will also increase since now people can afford to let their children go to school. To afford to go to school is not just a question of affording a school fee or school materials, but also if the parents or the student can afford not to work the time he or she is attending school and studying.</td></tr>
<tr><td>Secondary school dropout</td><td>secondary school student*secondary school dropout fraction</td></tr>
<tr><td colspan="2"><u>Unit: person/Year</u>
The secondary school dropout is representing all the students that drop out of secondary school before they graduate.</td></tr>
<tr><td>Secondary school dropout fraction</td><td>initial secondary dropout fraction*effect of gdp on secondary school dropout fraction*effect of electricity price on primary and secondary dropout rate</td></tr>
<tr><td colspan="2"><u>Unit: 1/Year</u>
This is the fraction of secondary school students that drop out per year. The fraction is determined by two effects, coming from GDP and the electricity price, multiplied with an initial value. The relative changes in both the GDP and the electricity price are the main determining factors for these effects. The initial value is taken from empirical reference data[33].</td></tr>
<tr><td>Effect of gdp on secondary school dropout fraction</td><td>relative GDP per capita^elasticity of secondary school dropout fraction to gdp</td></tr>
<tr><td colspan="2"><u>Unit: Dimensionless</u>
This variable is meant to represent the effect that changes in income per capita has on the secondary school dropout fraction. It has a negative polarity with GDP per capital, such as when the GDP per capita increases the effect causes the dropout rate to fall. This is due to the elasticity being negative.</td></tr>
<tr><td>Secondary school graduation</td><td>secondary school student/secondary school time to graduate</td></tr>
<tr><td colspan="2"><u>Unit: person/Year</u>
This represents the number of students that graduate from secondary school each year. Time to graduate is the number of years the average student stays in school. For secondary school it is 6 years[34].</td></tr>
<tr><td>Potential college/university student</td><td>MAX("Collage/University age population 18-23"-"college/university student",0)</td></tr>
<tr><td colspan="2"><u>Unit: person</u>
This is meant to represent the number of potential students available for enrolment into the collage/university level. The concept behind this variable is that every person belonging to the relevant age cohort that is not already enrolled in school is a potential student. As the number of enrolled students increase the less potential students will remain. The reason why there is a MAX function is to ensure that the variable does not go negative.</td></tr>
<tr><td>Enrolment in college/university</td><td>"fractional enrolment in college/university"*"potential college/university school students"</td></tr>
<tr><td colspan="2"><u>Unit: person/Year</u>
This is the inflow into the stock college/university students. It is meant to represent the number of new students entering the secondary school per year. They are recruited from the potential college/university students which is the difference between the corresponding age cohort and the current level of enrolled collage/university students.</td></tr>
<tr><td>Fractional enrolment in college/university</td><td>MIN("initial fractional enrolment in college/university"*"effect of gdp on college/university enrolment", 1)</td></tr>
<tr><td colspan="2"><u>Unit: 1/Year</u></td></tr>
</table>

[33] http://schooldropoutprevention.com/country-data-activities/cambodia/

[34] http://www.ibe.unesco.org/fileadmin/user_upload/Publications/WDE/2010/pdf-versions/Cambodia.pdf

This is the fractional rate that governs the proportion of potential students that will enrol per year. This variable is determined by an initial value multiplied by an effect coming from the GDP. As this fraction increases the rate of enrolment into collage/university increases as well. The MIN function is there to ensure that the fractional rate does not exceed 100% enrolment since this would be conceptually wrong.	
Effect of gdp on college/university enrolment	relative GDP per capita^"elasticity of college/university enrolment to gdp"
Unit: Dimensionless *The concept behind this effect is that as the GDP per capita increases the fractional enrolment rate will also increase since now people can afford to let their children go to school. To afford to go to school is not just a question of affording a school fee or school materials, but also if the parents or the student can afford not to work the time he or she is attending school and studying.*	
College/university dropout	"college/university student"*"college/ university dropout fraction"
Unit: person/Year *The college/university dropout is representing all the students that drop out of college or university school before they graduate.*	
College/ university dropout fraction	"initial college/university dropout fraction"*"effect of gdp on college/university dropout fraction"
Unit: 1/Year *This is the fraction of college/university students that drop out per year. The fraction is determined by two effects, coming from GDP and the electricity price, multiplied with an initial value. The relative changes in both the GDP and the electricity price are the main determining factors for these effects.*	
Effect of gdp on college/university dropout fraction	relative GDP per capita^"elasticity of college/university dropout fraction to gdp"
Unit: Dimensionless *This variable is meant to represent the effect that changes in income per capita has on the college/university dropout fraction. It has a negative polarity with GDP per capital, such as when the GDP per capita increases the effect causes the dropout rate to fall. This is due to the elasticity being negative.*	

Table 3: Equations of the Education sector

3.5 Land sector

The land sector has five stocks. Each of the stocks represent a status or a category of land. The categories of land are into *agriculture land*, *forest land*, *settlement land*, *flooded land* and *eroded land.* All the stocks put together represent the total landmass of Cambodia.

Agriculture land is land that is cultivated and used for food production. It is an important input into the production of food together with sediment or fertilizers and rain. The amount of agriculture land is proportional to the amount of food that is produced given a level of productivity per hectare of land (Graeme Blair 2010), (David R. Montgomery 2007).

Forest land is all the land that is not cultivated, settled or developed in any way. Forest is essential for a well-functioning ecosystem with regards to the people and other species that depend on it to live. The forest provides a biosphere and a living habitat for a diverse range of plants and animals. The forest also provides a steady source of biomass through growth if it is not over exploited (DEBORAH A. CLARK 1999).

Settlement land is the land that is used for housing, industry, infrastructure and other activities relating to human settlements. The main driving force behind the demand for settlement land in population growth. An increase of settlement land can cause significant stress on an ecosystem.

In this model, *Flooded land* represent all the land that becomes flooded due to the constructing of hydropower dams. The rate of flooded land is based on an estimate of how much agriculture land and how much forest land is on average flooded per MW of hydropower capacity.

Eroded land is land that used to be Agriculture land, but has depreciated and is drained of soil and nutrients. Thus, this land is no longer useful for agricultural purposes.

The conversion from one type of land to another type of land is largely driven by human activates for development and economic desires. Such as the construction of electricity capacity, agriculture and settlements. The conversion of eroded land back to useable agriculture land is a natural process going on by itself, this can however be sped up by human intervention, but this is not included in the model.

Reinforcing feedback loops:

R12: This loop goes between *GDP*, the *desired agriculture land* and *agriculture land* through the *agriculture land gap.* When *GDP* increases the demand for food increases. An increased demand for food leads to an increase in *desired agriculture land,* when the desire for agriculture land increases the *agriculture land gap* increases as well. This leads to an increase in the stock of *agriculture land*. When *agriculture land* increases crop production increases as well, this has a positive effect on *TFP* leading to an increase in *GDP*, thus completing the loop.

Balancing feedback loops:

B12: This loop goes between *agriculture land gap* and the *agriculture land*. This loop is practically the same loop as the **B7** loop from the GDP sector, but for the purposes of emphasizing its effect in this sector we call it **B12**. As the gap increases the *forest to agriculture land* flow increases causing the agriculture land to increase. As the amount of agriculture land increases the gap closes causing the *forest to agriculture land* flow to decrease and eventually stop as the gap is closed.

B12: This is a simple balancing feedback loop going between the *settlement land gap* the *settlement land*. As the gap increases the conversion of forestland to settlement land increases causing the settlement land to increase. However, as the settlement land increases the gap decreases and eventually closes, thus causing the conversion from forest to settlement land to stop as well.

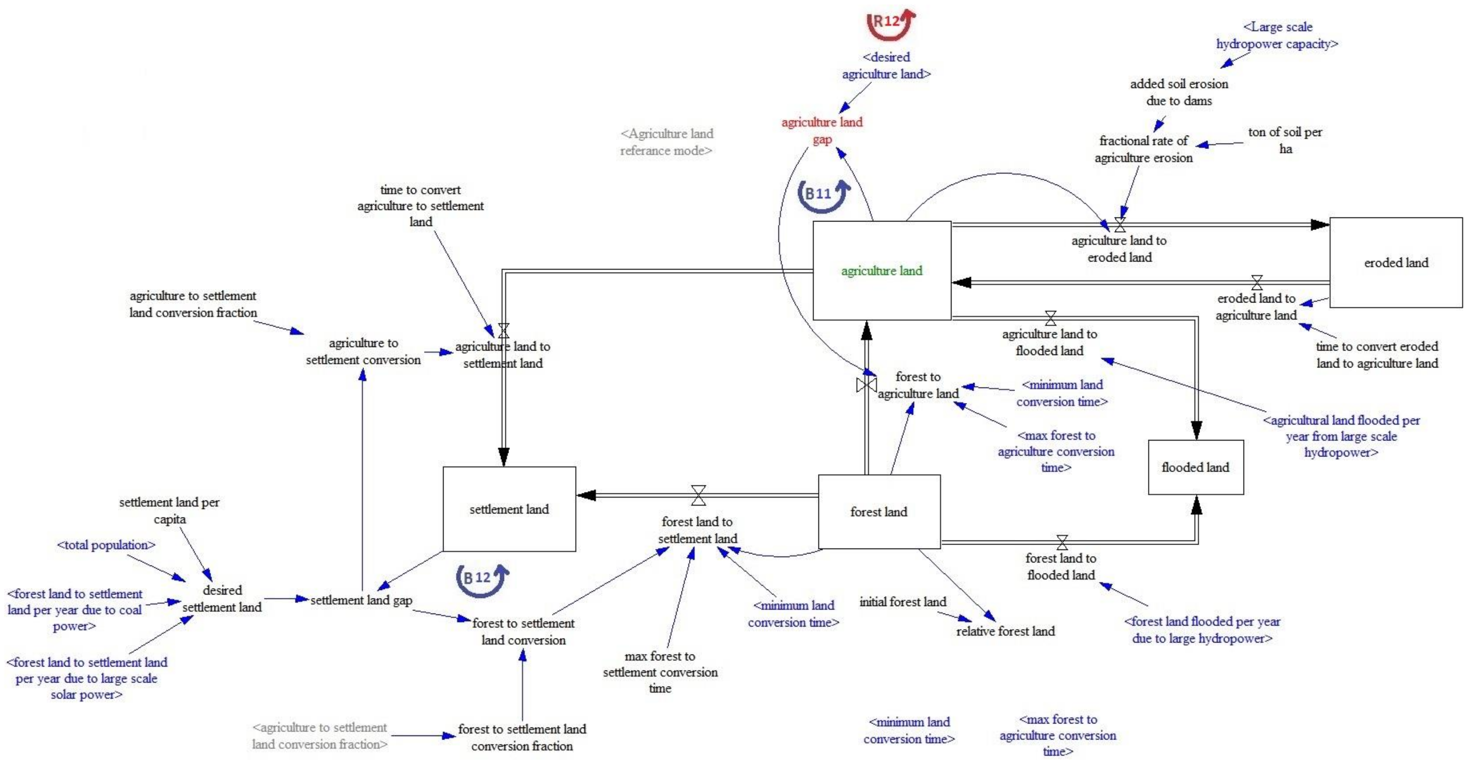


Figure 10: Land sector

This is the model structure for the land sector. Each of the stocks represent a category of land.

<table>
<tr><th><u>Name</u></th><th><u>Equation</u></th></tr>
<tr><td>Agriculture land gap</td><td>MAX(desired agriculture land-agriculture land,0)</td></tr>
<tr><td colspan="2"><u>Unit: hectare</u>
This is meant to represent the gap between the desired agriculture land and the actual amount of agriculture land. When desired agriculture land increases and becomes greater than the current level of agriculture land the gap increases. The agriculture gap is governing the conversion from forest land to agriculture land.

The reason why there is used a MAX function in this equation is to represent that once land has been cultivated and turned into agriculture land it is not just abandoned as long as it is possible to grow crops on it and generate income from it. The concept supporting this idea is that if the demand in the country is satisfied then the remaining food produce is exported. The gap changes only when the demand for agriculture land exceed the current level of agriculture land.</td></tr>
<tr><td>Forest to agriculture land</td><td>MIN(agriculture land gap/minimum land conversion time, forest land/max forest to agriculture conversion time)</td></tr>
<tr><td colspan="2"><u>Unit: hectare/Year</u>
This flow is representing the conversion of forest land to agriculture land. It is governed by the time it takes to convert forest land to agriculture land. However, there is a limit to how much forest land that can be converted into agriculture land at once, with regards to the remaining size of the forestland stock. This is represented in the equation using the MIN function choosing the lesser of the two expressions. The 'max forest to agriculture conversion time' is the limiting factor. As forest land decreases the latter expression becomes smaller and this becomes the rate that governs the forest to agriculture land rate.</td></tr>
<tr><td>Agriculture land to eroded land</td><td>agriculture land*fractional rate of agriculture erosion</td></tr>
<tr><td colspan="2"><u>Unit: hectare/Year</u>
This is the rate at which agriculture land erodes. There is always a natural rate of erosion going on, as it is a natural rate of new soil being formed. Over time an ecosystem finds a balance between the erosion and the soil formation. However, with the construction</td></tr>
</table>

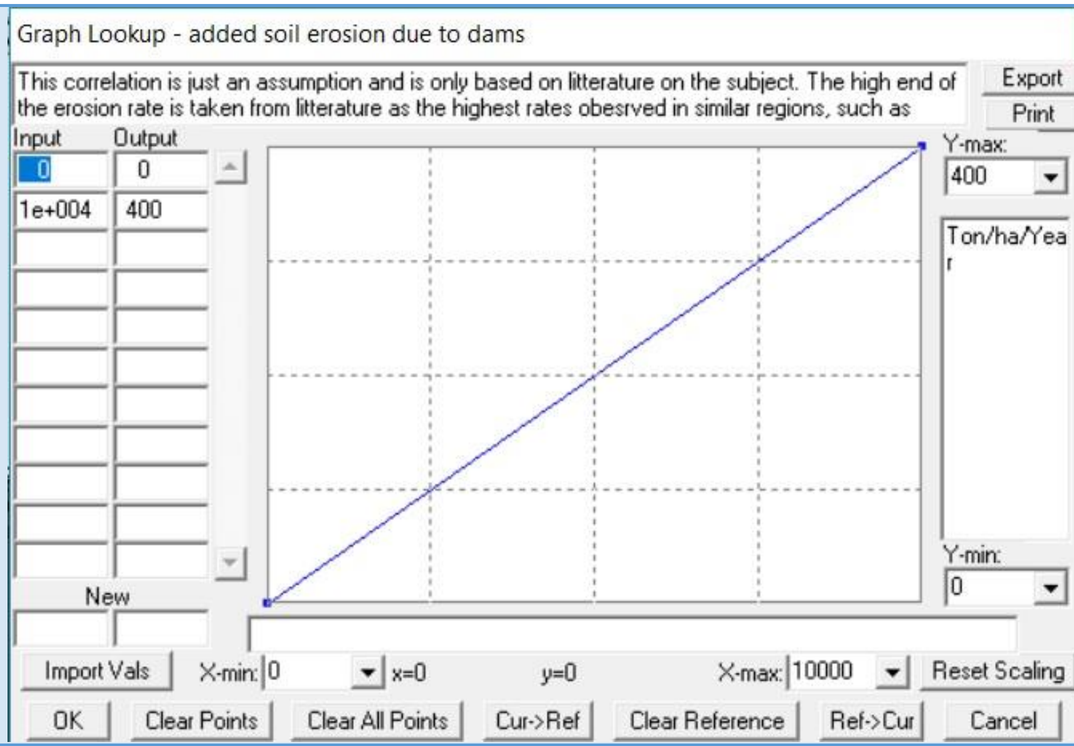
of dams or with extended agriculture activity in general this erosion rate tends to increase. Agriculture land is extra vulnerable for erosion as it is open and unprotected, compared to forest land that is covered and has a network of roots to keep it in place.

Fractional rate of agriculture erosion	added soil erosion due to dams/ton of soil per ha

Unit: 1/Year

The fractional rate of agriculture erosion is governed by added soil erosion due to dams. This fractional rate of agriculture land erosion is found by dividing the number of tons of soil eroded per year with the number of tons of soil per hectare. The reason why it is done this way is to convert the number of tons that are eroded per year to the corresponding amount of hectare that will be lost from the agriculture land.

Added soil erosion due to dams



Unit: Ton/ hectare /Year

This correlation is just an assumption and is only based on literature of the subject. The high end of the erosion rate is taken from literature as the highest rates observed in similar regions, such as China in relation to development projects and agriculture, the low-end of the scale is assumed to be zero as there are no dams built. The idea behind this concept is that before dams are built the net erosion is zero. Also, for the purpose of this model it is done like this to give emphasis to the erosion that specifically occurs due to dam construction.

The input into this graphical function is large-scale hydropower capacity. The output are tons of soil that will erode corresponding to the input of hydropower capacity. When hydropower dams are built, it causes erosion to take place. Upstream above the dam water is flooding over its banks and washing sediment away with it. However, when they get to the dam the sediment falls to the bottom of the dam. Downstream the water is lacking sediments because the dam has cut of the sediment flow and thus the water will drain the soil along the river banks by absorbing minerals from them.

Ton of soil per ha	2040 ton/ha

Unit: ton/hectare

Assuming an average tolerance loss of 6 inches of soil, and 1 inch (25mm) of soil per hectare is 340tons then 1 hectare with 6 inches is 2040 tons[35]

Forest land to settlement land	MIN(forest to settlement land conversion/minimum land conversion time , forest land/max forest to settlement conversion time)

Unit: hectare/Year

This is the conversion from forest land to settlement land. This conversion is driven by the desired settlement land and the settlement land gap. Like in the case of converting forest to agriculture land there is a limitation to how much forest land that can be converted at once. This is represented in the equation using the MIN function choosing the lesser of the two expressions. The 'max forest to

[35] http://www.jstor.org/stable/pdf/1310591.pdf

settlement conversion time' is the limiting factor. As forest land decreases the latter expression becomes smaller and this becomes the rate that governs the forest to settlement land rate.	
Forest to settlement land conversion	settlement land gap*forest to settlement land conversion fraction
Unit: hectare *This represents the portion of the settlement land gap that is to be covered by converting forest land into settlement land.*	
Settlement land gap	MAX(0, desired settlement land-settlement land)
Unit: hectare *This variable show the gap between the desired level of settlement land and the actual level of settlement land. This gap governs the development of settlement land.*	
Desired settlement land	(total population*settlement land per capita)+forest land to settlement land per year due to coal power+forest land to settlement land per year due to large scale solar power
Unit: hectare *The desired settlement land represents the level of demand for settlement land as the population changes. The building of electricity generating capacity other than hydropower will also result in an additional desire for settlement land. Settlement land can be understood as land developed by humans where they either live or work.*	
Agriculture land to settlement land	agriculture to settlement conversion/time to convert agriculture to settlement land
Unit: hectare/Year *This is the conversion of agriculture land to settlement land.*	
Agriculture to settlement conversion	settlement land gap*agriculture to settlement land conversion fraction
Unit: hectare *This represents the portion of the settlement land gap that is to be covered by converting agriculture land into settlement land. This portion is determined by the 'agriculture to settlement land conversion fraction'. This fraction tells us how much of the gap is to be covered by converting agriculture land to settlement land. Since agriculture land is productive and valuable to the people that own it agriculture land is rarely converted to settlement. This is an assumption and the fraction is set to 1%.*	

Table 4: Equations of the Land sector

3.6 Agriculture sector

The agriculture sector has no stocks of its own, but it uses stocks from other sectors as inputs. The agriculture sector represents the crop production in Cambodia. The sector also calculates the food demand in the country, and based on this gives us the desired crop production. The desired crop production together with agriculture land productivity determine the desired agriculture land. Thus, this sector is closely related to the land sector. The GDP sector is another sector that is closely related to the Agriculture sector. The *GDP per capita* influences the demand for food and the crop production influences the total factor productivity that in turn influences the *GDP*. This way this sector is involved in different loops of the model, however within the sector itself there are no loops per se. However, there are two loops that cross through the sector, **R13** and **B13**. Those two loops are significant to the sector and thus they merit proper attention.

Reinforcing feedback loops:

R13: This feedback loop go between *desired agriculture land* and *crop production,* through the land sector and the *GDP* sector respectively. As *crop production* increases *GDP* increases. An increase in the *GDP* leads to an increase in food demand. Increased food demand leads to an increase of desired crop production, this causes an increase in the *desired agriculture land* that eventually leads to a rise in the *agriculture land* stock. As *agriculture land* increases, *crop production* increases as well, thus completing the loop.

Balancing feedback loops:

B13: This loop goes between *crop production* and *total population*. An increase *in crop production* leads to an increase in *GDP*. When *GDP* increases the *fertility rate* decreases. A decrease in the *fertility rate* has a negative effect on the *total population*. *Total population* is positively linked with *desired crop production*, thus a negative effect on *total population* also has a negative influence on the *desired crop production*. A dampening effect on the *desired crop production* will eventually have a dampening effect on the *crop production*, thus completing the loop.

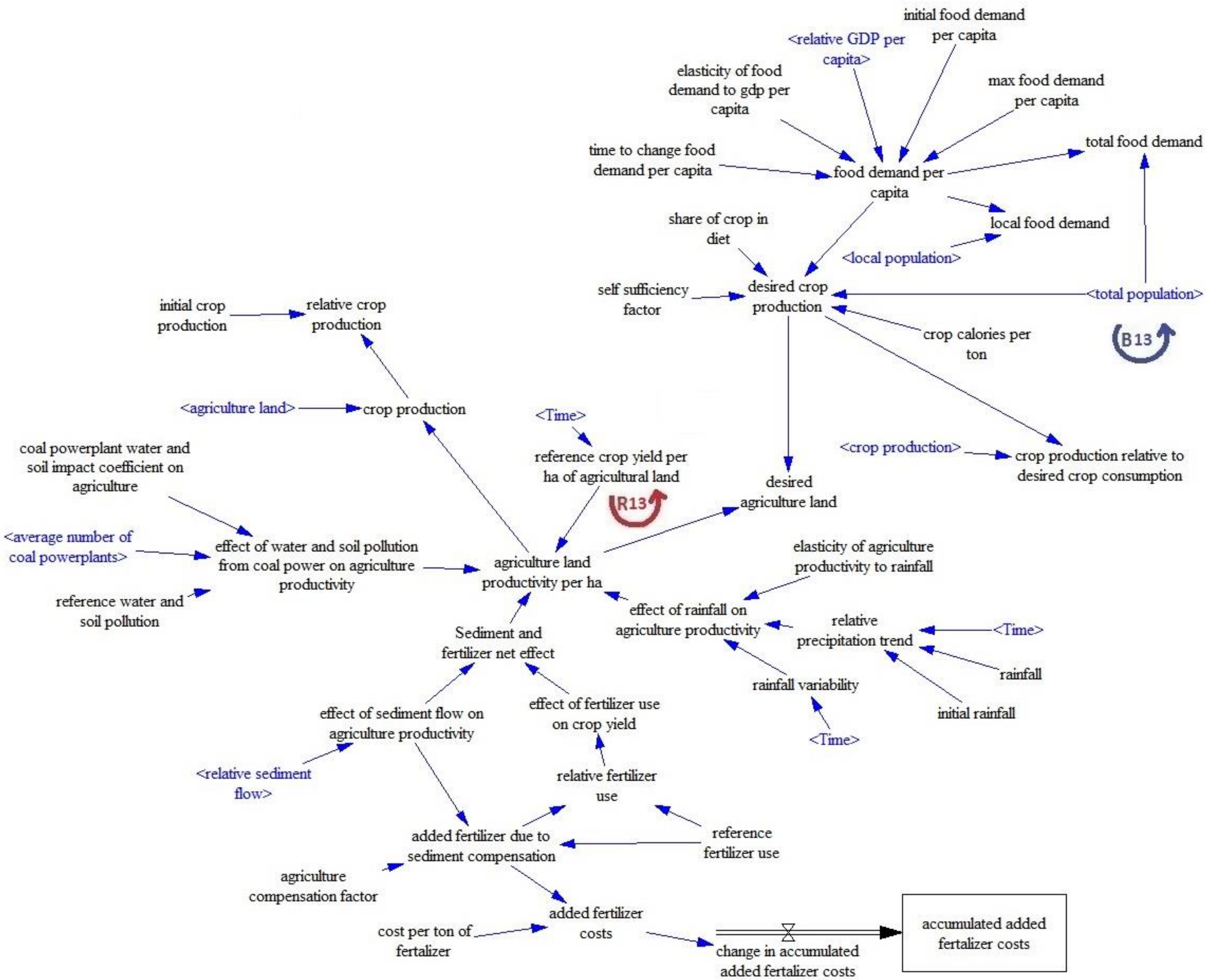


Figure 11: Agriculture sector

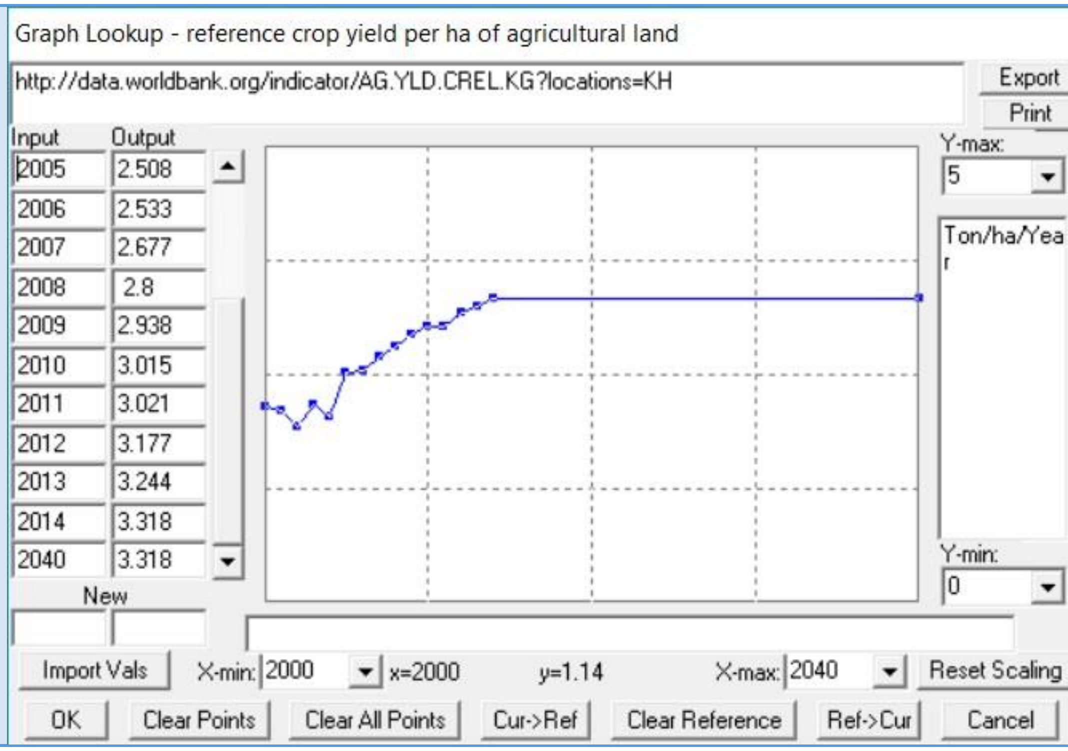
This is the model structure of the agriculture sector.

Name	**Equation**

<table>
<tr><td>Food demand per capita</td><td>SMOOTH N(MIN(max food demand per capita,(relative GDP per capita^elasticity of food demand to gdp per capita)*initial food demand per capita
), time to change food demand per capita, initial food demand per capita, 1)</td></tr>
<tr><td colspan="2"><u>Unit: calories/(Year*person)</u>
Food demand per capita show us how many calories per year that is demanded per person in the country. As the ‘GDP per capita’ increases the demand for food increases as well, but with regards to an elasticity. Even if income increases this does not translate to an immediate increase in demand. The SMOOTH N function is there to represent this delay in the response to an increase in the income. The MIN function and the ‘max food demand per capita’ is there to make sure that the demand does not grow without limitation. This is done to ensure realism in the model. The demand for food eventually evens out and additional income with not increase the demand for further calories. The demand of calories per person in the developed world is used as a reference for the maximum value[36].</td></tr>
<tr><td>Desired crop production</td><td>((total population*food demand per capita)/crop calories per ton)*self sufficiency factor*share of crop in diet</td></tr>
<tr><td colspan="2"><u>Unit: Ton/Year</u>
Desired crop production governs the demand for agriculture land and crop production. It is influenced by the size of the population and the food demand per capita.

The ‘self sufficiency factor’ represents how well supplied the country is with food on its own compared to its needs. The current assumption of the ‘self sufficiency factor’ is assuming a relatively high level of 1.35, this means that they are producing 1.35 times what they need themselves, exporting 35% of all their produce.</td></tr>
<tr><td>Desired agriculture land</td><td>desired crop production/agriculture land productivity per ha</td></tr>
<tr><td colspan="2"><u>Unit: Hectare</u>
This represents the amount of agriculture land that is needed to satisfy the current level of demand for crop produce expressed through desired crop production.</td></tr>
<tr><td>Agriculture land productivity per ha</td><td>effect of rainfall on agriculture productivity*effect of water and soil pollution from coal power on agriculture productivity*Sediment and fertilizer net effect*reference crop yield per ha of agricultural land</td></tr>
<tr><td colspan="2"><u>Unit: Ton/hectare/Year</u>
This is a key variable that influences how much land is needed in order to produce the desired amount of crop produce. It is meant to represent the product of several effects coming together; rain fall, sediment flow and fertilizers multiplied with a reference yield. This done to show how the yield per hectare deviates from the reference based on the influences of the different effects.</td></tr>
</table>

[36] http://www.who.int/nutrition/topics/3_foodconsumption/en/

Reference crop yield per ha of agricultural land	

Unit: Ton/hectare/Year

The reference data is taken from the world bank[37]. The data set is based upon historical data up until the year 2014. The assumption is that after the year 2014 the crop yield stays on the same reference level and the variation in productivity per hectare of agriculture land is determined by the variation of for example rainfall and other effects that are multiplied with this reference productivity.

Effect of fertilizer use on crop yield	DELAY N(relative fertilizer use, 3, 1, 1)

Unit: Dimensionless

The use of fertilizer has a positive influence on the agriculture land productivity. From the time when the fertilizer is applied there is a delay until the full effect takes hold, this is represented through the DELAY N function.

Added fertilizer due to sediment compensation	reference fertilizer use*(1-effect of sediment flow on agriculture productivity)*agriculture compensation factor

Unit: Ton/Year

The concept behind this variable and the way it is modelled is to capture the mechanism of the policy to substitute the loss of sediment with artificial fertilizer. As the effect coming from the sediment flow diminishes the added fertilizer increases. The agriculture compensation factor represents how many time you increase the use of fertilizers to compensate for the loss of sediment nutrition to the soil. The variable is adjustable and can be included into policy adjustment. There is a cost increase associated with increasing the compensation.

Relative fertilizer use	(reference fertilizer use+added fertilizer due to sediment compensation)/reference fertilizer use

Unit: Dimensionless

The relative fertilizer stays the same at value 1 without any changes until added fertilizer kicks in when the effect from the sediment flow starts to decrease.

Effect of water and soil pollution from coal power on agriculture productivity	reference water and soil pollution/(1+average number of coal powerplants)^coal powerplant water and soil impact coefficient on agriculture

Unit: Dimensionless

This represents the adverse effects of pollution coming from coal power. This is expressed through the mathematical formulation 1/(1+A)^c. The reference water and soil pollution has a relative value of one (1), this represents the current level of pollution in the water and soil, and this remains unchanged until coal powerplants are built. The (A) represents the number of powerplants that are

[37] http://data.worldbank.org/indicator/AG.YLD.CREL.KG?locations=KH

built. Given the formulation this increases the pollution in the soil and water and is expressed through a decrease in the variable. When the value of the variable decreases the productivity per hectare of agriculture land decreases as well. The (c) is a coefficient determining the strength of impact on pollution that each powerplant has. The value of the coefficient is currently just an assumption and further empirical research is needed.

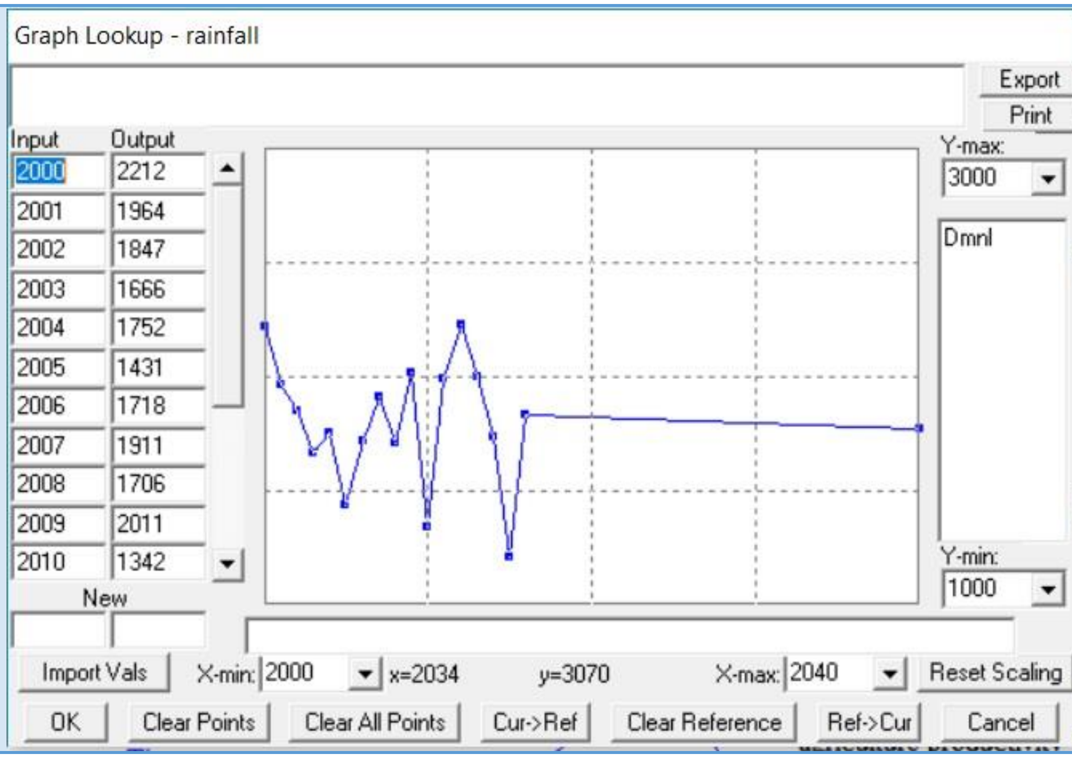
Effect of rainfall on agriculture productivity	(relative precipitation trend*rainfall variability)^elasticity of agriculture productivity to rainfall

Unit: Dimensionless
This is meant to represent how rainfall influences crop production. The effect starts off using historical reference data to generate its effect, but after the year 2016 a RANDOM UNIFORM function takes over as you can see below. The elasticity decides to which degree the relative variations in rainfall will influence the crop production.

Rainfall variability	if then else(Time <2016, 1, RANDOM UNIFORM(0.75 , 1.25 , 0))

Unit: Dimensionless
This variable uses a RANDOM UNIFORM function to generate behaviour. The randomness is meant to simulate a plausible rainfall pattern for the future based on past observations. The input into the function gives it the maximum and minimum range of variability that the randomness will operate within.

Rainfall



Unit: Dimensionless
This is historical data for rainfall going from the year 2000 to 2016.

Effect of sediment flow on agriculture productivity	DELAY N(relative sediment flow, 3, 1, 1)

Unit: Dimensionless
This effect is meant to represent how sediment influences the crop production. The loss of sediment flow causes the soil to lose nutrition and has an adverse effect on crop production.

Sediment and fertilizer net effect	MIN(effect of fertilizer use on crop yield*effect of sediment flow on agriculture productivity, 1)

Unit: Dimensionless
This is the net effect of sediment flow and fertilizer on agriculture productivity. As the sediment falls fertilizers will be used to compensate and this variable show the change in the net effect between the two. The MIN function is there to make sure that the effect does not increase above 1 as the fertilizer only compensated for the loss off sediment nutrition.

Crop production relative to desired crop consumption	if then else(desired crop production<=0, 0, crop production/desired crop production)
Unit: Dimensionless *This represents the relative satisfaction of food demand. This is an important indicator to tell us about social conditions and nourishment. This variable is meant to be an indicator, the concept is that if this relative value goes under 1 it may give cause to dissatisfaction and unrest. The logical function is there to ensure that there is no division by zero so that the model functions in cases of zero demand.*	

Table 5: Equations of the Agriculture sector

3.7 Sediment flow sector

The sediment flow sector has one stock called *sediment catchment.* This is a relatively small sector, but it has important implications for the agriculture sector, since sediment is an important input for the productivity per hectare of agriculture land. The sediment catchment represents the sediment that gets trapped by dams and prevented from flowing freely down the stream. The more dams that are built the less sediment escapes downstream. This is represented by the equation in sediment flow out.

The sector is modeled in order to represent the relative change in sediment flow with regards to the number of dams built along the Mekong river. The baseload is a relative number set to 1. This represent that by default there is a perpetual baseload of sediment ready to flow down the river every year. However, dams prevent this flow as each dam is set to catch an average fraction of 20% of the sediment baseload. This is represented by the variable *Trapping effect.* The fractional catch of 20% of the remaining baseload is an assumption, and further empirical research is needed to confirm this. However, the concept remains the same even if the fractional catchment per dam changes (Des E. Walling 2008), (Carolina Boix-Fayos and V´ıctor Castillo 2008).

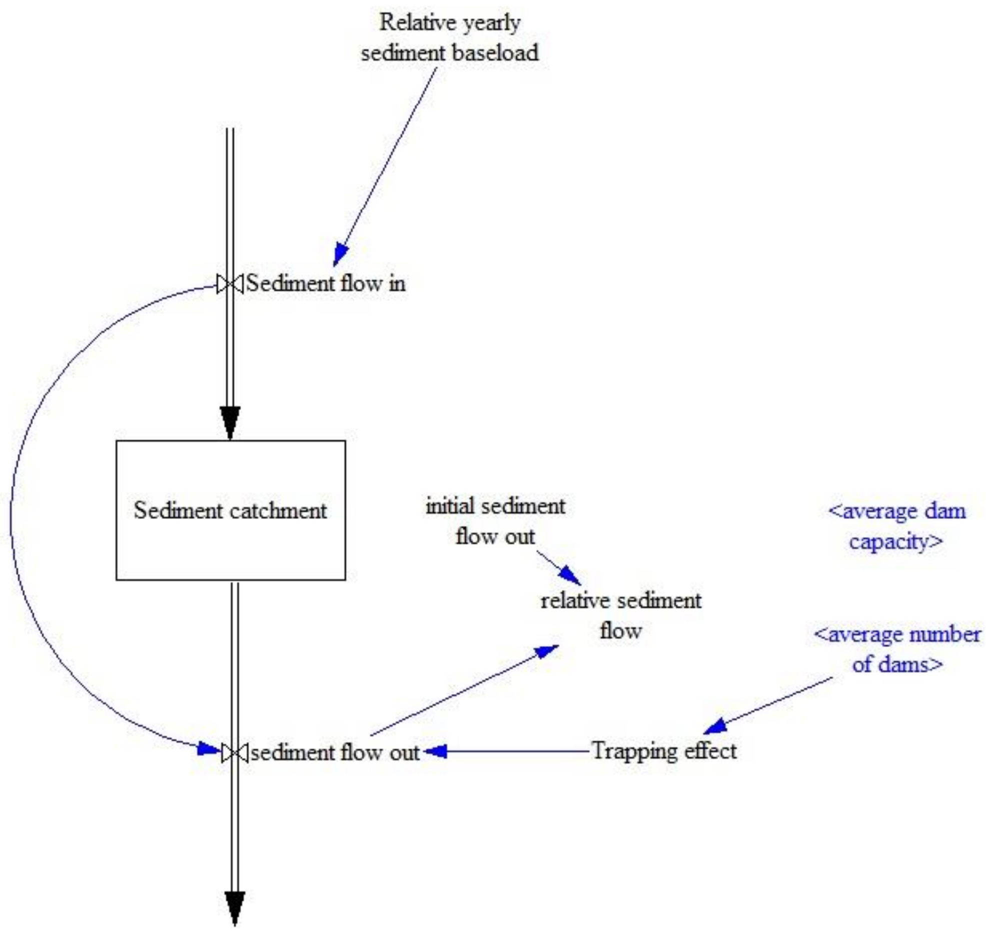


Figure 12: Sediment sector

This is the model structure of the sediment sector

Name	**Equation**
Relative yearly sediment baseload	1
Unit: 1/Year *This is a relative number representing the full baseload. Before the sediment baseload is trapped behind dams the baseload is 100%. This is represented by the relative number 1.*	
Sediment flow in	Relative yearly sediment baseload
Unit: 1/Year *This is the sediment flow before encountering any man made dams.*	
Sediment flow out	Sediment flow in*(1-Trapping effect)
Unit: 1/Year *This is the relative flow of sediment that is left leaving the dams. As we can see from the equation, the larger the "Trapping effect" the smaller the sediment outflow. What does not flow out remains in the sediment catchment stock.*	

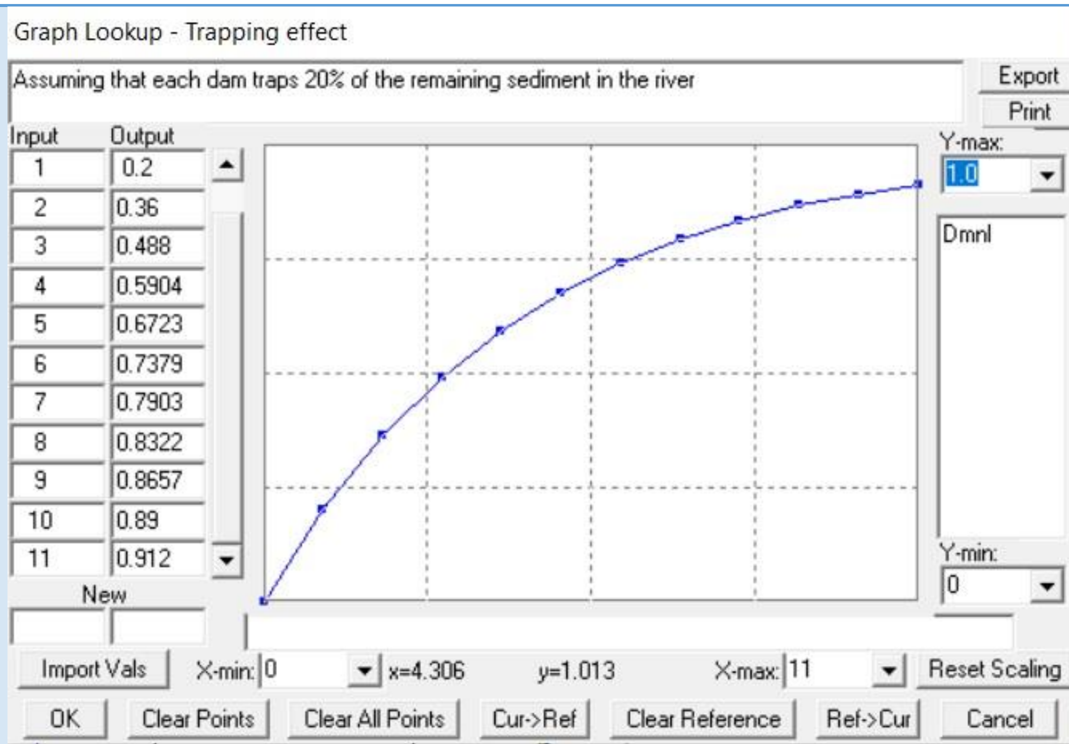
Trapping effect	
Unit: Dimensionless *Each dam removes 20% of the sediment that is left in the river. This means that the first dam catches 20% of 1. The second dam catches 20% of 0.8 and so forth. This is reflected in the shape of the graph.*	
Relative sediment flow	sediment flow out/initial sediment flow out
Unit: Dimensionless *The relative sediment flow reflects how much sediment is left in the river compared to the status quo of full sediment flow. This relative value determines the effect of sediment flow on agriculture productivity per hectare. Thus, the relative status of the sediment flow has important economic implications. As the building of dams increases this relative value will drop causing a loss in agriculture productivity, thus offsetting some of the gains by building hydropower dams.*	

Table 6: Equations of the Sediment sector

3.8 Fish sector

The fish sector has two stocks. One stock represents the total fish population for the whole country, this stock is called *fish stock.* The second stock is called *local fish stock* and represents the fish population in the Kratie and the Stung Treng regions in Cambodia where the dam projects on the Mekong River is taking place. The effect on the local landscape where the hydropower development is taking place is different than from on the national level. That is why the fish population on the local level is represented by its own stock. This is valuable information for decisionmakers to consider when they are planning development projects. What may seem as a reasonable and a feasible policy on the national level may not be a suitable alternative for the local ecosystem and the people that live there.

The danger with large development projects is that the costs of externalities are not carried by those who receive the benefits. In the case of the planned hydropower development along the Mekong river in Cambodia the risk is that large costs are placed disproportionally on the local population compared to the rest of the country without receiving proper compensation for it. By including the effect on the local fish stock in the model we can highlight the local impact of national development policies.

When cost of externalities are carried locally and benefits are enjoyed centrally it becomes a de facto wealth transfer from periphery to center and in this case, it involves a depletion of natural capital. Once depleted it is hard to regenerate a fish stock or to compensate the local population for the loss of subsistence and income.

The consequences for the fish stocks due to the building of dams on the Mekong river are represented in the model through the *fish breeding success* and the *local fish breeding success*. This effect is governed by the number of dams that are built and the MW capacity. As the MW capacity of hydropower increases the fish breeding success decreases reducing the fish breeding inflow into the fish stocks.

In a sense, we can call this a liquidation of a natural capital stock to gain human built capital in the form of hydropower dams that generate electricity. This is one of the tradeoffs that this thesis will look closer at in the policy scenarios and discussion section (Vo Thi Thanh Loc and Nguyen Tri Khiem 2009).

Reinforcing feedback loops:

R14a: This loop goes between *fish breathing* and the *fish stock.* This loop governs the natural growth of the fish stock and is the only inflow into the stock. Growth in the *fish stock* causes the *fish breathing* to increase, and as the *fish breathing* increases this causes the *fish stock* to increase further, thus completing the loop.

R14b: This loop is the same loop as in **R14a**, only it is for the *local fish stock.* This loop governs the natural growth of the *local fish stock* and is the only inflow into the stock. Growth in the *local fish stock* causes the *local fish breathing* to increase, and as the *local fish breathing* increases this causes the *local fish stock* to increase further, thus completing the loop.

R15: This loop goes between *Total food demand* and *fish catch* through the *GDP.* As the demand for food increases the *desired fish consumption* increase as well. When the *desired fish consumption* increases, *fish catch* increases as well. An increase in *fish catch* leads to a positive effect on *TFP* that causes the *GDP* to increase. When the *GDP* increases, this causes demand for food to further increase, thus completing the loop.

Balancing feedback loops:

B14a: This loop goes between the *fish stock* and *fish catch.* As the *fish catch* increases the *fish stock* decreases. A decrease in the *fish stock* leads to a decrease in the *maximum fish catch*. A decrease in the *maximum fish catch* will eventually decrease the *fish catch*, thus completing the loop.

B14b: This loop is the same loop as in **B14a**, only it is for the *local fish stock.* This loop goes between the *local fish stock* and *local fish catch.* As the *local fish catch* increases the *local fish stock* decreases. A decrease in the *local fish stock* leads to a decrease in the *maximum local fish catch*. A decrease in the *maximum local fish catch* will eventually decrease the *local fish catch*, thus completing the loop.

B15: This loop goes between *total food demand* and *fish catch* through the *fish stock* and the *GDP*. As the *food demand* increases the *fish catch* responds by increasing as well. When the *fish catch* increases it decreases the *fish stock.* If the *fish stock* gets significantly decreased the *maximum fish catch* will decrease as well. With a significantly reduced *fish stock* the fish breeding will be reduced as well reducing the growth of the *fish stock*. A reduced *fish stock* leads to a lower *fish catch*. A fall in the *relative fish catch* has a negative impact on the *TFP* and the *GDP*, thus completing the loop.

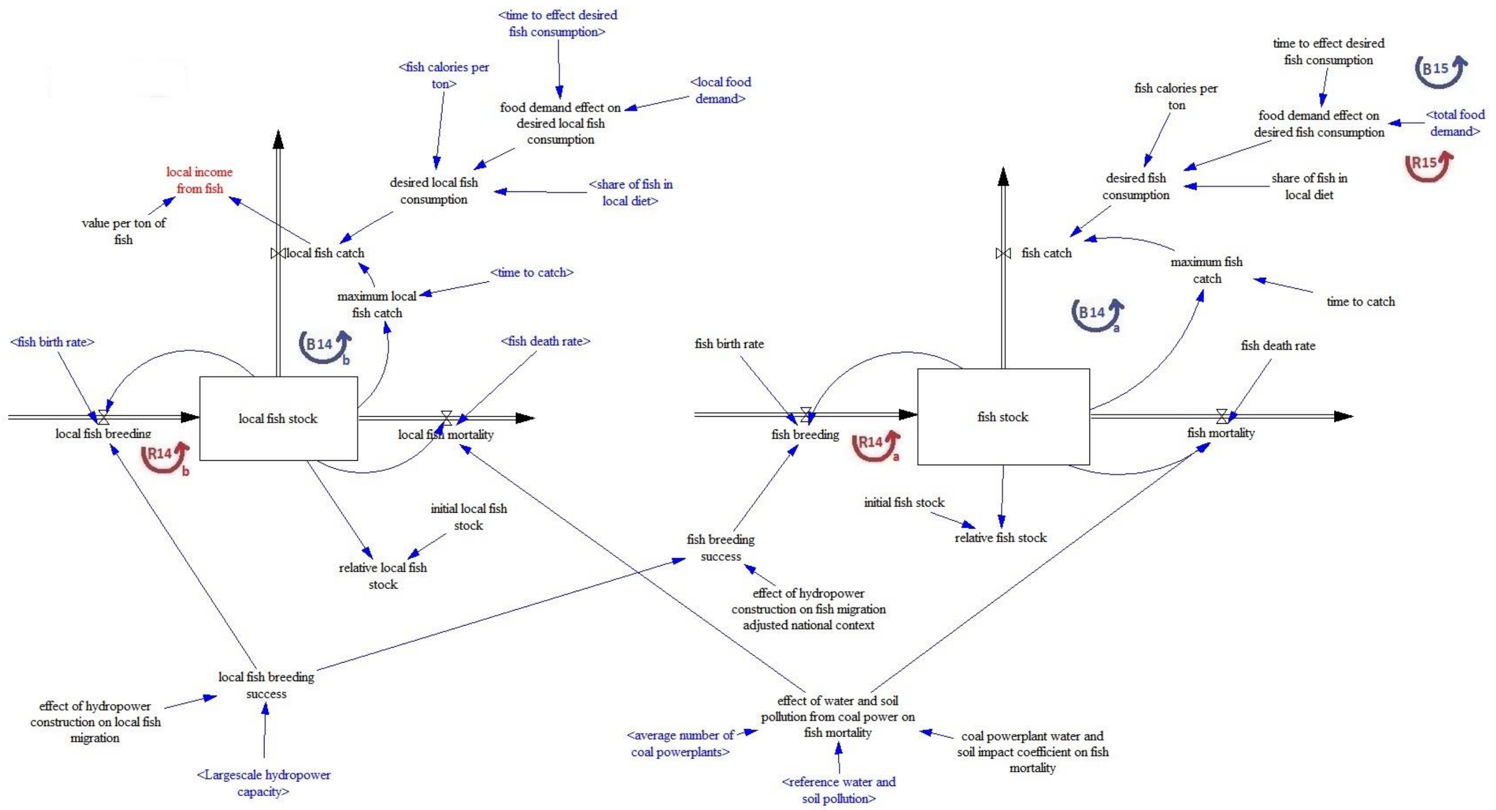
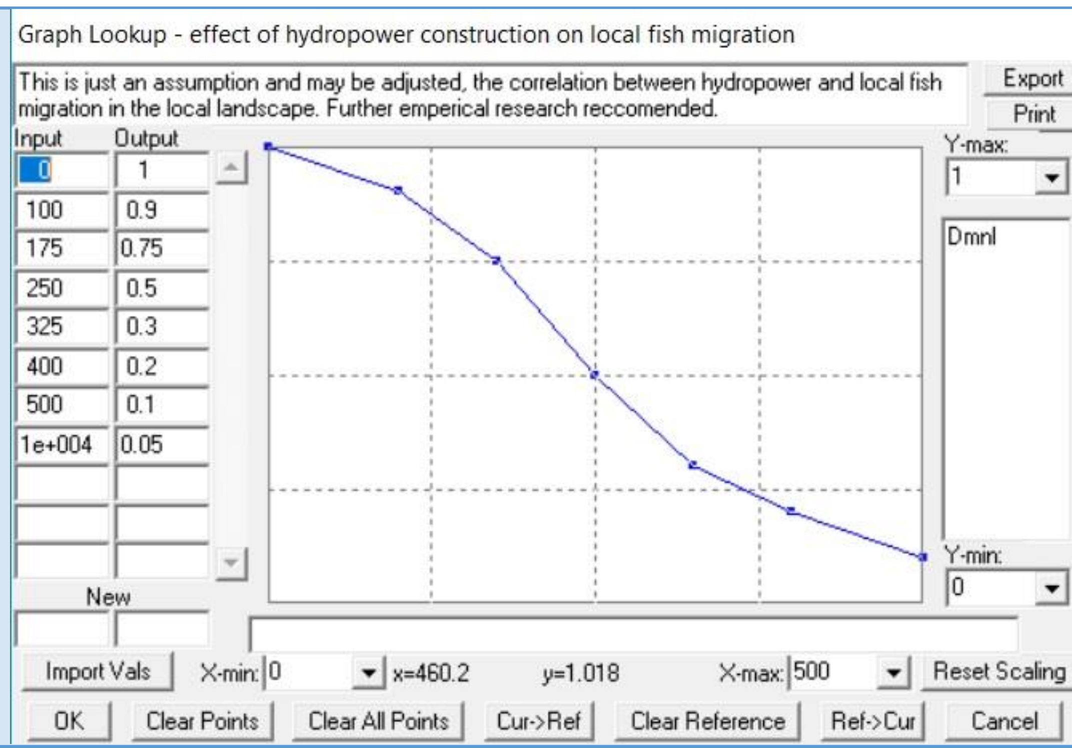


Figure 13: Fish sector

This is the model structure of the fish sector.

Name	Equation
Fish catch	min(desired fish consumption,maximum fish catch)
Unit: Ton/Year *This represents all the fish that is caught for food and commercial purposes in any given year. It is driven by the desired fish consumption.*	
Maximum fish catch	fish stock/time to catch
Unit: Ton/Year *This represents the maximum amount of fish that you can fish in one year. As the fish stock decreases it gets increasingly harder to catch fish, eventually leading to a fall in the maximum fish catch, setting a limit on fish catch.*	
Desired fish consumption	(food demand effect on desired fish consumption*share of fish in local diet)/fish calories per ton
Unit: Ton/Year *This represents the demand for fish. It increases when the demand for food increases. This demand has a positive polarity with the fish catch.*	
Food demand effect on desired fish consumption	DELAY N(total food demand , time to effect desired fish consumption , 8.912e+012 , 1)
Unit: calories/Year *This represents that it takes time before a change in the demand for food effects the fish catch. It takes time before the market and the fishermen increase their efforts to catch more fish.*	

<table>
<tr><td colspan="2"></td></tr>
<tr><td>Fish catch relative to desired fish consumption</td><td>IF THEN ELSE(desired fish consumption<=0, 0, fish catch/desired fish consumption)</td></tr>
<tr><td colspan="2"><u>Unit: Dimensionless</u>
This represents the relative satisfaction of fish demand. This is an important indicator to tell us about social conditions and nourishment. This variable is meant to be an indicator, the concept is that if this relative value goes under 1 it may give cause to dissatisfaction and unrest. The logical function is there to ensure that there is no division by zero so that the model functions in cases of zero demand.</td></tr>
<tr><td>Fish mortality</td><td>fish death rate*fish stock</td></tr>
<tr><td colspan="2"><u>Unit: Ton/year</u>
This is the natural rate of death for the fish stock. It makes a balancing feedback loop between itself and the fish stock. As the fish stock grows the mortality will increase, and thus dampen further growth in the fish stock.</td></tr>
<tr><td>Effect of water and soil pollution from coal power on fish mortality</td><td>reference water and soil pollution/(1+average number of coal powerplants)^coal powerplant water and soil impact coefficient on fish mortality</td></tr>
<tr><td colspan="2"><u>Unit: Dimensionless</u>
This represents the adverse effects of pollution coming from coal power. This is expressed through the mathematical formulation 1/(1+A)^c. The reference water and soil pollution has a relative value of one (1), this represents the current level of pollution in the water and soil, and this remains unchanged until coal powerplants are built. The (A) represents the number of powerplants that are built. Given the formulation this increases the pollution in the soil and water and is expressed through an increase in the variable. The increase comes from the negative value of the coefficient (c). An increase in this variable causes the fish rate of death to increase. The (c) is a coefficient determining the strength of impact on pollution that each powerplant has. The value of the coefficient is currently just an assumption and further empirical research is needed.</td></tr>
<tr><td>Fish breeding</td><td>fish stock*fish birth rate*fish breeding success</td></tr>
<tr><td colspan="2"><u>Unit: Ton/Year</u>
This is the inflow into the fish stock and represents all the fish spawning per year. It makes a simple reinforcing feedback loop with the fish stock, responsible for all the growth in the fish stock.</td></tr>
<tr><td>Fish breeding success</td><td>local fish breeding success^effect of hydropower construction on fish migration adjusted national context</td></tr>
<tr><td colspan="2"><u>Unit: Dimensionless</u>
This represents how the construction of dams influences the breathing success for fish in the Mekong river. This happens because several species depend on migration along the river to reproduce. When it is time to spawn, the fish move upstream to lay eggs. If the river is blocked off by dams then the fish is unable to finish their reproductive cycle successfully.</td></tr>
<tr><td>Effect of hydropower construction on fish migration adjusted national context</td><td>0.2</td></tr>
<tr><td colspan="2"><u>Unit: Dimensionless</u>
This is just an assumption and may be adjusted. The value of 0.2 rests on the assumption that the effect nationwide on the fish stock is less than on the local landscape where the dam construction is taking place. Further empirical research recommended.</td></tr>
<tr><td>Local fish catch</td><td>min(desired local fish consumption,maximum local fish catch)</td></tr>
<tr><td colspan="2"><u>Unit: Ton/Year</u>
This represents all the local fish that is caught for food and commercial purposes in any given year. It is driven by the desired local fish consumption.</td></tr>
<tr><td>Maximum local fish catch</td><td>local fish stock/time to catch</td></tr>
<tr><td colspan="2"><u>Unit: Ton/Year</u>
This represents the maximum amount of local fish that you can fish in one year. As the local fish stock decreases it gets increasingly harder to catch fish, eventually leading to a fall in the maximum local fish catch, setting a limit on local fish catch.</td></tr>
<tr><td>Desired local fish consumption</td><td>(food demand effect on desired local fish consumption*share of fish in local diet)/fish calories per ton</td></tr>
<tr><td colspan="2"><u>Unit: Ton/Year</u></td></tr>
</table>

This represents the local demand for fish. It increases when the demand for food increases. This demand has a positive polarity with the local fish catch.	
Food demand effect on desired local fish consumption	DELAY N(local food demand, time to effect desired fish consumption , 2.653e+011 , 1)
Unit: calories/Year *This represents that it takes time before a change in the demand for food effects the local fish catch. It takes time before the market and the fishermen increase their efforts to catch more fish.*	
Local fish catch relative to local desired fish consumption	if then else(desired local fish consumption<=0, 0, local fish catch/desired local fish consumption)
Unit: Dimensionless *This represents the relative satisfaction of local fish demand. This is an important indicator to tell us about social conditions and nourishment. This variable is meant to be an indicator, the concept is that if this relative value goes under 1 it may give cause to dissatisfaction and unrest. This indicator my especially important for the local population, since the dependency on fish is higher locally than in the country overall. The logical function is there to ensure that there is no division by zero so that the model functions in cases of zero demand.*	
Local fish breeding	fish birth rate*local fish breeding success*local fish stock
Unit: Ton/Year *This is the inflow into the local fish stock and represents all the local fish spawning per year. It makes a simple reinforcing feedback loop with the local fish stock, responsible for all the growth in the local fish stock*	
Local fish breeding success	effect of hydropower construction on local fish migration(Large scale hydropower capacity)
Unit: Dimensionless *This represents how the construction of dams influences the breathing success for fish in the Mekong river. This happens because several species depend on migration along the river to reproduce. When it is time to spawn, the fish move upstream to lay eggs. If the river is blocked off by dams then the fish is unable to finish their reproductive cycle successfully. The effect locally is stronger than on the national level.*	
Effect of hydropower construction on local fish migration	
Unit: Dimensionless	

This gives the correlation between hydropower and local fish migration in the local landscape. When the hydropower capacity reaches 500MW the river is assumed to be so blocked off that the fish migration is reduced by 90% in the local landscape. This is just an assumption and may be adjusted. Further empirical research recommended.	
Local fish mortality	fish death rate*local fish stock
<u>Unit: Ton/year</u> *This is the natural rate of death for the local fish stock. It makes a balancing feedback loop between itself and the local fish stock. As the local fish stock grows the mortality will increase, and thus dampen further growth in the local fish stock.*	

Table 7: Equations of the Fish sector

3.9 Life expectancy

This sector has no stocks. The life expectancy represents how many years on average a person can expect to live at birth. This sector is modelled using a baseline approach to show the development in life expectancy.

The estimation of life expectancy starts by using a reference value for the year 2000. This value is then multiplied with a net effect. There are several effects driving the life expectancy; an effect coming from the GDP, effect coming from electricity price and indoor air pollution, effect coming from outdoor air pollution and a balancing feedback loop called **B17** that dampens the growth.

In this model, the effects influencing the life expectancy that I have chosen to focus on are the effect coming from *electricity price* and air quality. I have a special focus on indoor air quality. The concept is that as electricity becomes more available and accessible to people, then more and more people will use electricity for cocking and lighting, moving away from using coal and kerosene as fuel for cocking and lighting. The idea is that this will result in cleaner indoor air and a healthier environment. This is thought to have positive influence on the average life expectancy (European Environment Agency 2011).

Reinforcing feedback loop:

R16:** This loop goes between the *Average life expectancy* and electricity generating capacity. **As an important side note to this loop: This loop is only active if the endogenous investment policy is turned on by activating the* ***Electricity investment endogenous switch*. This activates a policy that dedicates a fraction of the GDP to be invested in one or more of the electricity development options. Care should be taken when using this policy structure and deciding the fraction and time duration of this policy. A high fraction of GDP devoted only to electricity development is unrealistic and causes unrealistic outcomes*. * As the life expectancy increases the GDP increases also as a result of this. When the *GDP* increases, more will be invested into *electricity and infrastructure development spending* leading to an increase in the electricity generating capacity. This leads to an increase in electricity supply decreasing the electricity price. A fall in the electricity price causes the life expectancy to increase, this happens because of the negative polarity relationship between *effect of electricity price on indoor air quality* and *electricity price*.

R17: This loop goes between the *GDP* and the *life expectancy*, through the *effect of income per capita on average life expectancy*. It is a reinforcing loop because *GDP* causes the *life expectancy* to increase and in turn the *life expectancy* increases the *GDP* through the effect from *TFP*.

Balancing feedback loop:

B16: This loop goes between *Average life expectancy* and the *electricity price* through the *GDP*. An increase in the *Average life expectancy* increases the *TFP* leading to an increase in *GDP*. An increase in *GDP* leads to an increase in demand for electricity pushing the *electricity price* up. An increase in *electricity price* has a negative impact on the *effect of electricity price on indoor air quality*. A fall in the indoor air quality causes the *average life expectancy* to decrease, thus completing the loop.

B17: This loop goes between *life expectancy* and *effect of relative life expectancy on indicated life expectancy*. The *effect of relative life expectancy on indicated life expectancy* has a negative elasticity ensuring that when the *relative life expectancy* increases the effect decreases dampening the *net effect on life expectancy,* this in turn to a slowing down or a decrease in the life expectancy. This represents the fact that it gets harder and harder to further increase life expectancy as it increases. There is a biological limit to the human life-span and the closer we get to this limit, the more difficult it is to make further increases in the life expectancy.

B18: This balancing loop represents that there is a diminishing return to scale for *GDP per capita* with regards to the effect on average life expectancy. The loop goes between *GDP per capita* and the *life expectancy*. As the *life expectancy* increases causing the *GDP per capita* to increase the *effect of income per capita on average life expectancy* becomes less sensitive to further increases in the *GDP per capita*. This is done by reducing the elasticity as the *GDP per capita* increase. Thus, the effect of this loop is dampening further growth in the *life expectancy.*

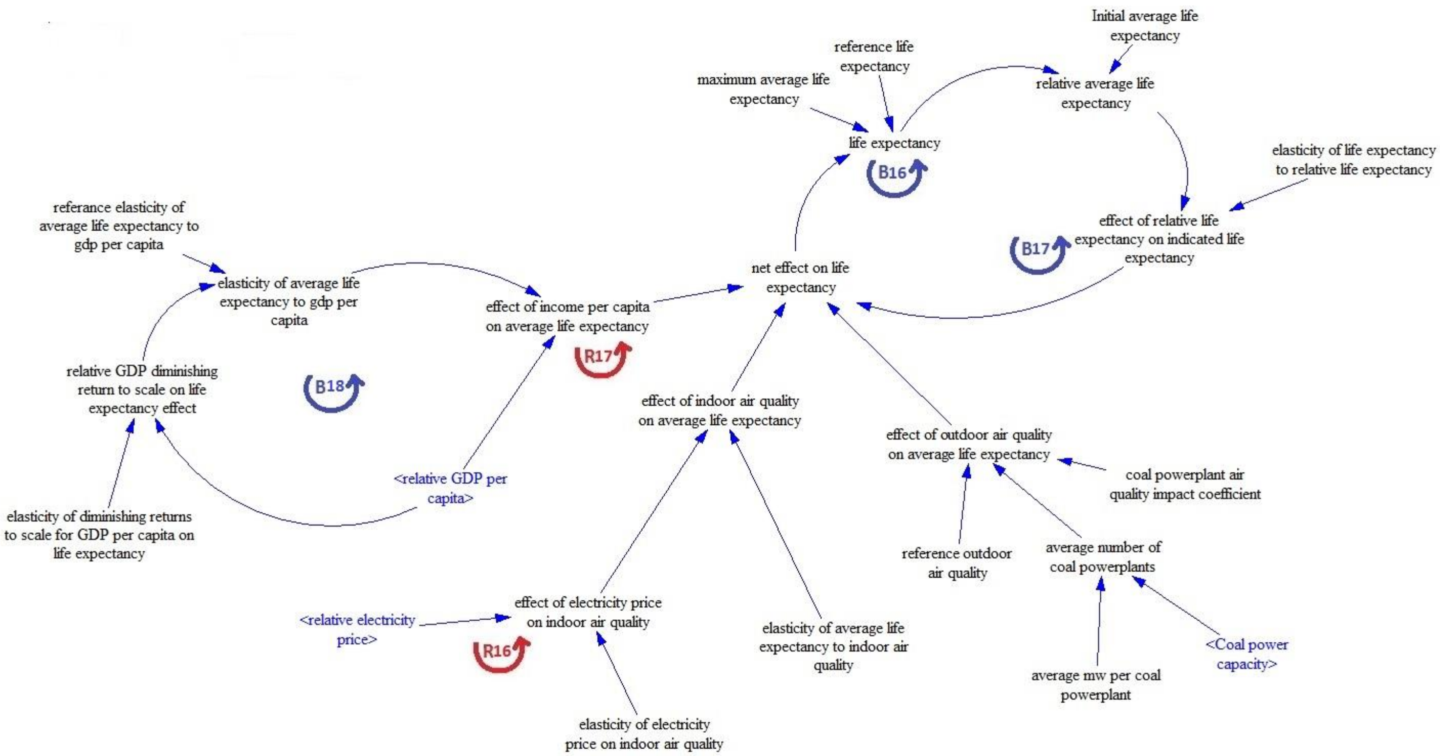


Figure 14: Life expectancy sector

This is the model structure of the life expectancy sector.

Name	Equation
Life expectancy	MIN(reference life expectancy*net effect on life expectancy, maximum average life expectancy)
Unit: Year/person	

<table>
<tr><td colspan="2">This represents the average expected lifespan at birth in the population. The MIN function is there to ensure that life expectancy does not go above the maximum average life expectancy. This is done to keep realism in the model as there is a biological limit to the human life span. The average life expectancy of Japan is used as a reference of the maximum life expectancy[38].</td></tr>
<tr><td>Net effect on life expectancy</td><td>effect of income per capita on average life expectancy*effect of indoor air quality on average life expectancy*effect of outdoor air quality on average life expectancy*effect of relative life expectancy on indicated life expectancy</td></tr>
<tr><td colspan="2"><u>Unit: Dimensionless</u>
This represents the effect of all the effects coming together and making one "net effect" deciding the development of the life expectancy. This is done by multiplying all the effects together.</td></tr>
<tr><td>Effect of indoor air quality on average life expectancy</td><td>effect of electricity price on indoor air quality^elasticity of average life expectancy to indoor air quality</td></tr>
<tr><td colspan="2"><u>Unit: Dimensionless</u>
The concept behind this effect is that as the indoor air quality increases there will be less diseases caused by air pollution coming from unclean cocking and lighting fuels, this contributing to a longer average life span.</td></tr>
<tr><td>Effect of electricity price on indoor air quality</td><td>relative electricity price^elasticity of electricity price on indoor air quality</td></tr>
<tr><td colspan="2"><u>Unit: Dimensionless</u>
This represents the effect that electricity price has on indoor air quality. The concept behind this effect is that a lower electricity price will lead to people substituting traditional firewood and fossil fuel with electricity. The elasticity is negative representing a negative polarity relationship with electricity price and the effect. This means that as electricity price decreases the effect increases.</td></tr>
<tr><td>Effect of outdoor air quality on average life expectancy</td><td>reference outdoor air quality/(1+average number of coal powerplants)^coal powerplant air quality impact coefficient</td></tr>
<tr><td colspan="2"><u>Unit: Year/person</u>
The concept behind this effect is that if electricity is generated using for coal power then this will cause air pollution as particles are released into the air as the coal is burned. The assumption is that these power plans are put up relatively close to population centres for logistical and economical purposes and thus exposing the nearby population to its effects.

This is expressed through the mathematical formulation 1/(1+A)^c. The reference water and soil pollution has a relative value of one (1), this represents the current level of pollution in the water and soil, and this remains unchanged until coal powerplants are built. The (A) represents the number of powerplants that are built. Given the formulation this increases the pollution in the soil and water and is expressed through a decrease in the variable. When the value of the variable decreases the productivity per hectare of agriculture land decreases as well. The (c) is a coefficient determining the strength of impact on pollution that each powerplant has. The value of the coefficient is currently just an assumption and further empirical research is needed.</td></tr>
<tr><td>Average number of coal powerplants</td><td>Coal power capacity/average mw per coal powerplant</td></tr>
<tr><td colspan="2"><u>Unit: Dimensionless</u>
This variable represents the estimated number of coal powerplants by dividing the accumulated coal power capacity that has been built and dividing it on the average size of a coal powerplant. The average MW per coal power plant is an assumption based on survey of planned and existing powerplants in Cambodia.</td></tr>
<tr><td>Effect of relative life expectancy on indicated life expectancy</td><td>SMOOTH N(relative average life expectancy^elasticity of life expectancy to relative life expectancy, 1, 1, 1)</td></tr>
<tr><td colspan="2"><u>Unit: Dimensionless</u>
This represents that as the relative life expectancy increases the harder it gets to increase it the next turn around. The SMOOTH N function represents that there is a delay between an increase in the life expectancy and a decrease in the effect acting on the life expectancy.</td></tr>
</table>

[38] http://data.worldbank.org/indicator/SP.DYN.LE00.IN?locations=JP

Effect of income per capita on average life expectancy	SMOOTH N(relative GDP per capita^elasticity of average life expectancy to gdp per capita, 1, 1, 1)
Unit: Dimensionless *This effect represents the relationship between GDP per capita and the life expectancy. When income increases then this also benefits the life expectancy. Higher income leads to improved living conditions, better nourishment and medicine. These effects are not explicitly modelled in this model, but they are intended to be indirectly represented through this effect coming from the GDP.* *The SMOOTH N represents that a change in GDP does not immediately change the life expectancy. There is a time delay before the effect will take its full hold. Even if income increased over night does not mean that living conditions would change the very same instant, this is what this time delay represents.*	
Elasticity of average life expectancy to gdp per capita	reference elasticity of average life expectancy to gdp per capita* Effect of relative GDP diminishing return to scale on life expectancy
Unit: Dimensionless *This elasticity changes as the GDP per capita increases. This represents that initial increase in relative GDP per capita have greater effect on the life expectancy than later increases. This decrease is caused by the "effect of relative GDP diminishing return to scale on life expectancy".*	
Effect of relative GDP diminishing return to scale on life expectancy	relative GDP per capita^elasticity of diminishing returns to scale for GDP per capita on life expectancy
Unit: Dimensionless *This effect makes sure that the elasticity decreases as the relative GDP increases. This represents the concept in economics called diminishing return to scale. To begin with additional increases in income goes a long way to improve health and living conditions, however as these needs are taken care of additional income will have a smaller and smaller effect, however still positive. The inverse relationship between this effect and the GDP per capita is ensured by a negative exponent.*	

Table 8: Equations of the Life expectancy sector

3.10 Local roads and infrastructure sector

The purpose of this sector is to estimate the effect of hydropower dam development on the local infrastructure and transportation factor. Traditionally the local population has used the river as a means of transportation of goods and the like from village to village along the river. Very few roads on land with significant capacity with regards to transportation exist between the local settlements. When dams are built the provision of this natural infrastructure along the river disappears.

This sector has one stock *local roads*. This stock represents the total length of provincial roads in the regions Stung Treng and Kratie. The local infrastructure investment is a policy option to invest in more roads in the regions in order to compensate for the loss of transportation along the river if dams are constructed.

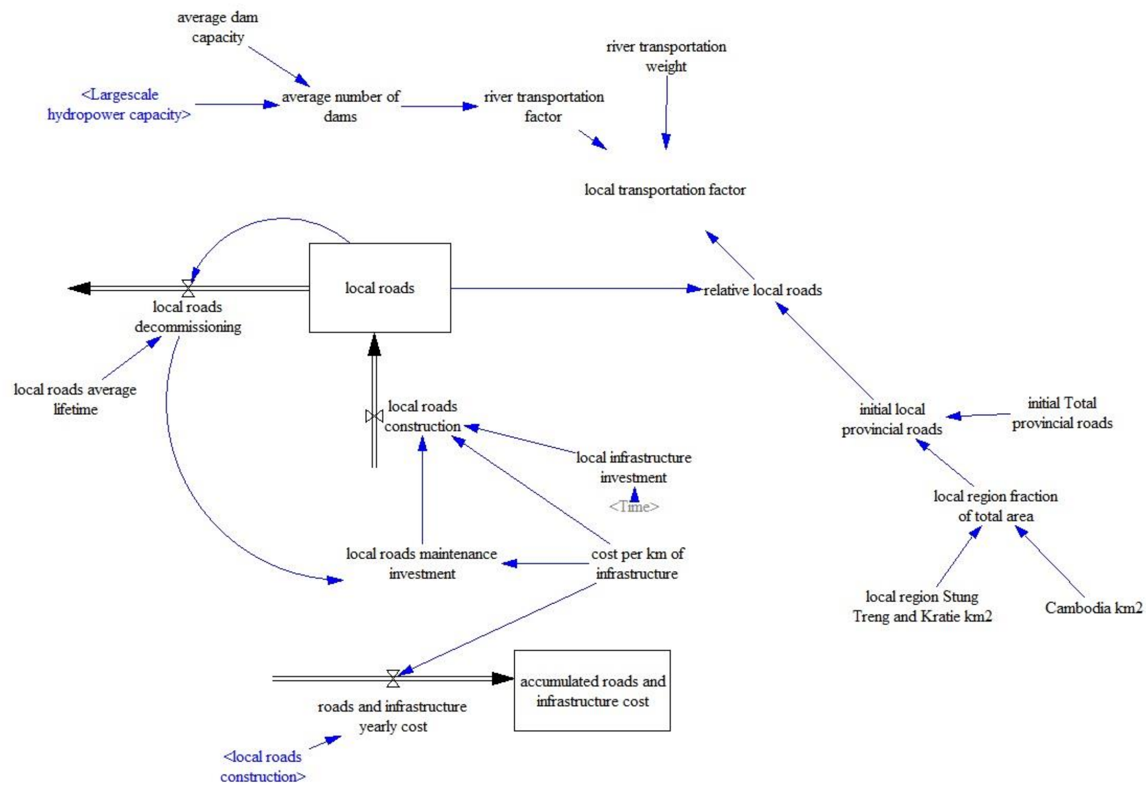


Figure 15: Local roads and infrastructure

This is the model structure of the local roads and infrastructure sector.

Name	**Equation**
Relative local transportation factor	local transportation factor/initial local transportation factor
Unit: Dimensionless This is an estimate of the relative development in the local transportation conditions. The local transportation factor is an indication of how easy it is to transport something from location to location.	
Local transportation factor	(river transportation factor*river transportation weight)+(relative local roads*(1-river transportation weight))
Unit: Dimensionless The local transportation factor is the weighted average of two effects. One coming from the local road network and another coming from the river transportation. In this variable, the river transportation factor is given 70% of the weight, or the relative importance, of the two. This means that changes in the river transportation factor weigh heavier than the changes in the roads. This is supported by an estimate done on the river transportation in Viet-nam[39], and the same proportion is assumed for Cambodia.	

[39] http://www.mrcmekong.org/topics/river-transport

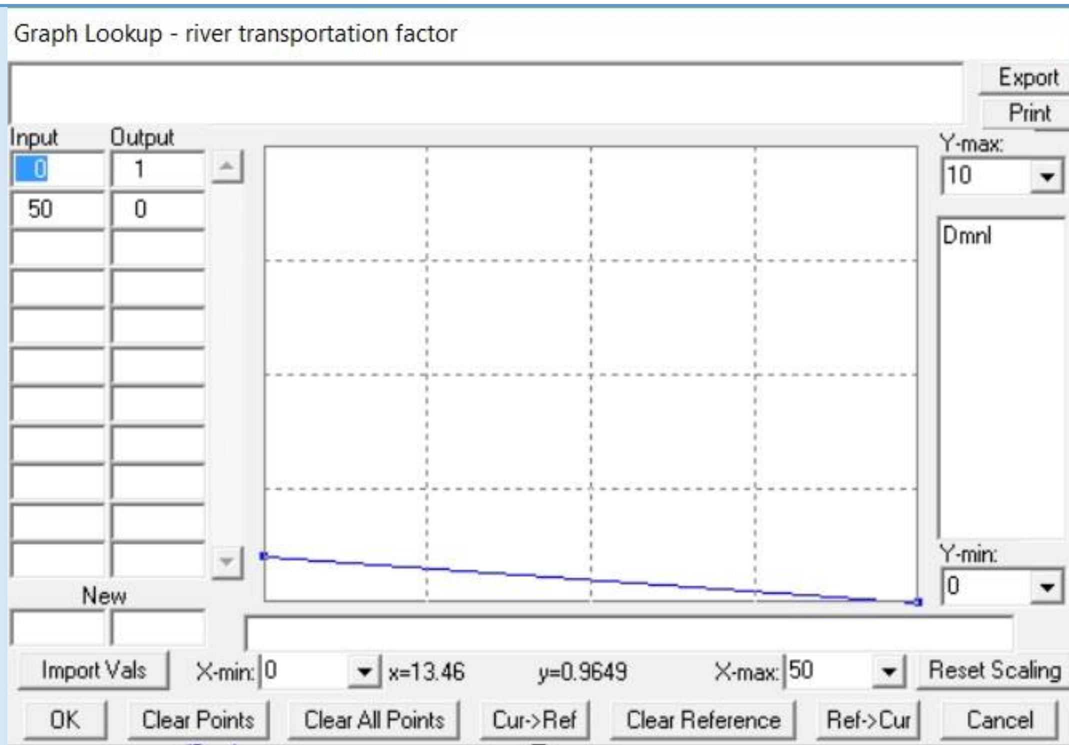
River transportation factor	
Unit: Dimensionless *The concept behind this graphical function is that as the number of dams increase along the river it hinders boat transportation. The input into this graph are the number of dams and the output is an estimate of the river transportation factor. This is based on an assumption that when there are no dams the factor is 1 and this factor is reducing to 0 when 50 dams are constructed, assuming that all meaningful traffic is blocked by dams.*	
Average number of dams	Large scale hydropower capacity/average dam capacity
Unit: Dimensionless *This variable gives us the estimate of how many dams are currently constructed. The estimated number of dams is given by dividing the current capacity on the average capacity per dam. The average capacity per dam is an assumption based of data*[40]. .	
Local roads construction	(local roads maintenance investment + local infrastructure investment)/cost per km of infrastructure
Unit: km/Year *This is the construction of local roads. It is governed by the amount of investment that is dedicated to the maintenance and the building of new roads.*	
Local roads maintenance investment	cost per km of infrastructure*local roads decommissioning
Unit: USD/Year *This meant to represent the upkeep of current roads in working condition. This is based on an assumption that a policy is in place. The investment is what is just enough to keep the local roads in equilibrium.*	
local roads decommissioning	local roads/local roads average lifetime
Unit: km/Year *This is the wearing out of current roads and is the basis for the need of maintenance investment.*	

Table 9: Equations of the Local roads and infrastructure sector

[40] https://opendevelopmentcambodia.net/profiles/hydropower-dams/

3.11 Hydropower large scale electricity sector

This sector has six stocks. Two of them are directly related to the construction of hydropower capacity. That is the *largescale hydropower capacity under construction* and the *largescale hydropower capacity*. The stock called *Largescale hydropower lost capacity* is an accumulation of capacity that is lost every year due to sedimentation. The concept behind this is that over time the dam get filled up with sands and sediments from the bottom up and loses some of its storage capacity for water, thus decreasing the power generating potential of the dam. The other two stocks are estimations of the running costs related to hydropower electricity generation. And the last one is an estimation of the accumulated emissions of co2 coming from this sector. Co2 emissions come from hydropower activities due to the dam. This happens because the biomass from the flooded land starts to decompose in the water. In tropical regions, this problem is extra pronounced. Also, the growth of algae in a dam causes decomposition of biomass leading to co2 emissions. The emission from the hydropower sector are considerably less than generating electricity from burning fossil fuels, however they are still significant (Fearnside 2004) and (LUIZ PINGUELLI ROSA, BOHDAN MATVIENKO et al. 2004).

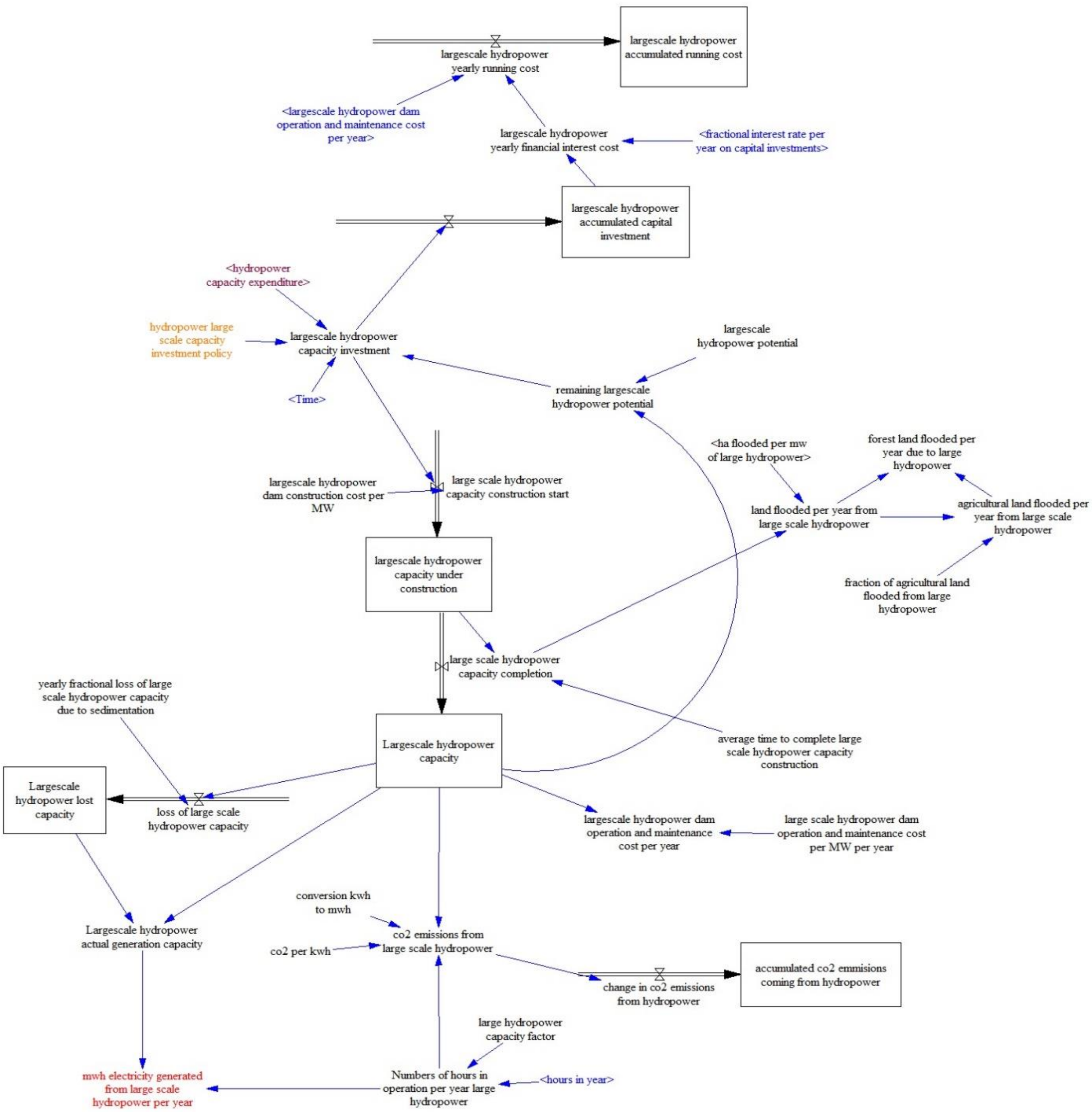


Figure 16: Largescale hydropower sector

This is the model structure of the hydropower sector.

The *capacity under construction* stock represents all capacity that has been ordered and is currently under construction, as the construction is completed the capacity will leave the under-construction stock and go over into the capacity stock and start generating electricity.

Name	Equation
Largescale hydropower capacity construction start	largescale hydropower capacity investment/large hydropower dam construction cost per MW
Unit: Mw/Year	

This represents capacity being ordered. As investments are made orders for the construction of capacity will be placed and construction will begin. This flow is "converting" currency USD to capacity MW.	
Largescale hydropower capacity completion	largescale hydropower capacity under construction/average time to complete large scale hydropower capacity construction
Unit: Mw/Year *This is the flow that goes between the capacity under construction and operating capacity generating electricity. The size of the flow is determined by the amount of capacity currently undergoing construction and the completion time per unit of capacity.*	
Loss of largescale hydropower capacity	Largescale hydropower capacity*yearly fractional loss of largescale hydropower capacity due to sedimentation
Unit: Mw/Year *The concept behind this flow variable is that every year there is a loss in capacity due to gravel and sediment filling up a portion of the dam, reducing the potential of water stored. This loss in capacity is estimated to be at a global average of 1% per year [41].*	
Largescale hydropower actual generation capacity	Largescale hydropower capacity-Largescale hydropower lost capacity
Unit: Mw *This is the capacity that is left after the lost capacity due to sediment and gravel filling up a portion of the dams have been subtracted. This is what is used in the calculation of the megawatt hours per year.*	
Numbers of hours in operation per year large hydropower	large hydropower capacity factor*hours in year
Unit: hour/Year *These are the number of hours in operation per year. Different generating technologies have different capacity factors determining the efficiency of the capacity and how many hours per year they are in operation. All the capacity is not active all the time at every hour. There is always need for maintenance that takes capacity offline, or lack of input causing the capacity to be idle. The estimations for the capacity factor for the different technologies are taken from the International Energy Agency[42].*	
Mwh electricity generated from large scale hydropower per year	Largescale hydropower actual generation capacity*Numbers of hours in operation per year large hydropower
Unit: Mw*hour/Year *This is the generated level of electricity measured in megawatt hours per year. This is the most important input for the rest of the model coming out of this sector.*	
Co2 emissions from large scale hydropower	Numbers of hours in operation per year large hydropower*Largescale hydropower capacity*co2 per kwh*conversion kwh to mwh
Unit: Ton/Year *These are the co2 emissions caused by the construction and the generation of electricity by hydropower. This is measured in tons of co2 per year. The emissions coming from hydropower are in relation to dams and the area of land that was flooded. When flooded biomass such as forest starts to decompose then this releases co2 into the atmosphere together with methane and other gasses. The growth and decomposing of algae in dams also causes emission of co2. This happens to a larger extent in tropical areas such as in Cambodia then in more temperate and colder parts of the world[43].*	
Largescale hydropower dam operation and maintenance cost per year	Largescale hydropower capacity*large scale hydropower dam operation and maintenance cost per MW per year
Unit: USD/Year	

[41] https://www.researchgate.net/profile/Varis_Olli/publication/222432554_Sediment-related_impacts_due_to_upstream_reservoir_trapping_the_Lower_Mekong_River/links/0fcfd50f560997c7c9000000/Sediment-related-impacts-due-to-upstream-reservoir-trapping-the-Lower-Mekong-River.pdf

[42] http://www.worldenergyoutlook.org/weomodel/investmentcosts/

[43] http://pubs.acs.org/doi/pdf/10.1021/es401820p

This represents the cost of operating and maintaining the current stock of capacity.	
Largescale hydropower yearly running cost	largescale hydropower yearly financial interest cost+largescale hydropower dam operation and maintenance cost per year
Unit: USD/Year *This is the total cost of running the current level of capacity, this include both the direct costs that are involved in operating and maintaining the capacity as well as the opportunity costs of investing the capital into he capacity.*	
Largescale hydropower capacity investment	if then else(remaining largescale hydropower potential>0, hydropower large scale capacity investment policy(Time)+hydropower capacity expenditure , 0)
Unit: USD/Year *This equation represents the level of investment that is devoted every year to the construction of hydropower capacity. The logical function is there to ensure that there will be no investments after the hydropower potential used up.*	
Remaining largescale hydropower potential	largescale hydropower potential-Largescale hydropower capacity
Unit: Mw *This represents the potential hydropower capacity that is left unexploited.*	
Largescale hydropower yearly financial interest cost	largescale hydropower accumulated capital investment*fractional interest rate per year on capital investments
Unit: USD/Year *This represent the capital cost per year of investing capital into a project, either in form of interest on loans or as an opportunity cost compared to other investments that the same capital could have been invested in.*	
Land flooded per year from large scale hydropower	large scale hydropower capacity completion*ha flooded per mw of large hydropower
Unit: hectare/Year *When a dam is constructed it leads inevitable to previous dry land coming under water. As hydropower capacity is constructed land is flooded and covered permanently with water. This variable gives us the estimation of how much land is flooded per year due to the construction of dams.*	
Agricultural land flooded per year from large scale hydropower	land flooded per year from large scale hydropower*fraction of agricultural land flooded from large hydropower
Unit: hectare/Year *From the land flooded due to the construction of dams a fraction of that flooded land will be agriculture land. This variable gives us the amount of agriculture land that is flooded per year form the construction of hydropower capacity.*	
Forest land flooded per year due to large hydropower	land flooded per year from large scale hydropower-agricultural land flooded per year from large scale hydropower
Unit: hectare/Year All the land that is flooded that is not agriculture land is by definition in this model forest land. Thus when you subtract the amount of agriculture land flooded from the total amount of land that is flooded you are automatically left with the amount of forest land that is flooded that year.	

Table 10: Equations of the Largescale hydropower sector

3.12 Coal power electricity sector

This sector has five stocks. Two of them are directly related to the construction of coal power capacity. That is the *coal power capacity under construction* and the *Coal power capacity*. Two other stocks are estimations of the running costs related to coal power electricity generation. And the last one is an estimation of the accumulated emissions of co2 coming from this sector.

Coal power is introduced as an alternative to the hydropower sector in order to see how they match up against each other. Coal power represents a cheap capacity investment alternative with a tried and proven mature technology. The drawback with Coal power is the cost of fuel and emission of air pollutants. This will be explored more in the results and discussion sections. Data on coal related technology was taken from several sources, among them: (International Energy Agency 2010).

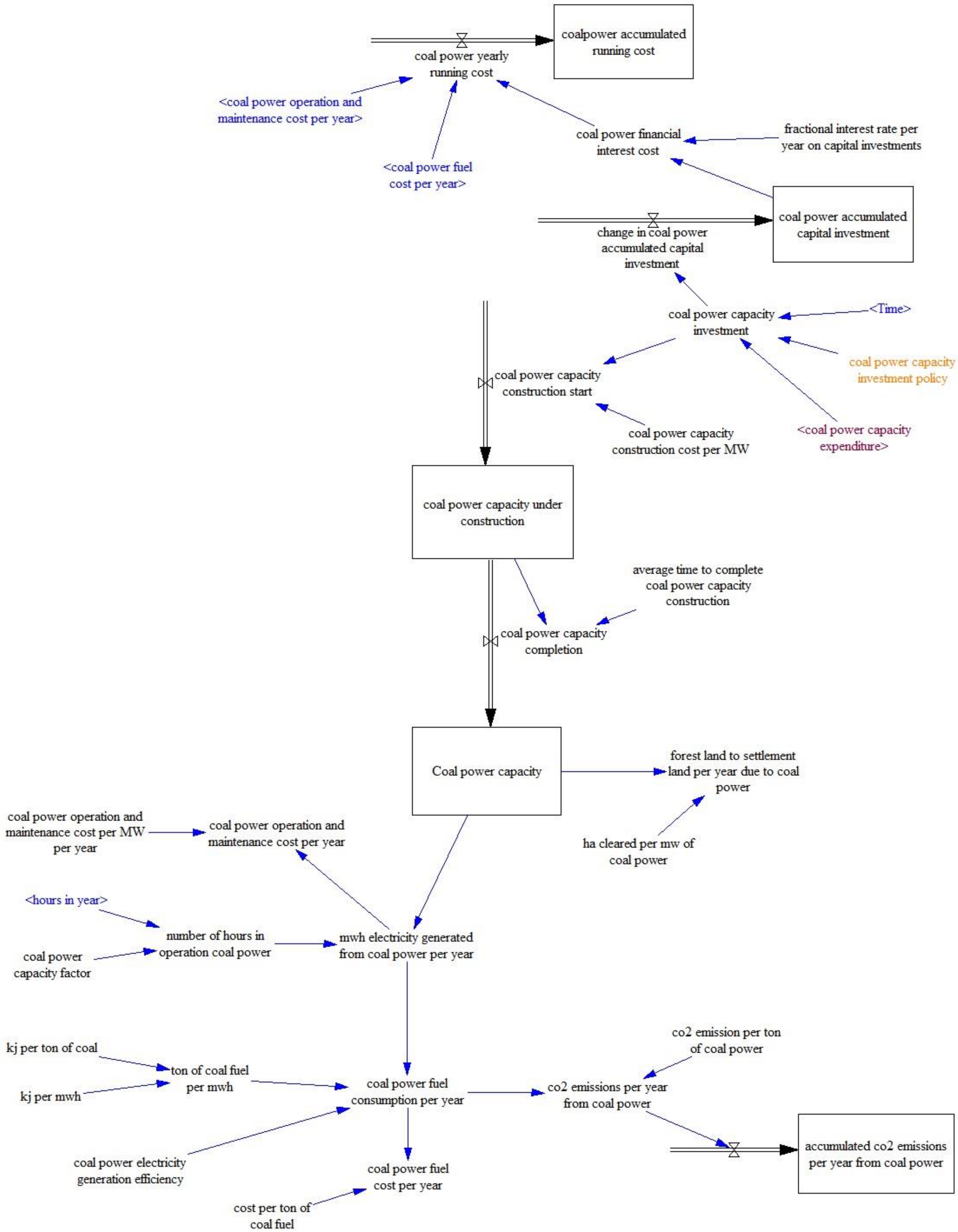


Figure 17: Coal power sector

This is the model structure of the coal power sector.

<table>
<tr><th>Name</th><th>Equation</th></tr>
<tr><td>Coal power capacity investment</td><td>coal power capacity investment policy(Time)+coal power capacity expenditure</td></tr>
<tr><td colspan="2">Unit: USD/Year
This equation represents the level of investment that is devoted every year to the construction of coal power capacity. The two inputs into this variable come from each their respective policy structure that determine the level of investment going to this technology option.</td></tr>
<tr><td>Coal power capacity construction start</td><td>coal power capacity investment/coal power capacity construction cost per MW</td></tr>
<tr><td colspan="2">Unit: USD/Year
This represents capacity being ordered. As investments are made orders for the construction of capacity will be placed and construction will begin. This flow is "converting" currency USD to capacity MW.</td></tr>
<tr><td>Coal power capacity completion</td><td>coal power capacity under construction/average time to complete coal power capacity construction</td></tr>
<tr><td colspan="2">Unit: Mw/Year
This is the flow that goes between the capacity under construction and operating capacity generating electricity. The size of the flow is determined by the amount of capacity currently undergoing construction and the completion time per unit of capacity.</td></tr>
<tr><td>Settlement land demanded per year due to coal power</td><td>Coal power capacity*ha demanded per mw of coal power</td></tr>
<tr><td colspan="2">Unit: Hectare
When coal powerplants are built, the land that they will occupy will be defined as settlement land. This demand will be satisfied by converting a ratio of forest land vs. agriculture land into settlement land.</td></tr>
<tr><td>Number of hours in operation coal power</td><td>coal power capacity factor*hours in year</td></tr>
<tr><td colspan="2">Unit: hour/Year

These are the number of hours in operation per year. Different generating technologies have different capacity factors determining the efficiency of the capacity and how many hours per year they are in operation. All the capacity is not active all the time at every hour. There is always need for maintenance that takes capacity offline, or lack of input causing the capacity to be idle. The estimations for the capacity factor for the different technologies are taken from the International Energy Agency[44].</td></tr>
<tr><td>Mwh electricity generated from coal power per year</td><td>Coal power capacity*number of hours in operation coal power</td></tr>
<tr><td colspan="2">Unit: Mw*hour/Year
This is the generated level of electricity measured in megawatt hours per year. This is the most important input for the rest of the model coming out of this sector.</td></tr>
<tr><td>Coal power operation and maintenance cost per year</td><td>coal power operation and maintenance cost per MW per year*mwh electricity generated from coal power per year</td></tr>
<tr><td colspan="2">Unit: USD*hour/Year
This represents the cost of operating and maintaining the current stock of capacity.</td></tr>
</table>

[44] http://www.worldenergyoutlook.org/weomodel/investmentcosts/

Coal power fuel consumption per year	(ton of coal fuel per mwh/coal power electricity generation efficiency)*mwh electricity generated from coal power per year
Unit: Ton/Year *In order to generate electricity coal powerplants need to burn and consume coal fuel to make heat for turbines so that they generate electricity. This variable give you the estimated consumption of coal every year with regards to the current level of capacity and electricity output.*	
Coal power fuel cost per year	coal power fuel consumption per year*cost per ton of coal fuel
Unit: USD/Year *Unlike hydropower and solar power, coal power needs a constant supply of fuel in order to generate electricity. The consumption of coal has a monetary cost. And the more electricity that is produced the larger the consumption of coal and thus the fuel expenses increases.*	
Co2 emissions per year from coal power	co2 emission per ton of coal power*coal power fuel consumption per year
Unit: Ton/Year *This gives you an estimate of how much co2 is released every year by the consumption of coal. When coal is burned co2 is released, thus the more you burn the more you release.*	
Coal power financial interest cost	coal power accumulated capital investment*fractional interest rate per year on capital investments
Unit: USD/Year *This represent the capital cost per year of investing capital into a project, either in form of interest on loans or as an opportunity cost compared to other investments that the same capital could have been invested in.*	
Coal power yearly running cost	coal power fuel cost per year+coal power operation and maintenance cost per year+coal power financial interest cost
Unit: USD/Year *This is the total cost of running the current level of capacity, this include both the direct costs that are involved in operating and maintaining the capacity as well as the opportunity costs of investing the capital into the capacity.*	

Table 11: Equations of the Coal power sector

3.13 Solar power large scale electricity sector

This sector has four stocks. Two of them are directly related to the construction of solar power capacity. That is the *solar power capacity under construction* and the *solar power capacity*. Two other stocks are estimations of the running costs related to solar power electricity generation. Solar power is introduced as an alternative to the hydropower sector in order to see how they match up against each other. Solar power is intended to represent an alternative to the plans of hydropower development. Solar power is a fast developing and growing technology, however the capacity investment cost has in the past been relatively expensive compared with other technologies. Therefore, thus far only developed nations have afforded significant investments into solar power. There are also practical problems concerning storage and output adjustment regarding solar power. This however is projected to change in the near coming future as the capital cost for solar power investment is set to decrease and battery technology improves.

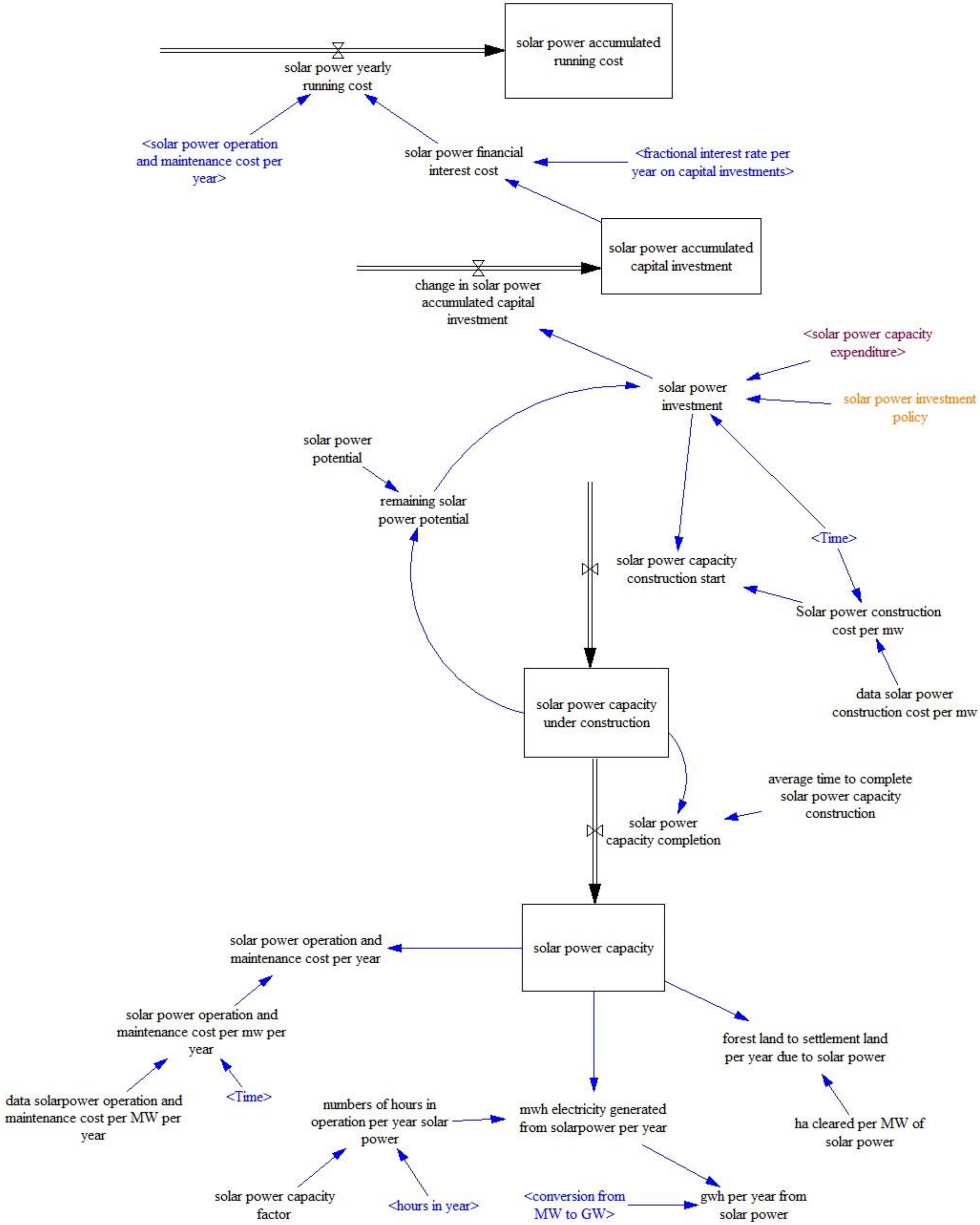

solar power accumulated running cost
solar power yearly running cost
<solar power operation and maintenance cost per year>
solar power financial interest cost
<fractional interest rate per year on capital investments>
solar power accumulated capital investment
change in solar power accumulated capital investment
<solar power capacity expenditure>
solar power investment
solar power investment policy
solar power potential
remaining solar power potential
solar power capacity construction start
<Time>
Solar power construction cost per mw
data solar power construction cost per mw
solar power capacity under construction
average time to complete solar power capacity construction
solar power capacity completion
solar power capacity
solar power operation and maintenance cost per year
solar power operation and maintenance cost per mw per year
data solarpower operation and maintenance cost per MW per year
<Time>
forest land to settlement land per year due to solar power
ha cleared per MW of solar power
numbers of hours in operation per year solar power
mwh electricity generated from solarpower per year
solar power capacity factor
<hours in year>
<conversion from MW to GW>
gwh per year from solar power

Figure 18: Solar power sector

This is the model structure of the solar power sector.

Name	**Equation**
solar power investment	if then else(remaining solar power potential>0, solar power investment policy(Time)+solar power capacity expenditure , 0)
Unit: USD/Year *This equation represents the level of investment that is devoted every year to the construction of solar power capacity. The two inputs into this variable come from each their respective policy structure that determine the level of investment going to this technology option. The logical function is there to ensure that there will be no investments after the solar power potential is used up.*	
Remaining solar power potential	solar power potential-solar power capacity under construction
Unit: Mw *This represents the potential solar power capacity that is left unexploited.*	
Solar power capacity construction start	solar power investment/Solar power construction cost per mw
Unit: USD/Year *This represents capacity being ordered. As investments are made orders for the construction of capacity will be placed and construction will begin. This flow is "converting" currency USD to capacity MW.*	
Solar power capacity completion	solar power capacity under construction/average time to complete solar power capacity construction
Unit: Mw/Year *This is the flow that goes between the capacity under construction and operating capacity generating electricity. The size of the flow is determined by the amount of capacity currently undergoing construction and the completion time per unit of capacity.*	
Mwh electricity generated from solar power per year	solar power capacity*numbers of hours in operation per year solar power
Unit: Mw*hour/Year *This is the generated level of electricity measured in megawatt hours per year. This is the most important input for the rest of the model coming out of this sector.*	
Numbers of hours in operation per year solar power	hours in year*solar power capacity factor
Unit: hour/Year *These are the number of hours in operation per year. Different generating technologies have different capacity factors determining the efficiency of the capacity and how many hours per year they are in operation. All the capacity is not active all the time at every hour. There is always need for maintenance that takes capacity offline, or lack of input causing the capacity to be idle. The estimations for the capacity factor for the different technologies are taken from the International Energy Agency[45].*	
Settlement land demanded per year due to solar power	solar power capacity*ha demanded per MW of solar power
Unit: hectare *When solar powerplants are built, the land that they will occupy will be defined as settlement land. This demand will be satisfied by converting a ratio of forest land vs. agriculture land into settlement land.*	
Solar power operation and maintenance cost per year	solar power capacity*solar power operation and maintenance cost per mw per year
Unit: USD/Year *This represents the cost of operating and maintaining the current stock of capacity.*	

[45] http://www.worldenergyoutlook.org/weomodel/investmentcosts/

Solar power financial interest cost	solar power accumulated capital investment*fractional interest rate per year on capital investments
Unit: USD/Year *This represent the capital cost per year of investing capital into a project, either in form of interest on loans or as an opportunity cost compared to other investments that the same capital could have been invested in.*	
Solar power yearly running cost	solar power financial interest cost+solar power operation and maintenance cost per year
Unit: USD/Year *This is the total cost of running the current level of capacity, this include both the direct costs that are involved in operating and maintaining the capacity as well as the opportunity costs of investing the capital into the capacity.*	

Table 12: Equations of the Solar power sector

3.14 Diesel generation electricity sector

This sector has three stocks. One stock, *diesel generation capacity*, represents the diesel capacity already installed in Cambodia. In this model there is no option to invest in more diesel generating capacity, but there is an option to decommission the capacity that exist. The two other stocks are estimations of the running costs related to diesel electricity generation. And the last one is an estimation of the accumulated emissions of co2 coming from this sector. Diesel power has been used in Cambodia as a source of electricity by using large diesel generators. However, this is a costly way of generating electricity, something that is reflected through the electricity price in the country. Diesel capacity has the advantage that it has a low initial capital cost compared to other alternatives and it is realtivley easy to set up and run. However, the fuel costs are exeedingly high compared with competing technologies. These high costs related to fuel when using diesel generators to produces electricity is a contributing reason to why the electricity price is so high in Cambodia compared to neighbouring countries. Emissions and air pollution are also negative side-effects from using disel generators.

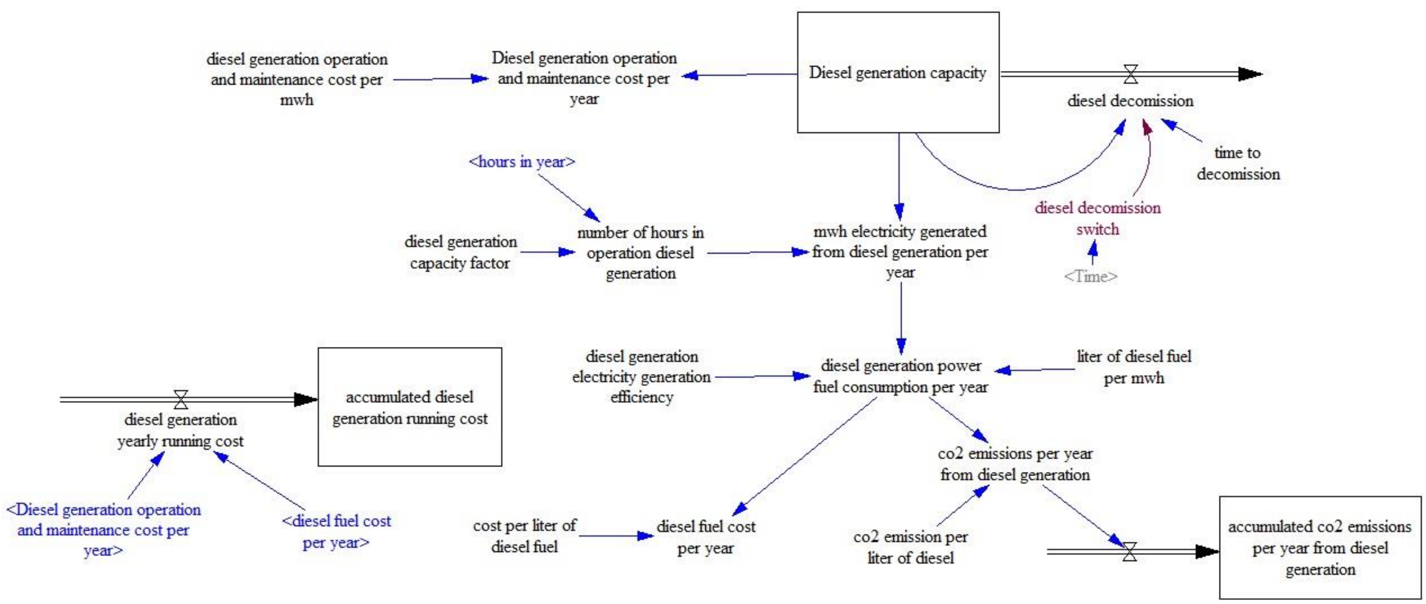


Figure 19: Diesel sector

This is the model structure for the diesel generation electricity sector.

<table>
<tr><th><u>Name</u></th><th><u>Equation</u></th></tr>
<tr><td>Mwh electricity generated from diesel generation per year</td><td>Diesel generation capacity*number of hours in operation diesel generation</td></tr>
<tr><td colspan="2"><u>Unit: Mw*hour/Year</u>
This is the generated level of electricity measured in megawatt hours per year. This is the most important input for the rest of the model coming out of this sector.</td></tr>
<tr><td>Diesel generation power fuel consumption per year</td><td>(liter of diesel fuel per mwh/diesel generation electricity generation efficiency)*mwh electricity generated from diesel generation per year</td></tr>
<tr><td colspan="2"><u>Unit: liter/Year</u>
In order to generate electricity diesel powerplants need to consume diesel fuel so that can they generate electricity. This variable give you the estimated consumption of coal every year with regards to the current level of capacity and electricity output.</td></tr>
<tr><td>Diesel fuel cost per year</td><td>diesel generation power fuel consumption per year*cost per liter of diesel fuel</td></tr>
<tr><td colspan="2"><u>Unit: USD/Year</u>
Unlike hydropower and solar power, diesel power needs a constant supply of fuel in order to generate electricity. The consumption of coal has a monetary cost. And the more electricity that is produced the larger the consumption of coal and thus the fuel expenses increases.</td></tr>
<tr><td>Co2 emissions per year from diesel generation</td><td>co2 emission per liter of diesel*diesel generation power fuel consumption per year</td></tr>
<tr><td colspan="2"><u>Unit: Ton/year</u></td></tr>
<tr><td>Diesel generation yearly running cost</td><td>diesel fuel cost per year+diesel generation financial interest cost+Diesel generation operation and maintenance cost per year</td></tr>
<tr><td colspan="2"><u>Unit: USD/Year</u>
This is the total cost of running the current level of capacity, this include both the direct costs that are involved in operating and maintaining the capacity as well as the opportunity costs of investing the capital into the capacity.</td></tr>
</table>

Table 13: Equations of the Diesel generation sector

3.15 Electricity grid

The purpose of this sector is to sum up all the electricity generation in the country and to calculate the electricity price. In this sector, the demand for electricity meets the supply of electricity and thus the electricity price is estimated. The relative change in electricity price is an important input for many effects throughout the model. This is a sector that is interacting with many other sectors. There are several loops going through this sector, but the sector has no loops of their own internally in the sector. This is because there are not stocks in this sector.

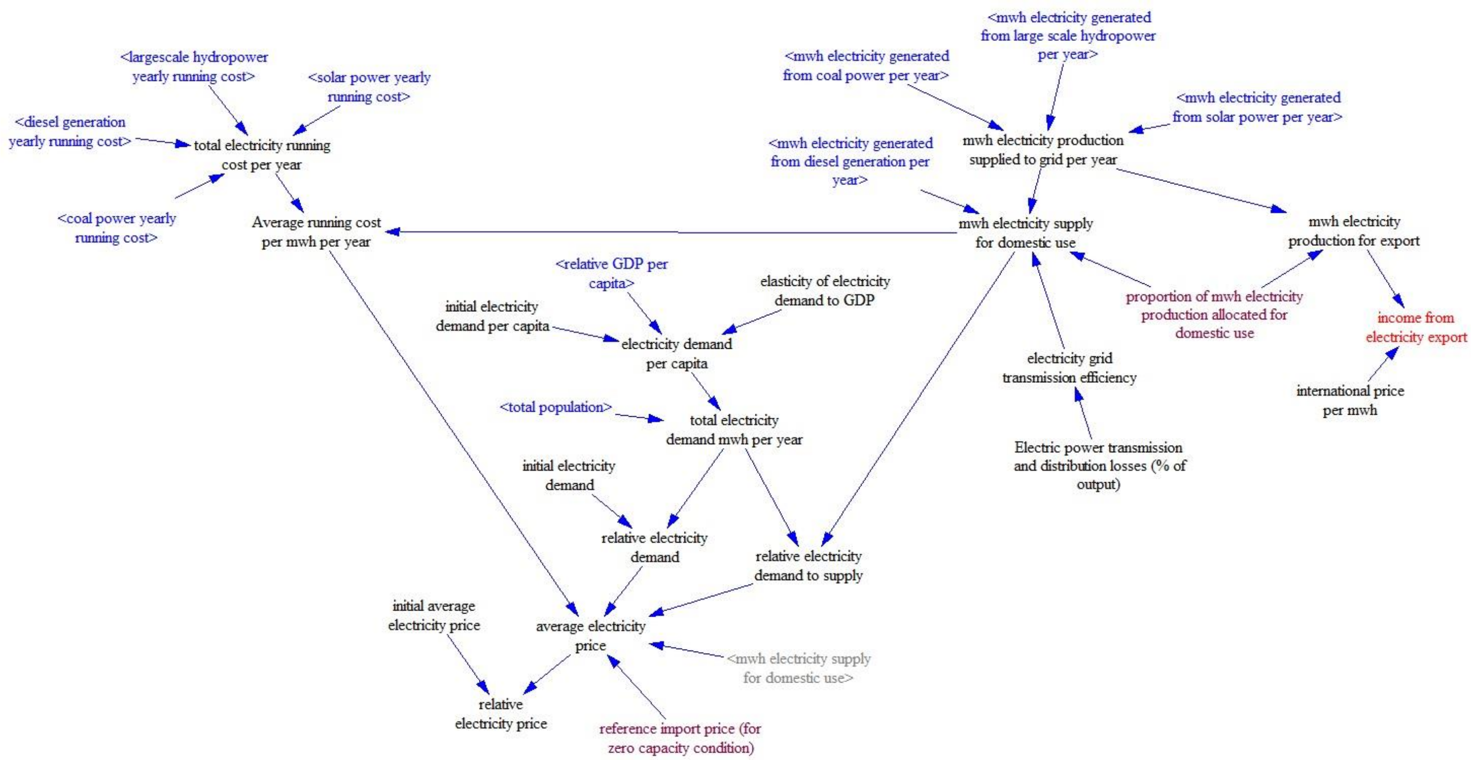


Figure 20: Electricity grid sector

This is the model structure for the electricity grid sector.

<table>
<tr><th><u>Name</u></th><th><u>Equation</u></th></tr>
<tr><td>Average electricity price</td><td>IF THEN ELSE(mwh electricity supply for domestic use<=0, relative electricity demand*"reference electricity price (for zero capacity condition)", MAX(Average running cost per mwh per year, Average running cost per mwh per year*relative electricity demand to supply))</td></tr>
<tr><td colspan="2"><u>Unit: USD/(Mw*hour)</u>
This is the key variable coming out of this sector. The electricity price is determined by finding a price floor. The MAX function chooses between the greater value of the two expressions. Even if supply increases relative to demand the unit price per mwh cannot go lower than the average running cost per mwh. The average running cost is used as a moving target that the relative demand to supply is multiplied with in order to generate a price estimate. Both variation in cost and in demand/supply influences the price.

The logical function “IF THEN ELSE” is there to ensure that the model functions under the zero electricity capacity condition. The concept under this condition is that the electricity price is determined by a electricity reference price. The reference price reflects the cost of importing electricity and a constriction in supply relative to the demand. This is mathematically represented by multiplying the relative demand with the reference price.</td></tr>
<tr><td>Relative electricity demand to supply</td><td>IF THEN ELSE(mwh electricity supply for domestic use<=0, 0, total electricity demand mwh per year/mwh electricity supply for domestic use)</td></tr>
<tr><td colspan="2"><u>Unit: Dimensionless</u>
This variable represents the relative relationship between electricity demand and electricity supply, and how this influences the electricity price. When supply increases, this will cause the price to fall. Or if demand increases this will cause the price to rise. This is mathematically represented by dividing the current demand on the current supply.

The logical function “IF THEN ELSE” is there to ensure that the model functions under the zero electricity capacity condition.</td></tr>
<tr><td>Total electricity demand mwh per year</td><td>electricity demand per capita*total population</td></tr>
</table>

<table>
<tr><td colspan="2"><u>Unit: Mw*hour/Year</u>
This represents the total electricity demand in Cambodia. The demand increases as the population increases and the per capita income increases. An increase in income causes the demand for electricity to go up.</td></tr>
<tr><td>Electricity demand per capita</td><td>initial electricity demand per capita*(relative gdp per capita^elasticity of electricity demand to GDP)</td></tr>
<tr><td colspan="2"><u>Unit: Mw*hour/Year/person</u>
This variable represents the demand for electricity per person. The relative gdp per capita and the electricity demand per capita have a positive polarity relation. For an example if income per capita increases the demand for electricity to will increase as well.</td></tr>
<tr><td>Relative electricity demand</td><td>IF THEN ELSE(total electricity demand mwh per year<=0, 0, total electricity demand mwh per year/initial electricity demand)</td></tr>
<tr><td colspan="2"><u>Unit: Dimensionless</u>
This is the relative demand. This variable is used to find the electricity price under the zero electricity capacity condition.

The logical function "IF THEN ELSE" is there to ensure that the model functions under the zero electricity capacity condition</td></tr>
<tr><td>Average running cost per mwh per year</td><td>IF THEN ELSE (mwh electricity supply for domestic use<=0, 0, total electricity running cost per year/mwh electricity supply for domestic use)</td></tr>
<tr><td colspan="2"><u>Unit: USD/(Mw*hour)</u>
This takes the total costs related to electricity production and divides it on the electricity supply. This way we find the average running cost per megawatt.

The logical function "IF THEN ELSE" is there to ensure that the model functions under the zero electricity capacity condition</td></tr>
<tr><td>Total electricity running cost per year</td><td>coal power yearly running cost+diesel generation yearly running cost+largescale hydropower yearly running cost+solar power yearly running cost</td></tr>
<tr><td colspan="2"><u>Unit: USD/Year</u>
In this variable all the costs related to electricity production are summed up.</td></tr>
<tr><td>Mwh electricity poduction supplied to grid per year</td><td>mwh electricity generated from coal power per year+mwh electricity generated from large scale hydropower per year+mwh electricity generated from solar power per year</td></tr>
<tr><td colspan="2"><u>Unit: Mw*hour/Year</u>
This is the sum of all the electricity that is generated per year and supplied to the grid.</td></tr>
<tr><td>Mwh electricity supply for domestic use</td><td>(((mwh electricity production supplied to grid per year*proportion of mwh electricity production allocated for domestic use)
+mwh electricity generated from diesel generation per year)*electricity grid transmission efficiency)</td></tr>
<tr><td colspan="2"><u>Unit: Mw*hour/Year</u>
This represents all the electricity supply that is available to the domestic market every year. Transmission loss and export is accounted for. The electricity coming from diesel power is not exported since that would not be profitable given the electricity price and cost.</td></tr>
</table>

Table 14: Equations of the Electricity grid sector

3.16 Policy comparison

The purpose of this sector is to make it easy to adjust parameters, implement different policy options and to compare results.

There are two important substructures in this sector. Both of these structures relate to the implementation of different policy options. These two substructures are called "*POLICY IMPLEMENTATION SUBSTRUCTURE A*" and "*POLICY IMPLEMENTATION SUBSTRUCTURE B*".

With "*POLICY IMPLEMENTATION SUBSTRUCTURE A*" you can choose how much to invest over a period of time and in which type of electricity generating technology. But there are not feedback going back into the structure influencing the course of further investment.

With “*POLICY IMPLEMENTATION SUBSTRUCTURE B”* you can also choose between the different electricity generating technologies and the level of investment. However, with this structure you get a reinforcing feedback loop going back into the policy structure generating further investment, thus making this structure an endogenous part of the model.

There are advantages and drawbacks with both method of implementing and comparing policies. The advantage with substructure A is that you can plan and choose beforehand knowing exactly how much you want to invest and then you see the trade-offs and benefits you receive directly in relation to the level of investment you made. The weakness with policy structure A is that there is no feedback loop going back to the investment decision, and thus missing out on an element that could be endogenously include into the model.

The strength of substructure B is that it endogenizes the investment policy so that it is not just some external force that influenced the model. The investment policy is a direct consequence of how the overall model is behaving. This is realistic with regards to how investments are done in the real world, if an economy’s overall performance is improving there is more to spare towards further investments. The overall performance is determining the future level of investment. The weakness of the policy implementation structure B however is that there are other effects that are not included in the model that would influence the investment decition. There are needs, obligations and investment options other than the options in the model that policy makers need to consider when deciding on the level of investment. The model does not capture how much should be spent on welfare, health, education and defense. To take an extreme case for an example, it is unrealistic to spend 100% of the GDP only on developing the electricity generating capacity.

With substructure A you have more direct control and with substructure B you can to a larger degree observe how the overall system behaves when left to itself under certain given conditions.

Policy structure B is not included in the result scenarios, but is intended to give policymakers and others additional flexibility and options when testing out policies for themselves.

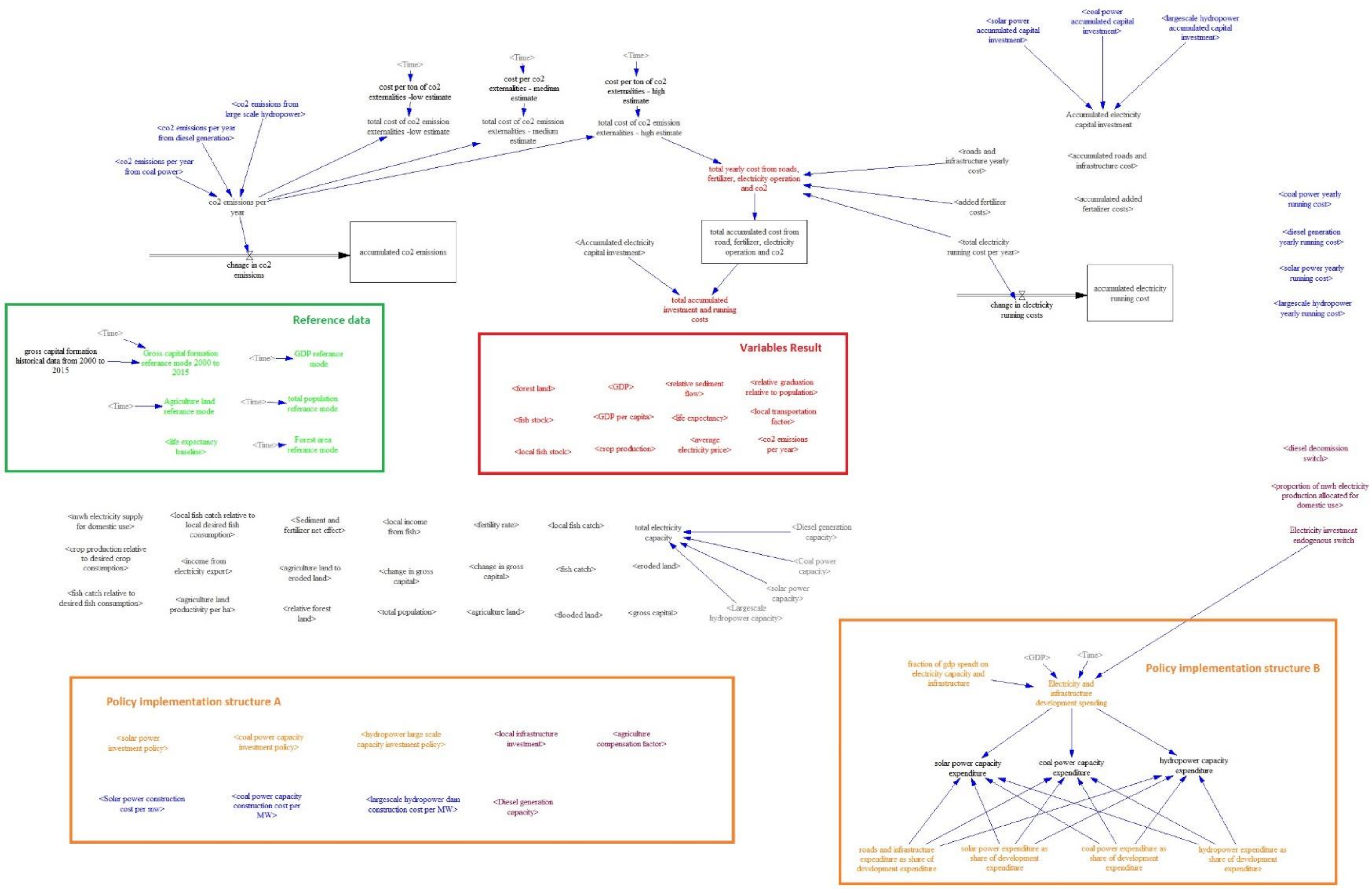


Figure 21: Policy comparison sector

POLICY IMPLEMENTATION SUBSTRUCTURE A:

Name	Equation
Hydropower large scale capacity investment policy	[(2000,0)-(2040,1e+006)],(2000,0),(2015,0),(2016,0),(2025,0),(2026,0),(2040,0)
Unit: USD/Year *This is a graphical function where you can write in the level of desired investment over an optional timeframe.*	
Coal power capacity investment policy	[(2000,0)-(2040,1e+007)],(2000,0),(2015,0),(2016,0),(2025,0),(2026,0),(2040,0)
Unit: USD/Year *This is a graphical function where you can write in the level of desired investment over an optional timeframe.*	
Solar power investment policy	[(2000,0)-(2040,1e+007)],(2000,0),(2015,0),(2016,0),(2025,0),(2026,0),(2040,0)
Unit: USD/Year *This is a graphical function where you can write in the level of desired investment over an optional timeframe.*	
Local infrastructure investment	([(0,0)-(2040,10)],(2000,0),(2015,0),(2016,0),(2025,0),(2030,0),(2035,0),(2040,0))
Unit: USD/Year	

This is a graphical function where you can write in the level of desired investment over an optional timeframe.

Table 15: POLICY IMPLEMENTATION SUBSTRUCTURE A

POLICY IMPLEMENTATION SUBSTRUCTURE B:

Name	**Equation**
Electricity and infrastructure development spending	if then else(Time>2016, GDP*fraction of gdp spendt on electricity capacity and infrastructure(Time) , 0)*Electricity investment endogenous switch
Unit: USD/Year	
Fraction of gdp spend on electricity capacity and infrastructure	[(2000,0)-(2040,0.2)],(2000,0),(2015,0),(2016,0.01),(2025,0.001),(2026,0),(2040,0)
This is where you choose the strength of investment into electricity capacity. It is currently set to go from 1% of GDP in the year 2016 and to go down to 0.1% in the year 2025 and then stop. The weakness with this structure is that	
hydropower expenditure as share of development expenditure	(0-1)
Unit: Dimensionless *A number between zero and one determining the weight of investment to receive relative to the other options.*	
Coal power expenditure as share of development expenditure	(0-1)
Unit: Dimensionless *A number between zero and one determining the weight of investment to receive relative to the other options.*	
Solar power expenditure as share of development expenditure	(0-1)
Unit: Dimensionless *A number between zero and one determining the weight of investment to receive relative to the other options.*	

Table 16: *POLICY IMPLEMENTATION SUBSTRUCTURE B*

4. Model testing and validation

Throughout the stages of developing a model the model is continuously tested and scrutinized for errors and biases, this is called model validation. Model validation is a gradual process of building confidence in the model that it represents the world with regards to its subject in an adequate way. There are a number of validation tests that can be performed to increase confidence in the model (Barlas 1996). The purpose of these tests is to establish confidence of the validity of the model *structure*. It is first and foremost the model structure that is of concern in a system dynamics model. The model structure is a description and explanation of causal relationships. The results generated by a system dynamics model does not only have to generate correct behavior matching empirical observations in the real world but also generate them for the "right reasons", in this sense system dynamics as a methodology is a marriage of qualitative and quantitate method.

The tests that have been used in this thesis are the following:

4.1 Direct structure tests

Direct testing is the first screen of validation. There is no simulation involved and it is done by directly comparing elements and structure from the model with knowledge of the real system in question. A way to ensure this is the practice called "model as you go". This entails to do research and modeling simultaneously and form structure based on the research you have done and then compare the output you get with the data you have gathered.

4.1.1 Structure verification test

This test can be performed both empirically and theoretically by comparing already established knowledge of the real system. Model structure is built up by mathematical equations and they represent causal relationships of the real system.

The test is performed by directly comparing the mathematical formulation of the model structure with observations of the real system and with established theoretical knowledge of the subject.

During the process of developing the model for this thesis I continually consulted reports from NGOs, the Cambodian government agencies and peer reviewed papers. The structure in the model is carefully based on concepts drawn from these sources. The purpose of this test is to ensure that the immediate logic of the causal relationships are in accordance with the real system. This continual process of scrutinizing the structure as it is built helps rule out many errors before it makes it into the model.

4.1.2 Parameter and data verification test

Constants and data series that are used in the model should, when possible, be based on empirical data found in literature, preferably confirmed by several independent sources. If multiple sources give different values for the same parameter then we can ascertain a degree of uncertainty, and it is advisable to perform a *sensitivity test* to see if varying the parameter significantly changes he simulation results (see more about this under *structure oriented behavior tests*).

In the case of Cambodia reliable data is not always easy to come by, given its history and status as a developing county. If reliable data cannot be obtained then one have to reason out a range of plausible values based on estimations from surrounding or related structure, again a *sensitivity test* is recommended. When this is the case it is important that all assumption are explicitly stated and made visible, since this contributes to the limitation of the model.

NB: Parameters and elasticities that I could not directly obtain data on were calibrated such that output matched historical reference data.

Name	Used for	Sources	Perceived accuracy
ton of soil per ha	input	Research Gate[46]	medium
self sufficiency factor	calibration	Food and Agriculture organization of the United Nations[47],[48]	medium
elasticity of preschool fractional death rate to average life expectancy	input	World Health Organization[49]	medium
elasticity of primary school fractional death rate to average life expectancy	input	World Health Organization[50]	medium
elasticity of secondary school fractional death rate to average life expectancy	input	World Health Organization[51]	medium
"elasticity of collage/university age fractional death rate to average life expectancy"	input	World Health Organization[52]	medium
elasticity of working age fractional death rate to average life expectancy	input	World Health Organization[53]	medium
elasticity of elderly age fractional death rate to average life expectancy	input	World Health Organization[54]	medium
elasticity of tfp to crop production	output	Food and Agriculture organization of the United Nations[55]	medium
elasticity of tfp to fish catch	output	Food and Agriculture organization of the United Nations[56]	medium
elasticity of TFP to local electricity price	output	N/A	low
elasticity of tfp to average life expectancy	output	N/A	low
elasticity of primary school dropout fraction to gdp	input	USAID[57]	medium
elasticity of secondary school dropout fraction to gdp	input	USAID[58]	medium
elasticity of primary and secondary school dropout rate to electricity price	input	USAID[59]	medium
"elasticity of college/university dropout fraction to gdp"	input	N/A	low
elasticity of tfp to education	output	N/A	low
elasticity of production to capital	output	Economicpoint[60]	medium

---

46 https://www.researchgate.net/profile/Kimberly_Stoner/publication/273241616_World_Agriculture_and_Soil_Erosion/links/55dc6fb908aed6a199adf10b.pdf
47 http://www.fao.org/cambodia/fao-in-cambodia/cambodia-at-a-glance/en/
48 http://www.fao.org/docrep/field/009/i3761e/i3761e.pdf
49 http://apps.who.int/gho/data/?theme=main&vid=60270
50 http://apps.who.int/gho/data/?theme=main&vid=60270
51 http://apps.who.int/gho/data/?theme=main&vid=60270
52 http://apps.who.int/gho/data/?theme=main&vid=60270
53 http://apps.who.int/gho/data/?theme=main&vid=60270
54 http://apps.who.int/gho/data/?theme=main&vid=60270
55 http://www.fao.org/cambodia/fao-in-cambodia/cambodia-at-a-glance/en/
56 http://www.fao.org/cambodia/fao-in-cambodia/cambodia-at-a-glance/en/
57 http://schooldropoutprevention.com/country-data-activities/cambodia/
58 http://schooldropoutprevention.com/country-data-activities/cambodia/
59 http://schooldropoutprevention.com/country-data-activities/cambodia/
60 http://economicpoint.com/production-function/cobb-douglas

elasticity of production to labor	output	Economicpoint[61]	medium
elastcity of capital investment to GDP	input	N/A	low
elasticity of relative gross capital formation on fractional growth rate	input	N/A	low
elasticity of food demand to gdp per capita	input	European Commission[62] Economicshelp[63]	medium
share of crop in diet	calibration	MMF model	medium
effect of hydropower construction on fish migration adjusted national context	output	(ICEM 2010) (Ziv, Baran et al. 2012)	medium
effect of hydropower construction on local fish migration	output	N/A	low

Table 17: Parameter confidence assessment

4.1.3 Direct extreme condition testing

This is a way to test equations continually as you go. By placing an input to a variable to an extreme condition you are able to predict what should be the logical direct outcome on the output variable. This way of testing is static, done isolating one part of the structure to look at its direct outcome. Direct extreme condition testing help us to early on rule out relations that are inconsistent with reality. The was one of the test that I performed as a part of the "model as you go" practice.

4.1.4 Dimensional consistency test

Unit consistency is a way of ensuring internal consistency in the model. This makes sense to do once the structure of the model is tested and verified to properly map on to reality and that the units themselves make sense to their context. Vensim, the modelling software used for this thesis, has a built-in function to check unit consistency. It is important however that parameters implemented to "correct" units are made explicit and open to scrutiny, and given an explanation as to why they are used and why they do not undermine the overall model consistency. This test is built into the software of Vensim and was performed throughout the modelling process as new structure and parameters were added.

4.2 Structure-oriented behavior tests

Behavior tests involve simulations and dynamics. It indirectly tests the structure of the model by looking at the generated behavior of the model.

4.2.1 Partial model testing

During the creation of this model I made several subsectors that I "lifted" out of the main model. The isolated model sections would then be fed data through external "exogenous" input and then analyzed how it behaved. Together with this type of partial model testing is was also useful to run *extreme condition* tests on these model sections to see if the output behavior was consistent with reasonable expectations of reality. In cases when

[61] http://economicpoint.com/production-function/cobb-douglas
[62] http://publications.jrc.ec.europa.eu/repository/bitstream/JRC98812/jrc98812_jrc_report_meta_analysis_final.pdf
[63] http://www.economicshelp.org/blog/2621/economics/elasticity-of-food/

output was not consistent with reality the structure would be revised and further research into the subject was be done until consistency with reality was achieved. This form of partial model testing was especially useful to do since my model builds around the previous work done on the MFF model.

4.2.2 Extreme condition test

In addition of running extreme conditions on parameters in subsections of the model, extreme condition testing was also performed on the model as a whole. Output was analyzed to see if it was consistent with reasonable anticipations and observations of the real system. The following is the result for zero population:

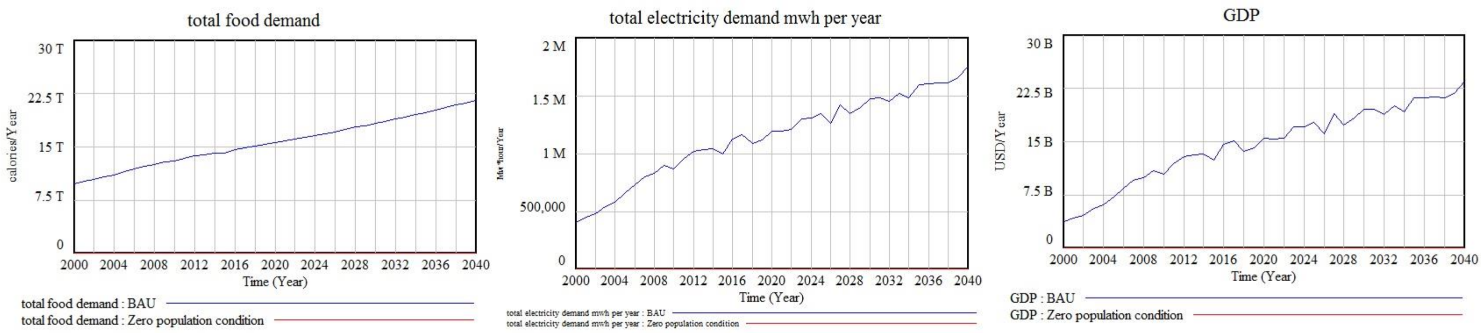


Figure 22: Zero population condition#1

This figure show the results for food demand, electricity demand and GDP at zero population condition. The blue graph represents the BAU and the red graph represents the respective variable at the zero condition.

As we can see from the results above, at zero population the GDP, electricity demand and food demand are all at zero. This corresponds well with our expectations and is realistic with regards to the real world.

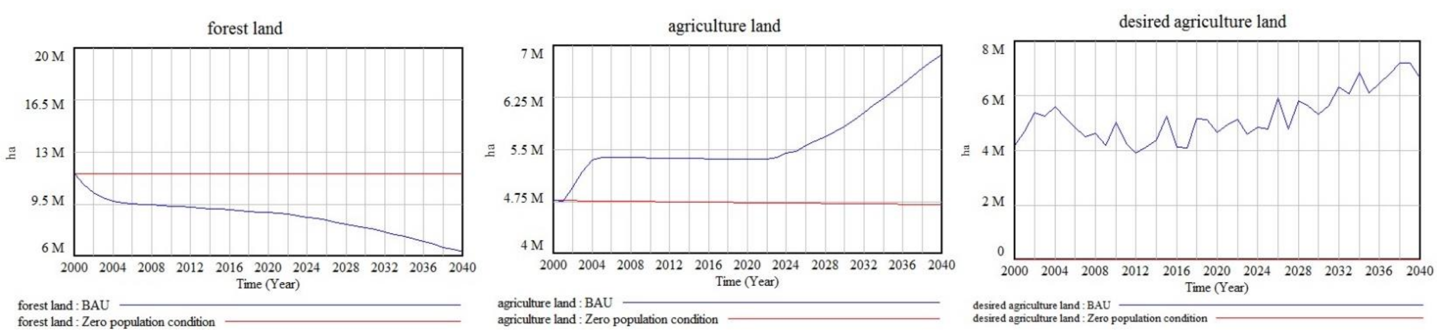


Figure 23: Zero population condition#2

This figure show the results for forest land, agriculture demand and desired agriculture land at zero population condition. The blue graph represents the BAU and the red graph represents the respective variable at the zero condition.

The results in figure 23 need to be seen in relation to each other. Since there are no people there will be no desire for agriculture land. As there is no desire for neither more, nor less agriculture land, the agriculture land will not change, except for the natural erosion rate. And thus there are no reasons to clear forest land, and it will stay the same.

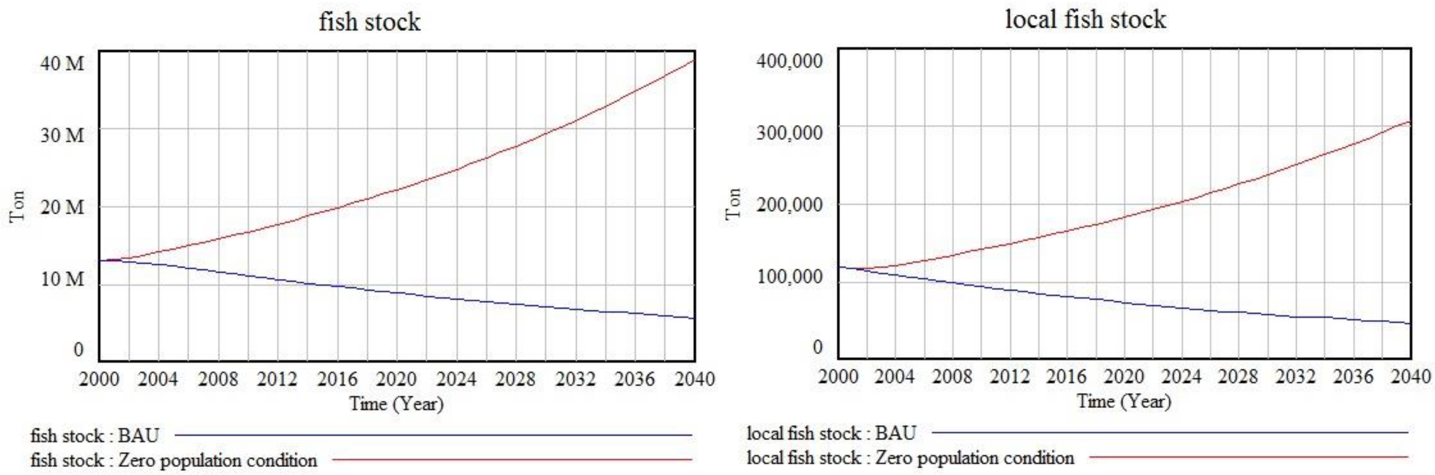


Figure 24: Zero population condition#3

This figure show the results for fish stock and local fish stock at zero population condition. The blue graph represents the BAU and the red graph represents the respective variable at the zero condition.

Notice how the zero condition and the BAU for the two fish stocks diverge and move in opposite directions of each other. This has to do with the fact that there are no fishing activities going on. The stock is left to itself and will grow at its natural growth rate. When there are no people, there will be no demand for fish and thus no fishing. These results correspond well with our understanding of the world.

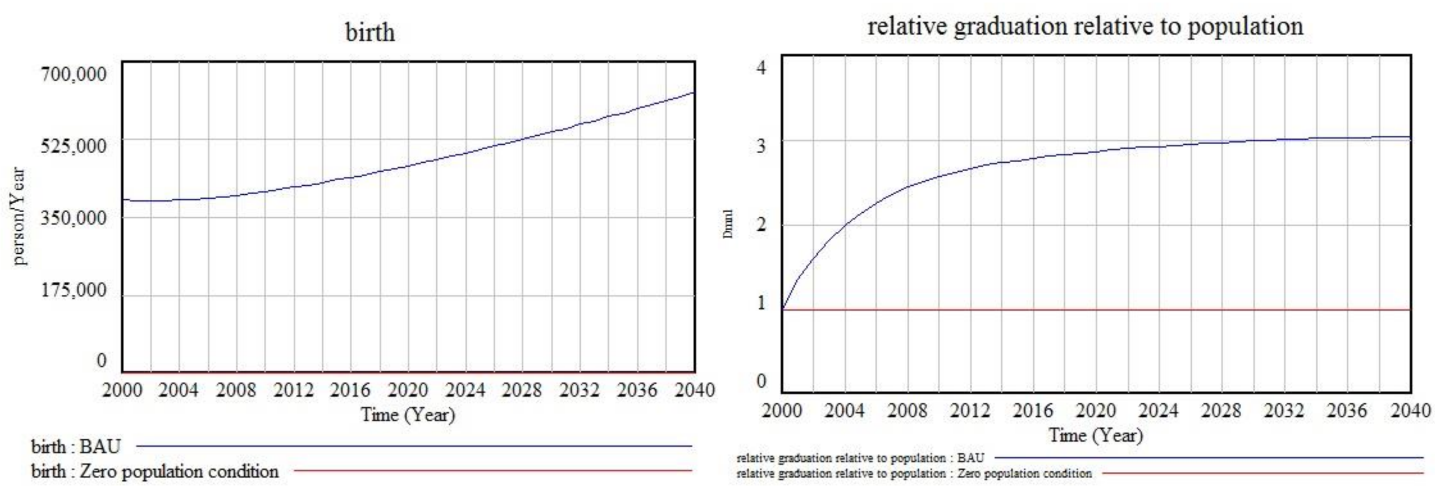


Figure 25: Zero population condition#4

This figure show the results for birth and relative graduation to relative population stock at zero population condition. The blue graph represents the BAU and the red graph represents the respective variable at the zero condition.

At zero population, there will be no births like the graph in figure 25 is showing. In the graph for the relative graduation relative population the value stays at 1. This indicates that the rate of graduation does not change, this is true since the rate will stay constant at 0 throughout the simulation.

The following are the results for the zero electricity capacity condition:

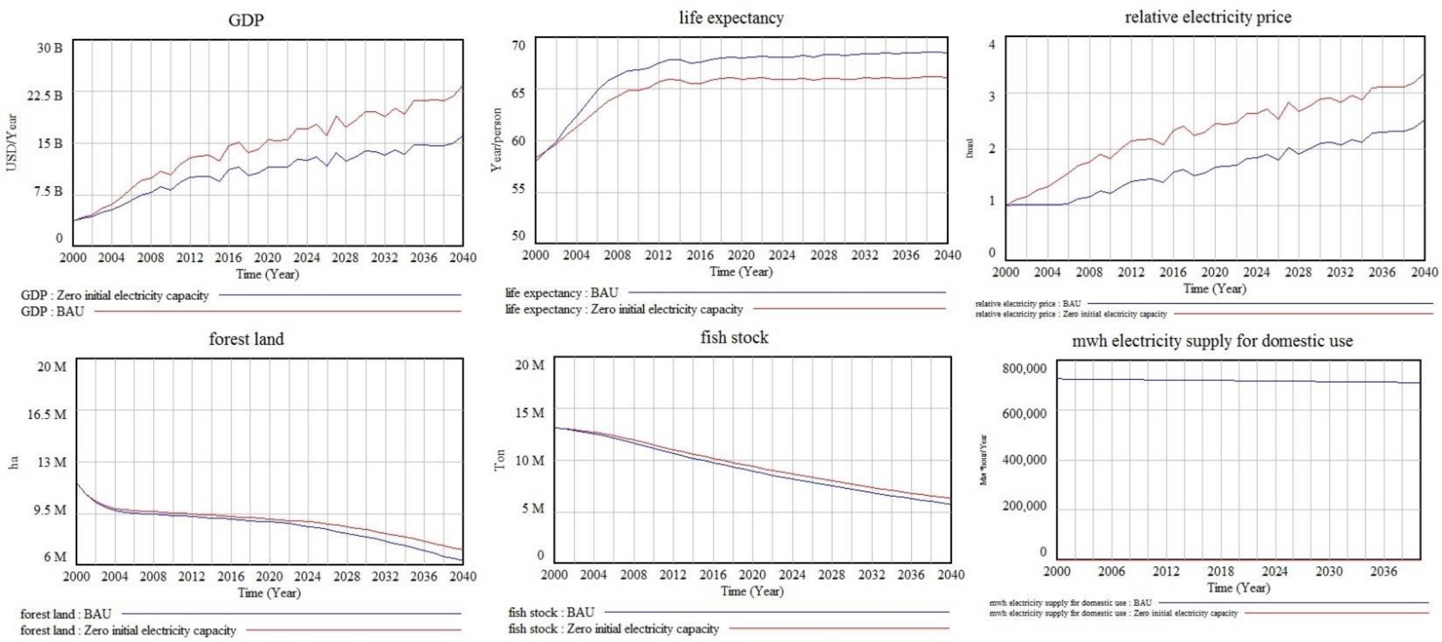


Figure 26: Zero electricity capacity condition

This figure show the results for GDP, life expectancy, relative electricity price, forest land, fish stock and electricity supply at zero population condition. The blue graph represents the BAU and the red graph represents the respective variable at the zero condition.

In the zero electricity capacity scenario there is no electricity generated by itself in Cambodia. This means that the supply decreases and they have to rely on import. The assumption under this scenario is that there is a fixed supply that can be imported every year and as the demand for electricity increases this drives the price up. From the results in the graphs above we can see that this has a negative impact on GDP and life expectancy. However the environmental impacts are less as well so the the forest and the fish stock are performing slightly better under this condition, as would be expected due to lower demand and less human activity.

4.3 Sensitivity test

Sensitivity tests are used in order to see the degree of change in one variable caused by change in another variable. An important question to ask when validating sensitivity is "would the real system exhibit the same sensitivity as the model with regards to the parameters in question?" This is especially important when it comes to elasticities. It is especially useful when it comes to ascertaining which variables or parameters, such as elasticities, are the most influential on the model results. This is useful to do when assumptions of the real system are made in order to see how much an error in those assumptions would affect the overall results.

We will be testing elasticities, parameters and other assumptions for the variables *GDP, life expectancy, total food demand, agriculture land, fish stock* and *total population* since these are all important outputs for the model determining the overall outcome.

The sensitivity tests were all run under the same conditions as the BAU scenario. The following parameters were tested for sensitivity with the following values and results:

elasticity of tfp to education
0.1
0.2
0.3
0.4
0.5
0.6 (BAU value)
0.7
0.8
0.9
1

Table 18: "Elasticity of tfp to education" sensitivity test values

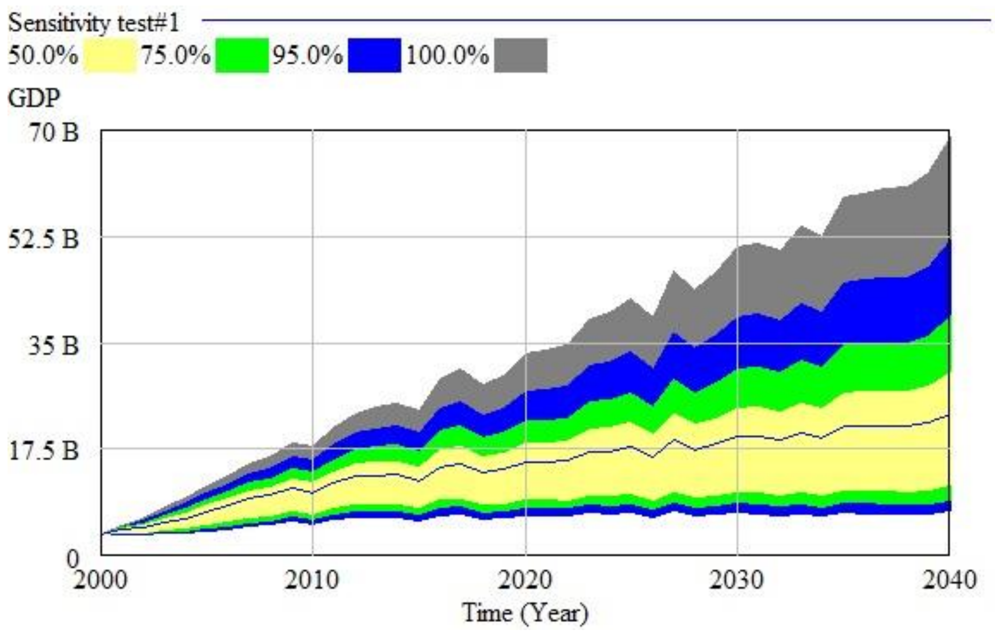


Figure 27: GDP sensitivity test for "elasticity of tfp to education"

In the baseline scenario, just like in BAU, *elasticity of tfp to education* value is set to 0.6. This is a relatively high value, and the concept is that education will have a significant impact on the economic development of the country. The reason why education is regarded to have such a high impact has to do with the situation Cambodia is in. Cambodia and other countries like it possess a large untapped potential of human resources that can be developed by education. Education will function as a multiplier on the human capital and make the workforce more effective per capita. In countries where this educational potential has already been tapped the effect of additional education will be less. We can see from the graph above that the GDP is very sensitive to changes in the *elasticity of tfp to education.* There is a wide spread going forward showing that initial small difference make huge differences later. The spread is roughly equally distributed on each side of the base run, and the base run is within the 50% confidence tile. This tells us that the value is within a reasonable range of realism with regards to the GDP and the rest of the system. It is important to note however that one should be very careful with changes in this parameter as an erroneous assumption can skew the output of the model quite a bit. Therefore, attention should be given to this elasticity and viewed with a critical eye, as it is a potential source that can cause significant error in the outcome.

elasticity of tfp to average life expectancy
0.5
0.6
0.7
0.8
0.9
1 (BAU value)
1.1
1.2
1.3
1.4

Table 19: "Elasticity of tfp to average life expectancy" sensitivity test values

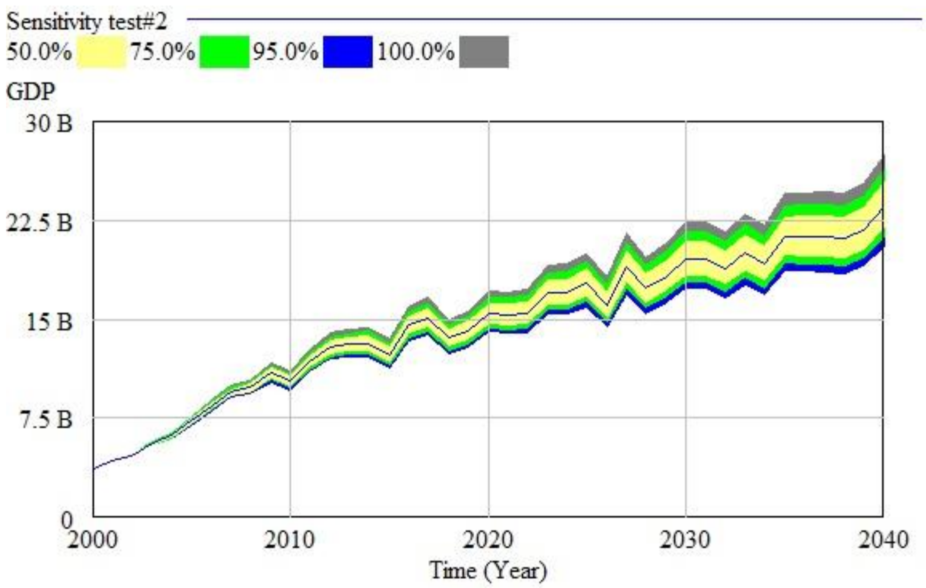


Figure 28: "Elasticity of tfp to average life expectancy" sensitivity test result

In the baseline scenario, just like in BAU, *elasticity of tfp to average life expectancy* value is set to 1. The *elasticity of tfp to average life expectancy* is within the lower 50% confidence interval, with a wide spread going upwards. This indicates that the chosen value of 1 is close fit to the causal relation in the real system.

Like in the case with the education, life expectancy and health are conceptually in a similar situation. Initial improvements will cause major gains over time. And there is a great untapped potential to improve human capital and worker effectiveness by improving the health condition represented by the life expectancy.

elasticity of tfp to fish catch
0.1
0.2
0.3
0.4 (BAU value)
0.5
0.6
0.7
0.8
0.9
1

Table 20: "elasticity of tfp to fish catch" sensitivity test values

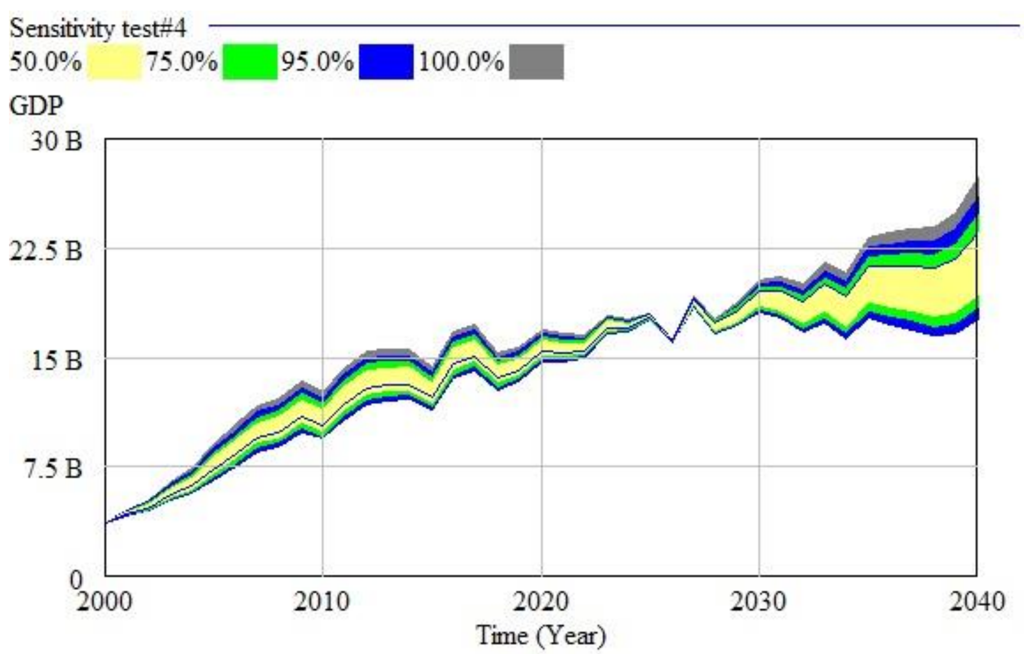


Figure 29: "elasticity of tfp to fish catch" sensitivity test result

In the baseline scenario, just like in BAU, *elasticity of tfp to fish catch* value is set to 0.4. This is in the upper bound of realism for this parameter, but the reasoning behind it is that together with the *crop production* they make up 100% of the income from the primary sector, absorbing all other residual activities into itself [64]. This is a limitation of the model and must be taken into consideration. Future improvements can be made on this aspect of the model. However, for the purpose of this thesis this assumption is still reasonable and do not undermine the underlying logic of the system. Since the primary sector has such a dominance in the economy of the country and that the majority of the population is supported by fishing activity, directly or indirectly, it is reasonable that the elasticity should reflect this relative importance.

The graph show that the baseline scenario is close to the border of the lower 75% confidence interval at the first half of the simulation. Around the year 2025 the graph considerably narrows in. This represents that the *fish*

[64] http://www.fao.org/cambodia/fao-in-cambodia/cambodia-at-a-glance/en/

catch at this point in time is getting relatively less and less important with regards to the GDP, and that changes in the elasticity has very little relevance for the outcome in GDP. This is directly related to the fact that the *relative fish catch* is approaching 1. However, the relative importance increases again after this, as the fish stock declines further. The sensitivity of GDP to the *elasticity of tfp to fish catch* increases the further away *relative fish catch* is from the value 1.

elasticity of tfp to crop production
0.1
0.2
0.3
0.4
0.5
0.6 (BAU value)
0.7
0.8
0.9
1

Table 21 "elasticity of tfp to crop production" sensitivity test values

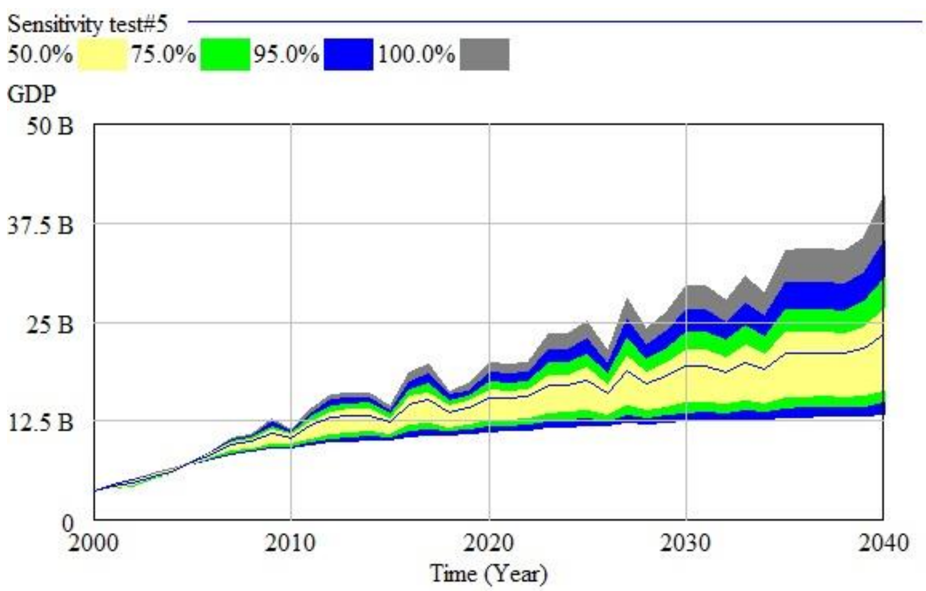


Figure 30"elasticity of tfp to crop production" sensitivity test result

In the baseline scenario, just like in BAU, *elasticity of tfp to crop production* value is set to 0.6. As mentioned above, the relative value of *elasticity of tfp to crop production* and *elasticity of tfp to fish catch* put together sums up to 1. The concept behind this is that the fish catch and the crop production makes up 100% of the primary sector. This is a limiting assumption of the model as mention before. The sensitivity of GDP to this parameter is quite high. We can see this from the increasing spread over time in the simulation. The baseline however has roughly an even distribution around it, staying slightly to the upper bound of the 50% confidence tile. This tells us that the assumption of this elasticity is within reasonable limits. It is important to note however that one should be very careful with changes in this parameter as an erroneous assumption can skew the output of the model quite a bit. Therefore, attention should be given to this elasticity and viewed with a critical eye.

elasticity of production to labor
0.1
0.2
0.3
0.4
0.5 (BAU value)
0.6
0.7
0.8
0.9
1

Table 22 "elasticity of production to labor" sensitivity test values

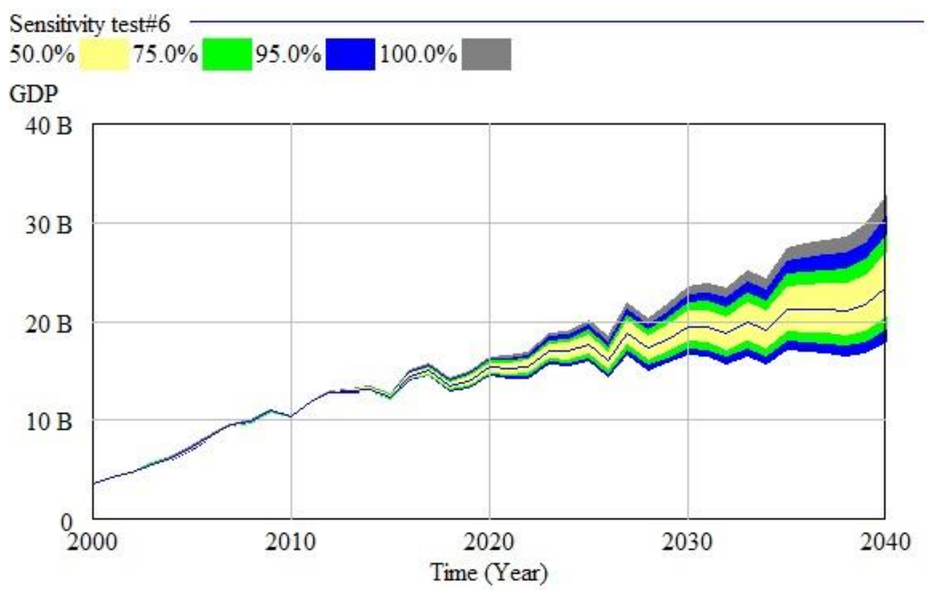


Figure 31"elasticity of production to labor" sensitivity test result

At the beginning of the simulation variation in the elasticity has very little to say for the output of the model. However, as the relative labor force increases, as the population increases, its relative significance increases also. The roughly equal distribution around the base run with an upwards trend indicates that the parameter value is within reasonable bounds as it does not create extreme behavior.

The parameter value of 0.5 should be considered together with the parameter value of *elasticity of production to capital.* This has to do with the theoretical concept behind the Cobb-Douglas production function. In the Cobb-Douglas production function the coefficients, or the elasticities in this case, of capital and labor (K and L) should sum up to 1. This mathematically represents the relative weight distribution between labor and capital with regards to economic output. Not finding exact data on the coefficients for Cambodia I gave an equal weight to others, minimizing the potential error one way or another.   Arguably, supported by certain literature, one can say that the greater emphasis should be placed on labor versus capital in an economy such as Cambodia, since the greater part of the economy is labor based versus capital intensive. However, this ignores the fact that relative increase in capital has greater potential in a developing economy than in an economy already saturated by capital. Weighing these two concerns up against each other coupled with lack of actual data on this relation I chose to settle on an equal weight for the two variables, as reflected in giving their respective elasticity 50% of the weight each.

elasticity of production to capital
0.1
0.2
0.3
0.4
0.5 (BAU value)
0.6
0.7
0.8
0.9
1

Table 23: "elasticity of production to capital" sensitivity test values

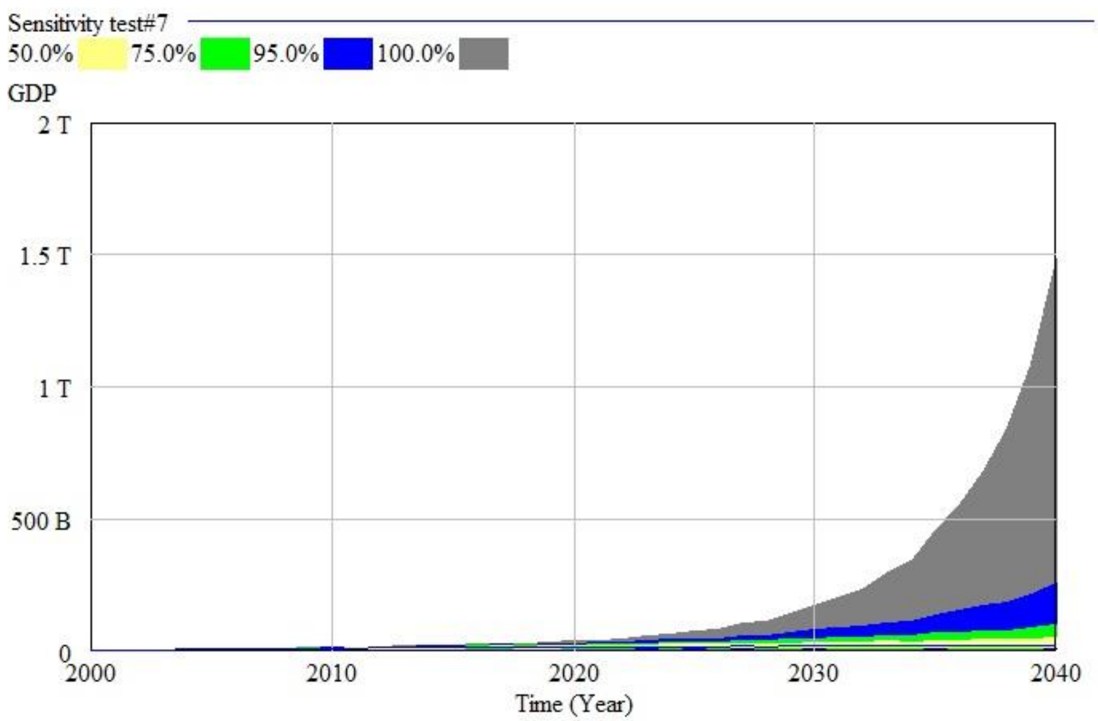


Figure 32: "elasticity of production to capital" sensitivity test results

The GDP is *very* sensitive towards increases in this parameter, and should therefore be treated with outmost care. This show a big limitation of the model and uncovers a factor that reduces robustness. However, the saving grace for this aspect is the conceptual relation this parameter has with the *elasticity of production to labor*. This means that if you increase the *elasticity of production to capital* then you conceptually *must* equally reduce the *elasticity of production to labor*, conceptually creating a balancing loop. Still this is not enough to completely offset the hyper sensitivity of GDP on higher values. This issue can be solved technically by implementing additional balancing structure representing diminishing returns to scale for capital or increasing costs of externalities. The underlaying concept however of capital having a growth rate and influencing the GDP with a positive polarity is in itself not wrong and still holds true. This technical limitation of the model must be addressed in the future, and in the meanwhile only careful use of moderate values can be applied.

elasticity of capital investment to GDP
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2 (BAU value)
1.3
1.35

Table 24: "elasticity of capital investment to GDP" sensitivity test values

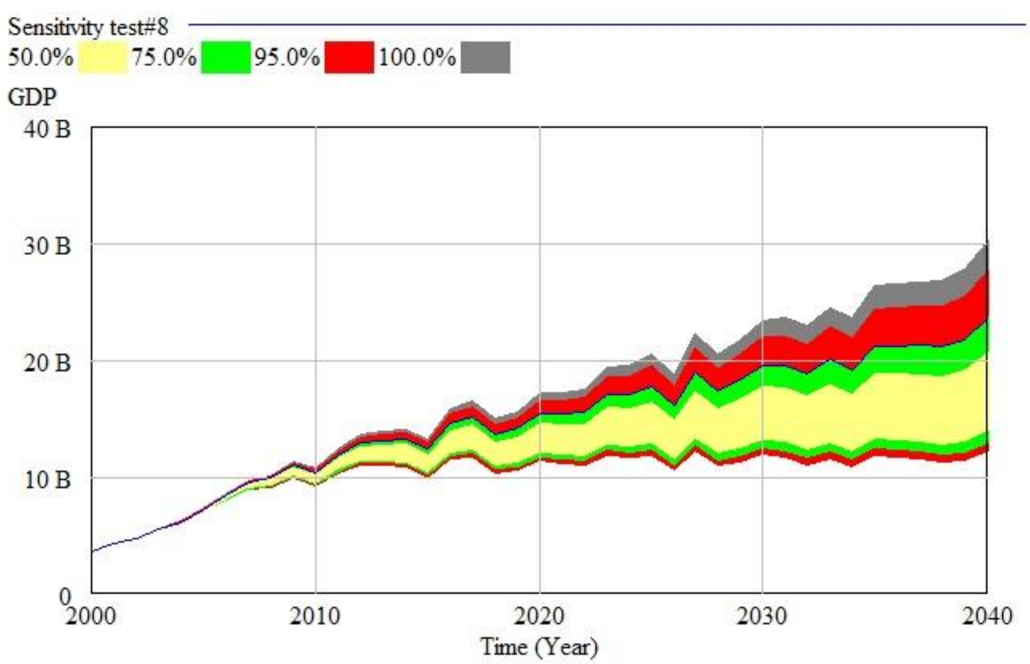


Figure 33: "elasticity of capital investment to GDP" sensitivity test results

The baseline follows the border between the upper 75% and 95% confidence intervals. The colors have been changed in this graph compared to the other diagrams to show the baseline that is marked as a blue line. This show how sensitive investment decisions are with regards to GDP. At the lower end of this graph the spread is quite low, thus changes in GDP at relatively low income levels causes very little extra investment in capital. This changes however as GDP increases in value relative to itself, causing investments to go up. This corresponds nicely both with intuition about the system and with literature on the subject. At relatively higher income people can spare more of their income towards investment to the future, not spending everything on basic consumption. This has a positive effect on the fractional growth rate of the capital stock, as reflected in the structure of the model.

self sufficiency factor
0.8
0.9
1
1.1
1.2
1.3 (BAU value)
1.4
1.45
1.5
1.55

Table 25: self sufficiency factor sensitivity test values

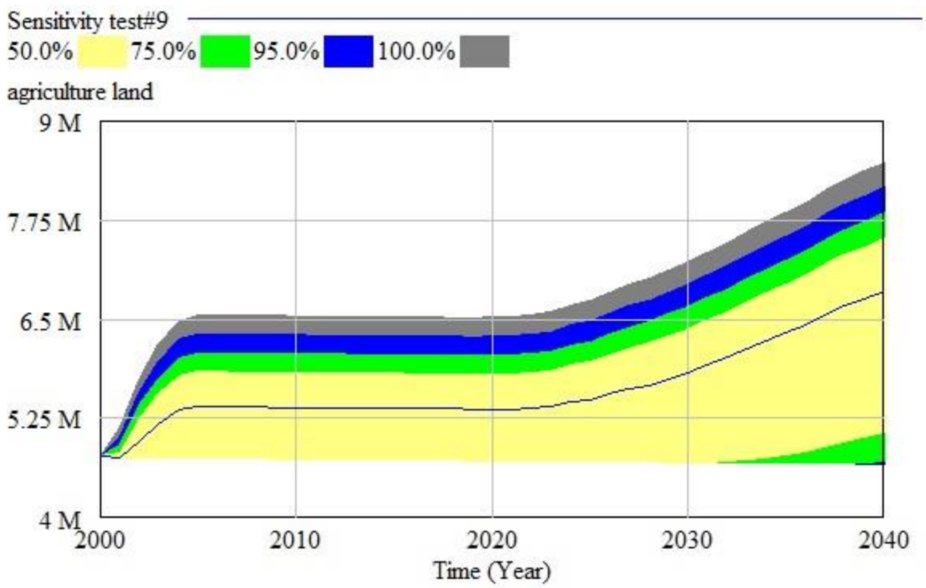


Figure 34: self sufficiency factor sensitivity test result

This parameter is an assumption about the level of self-sufficiency in the agriculture sector of Cambodia. The value of 1.3 indicates that 30% of the output is exported, raising the relative demand for agriculture land. As we can see from the result in the graph above, the agriculture land responds quite sensitively to changes in this parameter. What is important to note however is that the response to this parameter is even throughout the course of the simulation. This indicates that change in this parameter will only adjust agriculture land proportionally to a higher. Thus, this parameter is not in any danger to cause a “runaway” situation through a multiplicator effect within the model. This level is an assumption that is supported by literature on the subject. However, confidence can be increased by further research of this aspect. Due to limited time and resources for research and data collection in a master thesis certain assumption must be made based only on superficial literature review and not by inhouse research. In any case, the assumption is within reasonable bounds with regards to the variable output, corresponding to expectations of reality.

elasticity of relative gross capital formation on fractional growth rate
-0.7
-0.8
-0.9 (BAU value)
-1
-1.1
-1.2
-1.4
-1.6

Table 26: "elasticity of relative gross capital formation on fractional growth" sensitivity test values

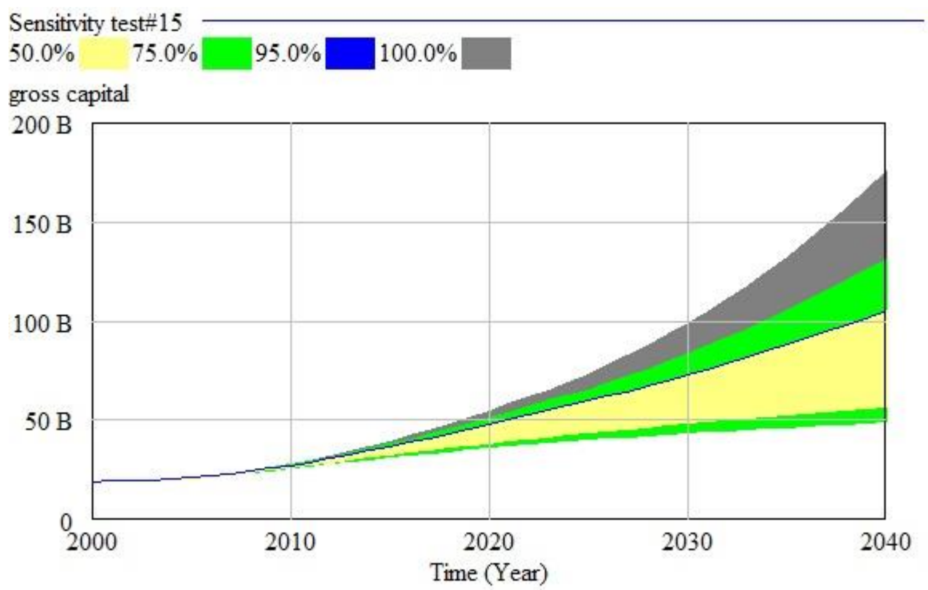


Figure 35: "elasticity of relative gross capital formation on fractional growth" sensitivity test results

This parameter has a negative value and an inverse relationship with the *gross capital*. The *gross capital* is highly sensitive to change increasing the *"elasticity of relative gross capital formation on fractional growth rate"* to higher values, moving it closer to zero. This elasticity determines the strength of the feedback loop dampening the growth of *gross capital* as it increases. This feedback loop represents the effect of diminishing returns to scale as the capital stock increases. This parameter should be treated with care as it has the potential to greatly skew model results. This is a limitation of the model that reduces robustness of extreme conditions in this parameter. However, as long as one is aware of this limitation the model operates within the bounds of reality.

4.4 Reference mode reproduction test

This test shows how well the model reproduces actual recorded behavior of the past. In the case of this model for this thesis the dependent variables that were used as a reference mode were *GDP*, *Population*, *Life expectancy*, and *Agriculture land*.

When it comes to reproducing the results of the real system it is better to be “wrong” for the right reasons than to be completely “right” for the wrong reasons. What you want to be is to be right for the right reasons. What this means is that the results that are generated from the model gives the right results because the model structure is actually a realistic representation of the real system in question. This is why the value of the reference mode testing hinges on the confidence built by previous structure tests. A reference mode test alone cannot validate a model, but it can uncover shortcomings and weaknesses with the model if the reference behavior and the model result are very different. Here are the results of the reference mode tests that I ran on the model:

4.4.1 GDP reference mode test

The reference data was taken from the World Bank[65]. The GDP in the simulation is driven by change in the capital stock, the labor force and the TFP. At the beginning of the simulation an up until about the year 2008 the model simulation is close but consistently above the reference data. From around year 2010 however there is a slump in the growth of the GDP and from 2014 until 2015 it has decreased a little. The reason for these changes in the simulation is due to the use of a random function in the agriculture sector relating to precipitation trend and rainfall variability. Despite the divergence around year 2015, the model simulation and the reference data match reasonably well with each other. The simulation run for the GDP could have come closer to the reference data, but at the cost of less realistic assumptions and values for a number of parameters, and at the expense of accuracy in other variables. It is better to be a little incorrect in the right way than to be 100% correct in the wrong way. Despite the discrepancy in the year 2014 and 2015 the R^2 value is 0.8326, still within a reasonable limit of accuracy.

[65] http://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=KH

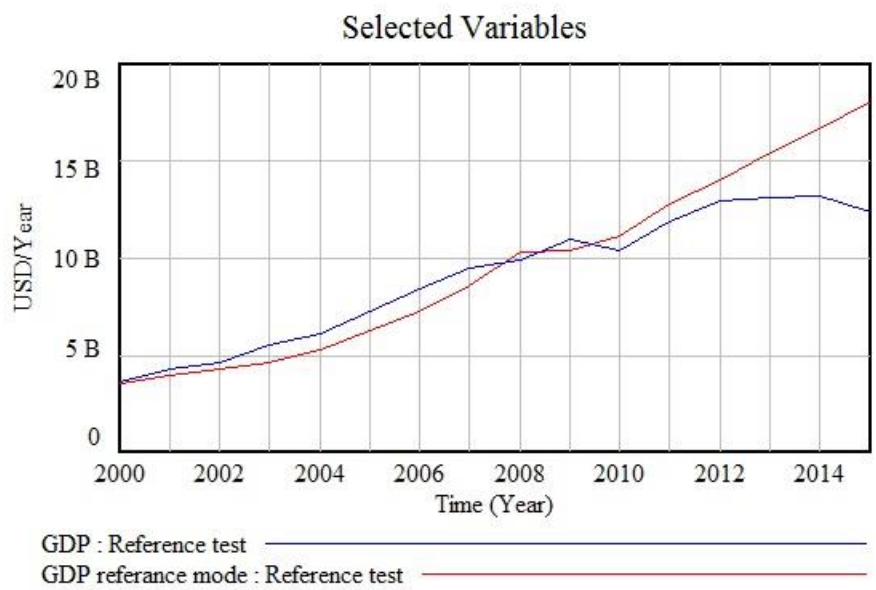


Figure 36: GDP reference mode

This graph show the reference mode of the *GDP*. The blue graph is the result of the GDP produced by the model and the red graph is the reference mode taken from a dataset from the World Bank. The reference mode applies up until the year 2015, that is when the reference data ends.

This table given an overview of the percentage difference between the model output and the reference data.

2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1.5%	*7.7%*	*8.9%*	*20.2%*	*15.4%*	*15.0%*	*15.6%*	*10.2%*	*-4.5%*	*5.6%*	*-6.6%*	*-7.6%*	*-7.9%*	*-14.9%*	*-20.7%*	*-31.6%*

4.4.2 Population reference mode

The reference data was taken from the World Bank[66]. The population growth is driven by the fertility rate and the number of fertile women in the population. The discrepancy between the reference data and the model output can be explained by the number of fertile women. However, the model simulation reproduces the historical reference data reasonably well with a R^2 of 0.9385.

[66] http://data.worldbank.org/indicator/SP.POP.TOTL?locations=KH

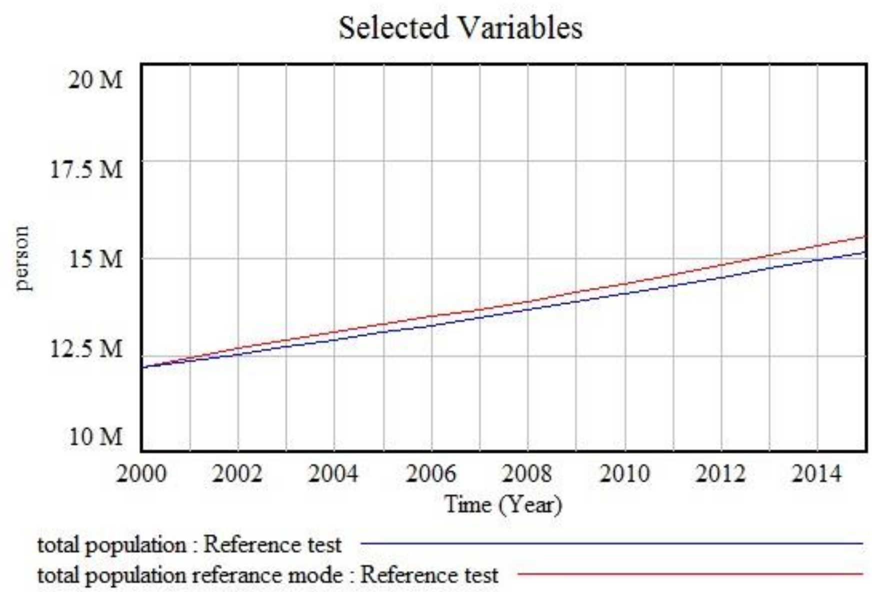


Figure 37: Population reference mode

This graph show the reference mode of the *population*. The blue graph is the result of the *population* produced by the model and the red graph is the reference mode taken from a dataset from the World Bank. The reference mode applies up until the year 2015, that is when the reference dataset ends.

This table gives an overview of the percentage difference between the model output and the Reference data. The model output is consistently under the reference mode, but only slightly. The biggest concern with this result is the growing discrepancy between the reference data and the model output. The fertile period is assumed to be 30 years. This assumption is based off the T21 model that uses the same value for its population sector. Tests show that a decrease in the fertile period may increase the birth rate and thus the population growth to better match historical data. However, this conflict conceptually with how the real system works. A better explanation and solution would be to find a better estimate for the number of fertile women. However, for the purpose of this thesis the reproduction of historical data by the model is with reasonable limits.

2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
0.07%	***-0.53%***	***-1.08%***	***-1.41%***	***-1.61%***	***-1.83%***	***-1.63%***	***-1.61%***	***-1.57%***	***-1.78%***	***-1.84%***	***-1.95%***	***-2.09%***	***-2.25%***	***-2.35%***

4.4.3 Life expectancy reference mode

The reference data was taken from the World Bank[67]. Life expectancy is driven by effects coming from GDP, electricity price and air quality. The reproduction of historical data by the model is reasonable. It starts off slightly under, but quickly goes above around the year 2003. Then the model output stays above the reference data until the year 2013. However, it comes very close around 2010 until 2012. The difference in the years between 2003 and 2010 can be explained by the GDP in the same time period also staying slightly above the reference data. The R^2 value is 0.9601. This tells us that it is a very good match between the two lines.

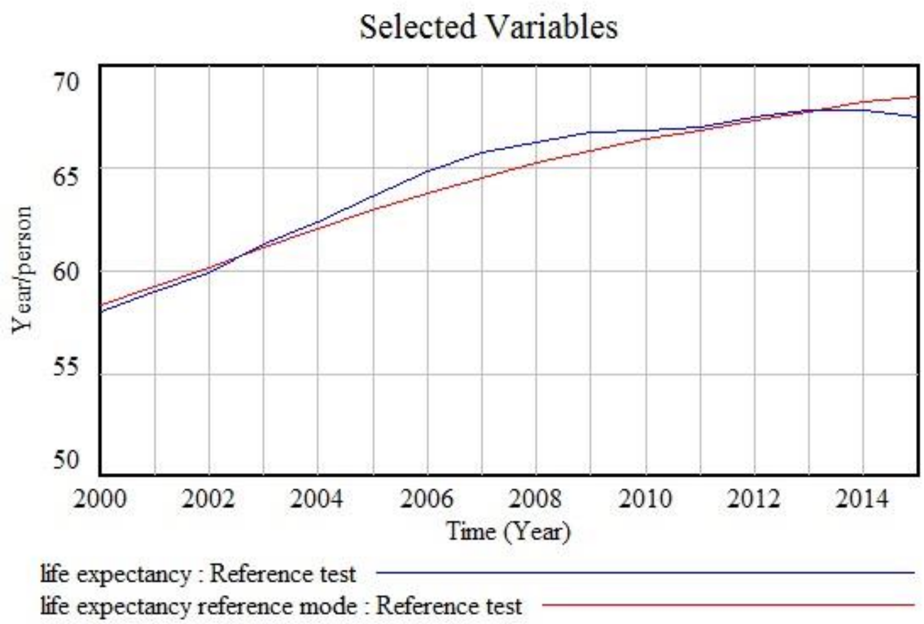


Figure 38: Life expectancy reference mode

This graph show the reference mode of the *life expectancy*. The blue graph is the result of the life expectancy produced by the model and the red graph is the reference mode taken from a dataset from the World Bank. The reference mode applies up until the year 2015, that is when the reference dataset ends.

This table show the percentage difference per year between the model output and the reference data for the life expectancy variable. The model reproduction deviates from the reference data only slightly throughout the simulation, with the largest difference at 1.93% in the year 2007. This scores the best fit of all the reference variables.

2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
-0.57%	*-0.44%*	*-0.38%*	*0.29%*	*0.54%*	*1.04%*	*1.61%*	*1.93%*	*1.58%*	*1.32%*	*0.63%*	*0.18%*	*0.30%*	*0.03%*	*-0.60%*

[67] http://data.worldbank.org/indicator/SP.POP.TOTL?locations=KH

4.4.4 Agriculture land reference mode

The reference data was taken from the World Bank[68]. The agriculture land is driven by the demand for food. As the population grows and the GDP increases this place extra pressure on the demand for food, and this subsequently leads to the cultivation of more land to produce food. As we can see from the graph below, the model reproduces a reasonably well fit with the reference data. The R^2 value is 0.8917.

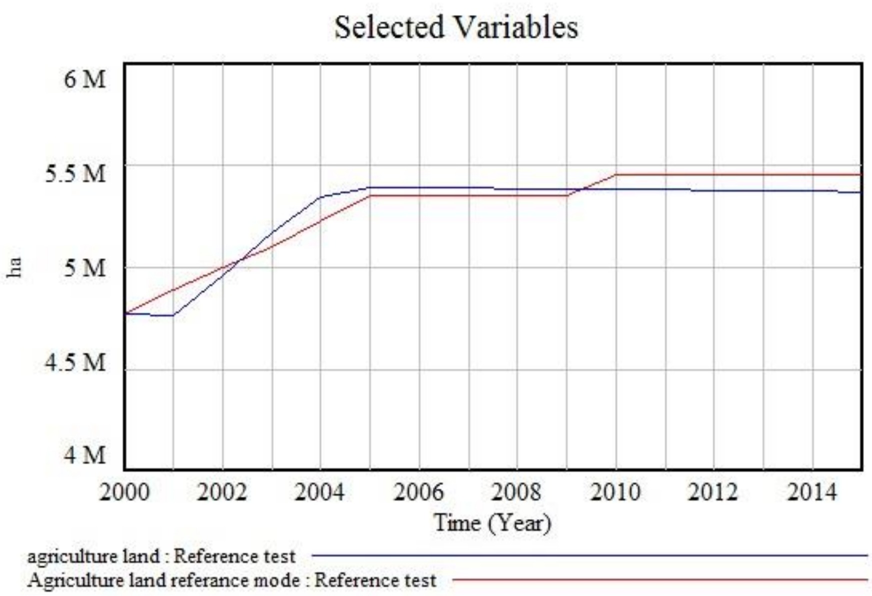


Figure 39: Agriculture land reference mode

This graph show the reference mode of the *agriculture land*. The blue graph is the result of the agriculture land produced by the model and the red graph is the reference mode taken from a dataset from the World Bank. The reference mode applies up until the year 2014, that is when the reference dataset ends.

This table show the percentage difference per year between the model output and the reference data for the agriculture land variable.

2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
0.00%	*-2.64%*	*-0.75%*	*1.45%*	*2.27%*	*0.70%*	*0.68%*	*0.64%*	*0.60%*	*0.56%*	*-1.33%*	*-1.37%*	*-1.41%*	*-1.45%*	*-1.49%*	*-1.53%*

[68] http://data.worldbank.org/indicator/AG.LND.AGRI.K2?locations=KH

5. Limitations

A model is always a simplification of reality and will thus "always" be wrong. That is not to say that a model cannot be useful however. It can still provide important insight into underlying mechanism driving behavior and development of a system. It is important to be aware and explicit about the assumptions and limitations you make for the model.

This model aims to negotiate between a local scope and a national view. Thus, the model must forgo certain aspects that would be included in either a pure local landscape model, or a pure macro level model. With regards to the micro aspect of the local regions the model does not include details such as development of local demographics or the tracking of local income. Instead the model stays on the national average for these variables. However, the model does follow the development of local fish stock and environmental degradation.

The aspects that the model has to let go of on the macro level are aspects such as imports and exports, national health budget and infrastructure plans. However, what the model can provide is a unique insight into the dynamic between national versus local needs. It can contribute towards finding ways to compensate, or negotiate, between these competing needs and desires.

A big challenge I encountered when building this model was the access to relevant and accurate data. Thus, several assumptions and simplifications had to be made. Such assumptions and simplifications are found in the sediment sector. The estimate of the sediment flow itself is turned into a relative value, changing in response to the effect of hydropower dams on sediment flow. Also, the effect of sediment on agriculture land productivity, are made on assumptions based of literature, but not on hard datasets on the topic.

Several reviews of papers regarding air pollution (indoor and outdoor), diseases and life expectancy were made. However, the challenge was to put this into concrete formulations for the model. The literature on the subject gave confidence in the causal relationship, but very little data on the degree and strength of this relation. Thus, reasonable assumptions had to be made about the effect of indoor and outdoor air pollution on the life expectancy. These are aspects that can be improved upon with specific and dedicated research into the topic. However, this falls outside the time and resources available for a thesis at the master level. Instead simplifications had to be made.

Initial conditions were also a challenge to find reliable data on from time to time. Especially the initial condition for electricity capacity already installed at the beginning of the simulation were particular challenging in different ways. First, reliable data on quantity and type of capacity in the year 2000 for Cambodia was hard to come by. Also, the stock of capacity changes due to development between the start of the simulation in 2000 and the implementation of the policies in the year 2016, however very little data is given on how much was installed when. A solution to this problem was to take an estimate of already installed capacity before the year 2016 and use this as an initial condition keeping it constant until the investment policies were implemented. This most likely gives the year 2000 a too high initial condition and may distort some reproduction of historical behavior, but you avoid the risk of making a false investment pattern that might distort historical reproduction even more. With this solution, you are sure to have the correct amount of capacity in store at the time the investment policy scenarios kicks in, getting the correct relative value from that point and onwards. The alternative to this would be to estimate an average investment into electricity capacity per year so that you end up with the same installed capacity in 2016 as I used for the initial condition. Both methods work with both their benefits and drawbacks.

The borders that you place on the model to limit the scope of what it can answer. There are dangers in both drawing the border too tight and too wide. When you go too wide you end up with a model that does not answer anything since it is trying to answer "everything". And if you draw it too narrow you might lose out on causal relationships and important dynamics. To find this balance is often more like an art, and a question of practice, rather than an exact science. However, there are best practices to lean upon. This is what makes the system dynamics disciple unique and into a unification of both quantitative and qualitative method.

Cognitive confirmation bias is also a danger when you engage in modeling processes. The danger is to model a desired outcome and not a structure that reflects the real system. To counter this, one should take a step back from the model one is building and ask control questions, and repeatedly check the output with available and established knowledge of the system. The use of reference data testing is useful in this regards and literature review. During the modeling process, I had to stop several times and read literature and reports on different subjects to make sure that the model stayed on track with reality.

As previously discusses in the sensitivity test there are a few parameters that the model is very sensitive around. Extra care should be taken around these parameters and further research into them is needed. These parameters are mainly elasticities for effects in the model guiding the strength of feedback loops. They are as follows:

- *elasticity of tfp to education*
- *elasticity of tfp to average life expectancy*
- *elasticity of production to capital (extra sensitive)*
- *elasticity of relative gross capital formation on fractional growth*

6. Scenarios and Results

This section of the thesis presents the results from the simulation model. The main emphasis is placed on the investment options between the three different electricity generating technologies. Thus, we will present three different scenarios. One scenario for each of the technologies represented in the model.

Each investment option will be investing an equal amount of USD per year. This amount is set to 900 million USD, or 100 million USD over 9 years. This is done to show their relative difference in performance given an equal amount of capital investment. Each scenario will be compared with BAU (business as usual) and then compared with each other.

The choice of 100 million dollars per year was chosen to give the model a significant input that would generate clear differences in the alternatives, but still an amount within the bounds of realism. This investment will construct a significant amount of electricity capacity locally on the landscape, and generate more than what is needed for local consumption. This supply of electricity will be distributed across the whole country and give a nationwide effect. This is done to contrast the local consequences with the national effect. This is part of the problem that will be revisited in the discussion part, with local costs and national benefits, creating a conflict of interest between the different horizontal layers.

The three different types of electricity generating capacity was chosen to give three alternatives that are principally different in how they generate electricity. The hydropower is already planned and under way and thus is a natural candidate in and of itself. The two others are principally different. The coal is a realistic option of a mature energy technology that heavily in use around the world. Including neighboring countries. It is thus a realistic alternative to hydro, but with a different set of social, environmental and economic implications. The solar power technology using photovoltaic cells is a comparatively younger technology still undergoing development and improvements, but are more and more moving into the energy market gaining larger shares every year. The solar technology is still mostly expending in the developed world due to the relatively expensive capital cost per capacity installed. Once installed it only requires maintenance costs to run, however it has problems with flexibility that still need to be solved. Although a less realistic option for Cambodia than coal power, solar power is still and exiting prospect to be considered. If nothing else, it provides context of comparison to the two other options.

For each scenario, we will review the development of several variables. These variables represent, either directly or indirectly, the development of environmental, health, economic or social aspects of Cambodia. Then we will investigate the tradeoffs between these different aspects and see if and how we can compensate for these tradeoffs. We will also look at the costs associated with each scenario.

The variables and the aspects that they comprise are the following:

Economic factors

- *GDP*
- *GDP per capita*
- *Crop production*
- *Average electricity price*

Environmental factors

- *Forest land*
- *Relative sediment flow*
- *Fish stock*
- *Local fish stock*
- *CO2 emissions per year*

Social factors

- *Relative graduation to relative population*
- *Local transportation factor*
- *Local fish stock*

Health factors

- *Life expectancy*

Associated costs

- *total accumulated investment and running costs*
- *total yearly cost from roads, fertilizer, electricity operation and co2*

These variables were chosen as indicators because they represent important elements comprising each aspect. The GDP is a measure of the total income in a country. It tells you something of the overall performance and size of that economy, however this is far from the whole picture. The GDP per capita gives an insight into the level of income for the average person. The country might grow its economic power, but the economic welfare for the individual person is better captured by the income per person. That is why this level of detail is included as well.

The crop production is given special attention for two reasons. First since it is a major contributor to the economy of Cambodia[69], and secondly because the livelihoods and food supply for the majority of people in the country is tied to this particular sector. The same is true for the fishing on the local level.

The electricity price was chosen as an indicator to give context to the economic development of the GDP variable after the investment policies were implemented. Reviewing the graph of the electricity price will give you a visual impression of the overall performance of the respective investment policies. It will provide you with some context of the relation between the electricity supply and economic development. That is why the electricity price was chosen as an indicator.

The cover of forestland in a country is an important benchmark and first impression to give you a quick indication of how well the ecosystem and the environment is doing. It does not give you a complete impression of the environmental condition in a country, but it is a reasonable point of departure into further review of the environment. The relative sediment flow has a direct link to the rate of erosion. The natural sediment flow is a major ecosystem service preserving both agricultural land and supporting the overall ecosystem with nourishment. Decline or change in its pattern will have environmental as well as economic consequences for local fauna, animal life and population.

Both the fish stock and the local fish stock are stocks of biodiversity over a whole range of species. In this model, individual species have not been modeled, due to levels of complexity. However significant decline or near collapse of the biomass in one or both of the socks will more than likely indicate the loss of certain species less capable to survive in a reduced biomass stock. Especially species depending on migration up and down the river are especially vulnerable.

CO2 is included as an indicator of human activity in general, as well as a contributor to the greenhouse effect.

Relative graduation rate relative to the population growth gives an indication of the overall level of education. Education is a major driver for social change in a country. Both culture and economy are influenced by education. Literacy rates are important for both political participation and organizing as well as for economic productivity.

[69] https://opendevelopmentcambodia.net/topics/agricultural-production/

This variable is both an indicator in itself for social development, as well as the basis for an effect feeding into the economic sector. This it is a key variable that one should keep an eye on.

As mentioned before, the local fish stock is especially important for the local population due to their subsistence on the fish. A significant decline in the fish stock would mean a decline in fish catch. If so a major source of food, especially protein, and income would disappear for the local population. Compensation for this is not explicitly modeled as a policy option in this model. However, looking at the local fish stock this can be implied as a side effect of hydropower dam construction and would need to be compensated for, if one want to avoid severe social consequences locally. This gives the fish stock both an environmental as well as a social dimension.

Life expectancy is a major and the only health indicator chosen for this review and analysis of results. An indicator of nourishment and proportion of protein in the diet could have been included as well. This is possible to do in future development of the model. However, in the interest of simplicity and to avoid extra levels of complexity I chose to leave this out of the results for now. The life expectancy is the single most powerful indicator of the overall performance of health in a population. Since at the bottom line health culminates down to the capacity to stay alive. The model has the potential to model a different performance of the local level life expectancy compared to an overall life expectancy compared with the average of the whole country. In the interest of time this was not done, however it is an interesting venue for future development of this model. One of the strengths of this model is its flexibility and ability to incorporate multiple levels both vertically between different sectors, and horizontally, ranging from local to global level. This can help decisionmakers to get a holistic picture before forming policy. However, when multiple horizontal levels are included, strict assumptions and guidelines must be made so that the model keeps its rigidity.

The associated costs are included to given an overview of the direct costs of enacting the different policy scenarios. These costs have to be carried by someone. This brings us to an important point of discussion that will be expanded upon later in the discussion part after the results are presented.

6.1 Scenario 1: Hydropower investment

Time period for investment: Year 2016 to year 2025

Investment per year: 100 million USD

Total investment: 900 million USD

Cost of capacity: 1 million per MW

This scenario represents hydropower investment option. The desired outcome of this policy is to enhance the overall economic performance of Cambodia as a nation. This is attempted by increasing the electricity supply, using a technology that is relatively inexpensive to run and operate, thus driving the electricity price down. A decrease in the electricity price has a wide range of positive benefits; both bolstering economic factors and is beneficial towards the health and welfare of the population.

However, when you build dams, there is a side effect causing loss of sediment flow downstream. This leads to an increase in erosion and a loss of nutrition in the soil, reducing the productivity per hectare of agriculture land. However, this can be compensated for by using fertilizers.

The table below compare the result from two different policies; one without any compensation with the result from full compensation. The scenario without any compensation is called "*Hydropower Investment, no compensation*", and the scenario with full compensation is called *"Hydropower Investment, comp. x7.5"*. It is called *"x7.5"* because in this scenario we compensate for the loss of productivity in the agriculture sector due to sediment loss with a factor of 7.5 times relative to the reference use of fertilizers.

This number of compensating 7.5 times might seem a bit high. However, one must take into consideration that this number is relative to a reference value. The reference value is quite low in real numbers since traditionally the use of fertilizers are largely not needed in Cambodia, especially not along the flood. This is due to the natural nourishment that the soil receives from the sediment in the river water. However, when this source of nourishment is lost due to the reduction of the sediment flow, then compensation is needed to come from elsewhere to keep productive levels up. In absolute tons, that is in real numbers, the actual use of fertilizer is not so high, and especially not when taken into consideration the increased landmass of agricultural land this will be spread across.

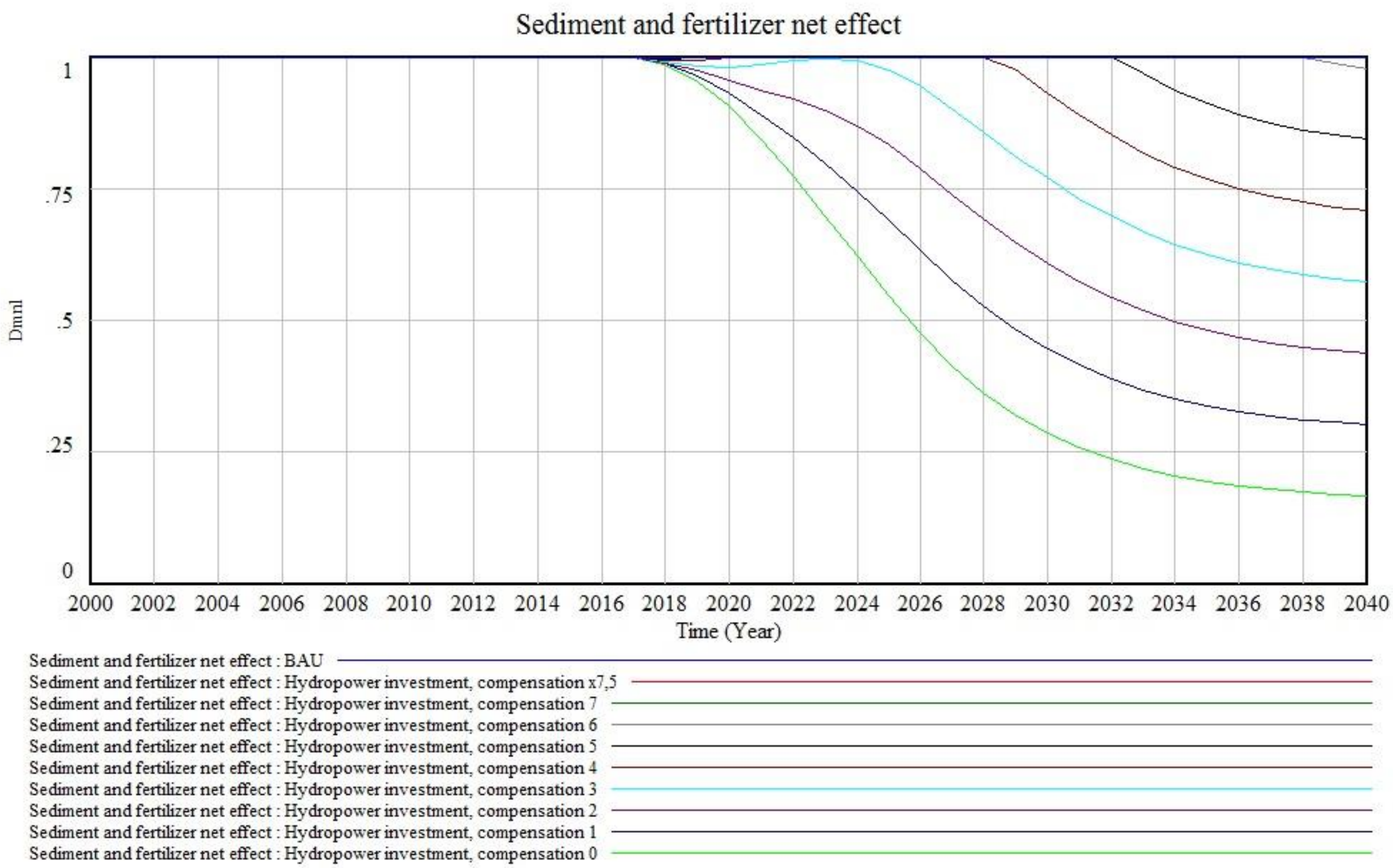


Figure 40: Sediment and fertilizer net effect; 0-7.5x compensation

From the graph above we can see the different outcomes in the *sediment and fertilizer net effect* based of different compensation policies. Each iteration increase the use of fertilizer by a magnitude of 1 until we achieve complete compensation. Only when reaching 7.5 times the current level of reference use of fertilizers is the loss of sediment completely compensated for in the net effect. The net effect is the product of multiplying the effect from the sediment loss with the effect coming from added fertilizer.

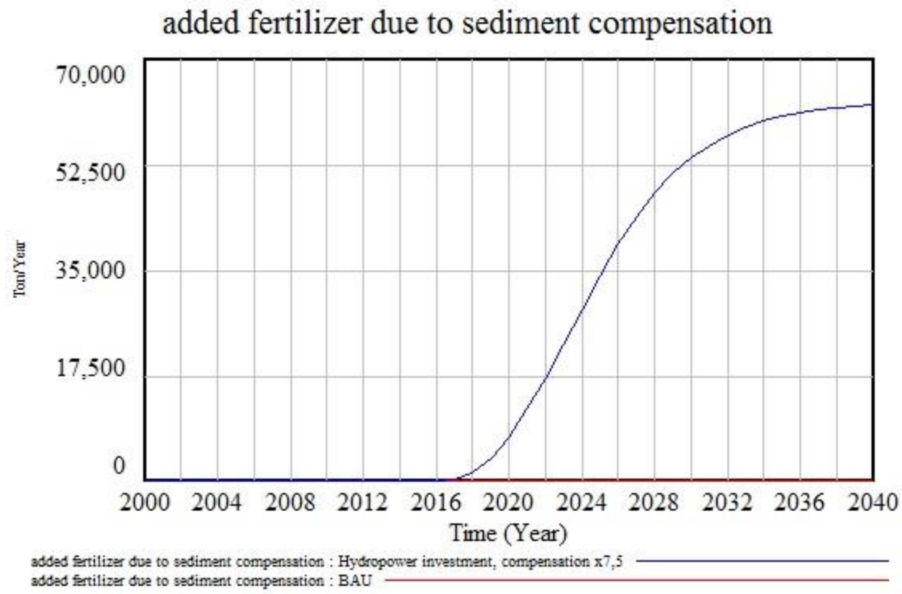


Figure 41: Added fertilizer due to sediment compensation

The reference value for fertilizer used per year in Cambodia is set to 10.000 ton/year[70]. This is a rough average estimated on data collected from tradingeconomics.com, claiming the World Bank as their source. This is a very small value compared to other countries that depend on the use of fertilizer for their food production. The values in the dataset varies from 0-20.000 ton/year, and 10.000 ton/year is a rough average based on this. As we can see in the graph below the total fertilizer use per year only increased to about 70.000 tons per year. Even if the reference value was increased to 20.000 tons/year, the increased use due to compensation would still only come to 140.000 ton/year. As a comparison, the sales of fertilizers for the use in Norway was in 2013 at 350.000 ton/year (only considering sales for domestic use from the largest supplier)[71].

However, there may be adverse effects coming from this increase in fertilizer use that is not accounted for in this model. This is a limitation of the model, and can be improved upon. More research is needed before this can be determined.

Other adverse effects of building hydropower dams is the disturbance and blocking of fish migration along the river. This decreases the breeding success of many species that relay on upstream spawning, thus reducing the fish stock over time. This can easily lead to a collapse in the fish stock. This can be compensated for by introducing fish-ladders, this policy has had a varying degree of success across the world. However, this policy option is not included in the model at the present time. Also, local boat transportation along the river, similar to the case with fish migration, will be hindered by the introduction of dams. This will reduce the local transportation capacity.

[70] http://www.tradingeconomics.com/cambodia/fertilizer-consumption-metric-tons-wb-data.html

[71] http://www.yara.no/gjodsel/Tools-and-Services/gjodselaktuelt/gjodselaktuelt-2013-1/Gjodselproduksjon-i-Norge-viktig-for-norsk-landbruk.aspx

6.1.2 Results

As we can see from the results, building a significant amount of hydropower capacity has adverse effects on the environment and eventually on the economy and the lives of the population. That is not to say however that such a policy could not be profitable for a number of people and companies in the short-run, profiting from the construction and the selling of electricity. However, taken in a holistic view of the whole country these profits amount to very little, and greater gains for everyone can be made in the long-run.

6.1.2.1 Economic factors

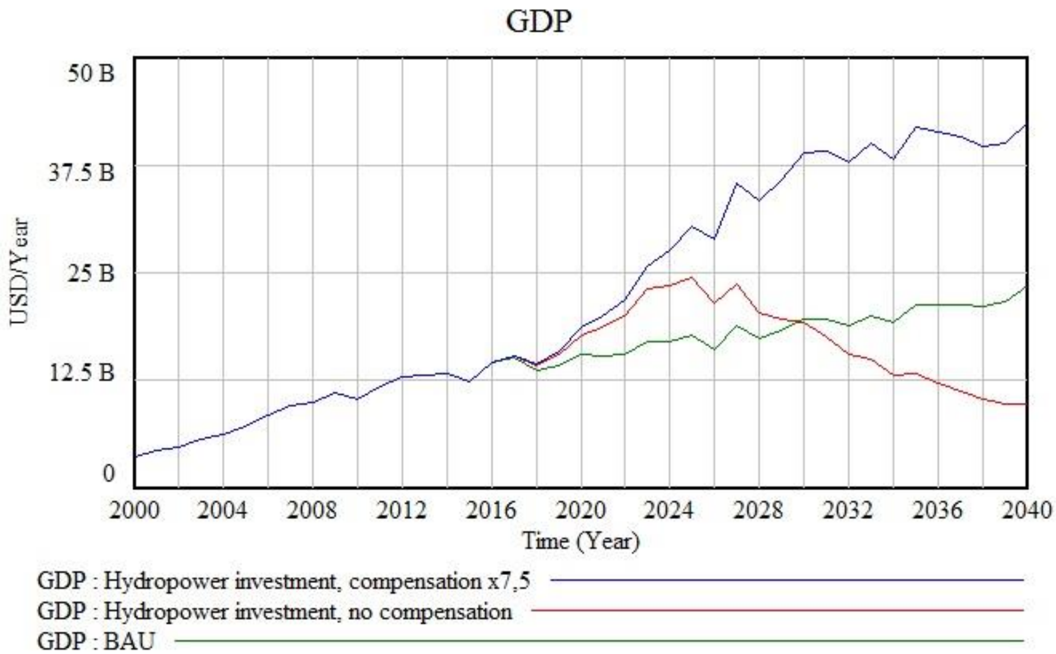


Figure 42: "GDP" Scenario 1: Hydropower investment

Graph of the "GDP" for three different runs; Blue: Hydropower with compensation, Red: Hydropower no compensation and Green: BAU.

The green line represents the BAU without any investment into hydropower or any other investment alternative. The red graph represents the hydropower investment option, but without any compensation. The blue graph represents the hydropower investment option with full compensation. The compensation entails the use of fertilizers. As the sediment flow diminishes due to the construction of hydropower the agriculture land loses their natural supply of fertilization from the river, plus the water downstream from the dam now lacking sediment has a tendency of draining the surrounding land of the sediment that is already in the soil until it is saturated again. This process causes the agriculture land to lose its productivity. To compensate for this, we can increase the use of fertilizers as the policy allows. The estimation of the use of fertilizers are based on the current level of fertilizer-use as a reference point of how much more you have to use to compensate for the loss of productivity. According to the assumptions used in the model a relative decrease in sediment have to be compensated by increasing the relative use of fertilizers 7.5 times. This stands to reason considering that the current use of fertilizer is quite low in Cambodia.

From the graph, we can see very clearly the archetype of a better before worse scenario. The prospect of initial gains without needing to compensate for externalities that are caused by the hydropower development may seem alluring at first, however in the long-term these initial benefits are all lost, not only compared with the BAU option, but also compared to itself. This GDP per capita closely follows the same pattern as GDP above.

Another important economic aspect to take into consideration is the level of crop production, this is important since such a considerable portion of the population is supported by their own agricultural activity both as a source of income as well as for their own subsistence.

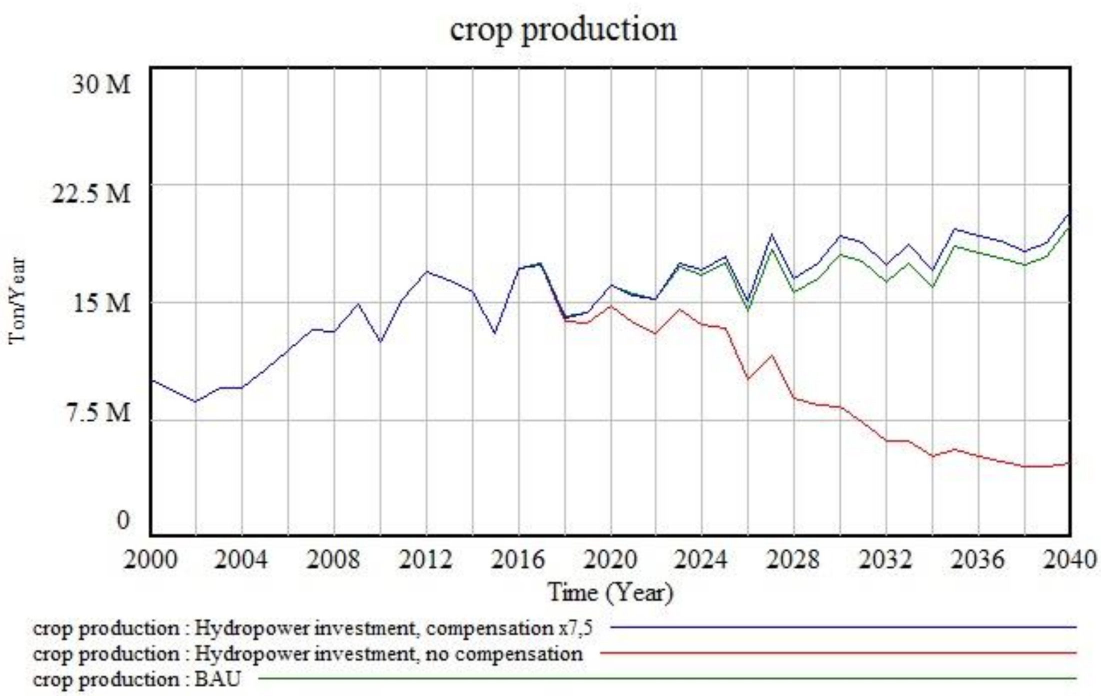


Figure 43: "Crop production" Scenario 1: Hydropower investment

Graph of the "crop production" for three different runs; Blue: Hydropower with compensation, Red: Hydropower no compensation and Green: BAU.

As we can see from this graph and from the table above the fall in crop production in the scenario with no compensation of fertilizers is quite significant. This must be seen in relation to the crop production relative to desired crop consumption. The lack of compensation does not only have economic consequences, but it also affects food security. The variable "*crop production relative to desired crop consumption*" represented in the graph you see below is not included in the table above, but from the shape of the graph you get the necessary impression to see the consequences. This variable gives a good indication of the food security of the country. It compares the level of food production relative to the level of food demand. A value lower than one indicates that the demand is not fully satisfied by the production in the country. In this case, one would have to rely on import or make room for more agriculture land to produce more food, putting further strain on the ecosystem and the forest.

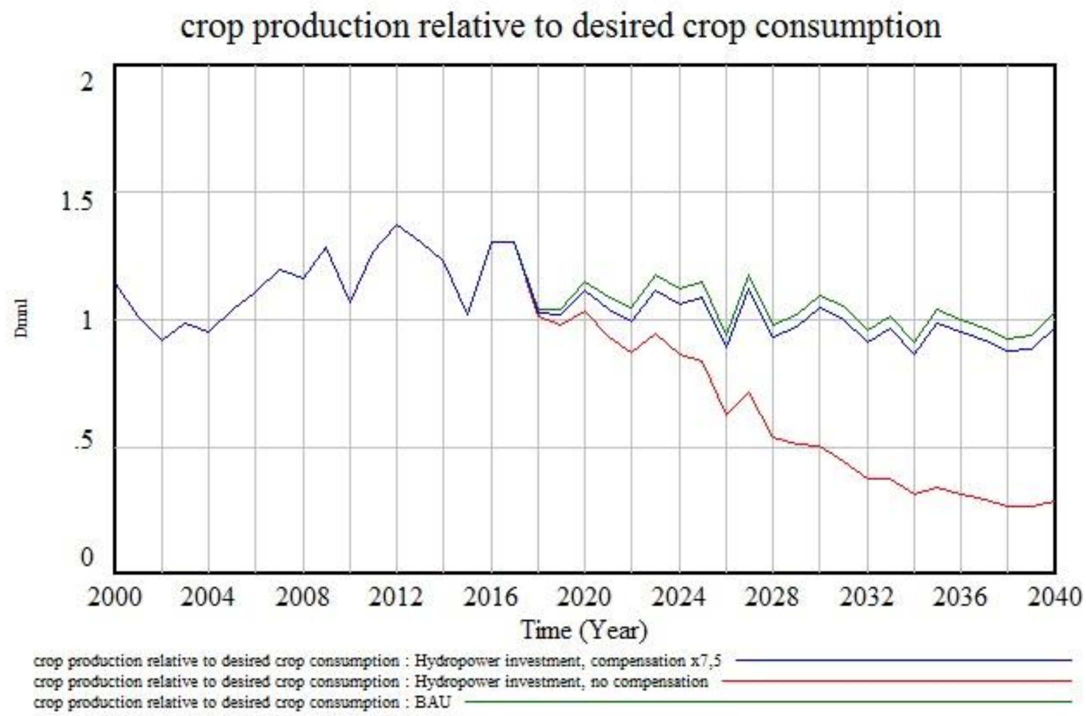


Figure 44: "Crop production relative to desired crop consumption" Scenario 1: Hydropower investment

Graph of the "crop production relative to desired crop consumption" for three different runs; Blue: Hydropower with compensation, Red: Hydropower no compensation and Green: BAU.

Still with compensation the food security still faces challenges, however we should keep in mind looking at this graph that the initial assumption for the "self-sufficiency factor" in the agriculture sector was set to 1.30, representing a surplus production and export of 30% of total production. However, a number below 1 would still mean a cut in exports in order to satisfy domestic demand and cause adverse economic effects, and everything below 0.7 on this graph would mean that domestic production is not enough to satisfy domestic demand, even when nothing is exported anymore, as is the case for the scenario without any fertilizer compensation.

6.1.2.2 Environmental factors

Economic factors are not the only aspects impacted by the construction of hydropower dams. There are several environmental effects as well we need to take into consideration if we want to get a fuller understanding.

The environment underpins human life and activity, including the economy. When the ecosystem and the environment suffers human life and economy eventually suffers as well. The first indicator on the status of the environment is "forest land". Forest land represent all land that is not developed or significantly disturbed by human activities and where the ecosystem and wildlife remains intact.

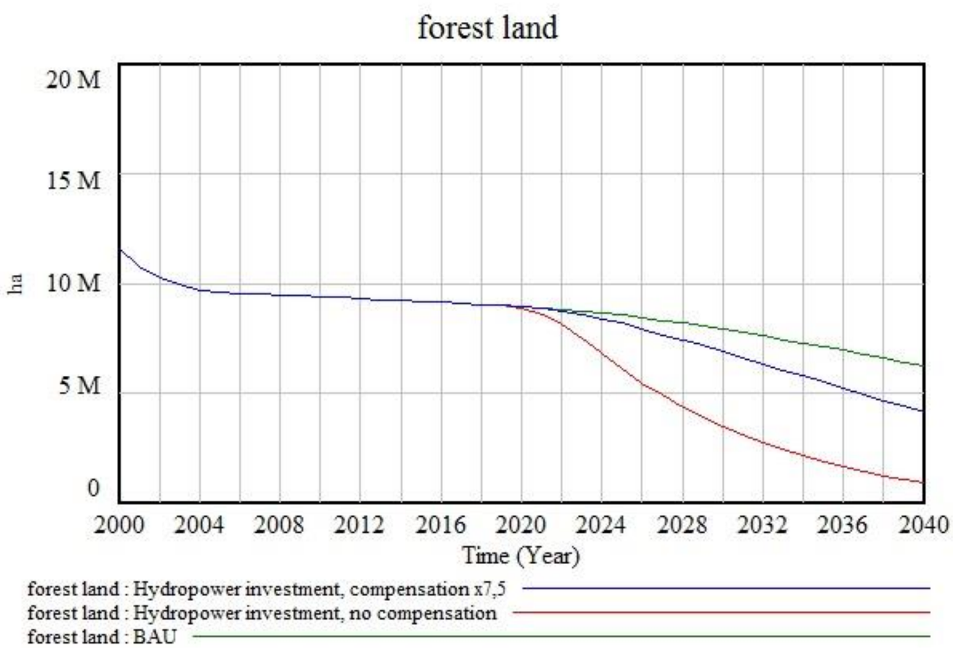


Figure 45: "forest land" Scenario 1: Hydropower investment

Graph of "forest land" for three different runs; Blue: Hydropower with compensation, Red: Hydropower no compensation and Green: BAU.

This graph show the development of forest land under the two different conditions. The difference between the use of fertilizer compensation and not is directly related to the productivity per hectare of agriculture land and food demand. When the productivity per hectare of agriculture land is reduced and the demand for food remains the same, or increases, then the only option to satisfy the food demand is to clear forest land and convert it into agriculture land. This new agriculture land may not be as productive and fertile as the initial land that was used since traditionally it is the naturally most fertile land that is used for agriculture. When this land is either eroded, or flooded the average productivity of the agriculture land goes down. The landmass of forest land declines in all three scenarios. In the BAU run the decline happens mostly due to an increase in food demand as the population grows and the GDP increases. In the run with the fertilizer compensation the GDP increases more than in the BAU run, thus driving up demand for food to a higher level, causing more forest to be cleared than in the BAU. However, this increased clearing of forest due to an upsurge in demand does not cause a near collapse of the forest, like in the case without any compensating measures. The difference is a fall of -34% compared to the BAU with compensation and and a fall of -86% compared to BAU without compensation. The difference between them to the BAU is 52%.

In both cases the building of hydropower dams causes the forest land to decline more than in the BAU. But in the case with a compensating policy the forest is not under immediate threat, however it is still placing a strain on the ecosystem.

The next indicator to look at with regards to environmental factors is the sediment flow. This represent the flow of sediments that bring nourishment to the fields surrounding the river and the ecosystem. As dams are built this flow is diminished, as we can see in the graph below. The more dams that are built the more does the sediment flow decrease.

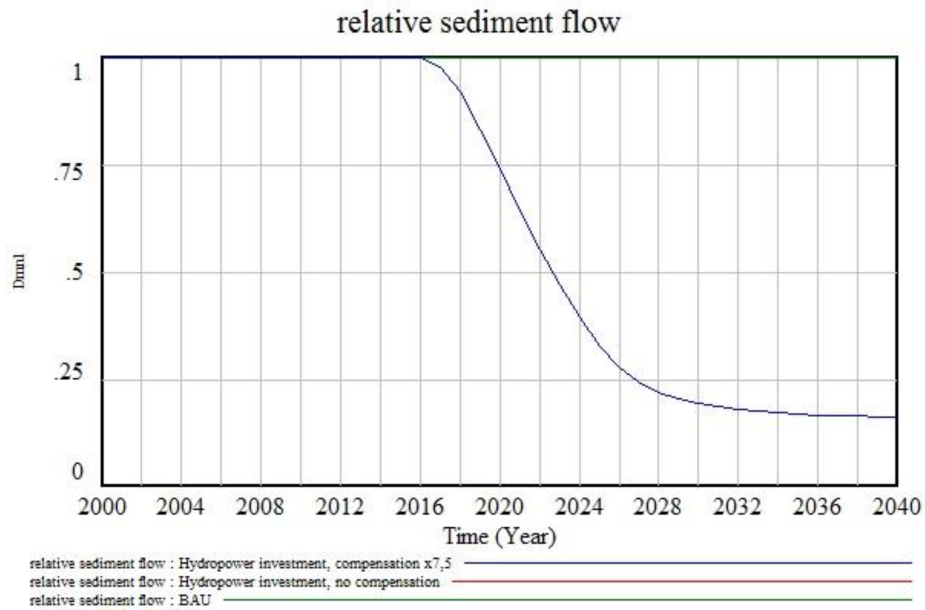


Figure 46: "relative sediment flow" Scenario 1: Hydropower investment

Graph of "relative sediment flow" for three different runs; Blue: Hydropower with compensation, Red: Hydropower no compensation and Green: BAU.

The sediment flow is measured in relative sediment flow. This gives us a useful indication on how much the flow has declined and can give us an estimation of the impact on the agriculture land and the ecosystem. It is this decline in the sediment flow that the fertilizer compensation policy is set to compensate for. The added cost of the fertilizer use is the added cost caused by the building of dams on the natural capital that was providing this fertilization through the free flow of the ecosystem. These added costs will be represented in the associated costs review below.

The next important aspect and indicator of the environment is the development of the fish stocks. We will look at both the stock on the national level and on the local level on the landscape where the dams are built. The adverse effects of the dams are stronger locally than for the rest of the country, thus causing costs to be unevenly distributed.

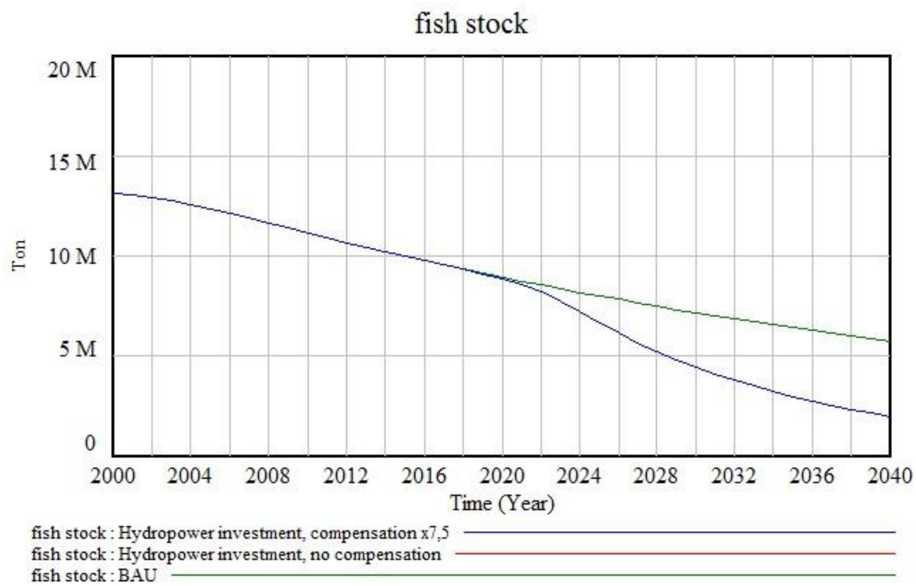


Figure 47: "fish stock" Scenario 1: Hydropower investment

Graph of "fish stock" for three different runs; Blue: Hydropower with compensation, Red: Hydropower no compensation and Green: BAU.

The fish stock is already declining in the BAU scenario as the demand for fish keeps on rising as the population grows and the GDP increases. As we can see the construction of hydropower dams causes the fall in the fish stock to decrease even more. This happens because of dams blocking the fish migration along the river causing the breeding success of fish to fall. In this case, there is not difference between the two hydropower dam policies, as none of them have any compensating policy for this adverse effect. Such policies exist, called fish ladders, but they are not modelled here in this model. This model scenario show you the effect of not putting in place such mitigating policy. The fall is significant; however, the stock is not collapsed and can be saved in this case. However, in either case this causes the fish-catch to be significantly reduced, and if conserving measures are to be taken to stop the continued decline of the fish stock then fish- catch has to be further curtailed. This means a significant drop in income and livelihoods for a significant number of people in Cambodia. The recommendation is to look for mitigating policies that will allow the fish to continue the migration along the river.

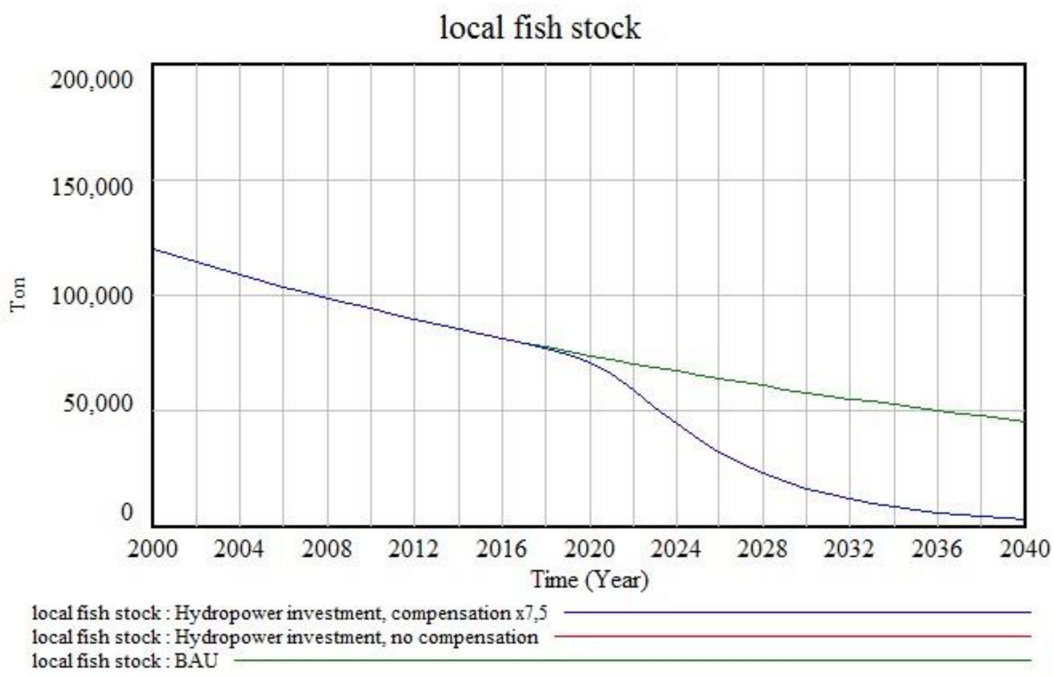


Figure 48: "local fish stock" Scenario 1: Hydropower investment

Graph of "local fish stock" for three different runs; Blue: Hydropower with compensation, Red: Hydropower no compensation and Green: BAU

When it comes to the local fish stock the case is significantly worse. Under the current set of assumptions and conditions the local fish stock in Kratie and Stung Treng are facing a total collapse by the year 2040. This will have significant ramifications for the local population and environment.

To save the fish stocks one need to compensate with alternative sources of food and income, as it is necessary to decrease the fish catch combined with a method to allow the fish to continue their migration along the river.

The next indicator for the environment is the level of CO2 emissions coming from the development activities. Concerns for the greenhouse effect increasing the average temperature on the planet has led many scientists to claim CO2 as an agent for climate change. This is predicated on CO2's role as a greenhouse gas, and by increasing the proportion of CO2 in the atmosphere the greenhouse effect is increased leading to a higher average temperature. Based on this, costs are associated with the increase of temperature and thus also with the emission of CO2.

As we can see the hydropower option is not free from CO2 emission as is often prompted to be the case. As flooded biomass starts to decompose in the dam it gives off CO2 emission, these emissions are continued by the growth and subsequent decay of algae. Both the hydropower options cause the same amount of CO2 emission since an equal amount of capacity is built in both scenarios.

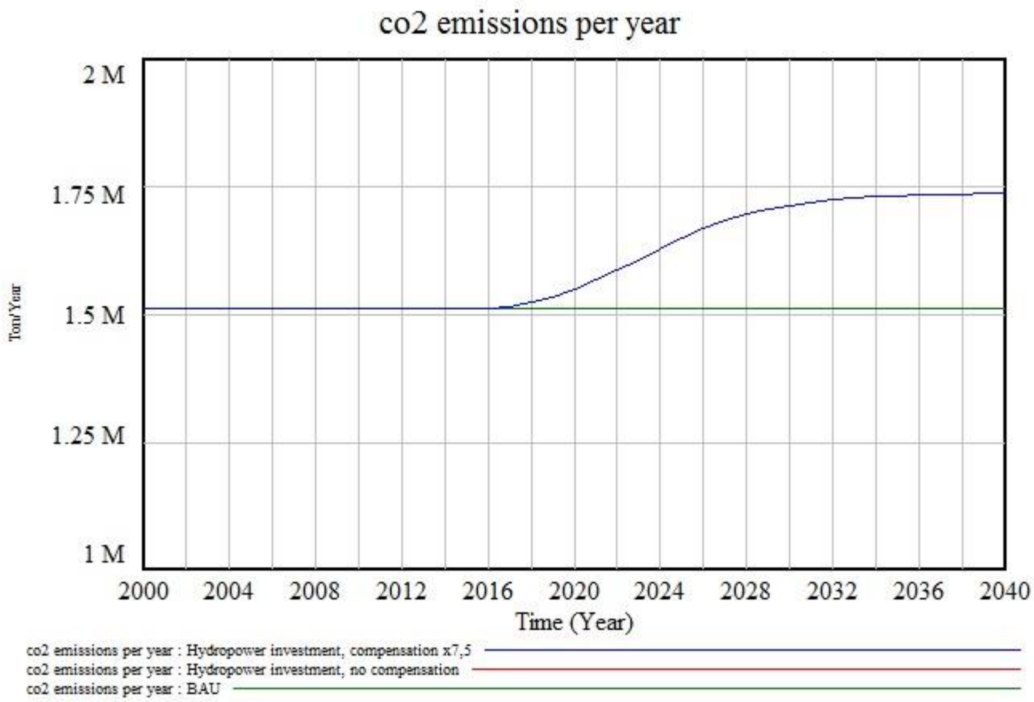


Figure 49: "CO2 emission per year" Scenario 1: Hydropower investment

Graph of "CO2 emission per year" for three different runs; Blue: Hydropower with compensation, Red: Hydropower no compensation and Green: BAU

Nearly 1.75 million tons of CO2 is estimated to be released into the atmosphere per year at the current level of investment and capacity.

6.1.2.3 Social factors

Besides the purely economic figures and the physical effects on the environment the construction of hydropower does provide an increase in electricity supply that bring with it other indirect and more intangible effect that have just as real impacts in the economy and society of the country. We call this the social factors. And the first indicator of the social impact is the "relative graduation relative to population" variable. This represents the relative increase in graduation and the overall level of education in the country.

As we can see in the graph below, the supply of hydropower electricity has at first a positive effect on the graduation rate. However, as it is in the case with the GDP and the economic factors, in the run without compensation the graduation rate falls towards the end. This is mainly caused by the decrease in the GDP. The GDP per capita has a significant influence on the enrolment and dropout rate in school. An increase in the GDP per capita causes more people to afford to go to school. The other positive effect of increasing the electricity supply is that this makes it easier for the student to study and to keep up with school work, curtailing dropout. That is why the drop in the run without compensation is relatively less here relative to BAU than it was in the case of the GDP per capita, since they are still receiving the benefit of increased electricity supply even if the GDP goes down.

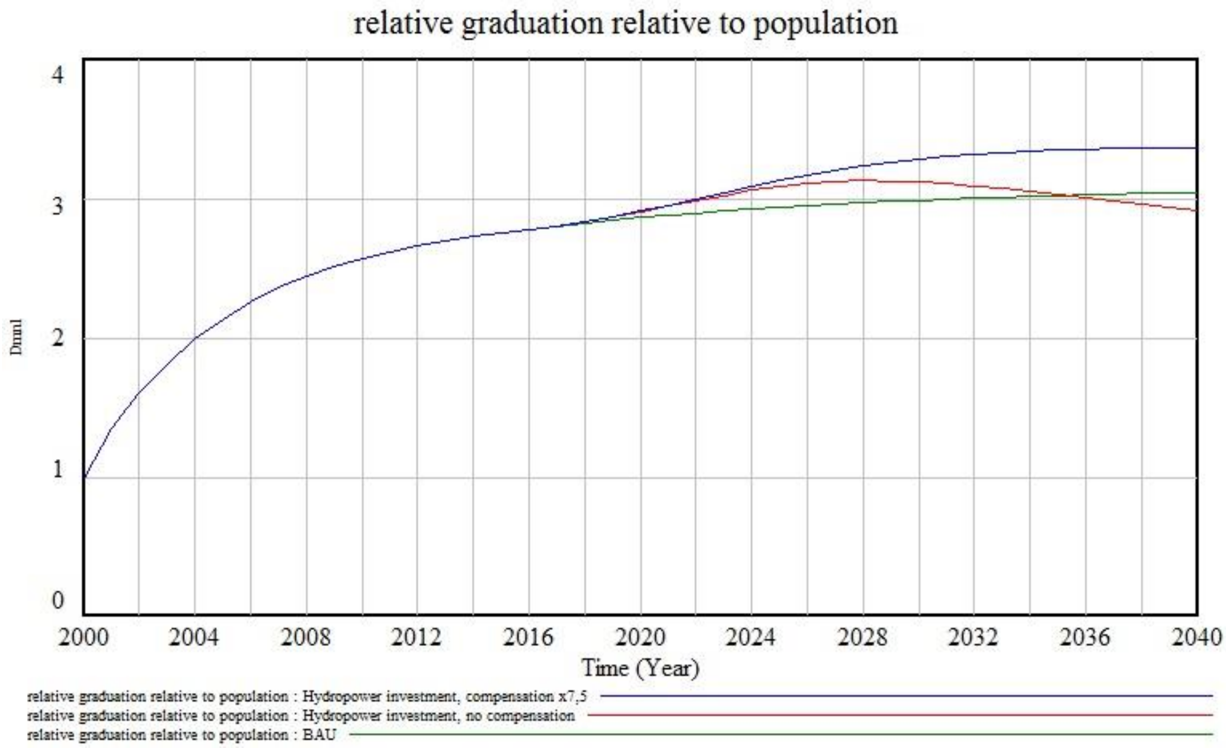


Figure 50: "relative graduation relative to population" Scenario 1: Hydropower investment

Graph of "relative graduation relative to population" for three different runs; Blue: Hydropower with compensation, Red: Hydropower no compensation and Green: BAU

Another important implication for the local society is the transportation factor. The river is used for boat-transportation long its shores. Similar to the fish migration, this transportation along the river is disrupted or stopped by the construction of dams that become physical obstacles to this boat traffic. Local communities depend on this route of communication both for economic as well as for social purposes. The way to compensate for this it to construct roads on land that could absorb this loss of transportation along the river. The construction and maintenance of additional infrastructure is an added cost to compensate for the side-effect of dam construction. The graph below show the different scenarios. This increased cost will be presented at the associated costs.

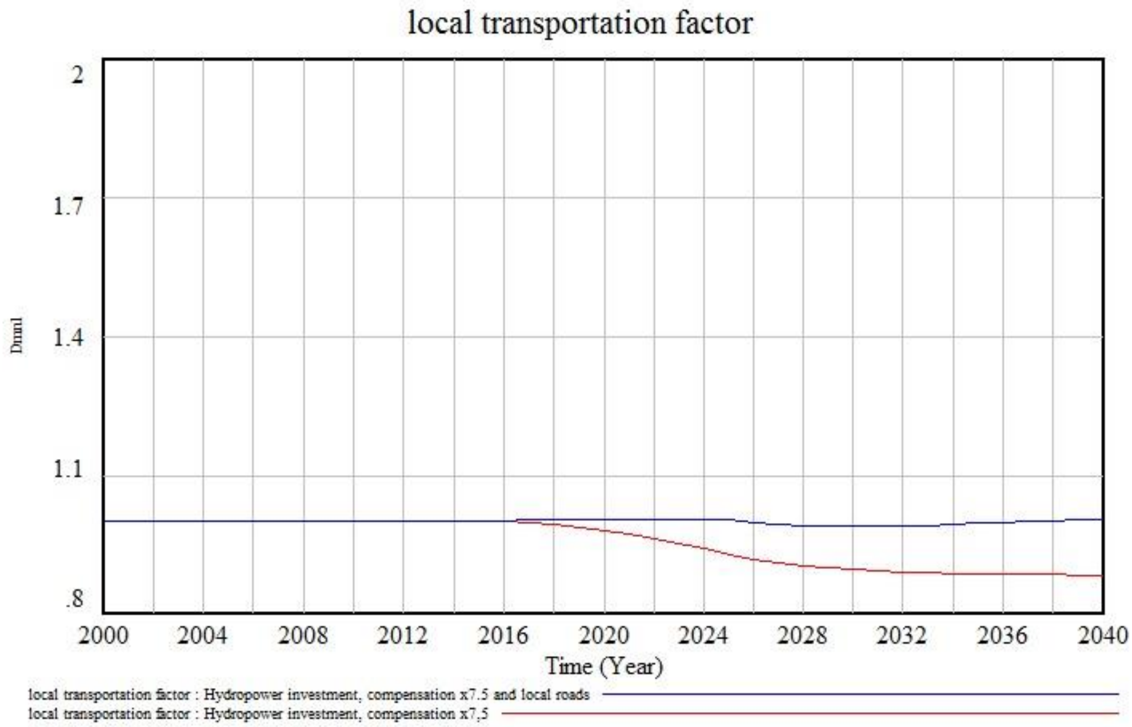


Figure 51: "local transportation factor" Scenario 1: Hydropower investment

Graph of "local transportation factor" for two different runs; Blue: Hydropower with compensation for local roads and Red: Hydropower with no compensation for local roads.

Here you can see the change in the local transportation factor. Without compensation, the local transportation capacity has an estimated capacity reduction of about 12%. In the blue graph above this is compensated for by investing in additional road capacity.

6.1.2.4 Health factors

Health issues are vital concerns for any country, but especially for countries undergoing development, since they are in a vulnerable phase of change before they stabilize again. It is important to weigh gains in one sector with relative losses in another sector.

The life expectancy is a proxy and an indicator for the overall health condition of the population in this model. It is a good proxy since the bottom line for most health issues results in our ability to stay alive. The worse health condition the harder to stay alive the higher the mortality and this this reduces the average life expectancy. This logic goes the other way as well, if something improves the health conditions you live under then your life expectancy is improved and the mortality rate of the country falls. Health and longevity have positive effects on the economy as well since this makes the work-force more productive.

In this model, several effects were set to influence the life expectancy. The electricity price has an impact, as it would affect the rate of substitution of cooking fuels that emit toxic fumes. A relatively lower electricity price will encourage this substitution leading to increased life expectancy. GDP is another factor influencing the life expectancy as more income helps people to get required medical care and medicine as well as improved sanitation and nutrition.

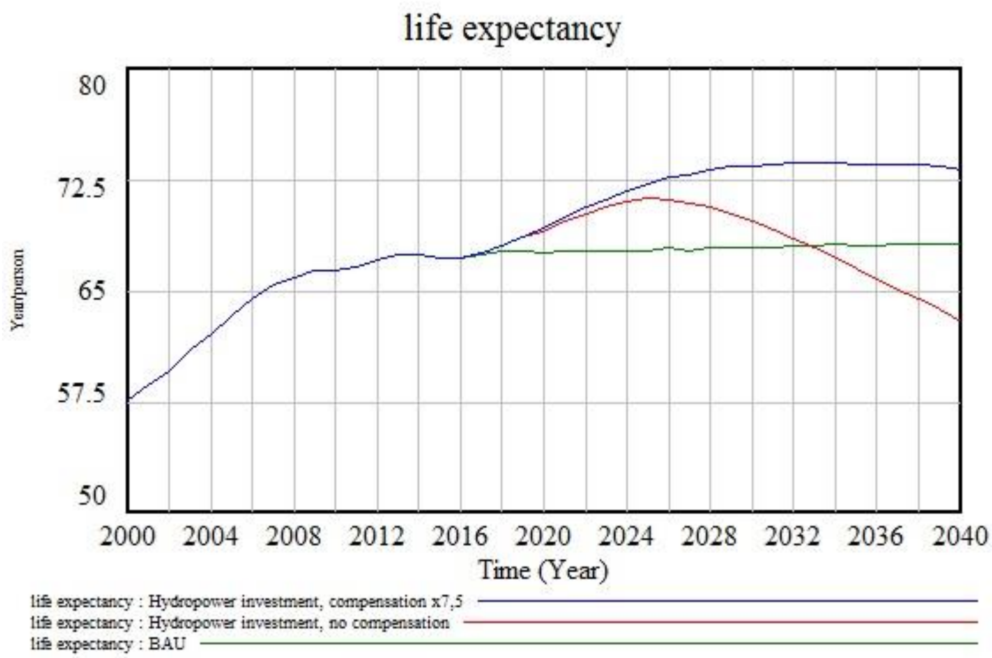


Figure 52: "life expectancy" Scenario 1: Hydropower investment

Graph of "life expectancy" for three different runs; Blue: Hydropower with compensation, Red: Hydropower no compensation and Green: BAU

In the case without any fertilizer compensation we see that the life expectancy increases at first, closely following the trend of the case with compensation. However, the fall in GDP overpowers the beneficial effect coming from the lower electricity price pulling the electricity price down.

6.1.2.5 Associated costs

This gives an overview of the costs per year and accumulated for each of the runs compared with the BAU. The compensation policies reduce the adverse effects as we have seen in the table and the graphs above, however they each come with a price. The compensation policy for the use of fertilizers in the agriculture sector increases the yearly costs of nearly 8% more compared to BAU then the run without compensation. And the policy with the compensation for the local transportation loss adds another 0.72% to the compensation cost compared with the BAU.

Even if the compensating policies makes sense from an economic and social standpoint, the challenge is often to find who should pay for this compensation. Often those who suffer the costs of development policies locally are not strong enough to demand or ensure this compensation themselves, thus it often falls on the government to take this responsibility. Then it becomes a question about the government's willingness to either push and follow up the contractors to include this compensation in their plans, or to pay for this compensation themselves.

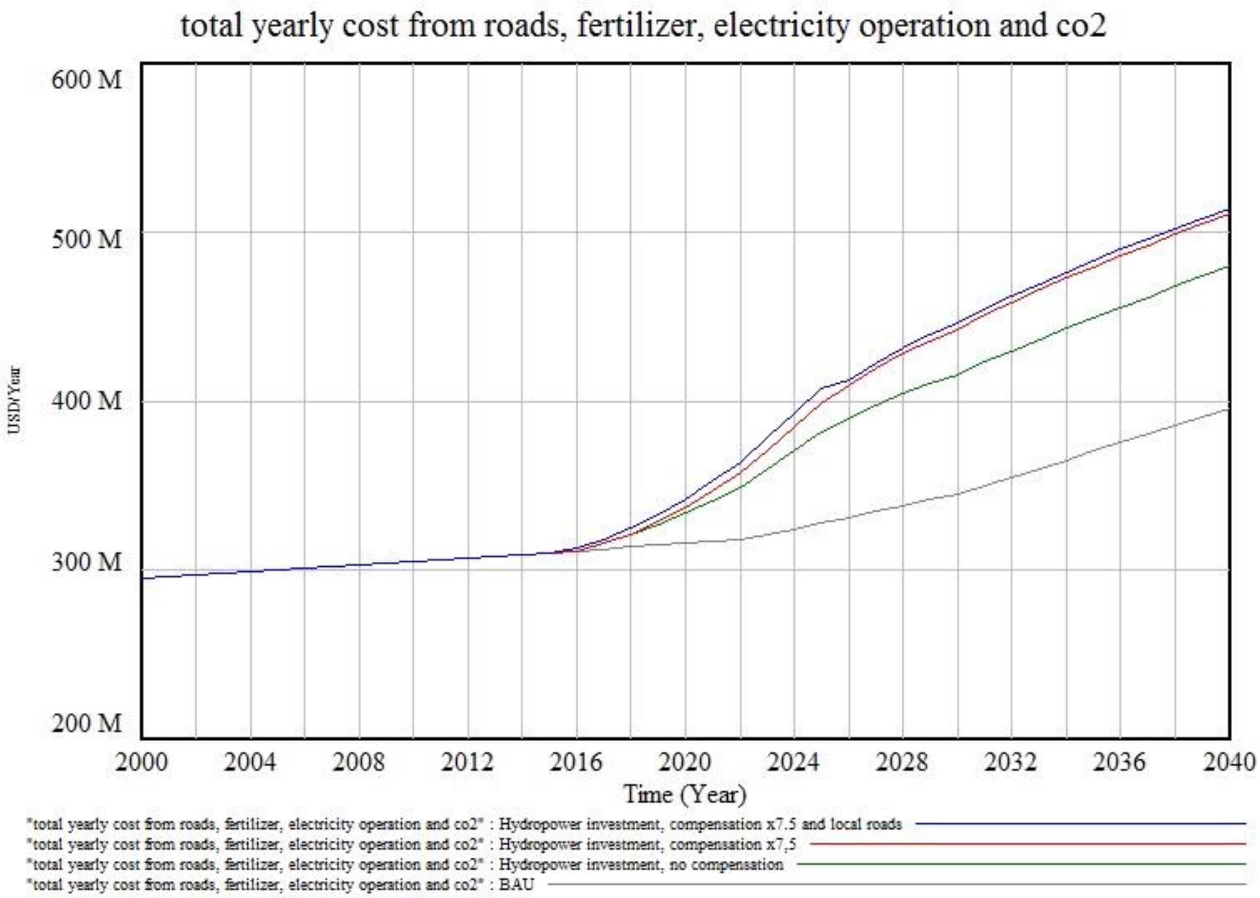


Figure 53: "total yearly cost from roads, fertilizer, electricity operation and co2" Scenario 1: Hydropower investment

Graph of "total yearly cost from roads, fertilizer, electricity operation and co2" for four different runs; Blue: Hydropower with compensation x7.5 and local roads, Red: Hydropower with compensation x7.5, Green: Hydropower no compensation and Gray: BAU.

This graph show the associated costs per year to the four different runs. This gives you an impression of the cost dimensions involved, with the compensation policies it adds to about a little more than half a billion dollars per year in total running and compensation costs. The costs shown by the green graph for the no compensation option are all the necessary costs in order to run the electricity production, such as operation and maintenance of the capacity. Every cost above that is associated with compensation for adverse effects.

One possible compensation policy that is not included in this model, as mentioned earlier, is the compensation or conservation of the fish stocks. The reduction of these stocks is clearly a cost and a reduction of the natural capital of the country. This thesis show the tradeoffs and the consequences of constructing human built capital in the form of hydropower dams, but not all the possible compensation policies, as this would be too large a project within the scope of a master thesis.

The following table show the model outputs by scenario. Changes are differences relative to the BAU value.

Name	Scenario	2015	2020	2025	2030	2035	2040
GDP (*USD/year*)	**BAU**	**12347987968**	**15445494784**	**17759885312**	**19566000128**	**21220493312**	**23560380416**
	Δ Hydropower Investment, no compensation	*0.00%*	*15.26%*	*37.41%*	*-1.26%*	*-37.38%*	*-58.70%*
	Δ Hydropower Investment, comp. x7.5	*0.00%*	*20.70%*	*70.98%*	*98.58%*	*97.16%*	*80.18%*
GDP per capita (*USD/person/year)*	**BAU**	**813**	**944**	**1007**	**1028**	**1033**	**1062**
	Δ Hydropower Investment, no compensation	*0.00%*	*15.19%*	*36.90%*	*-1.91%*	*-37.77%*	*-58.74%*
	Δ Hydropower Investment, comp. x7.5	*0.00%*	*20.62%*	*70.26%*	*96.81%*	*94.56%*	*77.15%*
Crop production (*Ton/year*)	**BAU**	**13028968**	**16087658**	**17457620**	**18105382**	**18548772**	**20036918**
	Δ Hydropower Investment, no compensation	*0.00%*	*-8.20%*	*-23.56%*	*-54.00%*	*-69.72%*	*-76.36%*
	Δ Hydropower Investment, comp. x7.5	*0.00%*	*-0.22%*	*2.79%*	*6.38%*	*6.41%*	*4.40%*
Average electricity price (*USD/(Mw*hour)*)	**BAU**	**530**	**637**	**723**	**795**	**866**	**958**
	Δ Hydropower Investment, no compensation	*0.00%*	*-43.68%*	*-75.95%*	*-81.98%*	*-83.73%*	*-84.92%*
	Δ Hydropower Investment, comp. x7.5	*0.00%*	*-41.83%*	*-74.76%*	*-81.73%*	*-82.69%*	*-83.03%*
Forest land *(hectare)*	**BAU**	**9173380**	**8941638**	**8559188**	**7919266.5**	**7107452**	**6240859.5**
	Δ Hydropower Investment, no compensation	*0.00%*	*-1.12%*	*-28.64%*	*-56.12%*	*-73.70%*	*-85.70%*
	Δ Hydropower Investment, comp. x7.5	*0.00%*	*-0.16%*	*-4.40%*	*-12.92%*	*-22.61%*	*-33.89%*
Relative sediment flow *(dmnl)*	**BAU**	**1**	**1**	**1**	**1**	**1**	**1**
	Δ Hydropower Investment, no compensation	*0.00%*	*-25.89%*	*-67.32%*	*-80.69%*	*-83.43%*	*-84.10%*
	Δ Hydropower Investment, comp. x7.5	*0.00%*	*-25.89%*	*-67.32%*	*-80.69%*	*-83.43%*	*-84.10%*
Fish stock (Ton)	**BAU**	**9976230**	**8935652**	**8003613**	**7168790**	**6421038**	**5751287**
	Δ Hydropower Investment, no compensation	*0.00%*	*-0.83%*	*-16.74%*	*-37.93%*	*-53.77%*	*-65.57%*
	Δ Hydropower Investment, comp. x7.5	*0.00%*	*-0.83%*	*-16.74%*	*-37.93%*	*-53.77%*	*-65.57%*
Local fish stock *(Ton)*	**BAU**	**83465**	**73952**	**65522**	**58054**	**51437**	**45574**
	Δ Hydropower Investment, no compensation	*0.00%*	*-3.81%*	*-42.62%*	*-71.73%*	*-86.08%*	*-93.15%*
	Δ Hydropower Investment, comp. x7.5	*0.00%*	*-3.81%*	*-42.62%*	*-71.73%*	*-86.08%*	*-93.15%*
Co2 emissions per year *(Ton/year)*	**BAU**	**1513771**	**1513771**	**1513771**	**1513771**	**1513771**	**1513771**
	Δ Hydropower Investment, no compensation	*0.00%*	*2.43%*	*8.99%*	*13.24%*	*14.46%*	*14.81%*
	Δ Hydropower Investment, comp. x7.5	*0.00%*	*2.43%*	*8.99%*	*13.24%*	*14.46%*	*14.81%*
Relative graduation relative to population *(dmnl)*	**BAU**	**2.75**	**2.86**	**2.94**	**2.99**	**3.02**	**3.04**

	Δ Hydropower Investment, no compensation	*0.00%*	*1.42%*	*5.17%*	*4.42%*	*0.30%*	*-4.21%*
	Δ Hydropower Investment, comp. x7.5	*0.00%*	*1.59%*	*6.52%*	*9.89%*	*10.91%*	*10.46%*
Local transportation factor *(dmnl)*	**BAU**	**0.9978**	**0.9978**	**0.9978**	**0.9978**	**0.9978**	**0.9978**
	Δ Hydropower Investment, no compensation	*0.00%*	*-1.90%*	*-7.03%*	*-10.36%*	*-11.31%*	*-11.58%*
	Δ Hydropower Investment, comp. x7.5	*0.00%*	*-1.90%*	*-7.03%*	*-10.36%*	*-11.31%*	*-11.58%*
Life expectancy *(Year/person)*	**BAU**	**67.1**	**67.6**	**67.7**	**67.9**	**68.0**	**68.1**
	Δ Hydropower Investment, no compensation	*0.00%*	*2.09%*	*5.17%*	*2.74%*	*-2.22%*	*-7.56%*
	Δ Hydropower Investment, comp. x7.5	*0.00%*	*2.38%*	*6.64%*	*8.20%*	*8.13%*	*7.45%*
total yearly cost from roads, fertilizer, electricity operation and co2 *(USD/year)*	**BAU**	**310312448**	**315473056**	**327755232**	**344785152**	**370140800**	**395496480**
	Δ Hydropower Investment, no compensation	*0.00%*	*5.76%*	*16.44%*	*20.59%*	*21.37%*	*21.30%*
	Δ Hydropower Investment, comp. x7.5	*0.00%*	*6.89%*	*21.63%*	*28.36%*	*29.54%*	*29.19%*
Total accumulated investment and running costs *(USD)*	**BAU**	**4538513920**	**6102957056**	**7703858176**	**9385141248**	**11172357120**	**13086350336**
	Δ Hydropower Investment, no compensation	*0.00%*	*7.06%*	*14.36%*	*15.20%*	*16.15%*	*16.91%*
	Δ Hydropower Investment, comp. x7.5	*0.00%*	*7.12%*	*15.07%*	*16.98%*	*18.93%*	*20.47%*

Table 27: Results for Scenario 1: Hydropower investment

6.2 Scenario 2: Coal power investment

Time period for investment: Year 2016 to year 2025

Investment per year: 100 million USD

Total investment: 900 million USD

Cost of capacity: 1 million per MW

This scenario represents investment in Coal power. Like in the case of hydropower, the goal of this policy is to increase the overall economic and social welfare of Cambodia by building electricity generating capacity, increasing supply and driving down the price of electricity. But this policy scenario as well has its benefits and adverse consequences.

The scenario has the same level of investment over the same period of time as in Scenario 1. This scenario is compared with *"Hydropower investment, compensation x7.5"*. This is done since there are already several projects planned for Hydropower in the Mekong region, thus making it the relevant technology to compare it with. A comparison for the Coal power with the BAU scenario would be interesting by itself, however placing it next to the hydropower in the same table gives more context.

Coal power has its own challenges compared with hydropower [72]. The burning of coal to generate electricity causes air pollution and toxic waste that need to be taken care of. The pollution from coal power causes acid rain and the acidity levels to rise in the water and the soil.[73] This increase in acidity levels decreases the productivity of agriculture land and has and adverse effect on human health and animal life. In the model this adverse effect of air pollution is represented by placing a negative effect on the development of the average life expectancy. Coal powerplants need water for their cooling[74]. When this water is returned to the river it causes what is called "thermal pollution"[75], increasing the temperature of the river locally with a few degrees. This increase in temperature can offset fish fertility and or increase mortality.

[72] http://www.ucsusa.org/clean_energy/coalvswind/c01.html#.WSqn72iGNPa

[73] http://www.ucsusa.org/clean-energy/coal-and-other-fossil-fuels/coal-air-pollution#.WSqn0miGNPZ

[74] http://www.ucsusa.org/clean-energy/coal-and-other-fossil-fuels/coal-water#.WSqn3miGNPZ

[75] http://www.ucsusa.org/clean-energy/coal-and-other-fossil-fuels/waste#.WSqn5WiGNPZ

6.2.1 Economic factors

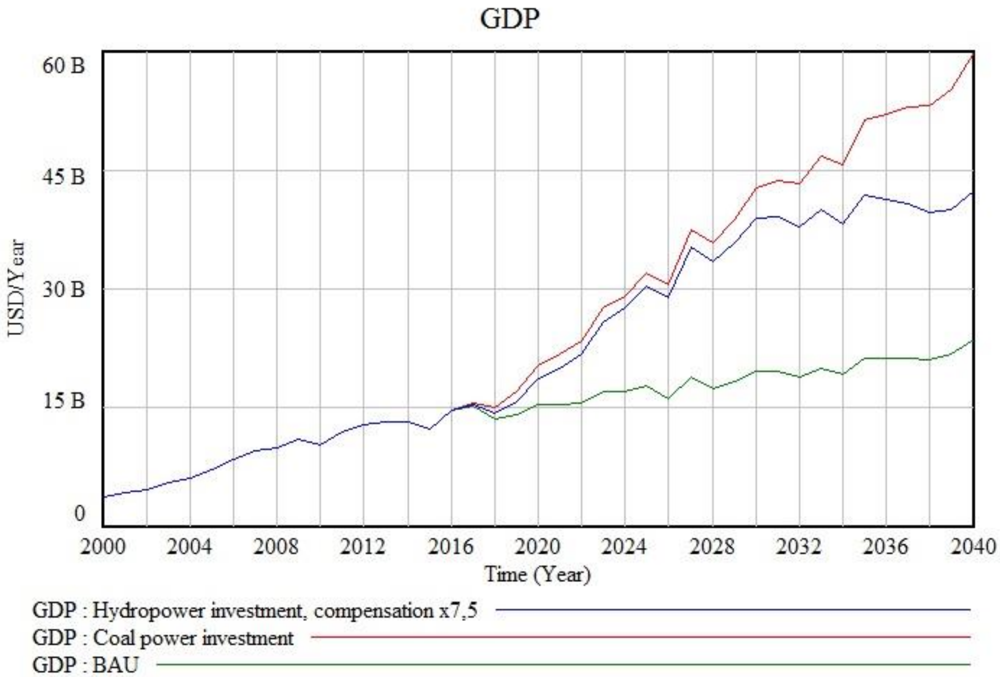


Figure 54: "GDP" Scenario 2: Coal power investment

Graph of "GDP" for three different runs; Blue: Hydropower with compensation, Red: Coal power investment and Green: BAU

In this scenario, the GDP grows significantly more than in the case of hydropower investment, even with the compensation policies. Right from the beginning we can see that the Coal power causes more rapid growth than with the Hydropower alternative. The initial reason for this is that the Coal power capacity requires a shorter construction time than does the hydropower. This means that the beneficial effects from increases electricity supply can start earlier. However, this is not the only reason. Coal power does not have the same negative effect on the fish stock as the Hydropower, but this gain is mostly offset by the comparatively lower result in life expectancy.

The hydropower also loses some capacity over time, about 1% per year, due to sediment accumulation in the dams. This, combined with slower construction time, causes the hydropower capacity to end up at a lower level than the Coal power capacity. This comparatively higher electricity supply gives off increased multiplicator effects in the system and returns a higher GDP. The GDP per capita has the same trend and development as in the case for the GDP.

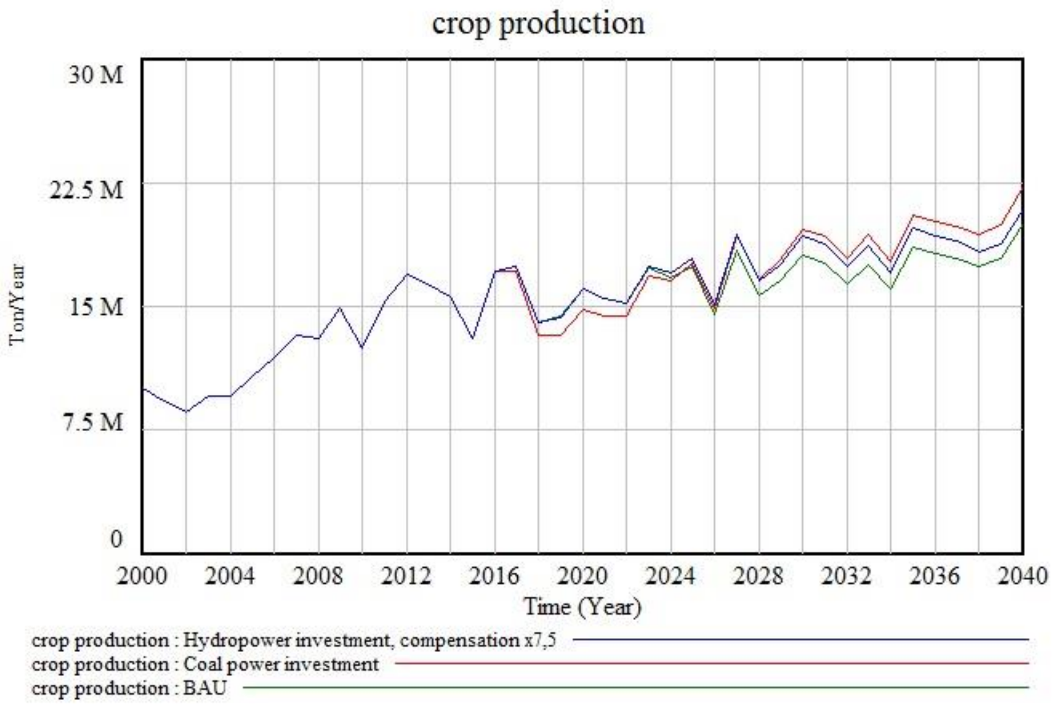


Figure 55: "Crop production" Scenario 2: Coal power investment

Graph of "crop production" for three different runs; Blue: Hydropower with compensation, Red: Coal power investment and Green: BAU

The crop production also increases comparatively to the hydropower alternative, this is mainly due to the increased demand caused by the higher GDP. This give the immediate impression of the overall increased economic benefits of investing in coal power over hydropower. However, we have not looked at the costs and the environmental effects yet.

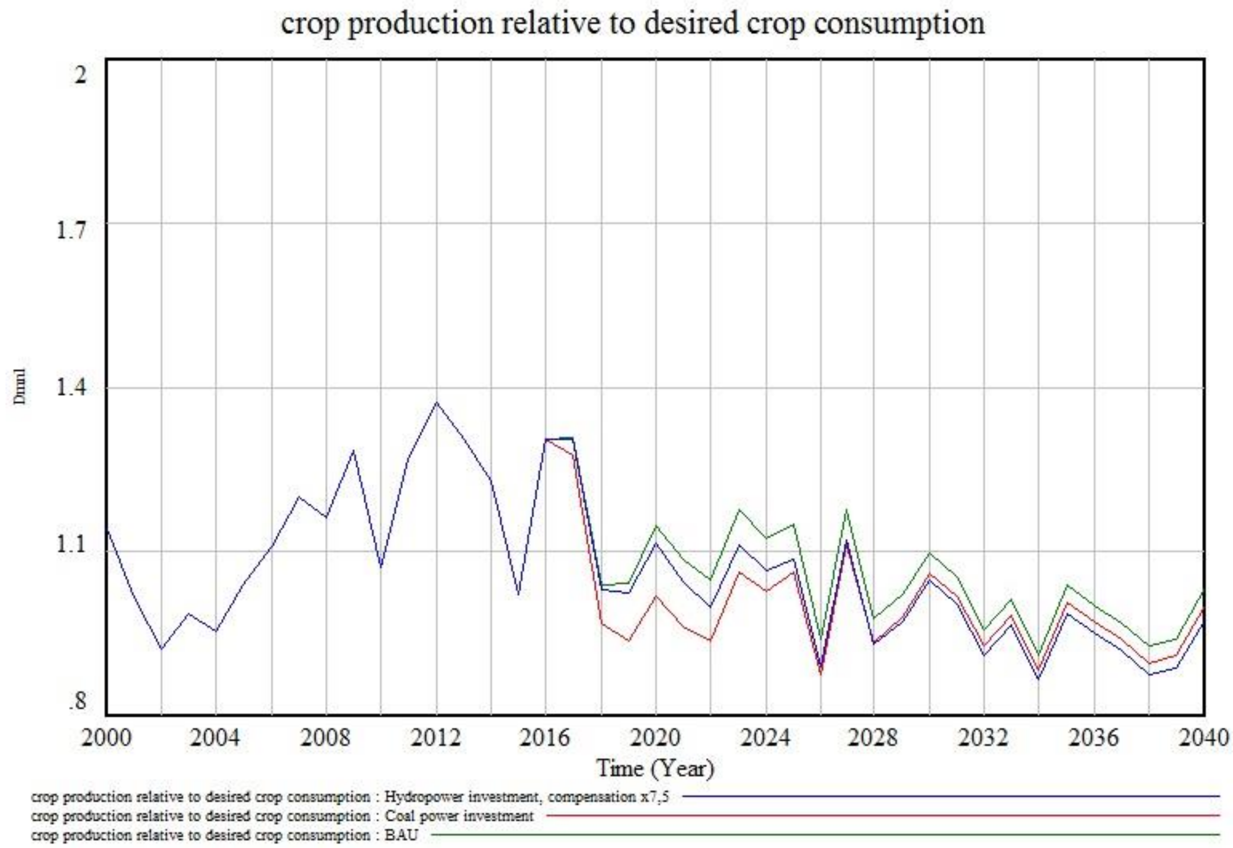


Figure 56: “Crop production relative to desired crop production” Scenario 2: Coal power investment

Graph of “crop production relative to desired crop consumption” for three different runs; Blue: Hydropower with compensation, Red: Coal power investment and Green: BAU

This show that the satisfaction of the food demand is relatively well met in both cases. Th biggest different comes right after the year 2016 when the policy is enacted. The Coal power investment option causes a dip in the crop production, but this is quickly compensated for as more land is converted to agriculture land. The dip is caused by an adverse effect of pollution coming from coal powerplants. Over time however the Coal power gains on the hydro power and come out on top. This has to do with the increased erosion rates in the hydropower option compared to the coal power option.

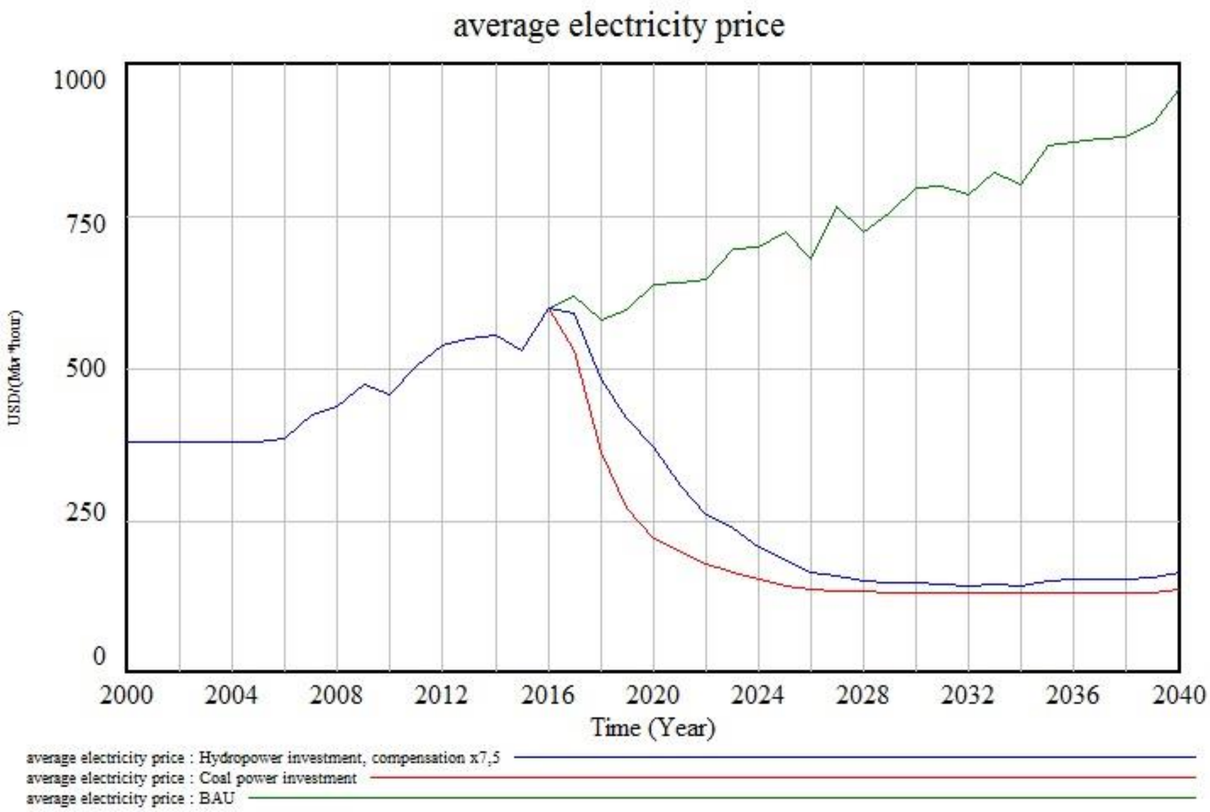


Figure 57: "crop production relative to desired crop consumption" Scenario 2: Coal power investment

Graph of "crop production relative to desired crop consumption" for three different runs; Blue: Hydropower with compensation, Red: Coal power investment and Green: BAU

This graph just further underscores the effect coming from the difference in electricity supply. Here we can see that the electricity price much more quickly decreases in the case of the coal power investment option than in the hydropower option, giving cause to a stronger economic growth.

6.2.2 Environmental factors

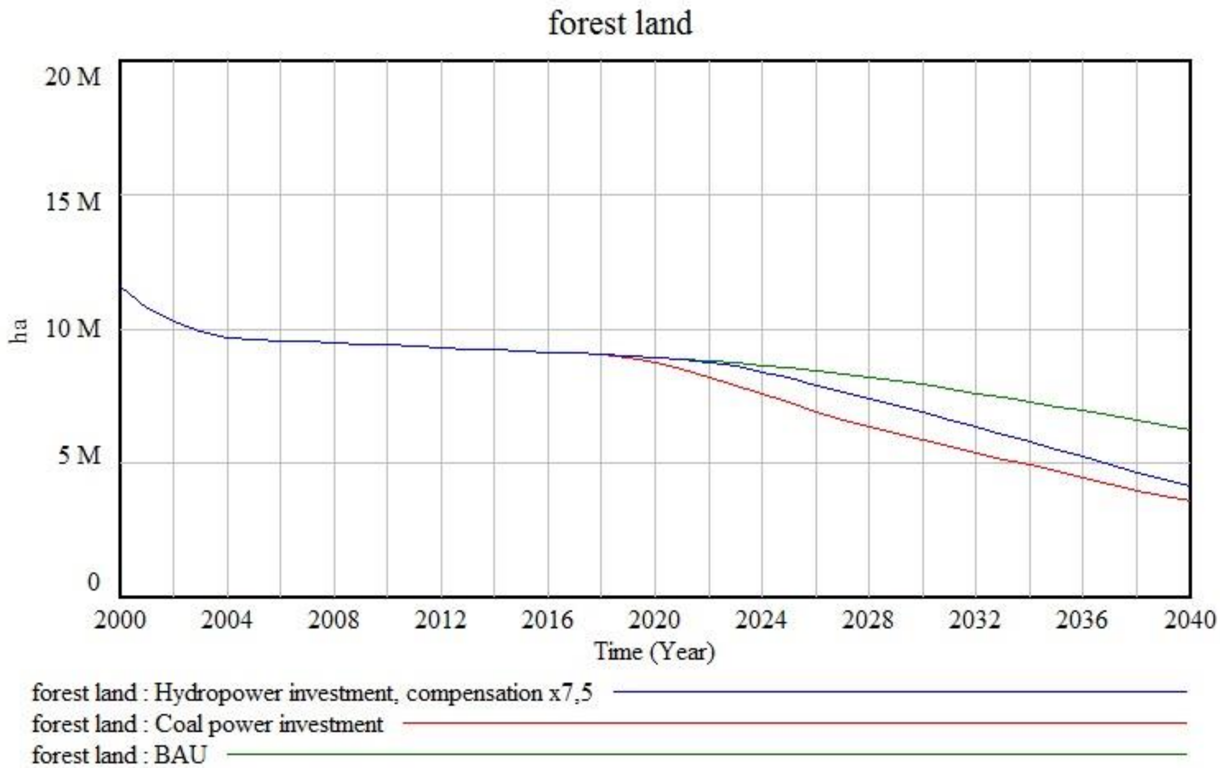


Figure 58: "forest land" Scenario 2: Coal power investment

Graph of "forest land" for three different runs; Blue: Hydropower with compensation, Red: Coal power investment and Green: BAU

In the case of the coal power alternative more forest land is cleared than in the hydropower option. This is initially caused by the fall in agriculture productivity and further reinforced by increase in demand from the increase in GDP.

This show us that there is considerable strain put on the forest, with about 40% reduction in the coal power run compared to the BAU, and close to a 60% reduction from the initial value of the year 2000. This trend cannot continue with severe ecological problems. However, this can be avoided by implementing conservation policies.

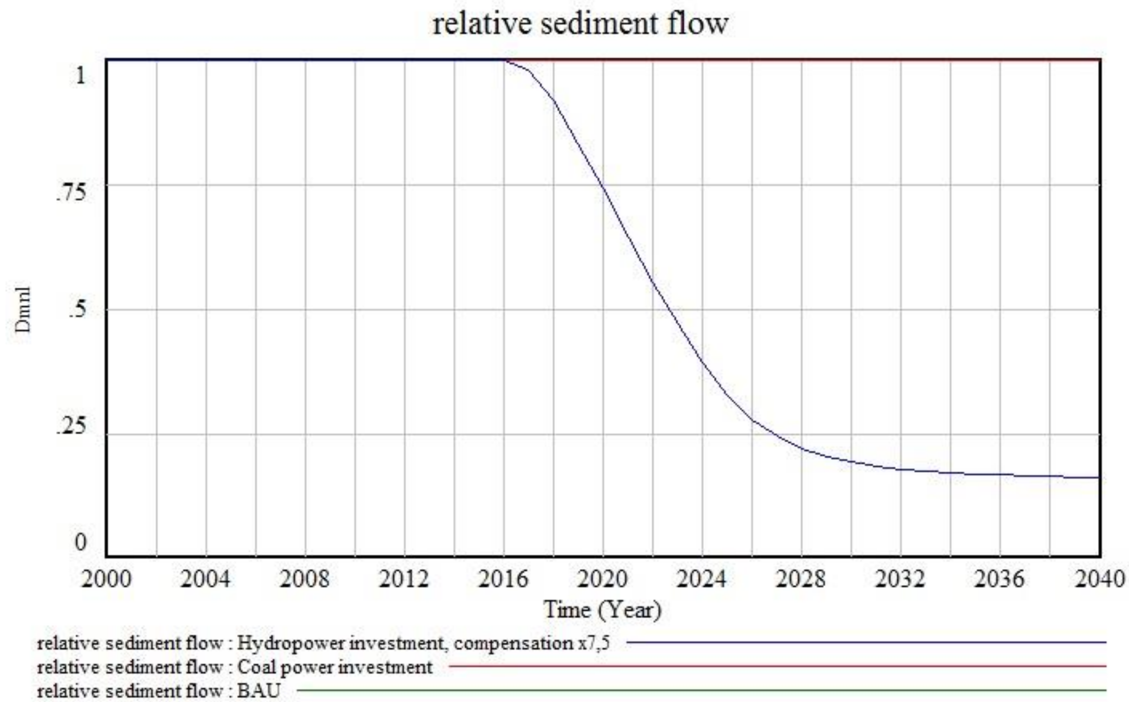


Figure 59: "relative sediment flow" Scenario 2: Coal power investment

Graph of "relative sediment flow" for three different runs; Blue: Hydropower with compensation, Red: Coal power investment and Green: BAU

This is one of the biggest differences between the hydropower and coal power alternative. The coal power does not interfere directly with the flow of the river even if it uses water for cooling. Thus, it does not stop the sediment flow like the hydropower dams do.

When it comes to the fish stock the coal power does cause adverse effects on the fish population, as compared with the BAU. However not as severe as in the case of the hydropower. The difference is quite significant. While the hydropower causes a reduction of – 65.6% compared to BAU of the same year the reduction with the coal power is "only" - 47%.

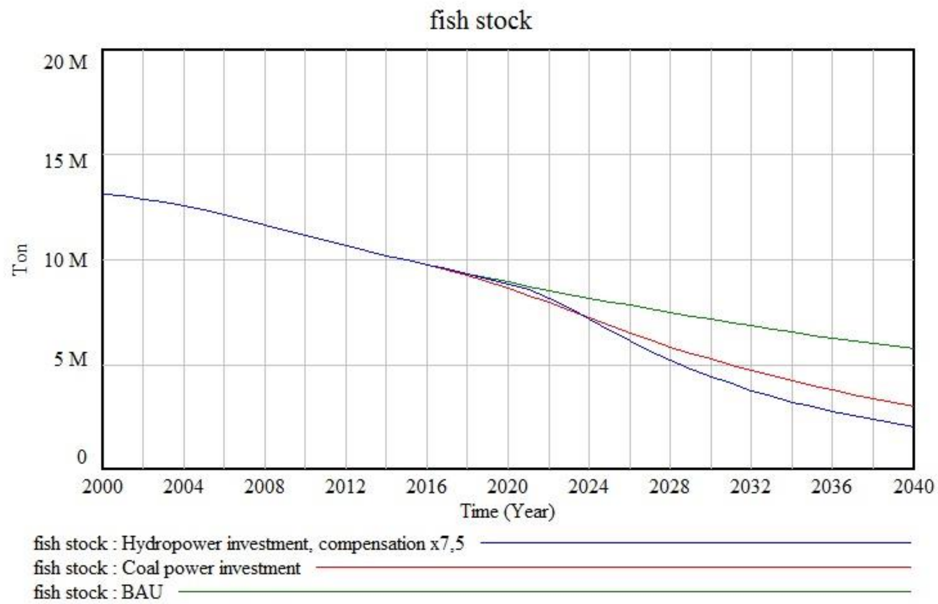


Figure 60: "fish stock" Scenario 2: Coal power investment

Graph of "fish stock" for three different runs; Blue: Hydropower with compensation, Red: Coal power investment and Green: BAU

The coal power option performs better than the hydropower option when it comes to the fish stock. In the scenario of the coal power the fish stock does not decline as much as in the case of the hydropower dams. However, the coal power scenario still under performs quite a lot compared with the BAU scenario. This is due to the effect that Coal powerplants placed near rivers have on the fish population. This is largely due to "thermal pollution" from the cooling water that is released back into the river, causing the temperate to increase with a couple of degrees. This change the environment for temperature sensitive spices just enough to for example decrease fertility. Other adverse effects on water from coal power plants included as an effect in this model is the release of toxins usually making the water and the soil acid. This also harms nearby plant and animal life, increasing the fish mortality rates. Causing the stock of fish to fall more than it otherwise would have, compared with the BAU.

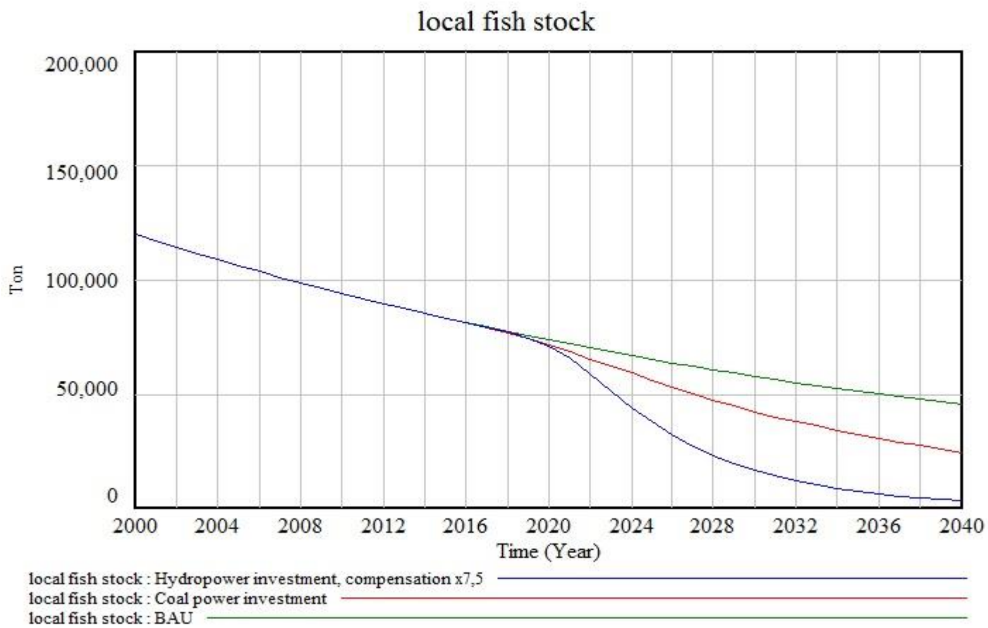


Figure 61: "local fish stock" Scenario 2: Coal power investment

Graph of "local fish stock" for three different runs; Blue: Hydropower with compensation, Red: Coal power investment and Green: BAU

In the case of the local fish stock the difference between the two investment options is even more significant, with -47% reduction compared with BAU for the coal power option, and -93% reduction in the hydropower option. With the coal power option the fish stock is still less than in the BAU run, but it has not collapsed. This means that the fish stock, and thus by extension the livelihoods for the local population, are doing better under the coal power option than in the hydropower option. With regards to the natural capital stock of fish the coal power option is more beneficial than the hydropower option.

However, when it comes to CO2 emissions, the hydropower outperforms the coal power. In comparison, the emission from hydropower is hardly significant in comparison with the coal power. But this effect is a global effect and not immediately experienced by the population where the powerplant is built, compared with the effect of the hydropower.

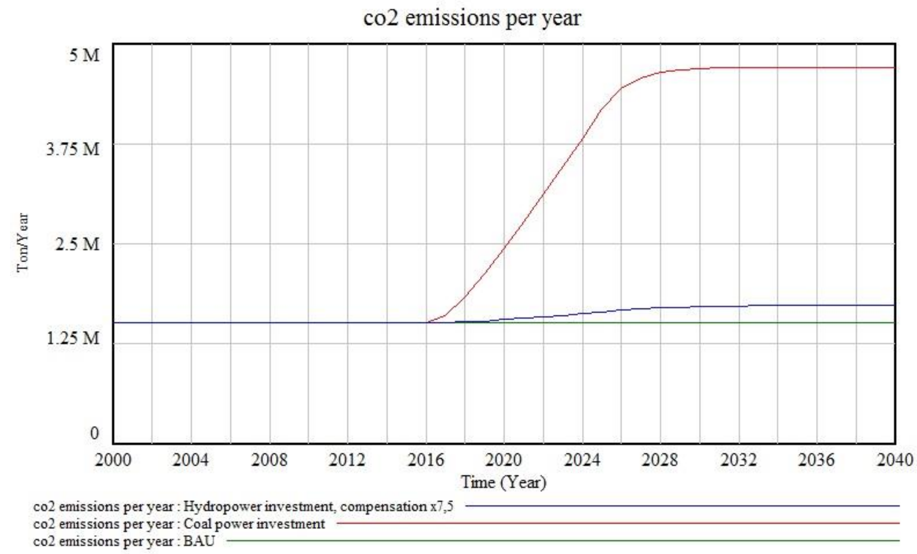


Figure 62: "CO2 emissions per year" Scenario 2: Coal power investment

Graph of "local fish stock" for three different runs; Blue: Hydropower with compensation, Red: Coal power investment and Green: BAU

This graph gives an overview of the CO2 emissions coming from coal power per year, compared with hydropower. As we can see from the graph the difference is huge. The initial emissions of CO2 come from the diesel generators production electricity from the beginning of the simulation as an initial condition. An interesting policy alternative in this model that has not been included in the results is the use of the decommissioning switch that starts to decommission diesel generators as a given point in time, phasing them out as other capacity is constructed. This will lower the rate of emissions with regards to electricity output. It would also decrease yearly costs.

6.2.3 Social factors

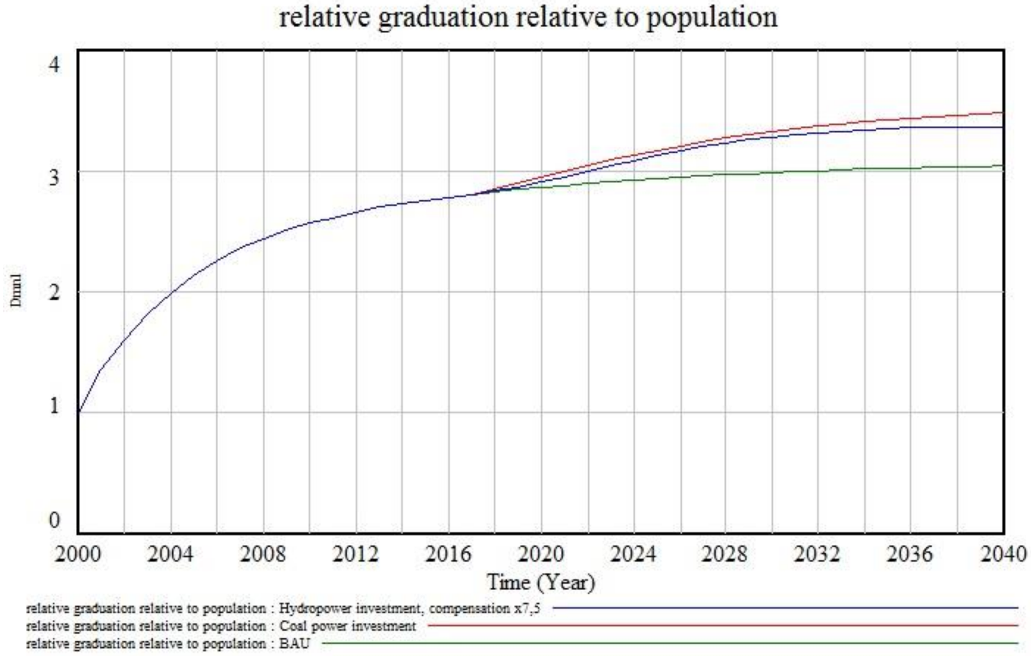


Figure 63: "relative graduation relative to population" Scenario 2: Coal power investment

Graph of "relative graduation relative to population" for three different runs; Blue: Hydropower with compensation, Red: Coal power investment and Green: BAU

Again, the lower electricity price and the higher GDP in the case of the coal power option yields a slightly better result in the education indicator "*relative graduation relative to population*". Also, when it comes to the local transportation factor along the river it is not hindered or disturbed as is the case with the hydropower option. Without compensation with roads, this leaves the local population better off with the coal power option.

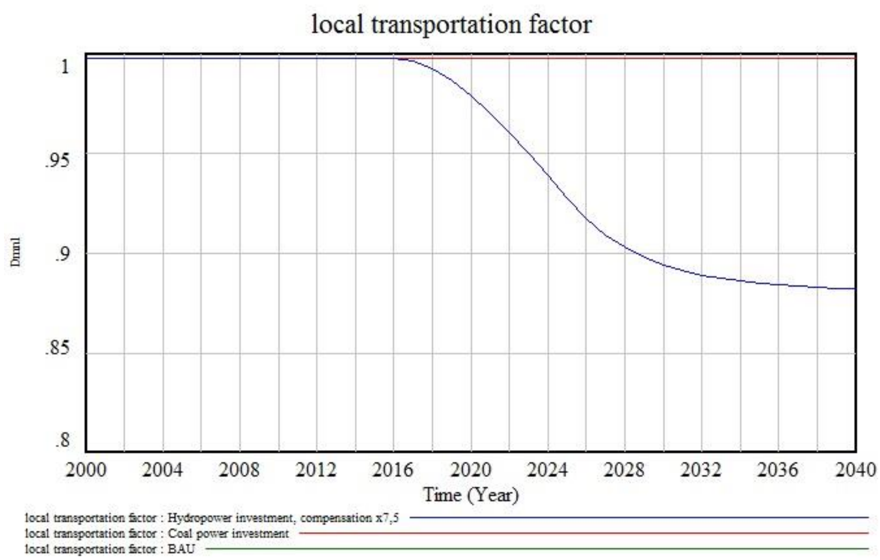


Figure 64: "local transportation factor" Scenario 2: Coal power investment

Graph of "local transportation factor" for three different runs; Blue: Hydropower with compensation, Red: Coal power investment and Green: BAU

In the local transportation factor, there are no changes in the coal power alternative and the rivers stay open for transportation, if anything the roads would be improved due to the supply of coal that would have to be transported in to the powerplant. This means that the coal power alternative is less intrusive in this aspect than the hydropower alternative.

6.2.4 Health factors

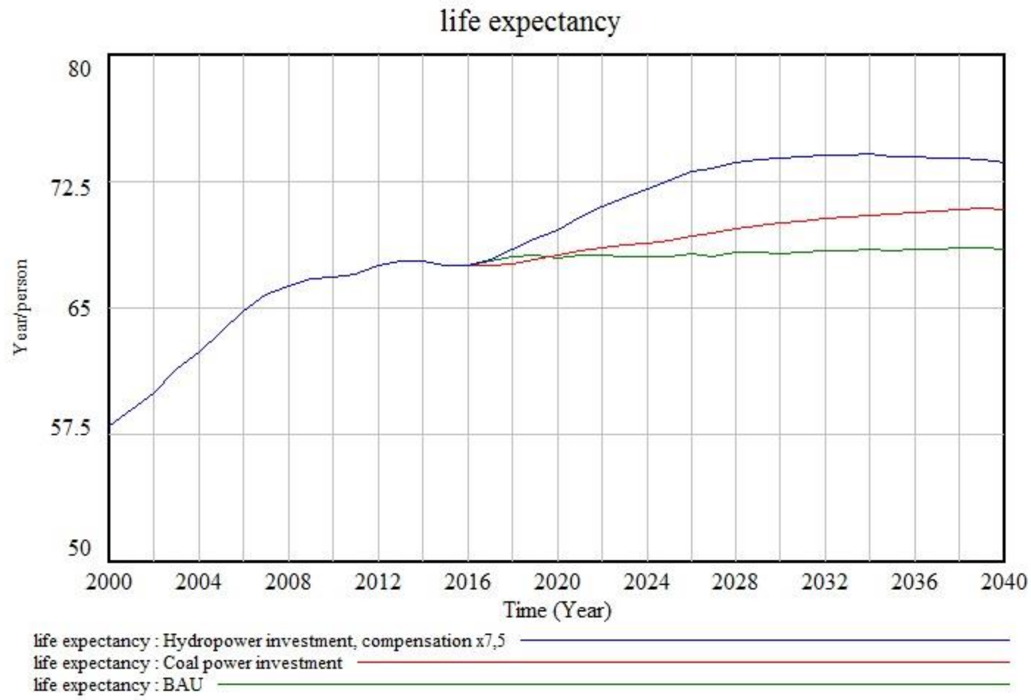


Figure 65: "life expectancy" Scenario 2: Coal power investment

Graph of "life expectancy" for three different runs; Blue: Hydropower with compensation, Red: Coal power investment and Green: BAU

This is where the hydropower option significantly outperforms the coal power. This is due to the adverse effect coming from air pollution caused by coal power plants when they generate electricity. The effect of the increase in GDP and lower electricity prices are significant enough that the life expectancy performs better than in the BAU run. However, it is below the hydropower alternative by more than 2 ½ years of average life expectancy, and that is a significant variation when it comes to this variable.

6.2.5 Associated costs

The use of coal power to produce electricity is considerably costlier than using hydropower. This is mostly due to the continued cost of coal required as fuel to operate the powerplant.

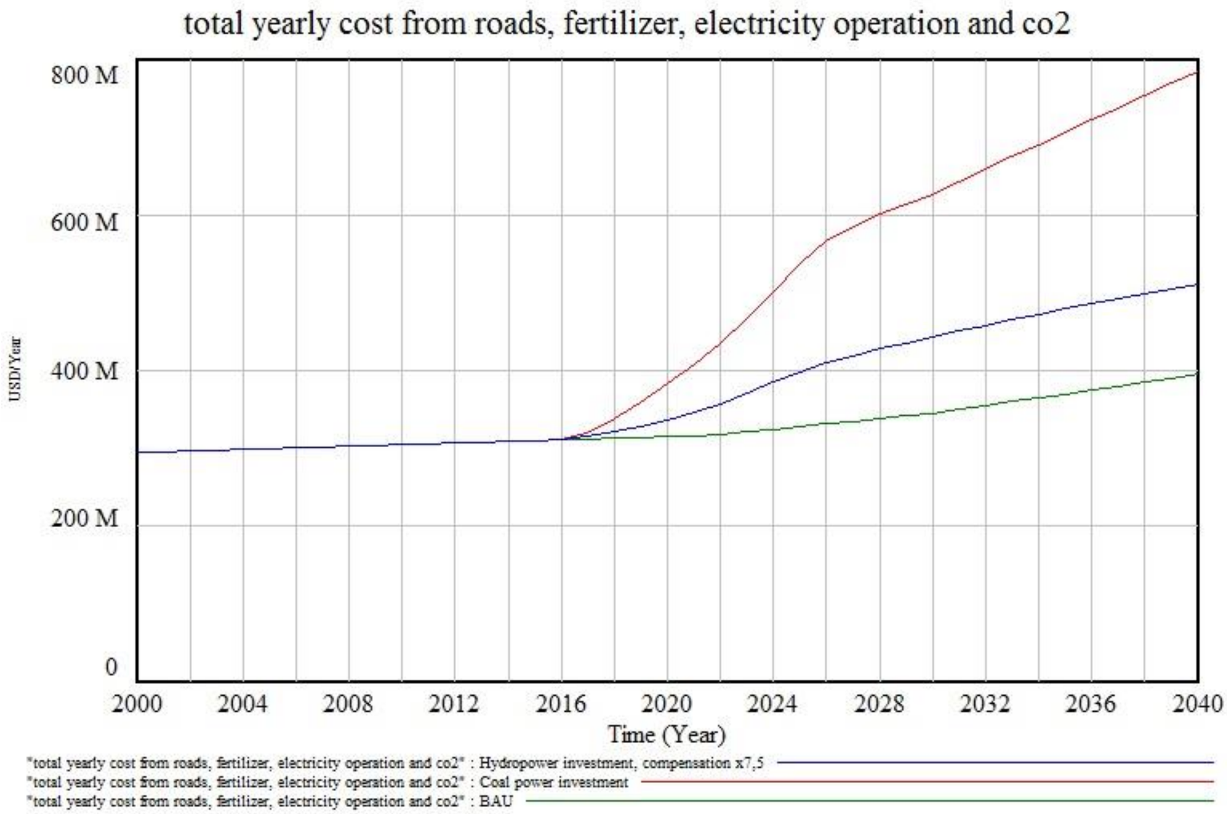


Figure 66: "total yearly cost from roads, fertilizer, electricity operation and co2" Scenario 2: Coal power investment

Graph of "total yearly cost from roads, fertilizer, electricity operation and co2" for three different runs; Blue: Hydropower with compensation, Red: Coal power investment and Green: BAU

The costs for coal power is almost up 100% in the year 2040 compare to the BAU run, whereas the hydropower option is only up 30% compared to the BAU in the same year. This makes a huge difference when it comes to decide which alternative to invest in. The hydropower may not be as effective per dollar spent when it comes to the installation of capacity, but accounting for the fuel costs it becomes cheaper to operate the hydropower per MWH produced.

Even when paying for the compensation required, the hydropower alternative is still much cheaper than the coal power. Compared relative to each other the coal power costs about 51% more to operate per year in 2040 than the hydropower does. In real numbers that is almost 300 million dollars per year more in operating and fuel costs. Then one can compare this with the relative increase in the GDP of the same year between coal and hydro. The relative increase of GDP in the coal compared option compared with Hydro is 41%. This is significant and is an increase of 17.5 billion dollars in real numbers. From a macroeconomics point of view the costs of the added 300 million dollars per year seems justified, however this is not necessarily in the interest of those making the investment that has to pay for the fuel and operating costs when there is a much cheaper option and their revenues may not differ that much between the options.

The following table show the model outputs by scenario. Changes are differences relative to the BAU value.

Name	Scenario	2015	2020	2025	2030	2035	2040
GDP ***(USD/year)***	**BAU**	**12347987968**	**15445494784**	**17759885312**	**19566000128**	**21220493312**	**23560380416**
	Δ *Coal power investment*	*0.00%*	*32.00%*	*80.65%*	*118.70%*	*142.18%*	*154.06%*
	Δ *Hydropower Investment, comp. x7.5*	*0.00%*	*20.70%*	*70.98%*	*98.58%*	*97.16%*	*80.18%*
GDP per capita (USD/person/year)	**BAU**	**813**	**944**	**1007**	**1028**	**1033**	**1062**
	Δ *Coal power investment*	*0.00%*	*32.05%*	*80.72%*	*118.67%*	*141.94%*	*153.60%*
	Δ *Hydropower Investment, comp. x7.5*	*0.00%*	*20.62%*	*70.26%*	*96.81%*	*94.56%*	*77.15%*
Crop production (Ton/year)	**BAU**	**13028968**	**16087658**	**17457620**	**18105382**	**18548772**	**20036918**
	Δ *Coal power investment*	*0.00%*	*-7.76%*	*0.81%*	*8.51%*	*10.89%*	*11.35%*
	Δ *Hydropower Investment, comp. x7.5*	*0.00%*	*-0.22%*	*2.79%*	*6.38%*	*6.41%*	*4.40%*
Average electricity price (USD/(Mw*hour))	**BAU**	**530**	**637**	**723**	**795**	**866**	**958**
	Δ *Coal power investment*	*0.00%*	*-65.28%*	*-80.42%*	*-83.67%*	*-85.04%*	*-85.93%*
	Δ *Hydropower Investment, comp. x7.5*	*0.00%*	*-41.83%*	*-74.76%*	*-81.73%*	*-82.69%*	*-83.03%*
Forest land (hectare)	**BAU**	**9173380**	**8941638**	**8559188**	**7919266.5**	**7107452**	**6240860**
	Δ *Coal power investment*	*0.00%*	*-2.38%*	*-15.13%*	*-25.97%*	*-34.22%*	*-42.98%*
	Δ *Hydropower Investment, comp. x7.5*	*0.00%*	*-0.16%*	*-4.40%*	*-12.92%*	*-22.61%*	*-33.89%*
Relative sediment flow (dmnl)	**BAU**	**1**	**1**	**1**	**1**	**1**	**1**
	Δ *Coal power investment*	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*
	Δ *Hydropower Investment, comp. x7.5*	*0.00%*	*-25.89%*	*-67.32%*	*-80.69%*	*-83.43%*	*-84.10%*
Fish stock (Ton)	**BAU**	**9976230**	**8935652**	**8003613**	**7168790**	**6421038**	**5751287**
	Δ *Coal power investment*	*0.00%*	*-3.09%*	*-14.05%*	*-26.63%*	*-37.59%*	*-46.92%*
	Δ *Hydropower Investment, comp. x7.5*	*0.00%*	*-0.83%*	*-16.74%*	*-37.93%*	*-53.77%*	*-65.57%*
Local fish stock (Ton)	**BAU**	**83465**	**73952**	**65522**	**58054**	**51437**	**45574**
	Δ *Coal power investment*	*0.00%*	*-3.09%*	*-14.05%*	*-26.63%*	*-37.59%*	*-46.92%*
	Δ *Hydropower Investment, comp. x7.5*	*0.00%*	*-3.81%*	*-42.62%*	*-71.73%*	*-86.08%*	*-93.15%*
Co2 emissions per year (Ton/year)	**BAU**	**1513771**	**1513771**	**1513771**	**1513771**	**1513771**	**1513771**
	Δ *Coal power investment*	*0.00%*	*60.90%*	*175.84%*	*209.88%*	*211.08%*	*211.13%*
	Δ *Hydropower Investment, comp. x7.5*	*0.00%*	*2.43%*	*8.99%*	*13.24%*	*14.46%*	*14.81%*
Relative graduation relative to population (dmnl)	**BAU**	**2.75**	**2.86**	**2.94**	**2.99**	**3.02**	**3.04**
	Δ *Coal power investment*	*0.00%*	*2.95%*	*8.14%*	*11.71%*	*13.82%*	*15.05%*
	Δ *Hydropower Investment, comp. x7.5*	*0.00%*	*1.59%*	*6.52%*	*9.89%*	*10.91%*	*10.46%*
Local transportation factor (dmnl)	**BAU**	**0.998**	**0.9978**	**0.9978**	**0.9978**	**0.9978**	**0.9978**
	Δ *Coal power investment*	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*

	Δ Hydropower Investment, comp. x7.5	*0.00%*	*-1.90%*	*-7.03%*	*-10.36%*	*-11.31%*	*-11.58%*
Life expectancy (Year/person)	**BAU**	**67.1**	**67.6**	**67.7**	**67.9**	**68.0**	**68.1**
	Δ Coal power investment	*0.57%*	*0.77%*	*1.98%*	*3.14%*	*3.74%*	*3.98%*
	Δ Hydropower Investment, comp. x7.5	*0.00%*	*2.38%*	*6.64%*	*8.20%*	*8.13%*	*7.45%*
total yearly cost from roads, fertilizer, electricity operation and co2 (USD/year)	**BAU**	**310312448**	**315473056**	**327755232**	**344785152**	**370140800**	**395496480**
	Δ Coal power investment	*0.00%*	*21.32%*	*63.92%*	*81.63%*	*90.90%*	*98.63%*
	Δ Hydropower Investment, comp. x7.5	*0.00%*	*6.89%*	*21.63%*	*28.36%*	*29.54%*	*29.19%*
Total accumulated investment and running costs (USD)	**BAU**	**4538513920**	**6102957056**	**7703858176**	**9385141248**	**11172357120**	**13086350336**
	Δ Coal power investment	*0.00%*	*8.32%*	*21.76%*	*31.38%*	*40.20%*	*48.20%*
	Δ Hydropower Investment, comp. x7.5	*0.00%*	*7.12%*	*15.07%*	*16.98%*	*18.93%*	*20.47%*

Table 28: Results for Scenario 2: Coal power investment

6.3 Scenario 3: Solar power investment

Time period for investment: Year 2016 to year 2025

Investment per year: 100 million USD

Total investment: 900 million USD

Cost of capacity: (Variates from year to year, these numbers are based on projections[76])

2016: 2.84 million per MW

2020: 2.06 million per MW

2030: 1.64 million per MW

2040: 1.44 million per MW

The solar power investment alternative is compared with the hydropower option as well for the same reasons given in the coal power scenario.

Solar power is a technology with a lot of recent technology making it more relevant as an option for more traditional sources of electricity. However, it is not without challenges. These challenges are mostly of a practical and technological nature. The main problem has to do with the flexibility in the production of electricity. This is

[76] http://www.worldenergyoutlook.org/weomodel/investmentcosts/, compared to Africa

caused by the dependency on sunlight. At night or on very cloudy days there will be little to electricity output whereas the demand for electricity remains. During daylight, the production may exceed the demand of the hour. However, the improvement in battery technology for the storage of electricity is contributing to the solution of this problem. Usually, solar power is operated and used in conjunction with other generating technology in order to compensate for this lack of flexibility. However, this issue of flexibility is not taken into consideration in the model or this scenario. The purpose of this scenario is to look at the aggregate consequences of investing in solar power.

This is the least intrusive and the most environmental friendly technology of the three technologies that we are comparing. But due to the capacity cost per MW and the technical challenges regarding flexibility it becomes a less likely alternative. However, this is a technology decisionmakers should consider in conjunction with other technologies, or on its own as the flexibility problem is solved.

6.3.1 Economic factors

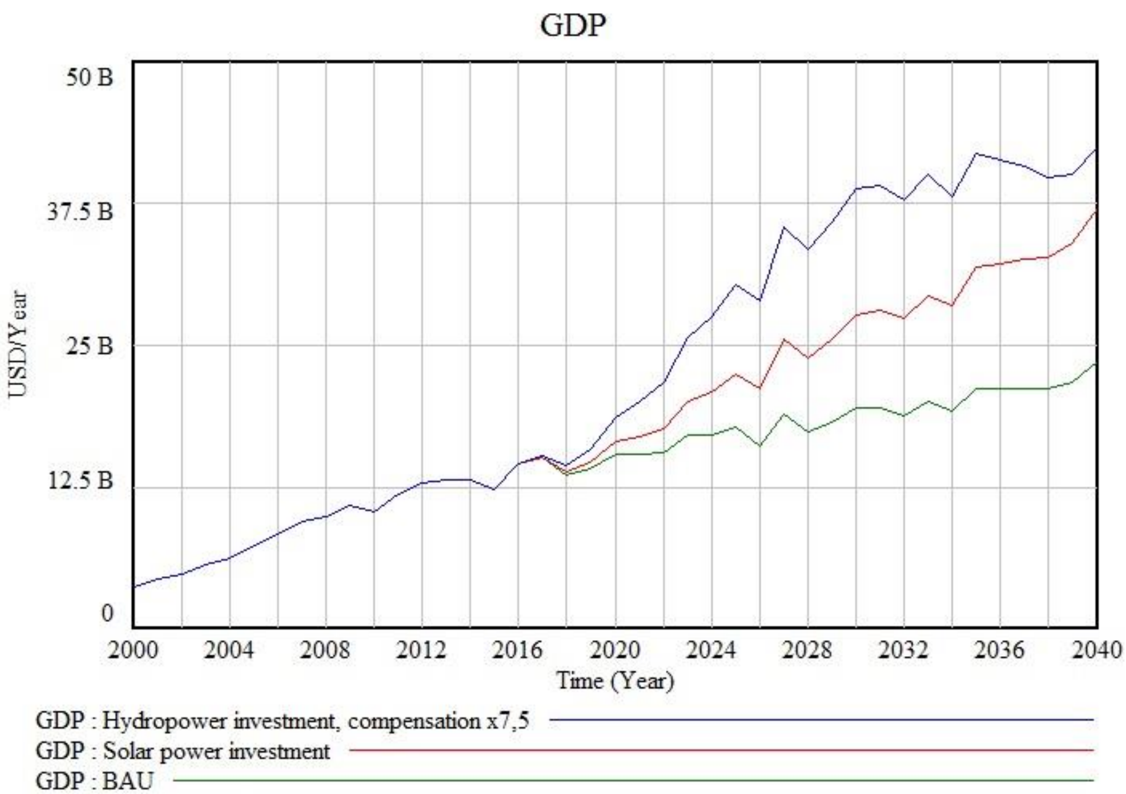


Figure 67: "GDP" Scenario 3: Solar power investment

Graph of "GDP" for three different runs; Blue: Hydropower with compensation, Red: Solar power investment and Green: BAU

The GDP does not increase as much in the solar power option as it does in the hydropower alternative. This is because the solar power capacity is more expensive per MW than hydropower. Thus, for the same amount of investment you are left with less electricity generating capacity when investing in solar power then when you are investing in hydropower. Due to this fact, there is less electricity supply than in the hydropower alternative. This is reflected in the electricity price as you can see below.

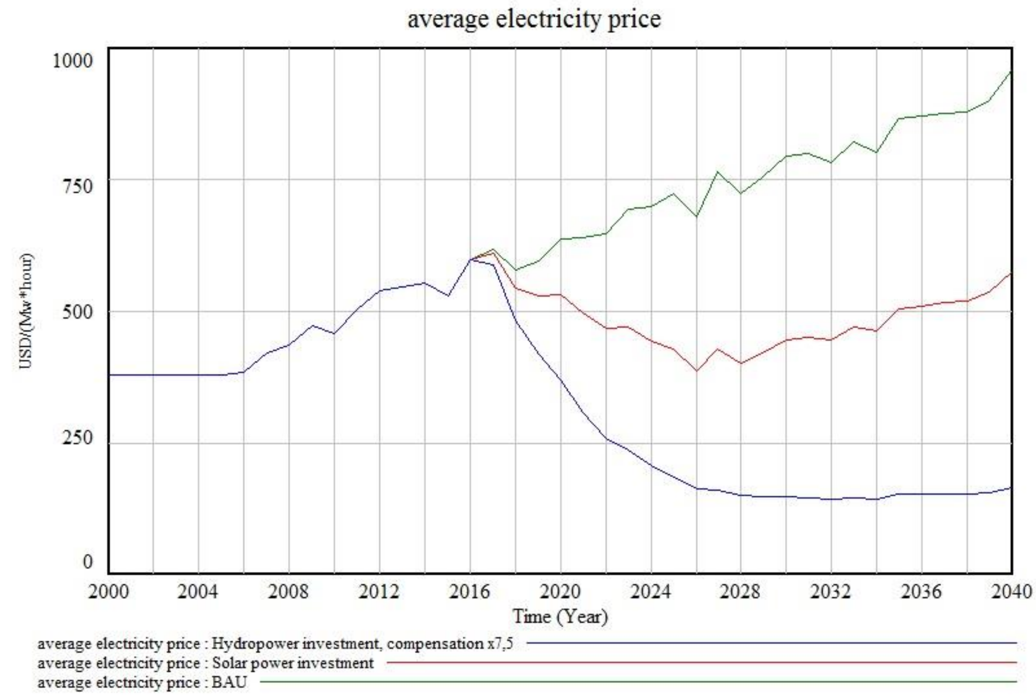


Figure 68: "average electricity price" Scenario 3: Solar power investment

Graph of "Electricity price" for three different runs; Blue: Hydropower with compensation, Red: Solar power investment and Green: BAU

The electricity price in the solar power option decreases relative to the BAU with as much as -40.5% in 2025, but not as much as the hydropower option in the same year, that has a reduction on about -75%. However, the electricity price in the solar power option starts to increase again right after that due to low supply compared to rise in demand. This puts a damper on the growth of the GDP, and in the year 2040 the relative difference between the solar power option and the BAU is still roughly at -40%. Whereas the hydropower option is now down -83% compared to the BAU in the same year.

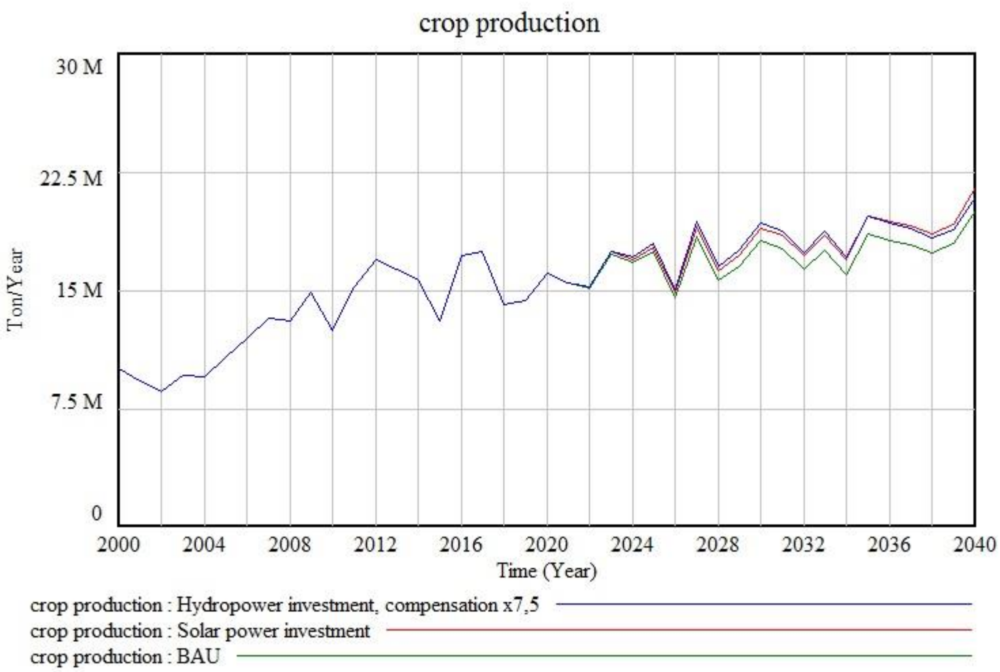


Figure 69: "crop production" Scenario 3: Solar power investment

Graph of "crop production" for three different runs; Blue: Hydropower with compensation, Red: Solar power investment and Green: BAU

The crop production is slightly under the hydropower scenario until the very end of the simulation, around year 2036. It stays at a lower level of production due to a lower level of demand since the GDP is not as large as in the hydropower option. The change around year 2036 happens due to erosion of agriculture land that is comparatively higher under the hydropower scenario then in the solar power scenario. At this point the decline in forest land under the hydropower scenario constricts the supply of new agriculture land, and thus the coproduction under the solar power alternative catches up with the hydropower. However, the difference between the two scenarios are marginal throughout the simulation.

6.3.2 Environmental factors

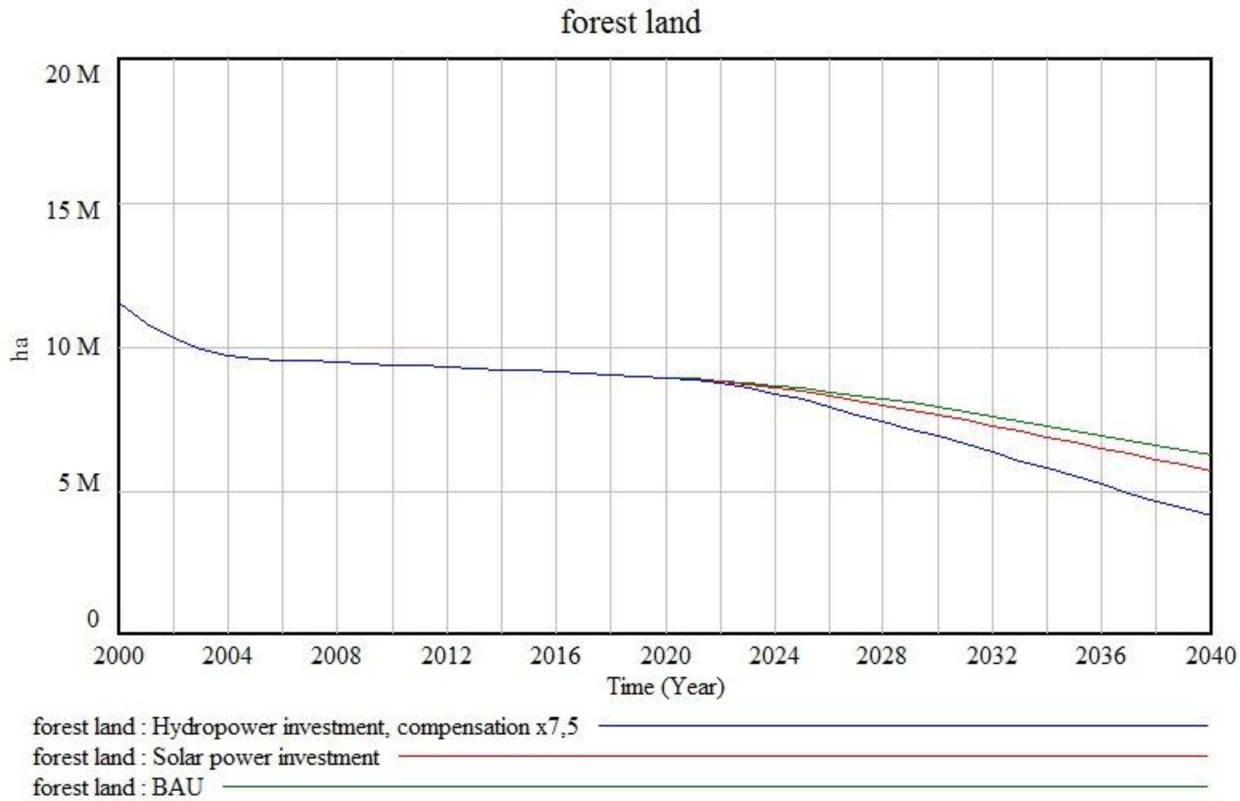


Figure 70: "forest land" Scenario 3: Solar power investment

Graph of "forest land" for three different runs; Blue: Hydropower with compensation, Red: Solar power investment and Green: BAU

As mentioned before the solar power is the least intrusive to the ecosystem of all the three technologies that are compared in this thesis. The difference in the year 2040 for the solar power option compared to the BAU is only -8.5%. The hydropower option of the same year is down approximately -34%. The change in forest land in the solar power scenario compared with the BAU is mostly caused by the increase in demand for additional agriculture land and not by any other way of intrusion other than the surface area needed to construct the solar powerplant.

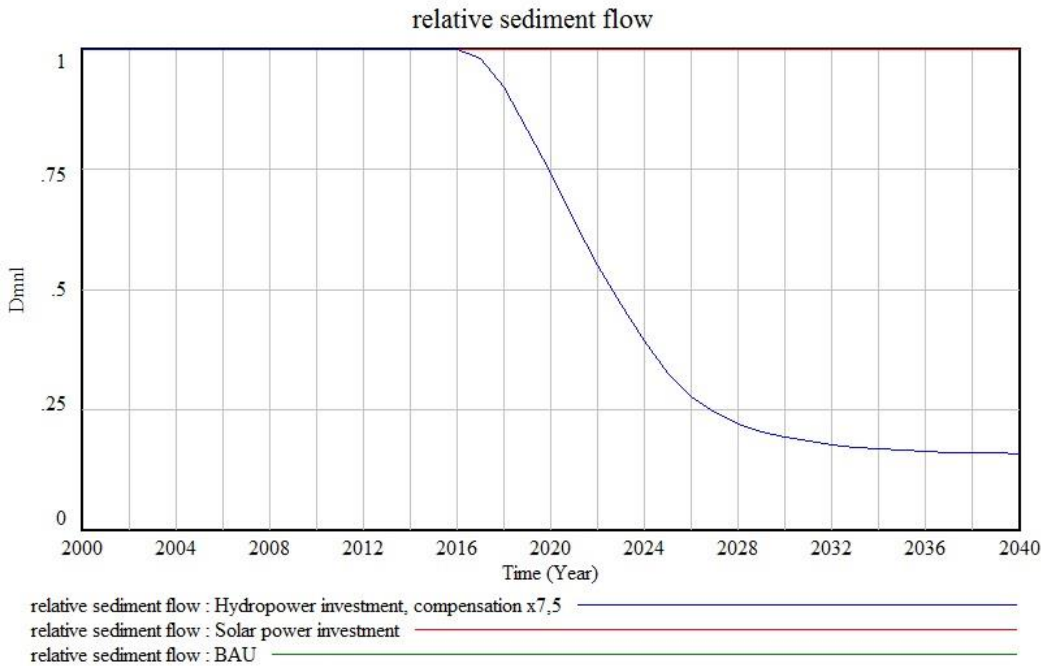


Figure 71: "relative sediment flow" Scenario 3: Solar power investment

Graph of "relative sediment flow" for three different runs; Blue: Hydropower with compensation, Red: Solar power investment and Green: BAU

The construction of solar power does not interfere with the sediment flow like the hydropower does. Thus, the river is left alone and the natural fertilization of the agriculture fields goes on unhindered. In this regard, the solar power is a less expensive alternative since there is no need to increase the use of fertilizer to compensate for the loss of sediment flow.

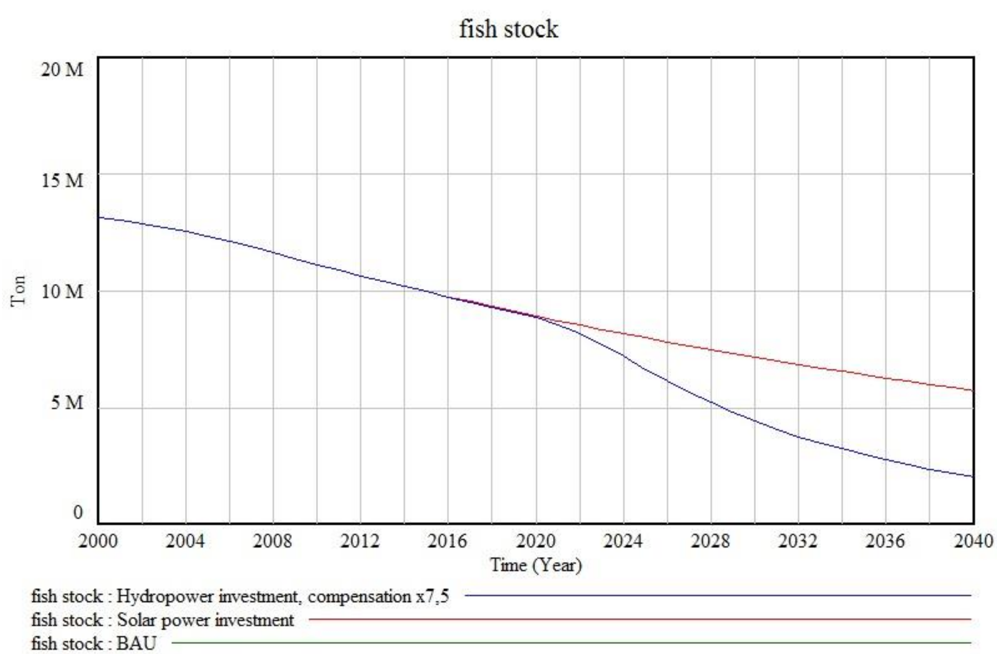


Figure 72: "fish stock" Scenario 3: Solar power investment

Graph of "fish stock" for three different runs; Blue: Hydropower with compensation, Red: Solar power investment and Green: BAU

Since the solar power does not interfere with the flow of the river, nor uses water in its operation the fish stock is left alone and untouched by the direct impacts of the solar power capacity construction and operation. The increase in demand for fish does not increase the fish catch more than in the BAU because of the constriction in the fish catch rate. The rate of catch depends on the size of the fish population and this sets the maximum catch rate. This reflects the fact that the fewer fish are left the harder it is to catch additional fish from the stock with the existing fishing technology. Thus, the possible fish catch is maxed out in both the BAU scenario and in the solar power investment scenario.

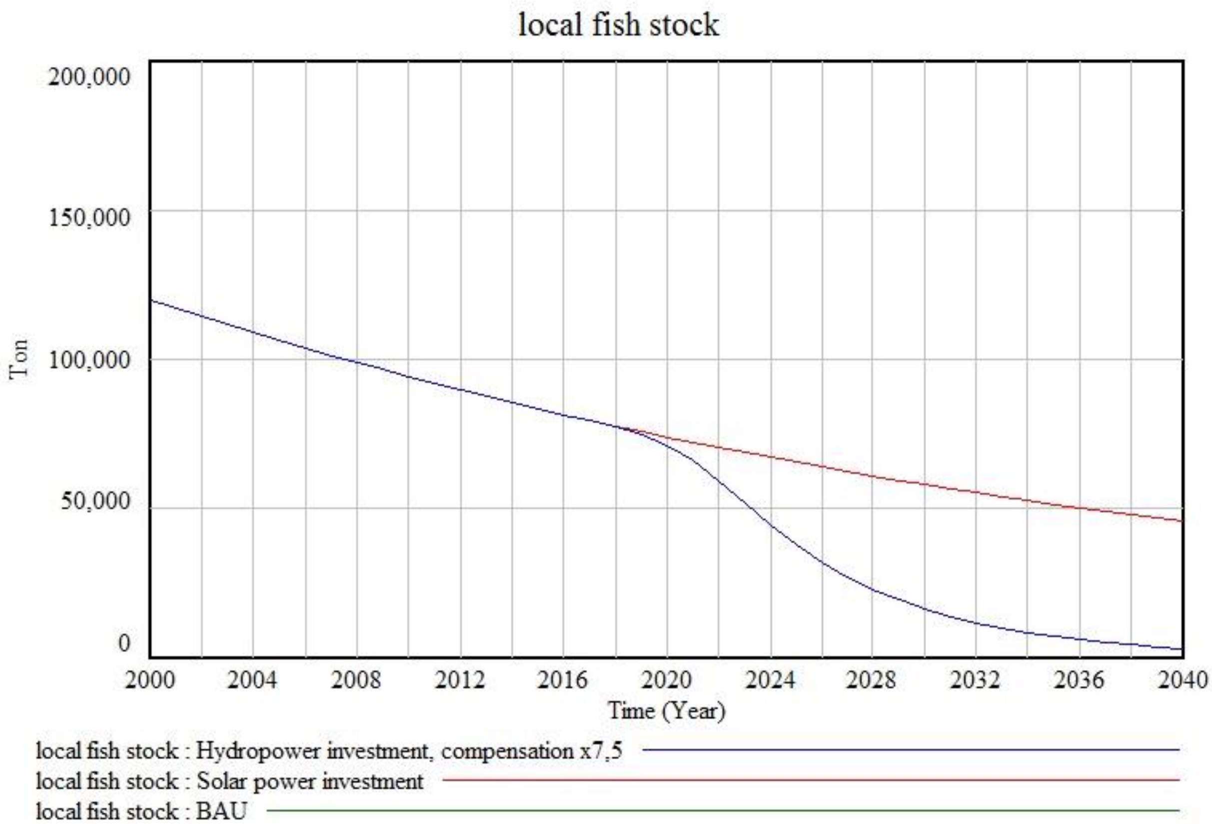


Figure 73: "local fish stock" Scenario 3: Solar power investment

Graph of "local fish stock" for three different runs; Blue: Hydropower with compensation, Red: Solar power investment and Green: BAU

The same is true for the local fish stock as is true for the nationwide fish stock shown above. The solar power investment alternative does not interfere with the fish stock.

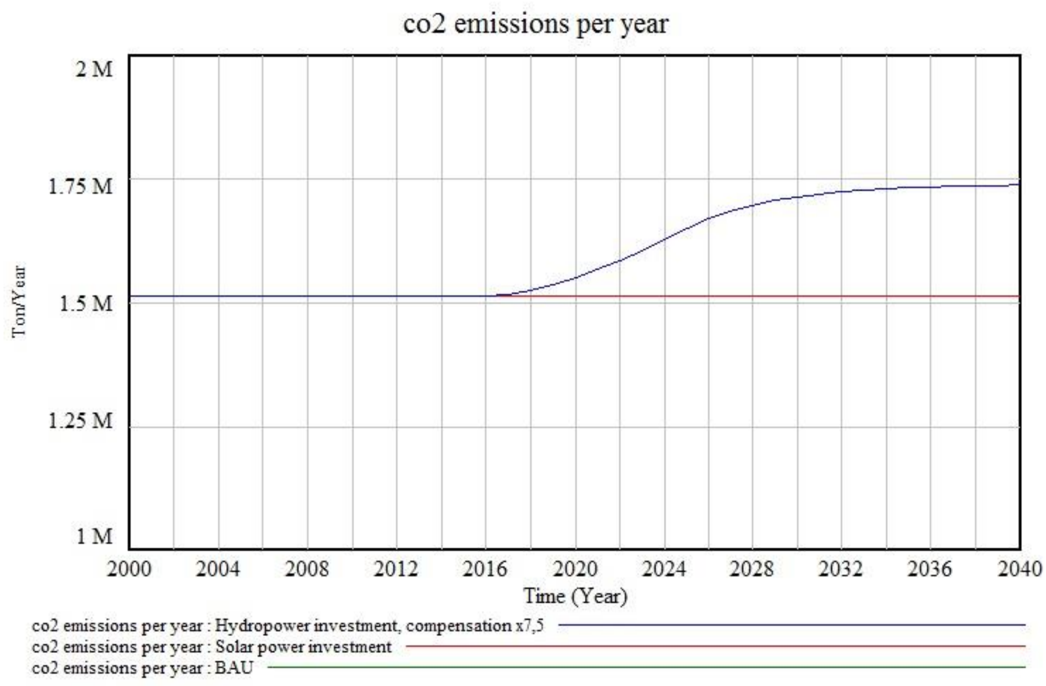


Figure 74: "CO2 emissions per year" Scenario 3: Solar power investment

Graph of "CO2 emissions per year" for three different runs; Blue: Hydropower with compensation, Red: Solar power investment and Green: BAU

The solar power does not emit any CO2 unlike the hydropower. The missions coming from the hydropower are relatively small in comparison with the coal power alternative, however they are still there.

With regards to the environmental factors, the solar power is a superior option to the hydropower option. It is by far the less intrusive option and does not harm the fish stock or deplete the forest like the hydropower capacity does.

6.3.3 Social factors

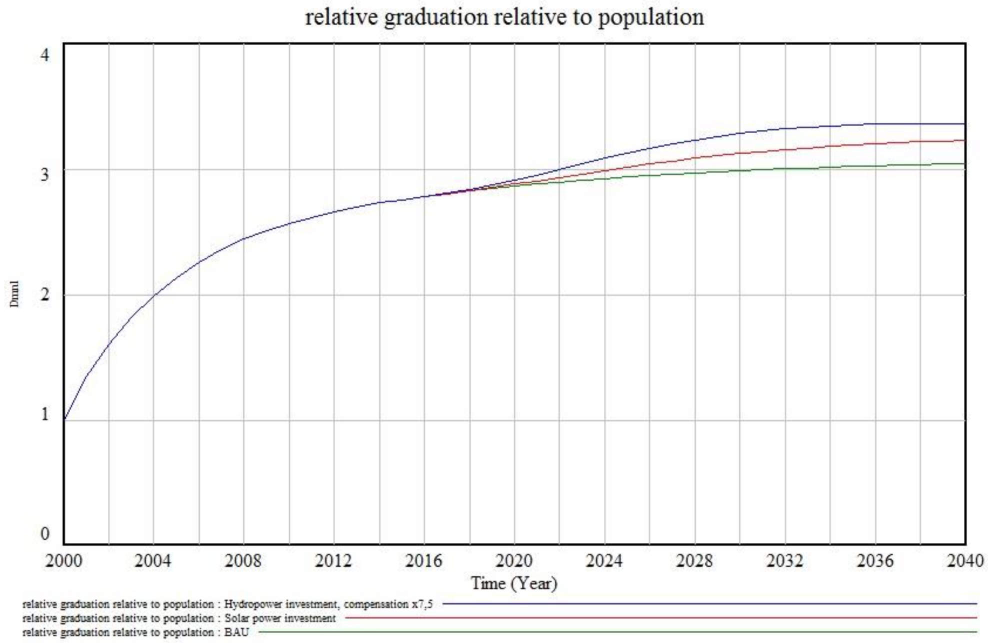


Figure 75: “relative graduation relative to population” Scenario 3: Solar power investment

Graph of “relative graduation relative to population” for three different runs; Blue: Hydropower with compensation, Red: Solar power investment and Green: BAU

The overall graduation rate is lower in the solar power option relative to the hydropower option mainly due to the difference in electricity supply and the subsequent difference in the GDP. However, the graduation rate does increase with about 6% relative to BAU by the year 2040, compared with 10.5% in the hydropower option of the same year compared to the BAU.

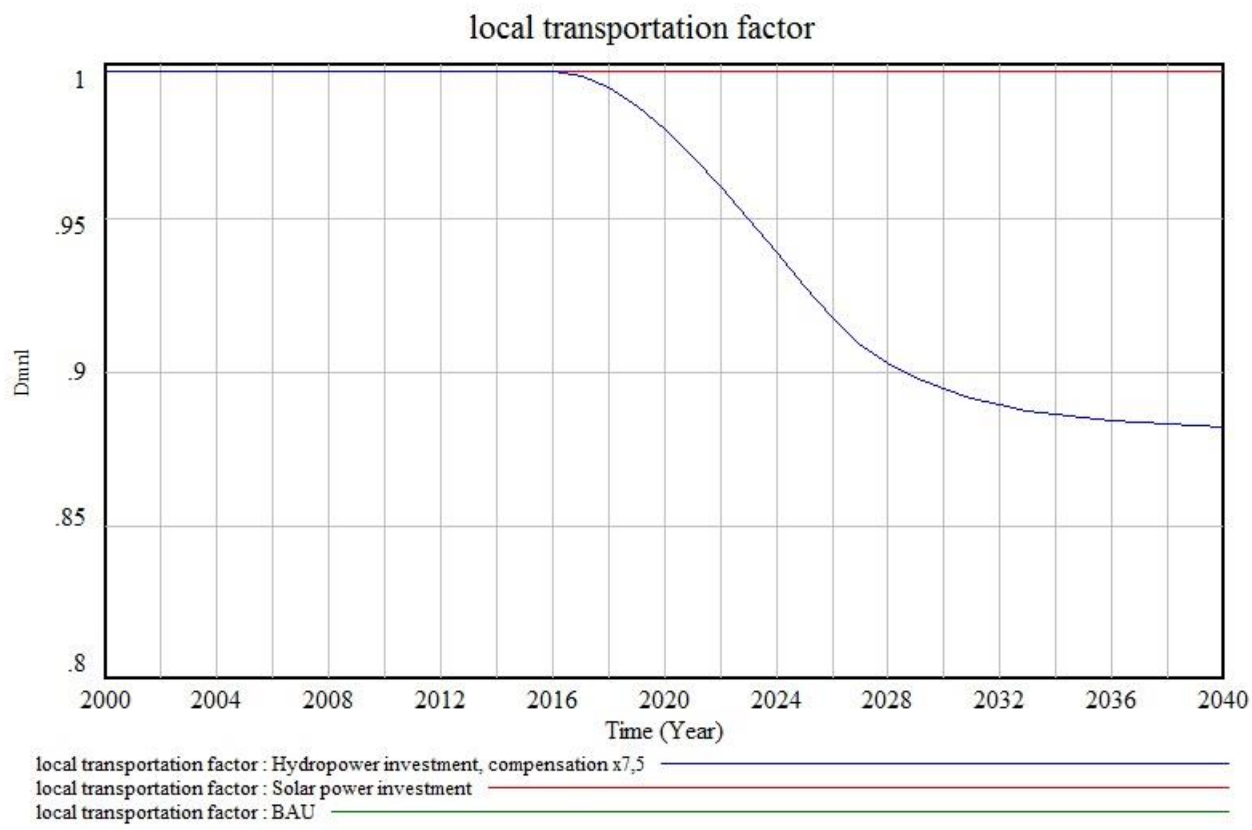


Figure 76: "local transportation factor" Scenario 3: Solar power investment

Graph of "local transportation factor" for three different runs; Blue: Hydropower with compensation, Red: Solar power investment and Green: BAU

Like in the case of the fish migration and the fish stock the rivers are not directly influenced by the solar power capacity and thus it does not impede the transportation along the river. Therefore, the local transportation factor does not change. This is a positive for the local population that can continue to enjoy the benefit of a free flowing and open river.

6.3.4Health

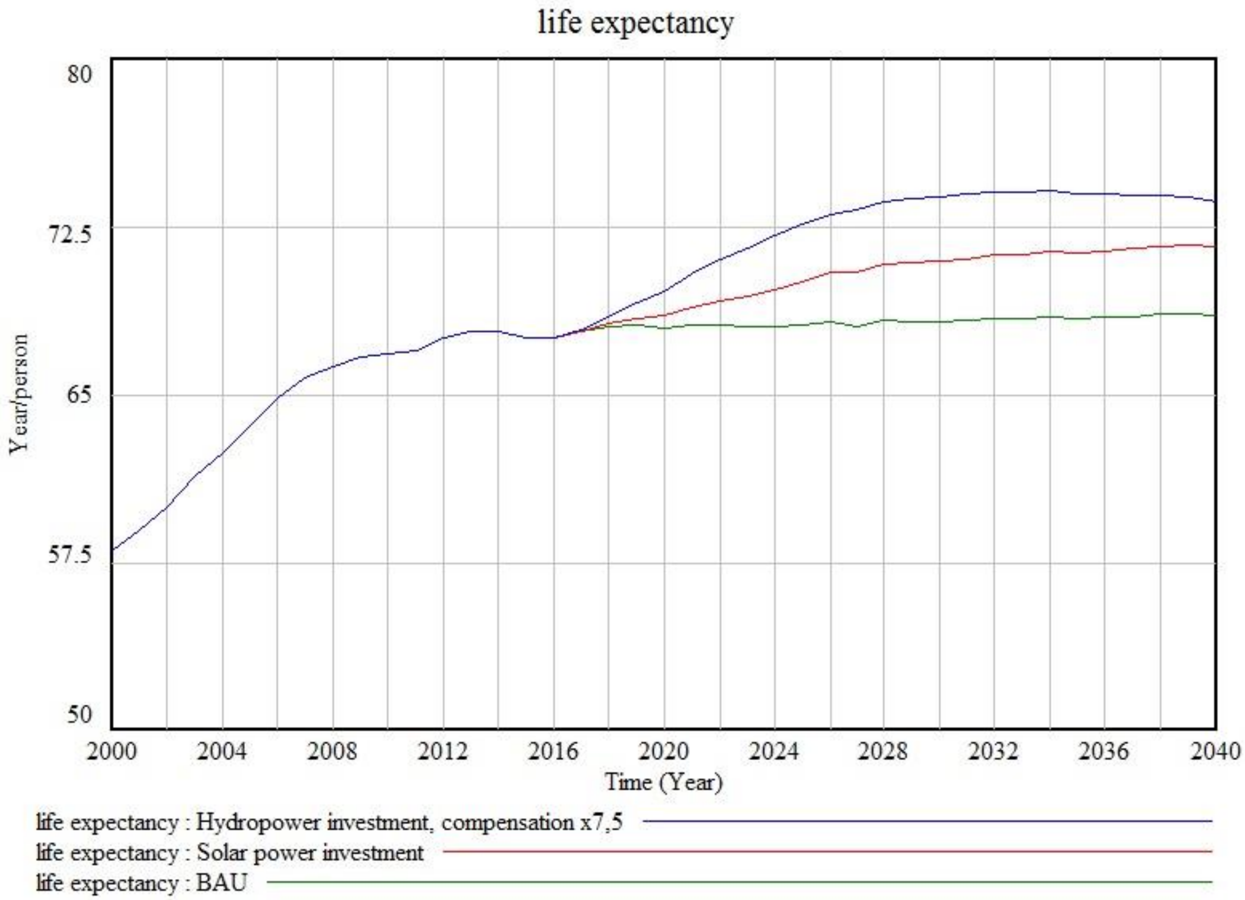


Figure 77: "life expectancy" Scenario 3: Solar power investment

Graph of "life expectancy" for three different runs; Blue: Hydropower with compensation, Red: Solar power investment and Green: BAU

The life expectancy does not increase as much in the solar power scenario as it does in the hydropower scenario. In both cases, it increases due to the increased supply of electricity and the increase of the GDP. Again, the difference between the two scenarios has its root in the different cost of capacity per MW. Since solar power is costlier per MW you can afford relatively more capacity when you invest the same sum in hydropower. This has a direct impact on the electricity supply and the subsequent electricity price. A lower electricity price is beneficial both directly and indirectly for the average life expectancy. The direct effect comes through the improvement of indoor air-quality and the indirect effect through the GDP because of an increase in the TFP. The result is clear in the graph above. The electricity price decreases more in the hydropower scenario than in the solar power scenario, and thus the life expectancy increases more.

6.3.5 Associated costs

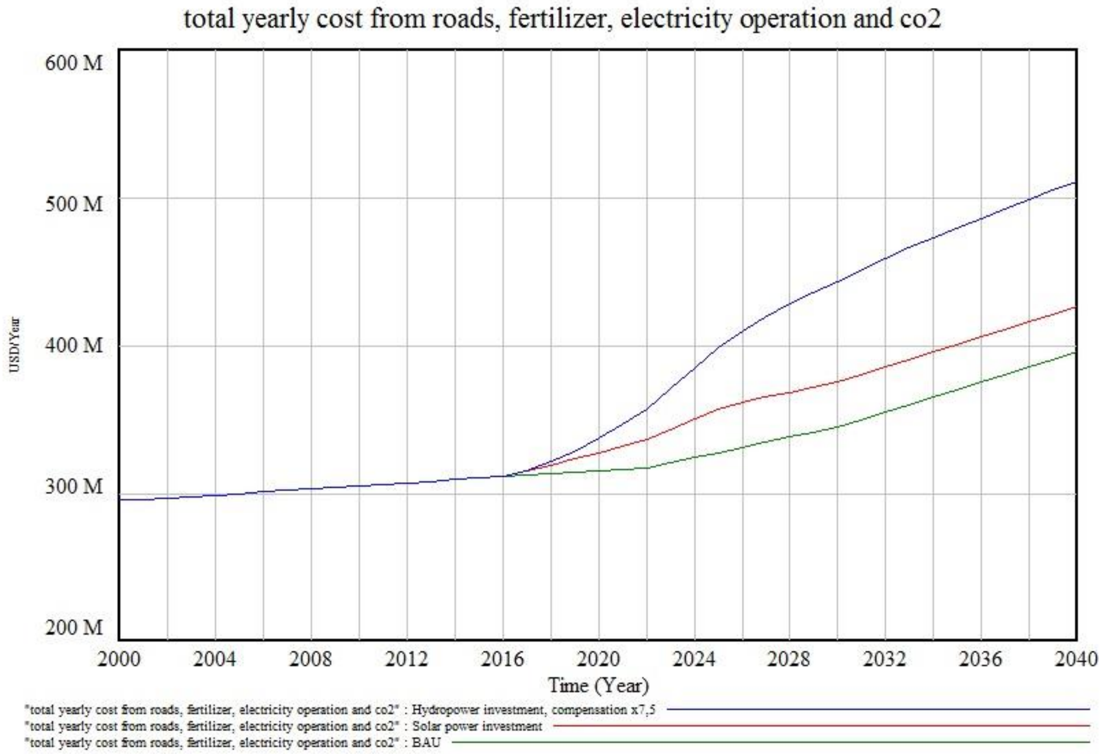


Figure 78: "total yearly cost from roads, fertilizer, electricity operation and CO2" Scenario 3: Solar power investment

Graph of "total yearly cost from roads, fertilizer, electricity operation and CO2" for three different runs; Blue: Hydropower with compensation, Red: Solar power investment and Green: BAU

This clearly show that the operation and running costs of the hydropower is much more expensive in the long run than compared with the solar power option. A small part of this is due to the fact that you have a smaller stock of capacity to maintain. This is due to higher capital costs so that in the solar power scenario you can afford less capacity for the same amount of investment compared with Hydropower. However, this does not explain the whole difference. Hydropower in this case is more expensive because you must compensate for adverse effects in the agriculture sector.

This is the strongest point in the case for Solar power. Despite relatively high initial costs, once installed they are inexpensive to run and has no intrusion on the environment around them except for the land that needs to be cleared where they are installed. However, this is not huge number of hectares, and other generating technologies require just as much, of not more space to operate. Even better, in cities and on settled land where humans already live, solar panels can be installed on rooftops and the like, saving space that otherwise would have to be taken from somewhere. If the problem of flexibility can be solved as previously mentioned solar power has so far only scratched the surface of its potential. In a country, such a Cambodia solar power would be advantageous since it is a country with lots of sun compared with other countries further north.

The following table show the model outputs by scenario. Changes are differences relative to the BAU value.

Name	Scenario	2015	2020	2025	2030	2035	2040
GDP (*USD/year)*	**BAU**	**12347987968**	**15445494784**	**17759885312**	**19566000128**	**21220493312**	**23560380416**
	∆ Solar power investment	*0.00%*	*6.70%*	*26.65%*	*41.69%*	*50.34%*	*57.54%*
	∆ Hydropower Investment, comp. x7.5	*0.00%*	*20.70%*	*70.98%*	*98.58%*	*97.16%*	*80.18%*
GDP per capita (*USD/person/year)*	**BAU**	**813**	**944**	**1007**	**1028**	**1033**	**1062**
	∆ Solar power investment	*0.00%*	*6.68%*	*26.42%*	*41.08%*	*49.32%*	*56.08%*
	∆ Hydropower Investment, comp. x7.5	*0.00%*	*20.62%*	*70.26%*	*96.81%*	*94.56%*	*77.15%*
Crop production (*Ton/year*)	**BAU**	**13028968**	**16087658**	**17457620**	**18105382**	**18548772**	**20036918**
	∆ Solar power investment	*0.00%*	*0.04%*	*1.70%*	*4.54%*	*6.18%*	*7.14%*
	∆ Hydropower Investment, comp. x7.5	*0.00%*	*-0.22%*	*2.79%*	*6.38%*	*6.41%*	*4.40%*
Average electricity price (*USD/(Mw*hour)*)	**BAU**	**530**	**637**	**723**	**795**	**866**	**958**
	∆ Solar power investment	*0.00%*	*-16.66%*	*-40.55%*	*-43.86%*	*-41.85%*	*-39.99%*
	∆ Hydropower Investment, comp. x7.5	*0.00%*	*-41.83%*	*-74.76%*	*-81.73%*	*-82.69%*	*-83.03%*
Forest land (hectare)	**BAU**	**9173380**	**8941638**	**8559188**	**7919267**	**7107452**	**6240860**
	∆ Solar power investment	*0.00%*	*-0.03%*	*-1.15%*	*-3.55%*	*-5.90%*	*-8.52%*
	∆ Hydropower Investment, comp. x7.5	*0.00%*	*-0.16%*	*-4.40%*	*-12.92%*	*-22.61%*	*-33.89%*
Relative sediment flow *(dmnl)*	**BAU**	**1**	**1**	**1**	**1**	**1**	**1**
	∆ Solar power investment	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*
	∆ Hydropower Investment, comp. x7.5	*0.00%*	*-25.89%*	*-67.32%*	*-80.69%*	*-83.43%*	*-84.10%*
Fish stock (Ton)	**BAU**	**9976230**	**8935652**	**8003613**	**7168790**	**6421038**	**5751287**
	∆ Solar power investment	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*
	∆ Hydropower Investment, comp. x7.5	*0.00%*	*-0.83%*	*-16.74%*	*-37.93%*	*-53.77%*	*-65.57%*
Local fish stock (Ton)	**BAU**	**83465**	**73952**	**65522**	**58054**	**51437**	**45574**
	∆ Solar power investment	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*
	∆ Hydropower Investment, comp. x7.5	*0.00%*	*-3.81%*	*-42.62%*	*-71.73%*	*-86.08%*	*-93.15%*
Co2 emissions per year (Ton/year)	**BAU**	**1513771**	**1513771**	**1513771**	**1513771**	**1513771**	**1513771**
	∆ Solar power investment	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*
	∆ Hydropower Investment, comp. x7.5	*0.00%*	*2.43%*	*8.99%*	*13.24%*	*14.46%*	*14.81%*
Relative graduation relative to population (dmnl)	**BAU**	**2.75**	**2.86**	**2.94**	**2.99**	**3.02**	**3.04**
	∆ Solar power investment	*0.00%*	*0.55%*	*2.69%*	*4.61%*	*5.55%*	*6.20%*
	∆ Hydropower Investment, comp. x7.5	*0.00%*	*1.59%*	*6.52%*	*9.89%*	*10.91%*	*10.46%*

Local transportation factor (dmnl)	**BAU**	**0.998**	**0.9978**	**0.9978**	**0.9978**	**0.9978**	**0.9978**
	Δ Solar power investment	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*
	Δ Hydropower Investment, comp. x7.5	*0.00%*	*-1.90%*	*-7.03%*	*-10.36%*	*-11.31%*	*-11.58%*
Life expectancy (Year/person)	**BAU**	**67.1**	**67.6**	**67.7**	**67.9**	**68.0**	**68.1**
	Δ Solar power investment	*0.00%*	*0.82%*	*2.87%*	*3.93%*	*4.29%*	*4.53%*
	Δ Hydropower Investment, comp. x7.5	*0.00%*	*2.38%*	*6.64%*	*8.20%*	*8.13%*	*7.45%*
total yearly cost from roads, fertilizer, electricity operation and co2 (USD/year)	**BAU**	**310312448**	**315473056**	**327755232**	**344785152**	**370140800**	**395496480**
	Δ Solar power investment	*0.00%*	*3.82%*	*8.91%*	*8.87%*	*8.24%*	*7.71%*
	Δ Hydropower Investment, comp. x7.5	*0.00%*	*6.89%*	*21.63%*	*28.36%*	*29.54%*	*29.19%*
Total accumulated investment and running costs (USD)	**BAU**	**4538513920**	**6102957056**	**7703858176**	**9385141248**	**11172357120**	**13086350336**
	Δ Solar power investment	*0.00%*	*6.92%*	*13.30%*	*12.54%*	*11.90%*	*11.33%*
	Δ Hydropower Investment, comp. x7.5	*0.00%*	*7.12%*	*15.07%*	*16.98%*	*18.93%*	*20.47%*

Table 29: Results for Scenario 3: Solar power investment

6.4 Results summary

This section show a summary of the results we have presented and briefly discussed thus far. Here we will compare the three alternatives with each other. First out is a comparison of the GDP.

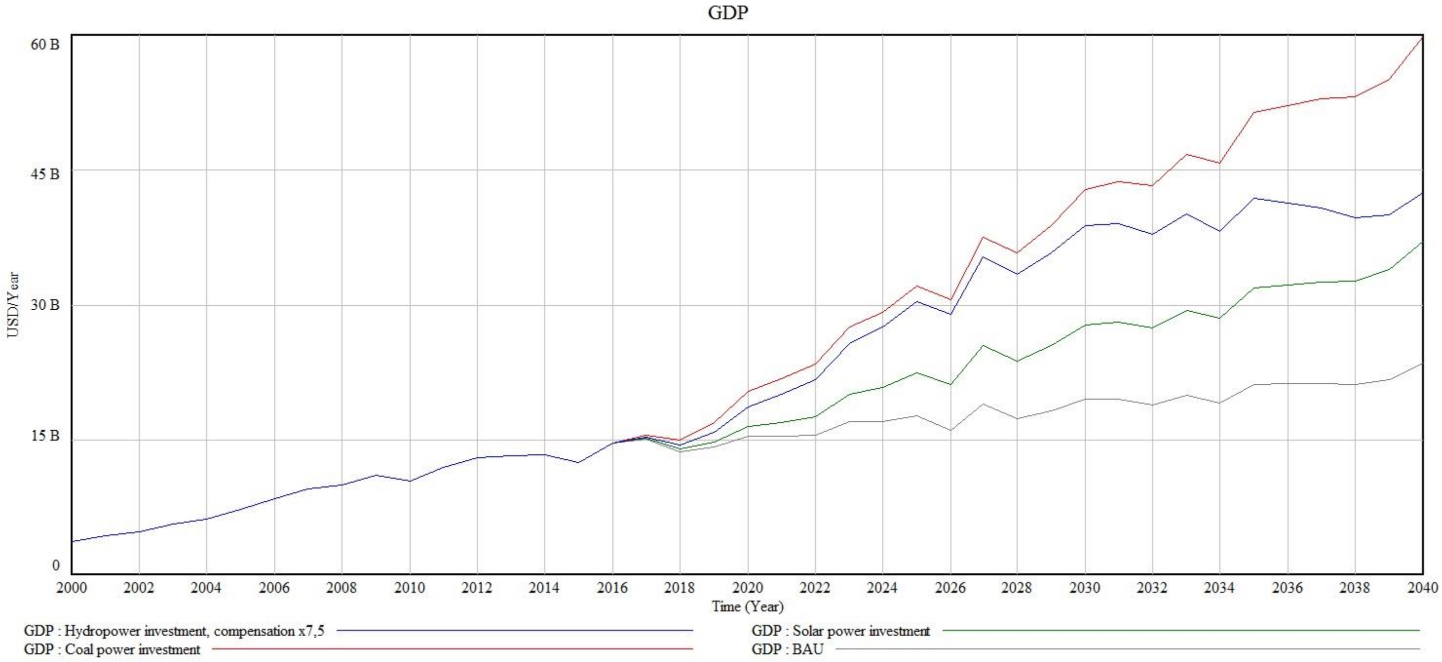


Figure 79: Result summary: GDP

The red graph is the coal power. The blue graph is the hydropower 7.5x comp. The green graph is the solar power. The gray graph is the BAU.

In all cases the GDP increases relative to the BAU as a result of investment in electricity capacity. But the respective capacities bring with different sets of results and consequences, offsetting their comparative advantages compared with each other. For a given amount of investment coal power is the technology that causes the greatest growth in GDP, but we have seen it is also the technology with the highest running costs of the three due to it s need for coal fuel to operate. It also causes some adverse effects on health and the surrounding environment driving up externality costs. The hydropower is the alternative that gives the second highest result in GDP. It has lower yearly running costs than coal and this is a big plus. One set up it only requires maintenance, no fuel needed. The same is true for Solar power. However, the hydro have severe adverse effect on the local fish stock and blocks transportation along the river. The solar power is the least intrusive on the environment of the three and cost the least to run and operate on a yearly basis once installed, but it is costly to install and it is dependent on sunlight thus lacking flexibility for hours lacking sun. Due to the higher capital cost per MW you get less effect for the same given amount of investment, and that is why Solar power end up as the alternative that causes the least increase in the GDP.

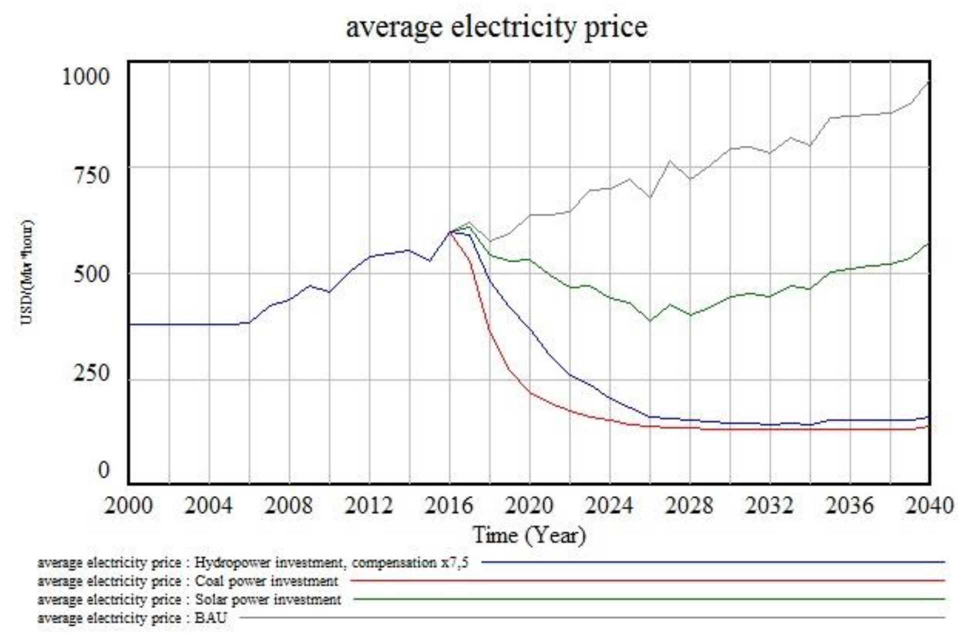


Figure 80: Result summary: electricity price

The red graph is the coal power. The blue graph is the hydropower 7.5x comp. The green graph is the solar power. The gray graph is the BAU.

What we have discussed above is also reflected in the development of the electricity price. It is the electricity price that is the underlying driver for much of the economic and social change in this model. That is why the level of electricity capacity is so significant and places the solar power on the lowest score with regards to economic performance when it performs the best of the three other in all other cases, except in life expectancy where it comes in as number two. However, what solar power has going for it that the other more mature technologies does not, is time. With time the prospects are good that the capital cost for solar power capacity will decline and the problems of flexibility will be solved.

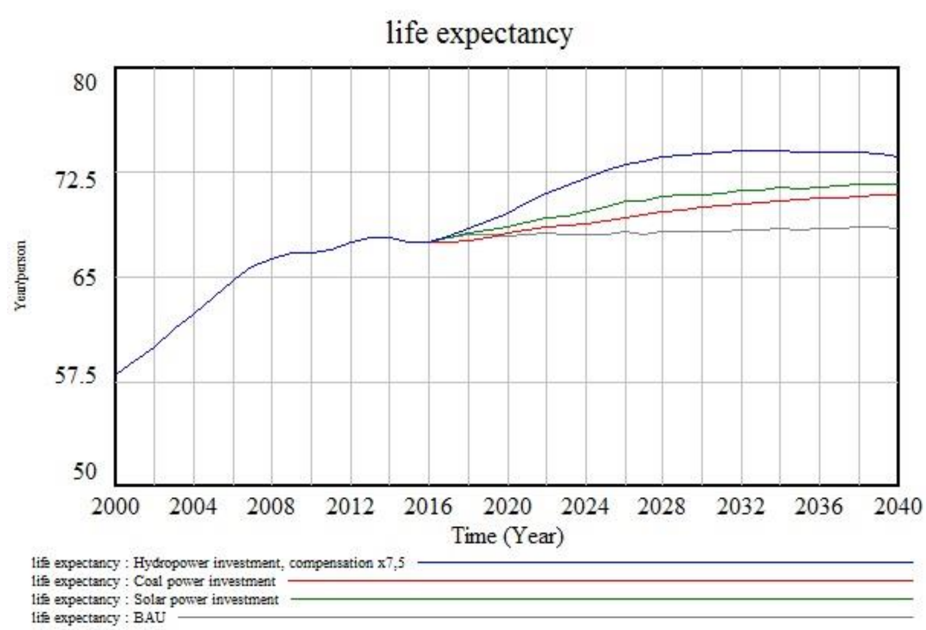


Figure 81: Result summary: GDP

The red graph is the coal power. The blue graph is the hydropower 7.5x comp. The green graph is the solar power. The gray graph is the BAU.

The life expectancy is perhaps one of the most important variable outputs in this model, if not the most important one with regards to human welfare. However, what puts a huge damper on the hydropower success in this regard is the severe effects is causes on the fish stock, especially on the fish stock in the local landscape. This tells us that efforts should be made to find policies that can mitigate these effects to a tolerable level. If this could be achieved then hydropower is a good candidate to be recommended as the best solution. However, as it stands right now with the current results this recommendation cannot be given in good faith. Regardless, it is still up to decisionmakers to decide.

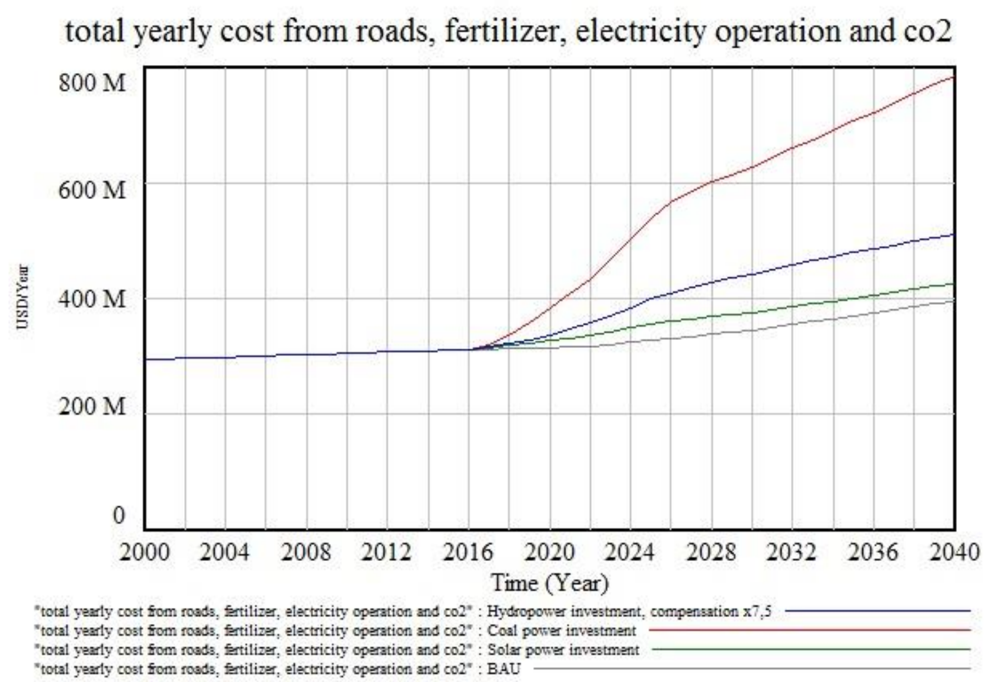


Figure 82: Result summary: Total yearly cost from roads, fertilizer, electricity operation and CO2

The red graph is the coal power. The blue graph is the hydropower 7.5x comp. The green graph is the solar power. The gray graph is the BAU.

This result is the main argument against the coal power option and the main argument in favor of the solar power. The hydro comes in as a good number two in the regard, despite having to compensate for the adverse effects in the agriculture sector.

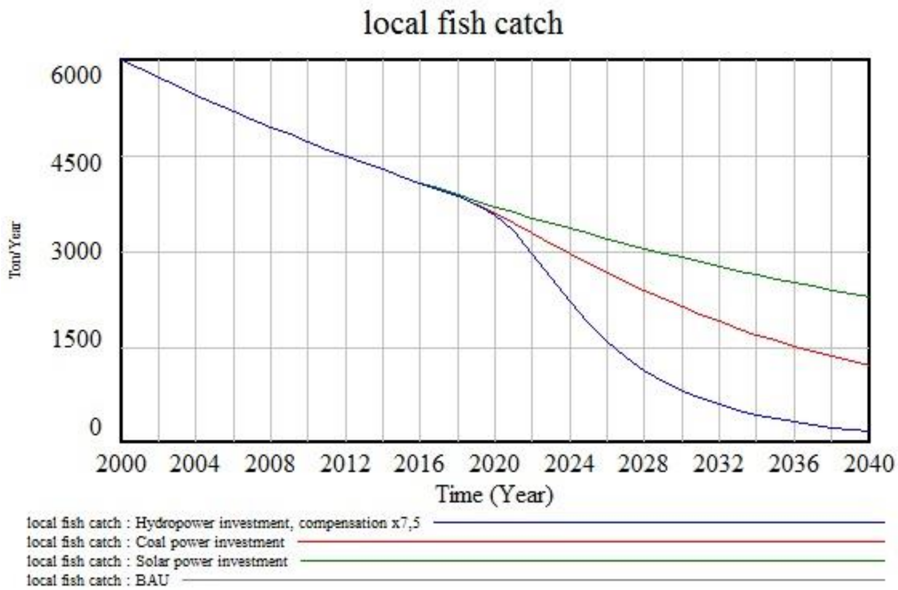


Figure 83: Result summary: local fish stock

The red graph is the coal power. The blue graph is the hydropower 7.5x comp. The green graph is the solar power. The gray graph is the BAU.

This graph show the pitfall of the hydropower sector. This is the "Achilles heel", the single point of failure, for the hydropower. The social and the environmental costs of this policy is so severe that it should be avoided. The model may show a too severe result in this scenario, however a 10% improvement does not save the fish stock. Even at a 50 % improvement of this result would still put it below the coal power alternative, and still threaten the fish stock in the year 2040 and beyond.

7. Discussion

One of the main concerns that I have that was uncovered by this model is the archetype of a system behavior called "worse before better".[77] This was uncovered by the hydropower investment policy without any compensation. In fact, this was my original hydropower investment run. Only after discovering, and building confidence around the validity of this result, did I seek out a mitigating policy. In my opinion the hydropower investment alternative is unfeasible without such a compensation policy. And that policy only compensates for the effect on erosion and agriculture productivity, and not for the effects on the fish stocks. We should always be aware and watch out for archetypes such as "better before worse". This is a sweet honey trap that it is easy to fall

[77] https://www.systemdynamics.org/DL-IntroSysDyn/bwb.htm

into. At first the results may seem fine, even better than fine, and this encourages even more of the same behavior, further increasing the consequences of the coming collapse.

Another issue, but related to this problem of the archetype is the issue of "center and periphery".[78] The dynamics of center and periphery does not only relate to issues between developed and developing countries (Wilson O. Simon 2011), but also between periphery and center within the context of a country. The center is typically represented by the Capitol and nearby urban clusters. This is a separate issue in and of itself. But put together with the archetype of "better before worse", the periphery and center dynamics can reinforce and increase the magnitude of the impending collapse caused by the underlying mechanics of the "better before worse" archetype.

To give this a hypothetical scenario of the dynamics of "center-periphery" coupled with "better before worse"; central government and contractors not belonging to the region may have vested economic interest in exploiting natural capital and developing hydropower dams for the production of cheap electricity. The center, in this case represented by the national government and contractors, possess the necessary authority, technical capacity and economic resources to initiate such a project, without the periphery, in this case the local population in Kratie and Stung Treng, in the first place being aware of the plans and secondly capable of safeguarding their own interest.

Thus, decisionmakers without a stake in the future of the region can unhindered move forward with seemingly lucrative and beneficial plans, that on the paper should benefit the entire nation with the supply of electricity. Once the first dams begin to produce electricity and generates benefits, this translates into increased returns and more investment of the same type, placing further stress on the local ecology and way of life.

However, being in the center and far removed from the consequences, decisionmakers are not sensitive to initial signs of distress and being more aware of the benefits that are ticking in. Thus, they have every incentive to continue their "formula of success". Coupled with low sensitivity of local signals and consequences there is a time delay before effects from the periphery are felt in the core, and in worst case irreparable damage has already been made before counter measure is taken.

This archetype is driven by a shift in dominance of the underlying system structure. In my model this has directly to do with the loop coming from the electricity price and the loop coming from crop production. For as long as the electricity price keeps on falling everything seems nice, masking the negative effect coming from the fall in crop production. The initial fall in crop production starting already in the year 2016 is small and has just a marginal impact in the *GDP* and the rest of the system. The change in electricity price however is immediately sharp causing a huge initial gain in *GDP*. This fit well with our intuition that the construction of a dam would not cause immediate collapse in the agriculture, but gradually increasing decline. When it comes to the electricity price a sharp decline in price because of sudden increase in supply stands to reason of how the electricity market can work. However, as the electricity price starts to flatten out, settling in on a new price level, the relative change in electricity price also slows down, no longer providing an increasing multiplicator to *TFP* and other parts of the model. By this time, the loss of crop production has increased even more, and the losses are no longer marginal. This is when we witness the tipping point of behavior across the system, most pronounced in the *GDP*, but also in other variables such as *life expectancy*. We can take a closer look at these graphs following graph to get a better overview:

[78] http://www.encyclopedia.com/social-sciences/dictionaries-thesauruses-pictures-and-press-releases/centre-periphery-model

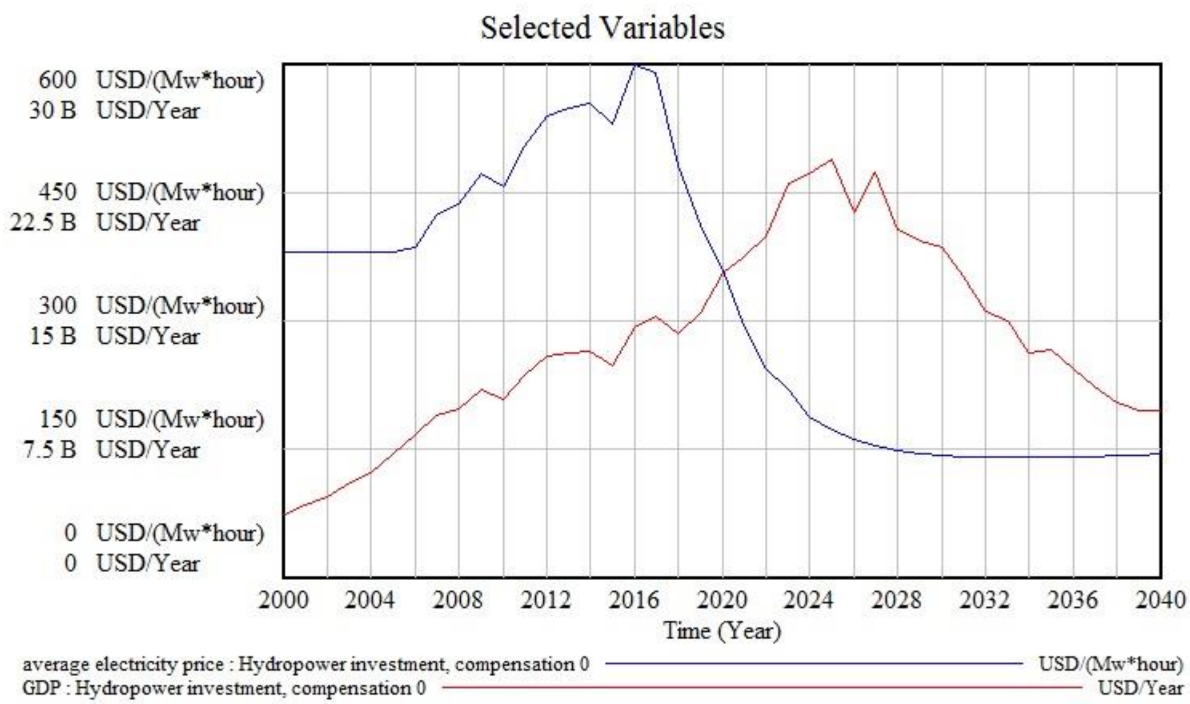


Figure 84: Electricity price – GDP comparison

Here we can clearly see that the tipping point in *GDP* at around year 2026 and the subsequent decline corresponds with the flattening out of the *electricity price* in the same year. Further setting this into context with the graph of the *crop production* below we can see that in 2026 the crop production has fallen significantly down from *BAU*.

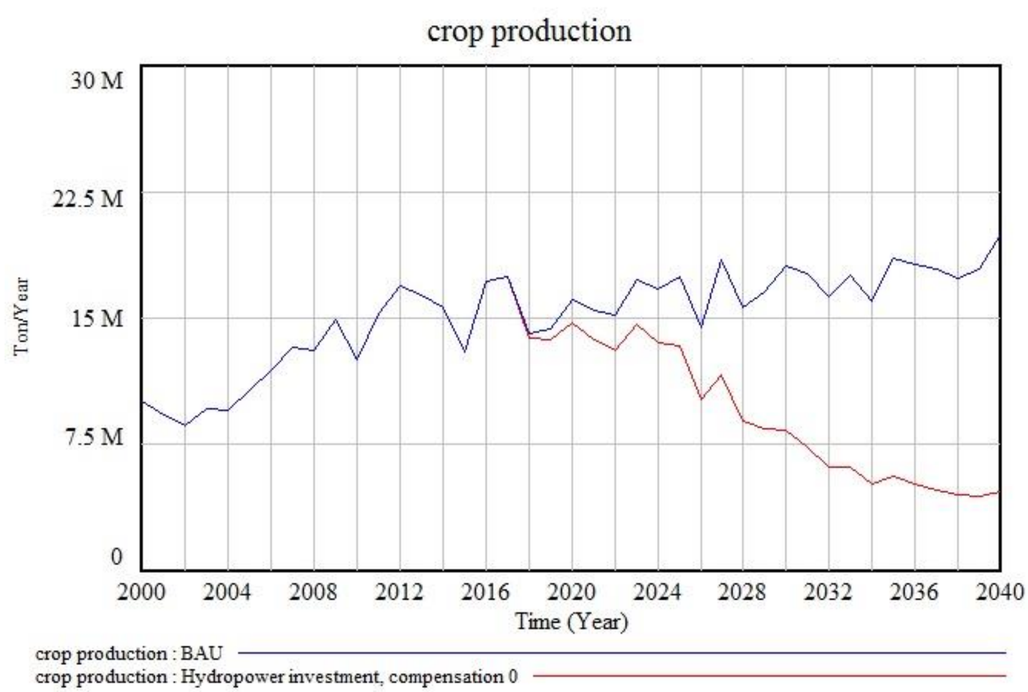


Figure 85: Crop production

An erroneous and dangerous response to such a decline in GDP would be to invest in a new hydropower dam project in order to repeats the initial "success" of the first dam, with the intention to trigger a new period of growth and increase in GDP, treating this as a counter cyclical measure. This would in fact lead to deeper and deeper problems and ecological deficits.

This construction of hydropower can be viewed as liquidation of "natural capital". The initial "quick" gains released by the hydropower dam is like selling off assets to gain cashflow in the short run. You release a "saved up" natural potential formed by nature in an ecosystem over thousands of years. This gains us economic benefits for the duration of a number of years. In the model simulation, this period was from 2016 to 2026 and falling below the BAU in 2030. Such a period can be longer or shorter. However, in the midst of such a period it is hard to see the coming collapse since the whole world is moving in the opposite direction of decline. It can be difficult to notice the warning signs unless one is "tuned in" and aware of underlying structure and causal relations. This brings us back to the initial problem of central/national level on the one side versus the peripheral/local on the other side. This is a conflict we can call for "local" costs and "global" gains. Often the center think or identify its interests as the "global interest". This can quickly lead to costs and benefits being unevenly distributed across the system. Like mentioned earlier, when you sit in the center it can be difficult to stay in tune to the needs and the workings on the local level. This is an argument in favor that leaders should have a stake in the future of the area where the development is taking place.

Not taking the cost and to compensate for the externalities caused by your activities is a de facto wealth transfer from those that experience the externality and those who perpetrate their continued activity. A developer may very likely be unwilling to take on additional costs to pay for compensating measures he does not regard as essential to the continued workings of his operation. This is now a question of governance and authority. Who has the interest and power to enforce long-term and sustainable policy?

One solution is increased autonomy and power to local institutions. Leaders should have "skin in the game" and physically live in the region where the planned development will take place. If those with the authority to make decisions have roots to the landscape and have to live with the consequence of their decision, and not only for themselves but for their descendants as well, then their interest and incentives are geared towards long-term thinking and sustainability.

The capital tradeoffs in my model consist largely of releasing or "liquidating" natural capital in exchange for electricity generating capacity or human welfare. However as discusses above lack of foresight and wisdom can cause a greater loss in human and environmental welfare if ecological factors are not considered.

8. Conclusion

This model and thesis examined the tradeoffs between different types of capitals and the consequences of different policy alternatives with regards to the hydropower and dam construction on the Mekong River in Cambodia. Answering my research questions:

1. "*What are the tradeoffs between Natural Capital and Built-up of capital?"*
2. *"Is there a way to compensate for these tradeoffs in order to ensure sustainable growth?"*

I can say that 1) yes there is a tradeoff between natural capital and built-up capital. And the tradeoff is quite dramatic under certain conditions. You risk the collapse of an entire fish stock locally in the Kratie and Stung Treng region if you are not careful. We also risk increased land erosion and land degradation. However, to answer the second question 2) both of these adverse effects can be compensated for. Fish ladders should be used and more research into making ladders that fist the right type of fish should be made. Contractors should be met with conditions to pay for such research as a part of compensating for the externalities they inflict upon the local population through their activities. Also, the use of fertilizer programs and irrigation should be paid by those who benefit from the hydropower development since this is a part of the total cost. If it is argued that this makes it too expensive to build hydropower dams then perhaps investments should be made in different electricity generating technologies. However, I do not think this is the case since the running costs of hydropower is considerably low and the profit margins are high.

To answer question 1 more specifically; the tradeoff comes in the form of increasing hydropower capacity and gaining increased electricity supply on the one hand and on the other hand risk collapse of the local fish stock, the loss of natural fertilization from sedimentation, increased erosion rates that will lead to the clearing of more forest and the blocking of rivers for local transportation. If this is not compensated for, then it is my conclusion that it is not worth to go through with the plans for hydropower dam construction. Then one is better off investing in coal power, which has a whole list of problems of itself. With compensation and mitigation so that the losses in the fish stock is not so severe, then I would be in favor of the hydropower alternative. In an ideal world, however I would have recommended the solar power option. However, I realize that this might be too costly an option when nearly the double amount of hydropower or coal power capacity can be constructed by the same level of investment.

Reflections and lessons learned

Looking back at when I embarked on this journey that became this thesis and model that you have before you right now I can say that I am not the same modeler I was then as I am now. It is hard to put into exact words what I have learned when a whole summer cannot be summed up by a sunny day. However, I shall make an effort.

I have discovered how important it is to have a proper point of departure when starting a modeling process. This is not a linear process that will take from point A to B. But a series of revisiting old places only discover them in a new light. Reevaluating assumptions as you go have though me to be flexible as a modeler, since the initial idea you have about a system is usually wrong, if not entirely.

I started by modeling the electricity generating technologies at the very first in the process having a large focus on hydropower dams, since this was the question in mind. Only later did I discover that this was far from the most important aspects when engaging in such sustainable project like this. Now I would have begun with the landscape or with the fish stocks. The hydropower dams are only secondary to this from a modeling point of view. When I began the process, I was modeling towards a goal, hoping to uncover the goal by enough effort. Instead I came to realize that you need to start in the center and go outwards, not the other way around.

When you build a model both you and your model need a center of gravity to build around. For me this became the GDP sector, and later on also the agriculture sector. I have also learned to set limits for myself and the modeling process, since one can continue modeling and searching for more details without limit.

I have also learned to become my own boss throughout this process, to set deadlines and conditions of quality of the work. I have become both more confident and humble at the same time with regards to my skills as system dynamics practitioner and as a man in general. This does not sum up everything. But it will do.

References

Abel, N., et al. (2006). "Collapse and reorganization in social-ecological systems: questions, some ideas, and policy implications." Ecology and Society **11**(1): 17.

Barlas, Y. (1996). "Formal aspects of model validity and validation in system dynamics." System Dynamics Review **12**(3): 27.

BBC (2012). "Solutions sought to end use of kerosene lamps." from http://www.bbc.com/news/business-18262217.

Carolina Boix-Fayos, J. d. V., Mar´ıa Mart´ınez-Mena, Gonzalo G. Barber´a, and V´ıctor Castillo (2008). "The impact of land use change and check-dams on catchment sediment yield." HYDROLOGICAL PROCESSES.

David R. Montgomery (2007). "Soil Erosion and Agricultural Sustainability." PNAS.

DEBORAH A. CLARK, D. B. C. (1999). "ASSESSING THE GROWTH OF TROPICAL RAIN FOREST TREES: ISSUES FOR FOREST MODELING AND MANAGEMENT." Ecological Applications.

Des E. Walling (2008). "The Changing Sediment Load of the Mekong River." Springer on behalf of Royal Swedish Academy of Sciences.

Energypedia (2016). "Cambodia Energy Situation." from https://energypedia.info/wiki/Cambodia_Energy_Situation.

European Environment Agency (2011). Industrial air pollution cost Europe up to €169 billion in 2009, EEA reveals. Copenhagen, Denmark, European Environment Agency,.

Fearnside, P. M. (2004). "Greenhouse gas emissions from hydroelectric dams: Controversies

provide a springboard for rethinking a supposedly “clean” energy source." Climatic Change: 1-8.

Graeme Blair, N. B. (2010). Soil fertility constraints and limitations to fertilizer recommendations in Cambodia. World Congress of Soil Science, Soil Solutions for a Changing World. Brisbane, Australia.

Hawken, P., et al. (1999). Natural Capitalism: Creating the Next Industrial Revolution, JSTOR.

ICEM, A. (2010). MRC Strategic Environmental Assessment (SEA) of hydropower on the Mekong mainstream. Hanoi, Viet Nam, ICEM, Australia.

Icopal (2016). "Nitrogen Oxide (NOx) Pollution." from http://www.icopal-noxite.co.uk/nox-problem/nox-pollution.aspx.

IED (2009). Sustainable Rural Electrification Plans for Cambodia, Innovation Energie Développement.

International Energy Agency (2010). "Power Generation from Coal." COAL INDUSTRY ADVISORY BOARD.

Leung, J. S. M. (1977). "Cigarette smoking, the kerosene stove and lung cancer in Hong Kong." British journal of diseases of the chest.

Liu, Q., et al. (1993). "Indoor air pollution and lung cancer in Guangzhou, People's Republic of China." American journal of epidemiology.

Luc Hoffmann Institute (2017). "Mekong Flooded Forest Ecosystem Health Synthesis Report."

LUIZ PINGUELLI ROSA, M. A. D. S., et al. (2004). "GREENHOUSE GAS EMISSIONS FROM HYDROELECTRIC RESERVOIRS IN TROPICAL REGIONS." Climatic Change.

Millennium Institute (2015). "Threshold 21: Integrated development model."

Open Development (2016). "Cambodia, Hydropower Dams." from https://opendevelopmentcambodia.net/profiles/hydropower-dams/.

Poch, K. and S. Tuy (2012). Cambodia's Electricity Sector in the Context of Regional Electricity Market Integration. Energy Market Integration in East Asia: Theories, Electricity Sector and Subsidies,

ERIA Research Project Report 2011-17. Y. Wu, X. Shi, and F. Kimura (eds.)**:** 141-172.

Van Paddenburg, A., et al. (2012). "Heart of Borneo: Investing in Nature for a Green Economy." WWF Heart of Borneo Global Initiative, Jakarta.

Vo Thi Thanh Loc, S. R. B., Le Xuan Sinh, and Nguyen Tri Khiem (2009). "High and low value fish chains in the Mekong Delta: challenges for livelihoods and governance." Springer.

Wilson O. Simon (2011). "CENTRE-PERIPHERY RELATIONSHIP IN THE UNDERSTANDING OF DEVELOPMENT OF INTERNAL COLONIES." International Journal of Economic Development Research and Investment, **Vol. 2** (No. 1): 9.

Worldbank (2016). "Access to electricity." from http://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=KH.

Ziv, G., et al. (2012). "Trading-off fish biodiversity, food security, and hydropower in the Mekong River Basin." Proceedings of the National Academy of Sciences **109**(15): 5609-5614.