EVALUATION OF ALTERNATIVE DEVELOPMENT STRATEGIES FOR PAPUA, INDONESIA:
A REGIONAL APPLICATION OF T21

Matteo Pedercini
Department of Information Science and Media Studies
University of Bergen, Norway
Supervisor: Professor I. Pål Davidsen
Acknowledgments

I am very grateful to the institutions that supported this work, the Information Science Department at the University of Bergen, the Millennium Institute and Conservation International.

In particular I would like to thank Professor Pål Davidsen who introduced me to System Dynamics and always encouraged and supported me.

A special thank to Dr. Gerald O. Barney and Dr. Weishuang Qu, for the inspiration and the opportunity they gave me to work in this exciting and challenging field of sustainable development.

I would also like to thank la señorita Arguitxu De La Riva Caballero, for the precious help and moral support, and all the friends that helped with their ideas and comments.

Thanks to my parents, who gave me the best opportunities for education and always motivated me.

Finally, I am especially indebted to Ronan Bellabarba, for editing my work and making it more clear and comprehensible.
INDEX

ABSTRACT .................................................................................................................... 9

1. INTRODUCTION ................................................................................................. 10

1.1 Geography ........................................................................................................ 10

1.2 History ................................................................................................................ 10

1.3 Critical Issues .................................................................................................... 12

1.4 Time horizon ..................................................................................................... 14

1.5 The parties involved in the project ..................................................................... 15

2. THE MODEL ......................................................................................................... 17

2.1 Model Boundaries ............................................................................................. 17

2.1.1 Prices, Tax, and Exchange Rates (exogenous) .............................................. 20

2.1.2 Foreign Investment (exogenous) ..................................................................... 20

2.1.3 Government Special Allocations and Foreign Aid Grants (exogenous) ....... 20

2.1.4 Routine Expenditure (exogenous) .................................................................. 20

2.1.5 Fishery Production (exogenous) ..................................................................... 21

2.1.6 Indonesian GDP and World Economic Trends (excluded) ......................... 21

2.1.7 Cross Border Pollution and World’s Climate Change (excluded) .............. 22

2.1.8 Corruption and People Political Feelings (excluded) ................................. 22

2.1.9 Mineral Resources Limitations ....................................................................... 22

2.1.10 Aggregated Demand ..................................................................................... 22

2.2 Overview of Model’s Characteristics ................................................................ 23
2.3 Overview of the Core part of the model........................................ 28
  2.3.1 Population, Births and Life Expectancy sectors ......................... 29
  2.3.2 Industry, Mining and Service......................................................... 31
  2.3.3 Agriculture, Forestry and Fishery ................................................. 33
  2.3.4 Investments ....................................................................................... 36
  2.3.5 Technology ......................................................................................... 37
  2.3.6 Employment ....................................................................................... 38
  2.3.7 Government ......................................................................................... 40
  2.3.8 Education ......................................................................................... 43
  2.3.9 Land ................................................................................................. 44

2.4 Special sectors: a necessary expansion of T21 .............................. 46
  2.4.1 Dam Physical Structure and Demand .............................................. 49
  2.4.2 Dam Impact on Production Activities .............................................. 57
  2.4.3 Dam Economic Costs and Revenues .............................................. 61
  2.4.4 Dam Impact on Labour Force and Forest ...................................... 63
  2.4.5 Highway Physical Structure ............................................................ 66
  2.4.6 Highway Impact on Production activities ...................................... 72
  2.4.7 Highway and Logging ..................................................................... 74
  2.4.8 Highway related Employment ......................................................... 79
  2.4.9 Highway Economic Costs ............................................................... 82
  2.4.10 Pollution ......................................................................................... 86
  2.4.11 Small Credit and Government Borrowing .................................... 92
  2.4.12 Training .......................................................................................... 97
  2.4.13 Workers Migration and GNrP ......................................................... 99
  2.4.14 Effects on Life Expectancy ............................................................ 104
  2.4.15 Indicators ....................................................................................... 109

3. MODEL VALIDATION ................................................................. 113
  3.1 Introduction ....................................................................................... 113
3.2 Structure tests ................................................................. 114
  3.2.1 Structure Confirmation Test ........................................ 114
  3.2.2 Parameter Confirmation Test ....................................... 115
  3.2.3 Dimensional Consistency Test ..................................... 118
  3.2.4 Behaviour Pattern Test ............................................. 119
  3.2.5 Sensitivity Analysis .................................................. 123

4. SCENARIOS DESCRIPTION AND ANALYSIS .......... 127

4.1 Base Case Scenario .......................................................... 131
  4.1.1 Description .............................................................. 131
  4.1.2 Results ................................................................. 134
  4.1.3 Preliminary Comments on the Results produced .......... 148

4.2 Big M Scenario .............................................................. 150
  4.2.1 Description .............................................................. 150
  4.2.2 Results ................................................................. 154
  4.2.3 Preliminary Comments on the Results produced .......... 174

4.3 More Roads Scenario ..................................................... 177
  4.3.1 Description .............................................................. 177
  4.3.2 Results ................................................................. 180
  4.3.3 Preliminary Comments on the Results produced .......... 203

4.4 Urban Scenario ............................................................. 205
  4.4.1 Description .............................................................. 205
  4.4.2 Results ................................................................. 209
  4.4.3 Preliminary Comments on the Results produced .......... 227

5. CONCLUSIONS ............................................................ 229

5.1 Base Case Scenario .......................................................... 229
Abstract

Irian Jaya, the Western part of the island of Papua, is a region characterised by a huge territory, a small population and an incredible abundance of natural resources. Precious metals, natural gas, oil and rich primary forest make this area a potential thriving ground for many production activities.

After a period of transition from a centralised to a decentralised form of government, the region is now facing a delicate moment in its growth. The present choices and the politics of the local government will dramatically influence Papuan’s development chances. The danger is that the expanding economic activities will be conducted with little regard for the precious, and largely undisturbed, natural environment that still exists in Papua. The biggest challenge faced is how to manage the production of resource based products while protecting the environment.

The objective of the work described in this thesis is to identify a developmental path for Papua that would generate a real increase in local people’s quality of life and guarantee a proper use of natural resources. In other words, we searched for a more long-term sustainable alternative to the development plan than the one that the Government of Papua is actually undertaking.

Given the multisectoral and multidisciplinary nature of the issue investigated, (our client and) we decided to use a System Dynamics model, the Threshold21 (T21), to support our analysis. A special version of T21 has been created, portraying the specific characteristics of the socio-economic-environmental system of Papua.

In order to demonstrate that, under certain conditions, a development plan that can generate better results in terms of local people’s income and resources conservation was possible, we ran, analysed and compared four different scenarios.

From the analysis carried out, we concluded that a more long-term sustainable alternative to the present regional development plan exists, and we recommended in particular one of the strategic plans analysed.
1. INTRODUCTION

Before describing the most problematic aspects of development in Papua that moved our clients and us to undertake this project, a brief summary of the main characteristics of the country and its history are necessary to have a complete picture of the issues being analysed.

1.1 Geography

Comprising the western half of what is widely known as New Guinea Island and its many offshore islands, Papua, or Irian Jaya, is Indonesia’s largest province. Located between the equator and ten degrees latitude south, Irian Jaya represents one of the world’s most incredible varieties of ecosystems, landscapes and climates. The 5000 meter high snow-capped mountains and the many thousand kilometres of tropical coastlines represent the most extreme and contrasting aspects of the rugged 422 sq km surface of the province, which is covered by the world’s second largest tropical rainforest.

Irian Jaya is inhabited by about two million people, of which about 10% live in the capital, Jayapura. Outside the capital, Papuans live in hundreds of tribes, each with its own language and costumes. Irian Jaya is also subject to large numbers of immigrants from other provinces who come to find a job on the island, and for this reason 10% of the population consists of Malayan settlers.

Subsistence farming is carried on and taro, bananas, sweet potatoes and sugarcane are the principal crops. Wild game is also trapped and there is fishing along the coasts and the rivers. These activities, however, account only for a very small part of the regional GDP, which is mainly generated by minerals extractions as well as logging. The province, in fact, is very rich in natural resources such as silver, copper, oil, natural gas, magnetite, nickel, cobalt, and of particular importance, gold, of which Irian Jaya has the world’s largest deposit.

1.2 History

Papuans have occupied the vast island of New Guinea as far back as 40,000 years ago. Early civilisation in the area was strongly influenced by India and dates back to 100 AD.
The first Europeans to sight New Guinea were the Portuguese in the beginning of 1500, whose sighting opened up the way for a series of visits by Spanish, Dutch, German and English explorers. The western portion of New Guinea became a Dutch colony in 1828, after the “Treaty of London”\(^1\) in 1824 shared this part of the Indies between England and the Netherlands. On April 19, 1942 the Netherlands surrendered the island to Japan, which, after a short period of occupation and losing the Asia-Pacific war, relinquished Irian Jaya to the administration of the Allied Forces. The Allies returned the authority to the Dutch government, which resumed development of the island, including establishing administration in the area. In the middle 50’s the newly independent Indonesia and the Dutch administration went through a prolonged diplomatic campaign to decide Irian Jaya’s fate: Indonesia’s desire to win back Irian Jaya was in opposition to the Netherlands’ plans of making it a new independent country. The incompatibility of the two visions led the Indonesian President Soekarno in 1961 to declare Irian Jaya returned to the unitary state of the Republic of Indonesia and start military operations to gain authority of the island. In 1962, to stop the conflict, the two parties agreed to UN administration of West New Guinea, and, pending a plebiscite, a transfer of the territory to Indonesian control. The plebiscite finally held in 1969 showed the will of the majority of Papuans, represented by their tribal leaders, to remain under Indonesian authority and the province was officially renamed Irian Jaya in 1973.

Even though the result of the referendum was irrefutable, a huge part of the population refused the annexation and supported a strong resistance movement. The opposition, already in operation since 1962, led sporadically to large-scale conflicts in the following years, but was repressed continually by army intervention. A last attempt to gain independence from Indonesia was held in 2000, when a congress of Papuan activists declared the province of West Papua an independent state. The action was clearly rejected by the central government, which responded with strong military intervention against the separatists and their supporters. Finally, partly to diminish the tensions between the central government and the independence movement, in 2001 Irian Jaya was granted a limited administrative autonomy. Although to some extent this initiative

\(^1\) This treaty also defined many of present borders of Indonesia
satisfied the separatists’ need of a national identity, there are still strong divisions within the population. In particular, tensions remain between the Papuans (the original inhabitants) and the Malaysians immigrated in Irian Jaya to work for the many foreign extraction and logging companies.

1.3 Critical Issues
As appears clear from the country’s history above, Irian Jaya is a region characterised by a huge territory, a small population and an incredible abundance of natural resources. Precious metals, natural gas, oil and rich primary forest make this area a potential thriving ground for many production activities.
After a period of transition from a centralised to a decentralised form of government, the region is now facing a delicate moment in its growth, as the choices and the politics of the local government will dramatically influence Papuan’s development chances. The way the new government will manage and regulate the inflow of foreign capital, local investment, available resources and the capacity to provide the necessary infrastructures and services will make the difference between mere economic growth in a few profitable sectors and a sustainable development of the region.
Different large-scale investment projects are currently under examination, which mainly concern infrastructure interventions, as the construction of a trans-regional highway network and a series of gigantic hydropower plants. An increase in land concessions for mining, agriculture (palm oil production in particular), and timber production seems to be also among the most likely policies on the government’s agenda.

A traditional economic short-term cost-benefit analysis of the actual possibilities would most likely support opening the country to foreign capital and fully exploiting the resources made available by the government, to sustain the economic growth in those sectors that have a comparative advantage with respect to other regions of Indonesia or neighbour nations.
The risks in which the region can easily occur following this kind of policies are numerous, as we learn from many other developing countries experiences. Detrimental outcomes possible include a huge environmental impact, the appropriation of natural
resources by foreign companies with little benefit for local people, the disruption of indigenous cultures and traditional socio-economic activities, among many others.

Actually, Irian Jaya is already partly facing these problems. The resource exploitation policies that characterised the past regimes, in fact, had a dramatic effect in eroding the forest cover on the island and left Papuans with the highest rate of poverty and the lowest levels of Human Development Indicators (HDI) in the whole country. Minerals, oil and gas resources have also been fully exploited, but very little of the production’s value has stayed in Papua to benefit local people.

Conservation International (CI), an American NGO involved in conserving the Earth’s living natural heritage and its biodiversity which already has been operating in Indonesia since 1990, is particularly interested in the social and environmental aspects of the development of this region. Faced with a lack of adequate tools and perspectives to address the problems described above and fearing that policy decisions under consideration would likely worsen the situation in Indonesia, CI contacted the Millennium Institute (MI) for support in conducting a more comprehensive analysis of these issues. The ultimate purpose of such study is to reach out to decision makers and parliamentarians in Papua and to evaluate jointly various possible development strategies’ impacts on the socio-economic-environmental system of the region.

The question we (MI) have been asked by our clients (CI) may be summarized as the following:

*How can we identify a developmental path for Papua that would not only generate a real increase in local people’s quality of life, but would also guarantee a proper use of natural resources and guarantee the conservation of flora, fauna and ancient civilisations which comprise the rainforest ecosystem?*

In order to consider these critical aspects, which cannot be addressed by the traditional macroeconomic analysis, in the planning process for the future of the country another kind of approach to the analysis of the problem is required. A framework becomes
necessary that can incorporate the economic, social and environmental analysis of the country’s situation and its possible developmental paths. Such a tool would demonstrate to decision makers the impacts of a specific policy, for example, on forests, education levels, access to clean water or real economic benefits to local inhabitants. The Millennium Institute’s T21 framework has been found to be a rigorous tool for conducting such analysis and was therefore adopted as the reference modelling structure in the study.

Using this approach we were able to create a series of policy scenarios, following the suggestions of our clients and their skilled and experienced staff working in Papua. These scenarios represented some of the most likely strategies the local government might follow in the next few years. We then simulated them and compared the results to a base case scenario in which all the current policies and ongoing projects were projected into the future. From these comparisons and from an analysis of the determinants of the observed behaviours we finally derived some important policy recommendations.

### 1.4 Time horizon

Given the characteristics of the issues motivating our study, we decided to set a time horizon for the analysis of 25 years, from 1995 to 2020. We took this decision to respond to two different requirements: to go back in time sufficiently to reproduce the actual causes of the observed problems, and to go far enough into the future to be able to observe all the effects of the policy scenarios we desired to test.

In the seven years from 1995 and 2002, we are able to observe all the dynamics considered of interest in the behaviour of our critical variables, as well as to trace out their actual causes. In addition, it would be extremely difficult to extend the simulation farther back in time, as data series for most of the crucial variables before 1995 are nearly impossible to gather.

On the other hand, projecting the model’s results into the next 18 years, far greater than the longest delay involved in the system, guarantees the possibility of correctly monitoring the results of governmental action on our major indicators. Moreover, we thought that while this time horizon is certainly enough for the purpose of our analysis, a longer horizon could have risked losing its focus on the current issues analysed.
1.5 The parties involved in the project

The Millennium Institute (MI), with which the author has been collaborating for this specific project, is an American NGO devoted to supporting policymakers in understanding the long-term consequences of their choices and identifying suitable paths to sustainable development.

MI has developed and implemented in several countries an integrated computer developmental model, the Threshold21 (T21), which can support comprehensive socio-economic-environmental analysis and integrated policy planning. The detailed description of the framework’s characteristics is reported in the following chapter.

The “direct” client of MI in this project is Conservation International. Although CI asked the Millennium Institute to implement a version of T21 for Papua, Indonesia, the final, or “indirect”, client of the study is the local government of Irian Jaya, whose behaviour we intend to influence.

The work was carried out through a series of meetings with Conservation International, to identify both goals and problems of the analysis, and to elicit knowledge from CI’s field staff about the characteristics of the system we wanted to describe.

Extensive consultations with CI experts were also integrated with discussions about the reliability of the data gathered in the field. Data collection at the local level was particularly difficult, and CI staff involved worked ceaselessly to supply a consistent database that significantly contributed to the development of this innovative model.

Weishuang Qu, Director of Modelling, John Shilling, macroeconomic modelling specialist and trustee of the Institute, and the author Matteo Pedercini constituted the Millennium Institute’s team working on the project. Weishuang Qu and John Shilling worked on the core of the model and managed meetings and the many inputs from the clients, and the author mainly worked on the creation of the new model’s sectors and special adaptations of existing sectors to represent the unique characteristics of the region and particular scenarios. In the following pages, therefore, even though the focus of the
study will be the model as a whole and the different behaviour it generates, particular attention will be paid to describing new sectors and modifications introduced by the author, as well as their importance for the results obtained.

Note
As the reader will note, in the following chapters the author uses alternatively “we” or “I to specify the subject that introduced certain assumptions or structures in the model. It is important to point out that when the author uses “we” in the description of the core sectors of the model, it should be understood as “Weishuang Qu, John Shilling and the author”; in the rest of the manuscript, “we” should be understood as “the client and the author”.
2. THE MODEL

The model, built to represent the dynamic behaviour of the critical issues addressed by our clients and to give them a variety of policy options, is based on the T21 framework, originally developed by the Millennium Institute. Threshold 21 (T21) is a system dynamics national model specifically developed to support policy design that addresses economic, social, and environmental issues. As portrayed in Figure 1, the model addresses three interrelated aspects of a nation, respectively, the society, the environment and the economy. Each application of the model is built around a Core model, a set of general structures that represent the socio-economic and environmental characteristics of most countries. This core may be tailored, parameterized, and initialized to any particular country for which an analysis and policy design is being conducted.

![Figure 1: T21 Structure Overview](image)

This thesis, consequently, does not constitute the typical T21 application. This is the first time that the model is being applied to a single province in a country. For this purpose, it has been necessary to introduce a variety of new model components and modifications of existing ones that we believe constitutes a strengthening of T21 at large.

2.1 Model Boundaries

There are a number of factors that lead us to model Papua as a province separate from the rest of the country. First, there is the regional character of the issues analysed. Though the
challenges Irian Jaya currently faces are certainly affected by some elements outside the province boundaries (such as national policies, political stability of the area, etc.) they are mainly related to the use of local resources and to the quality of life of local people. The mechanisms we traced out to be the key factors underlying the problem behaviour of critical variables were all identified to be associated with the regional level. Policy choices at the regional level, moreover, are supposed not to have any particular effect on the central government’s decisions or on the national economy that could substantially affect the problem behaviour under analysis.

Moreover, Irian Jaya is a world apart from Indonesia. Most of the characteristics observed in the Papuan society, economy, and environment are substantially different from what may be observed in other Indonesian islands, and given the fact that the model uses aggregated data for most of the critical variables, it would have made little sense to make a whole of many different realities that prevail in different parts of Indonesia. Note also that Papua gradually moves towards becoming a completely independent region with his own administrative structures and autonomy over many critical policies to be implemented. The population belongs to a different ethnic group from those of populations of other provinces. They have their own languages and national identity. Immigrants from the rest of the country are considered foreigners and mainly behave as such. They do not tend to integrate in the local society. They typically do not establish a family there, but remit to their original province most of their incomes and leave the island as soon as their economic conditions would allow it, indicating that visitors also consider Irian Jaya as an entity in part separate from Indonesia. For our purpose, therefore, we find it appropriate to consider Papua as such and to apply T21 accordingly for the purpose of analysis and policy design.

The boundary chart presented in Table 1 illustrates the scope of the model by indicating what key variables are endogenously represented, which are endogenous, which have been excluded, and which are considered policy variables. While, in the following sections, we will document fully the system structure underpinning the endogenous variables, it is useful to understand why we decided to
exclude or to treat as exogenous certain variables, and how the model behaviour should be interpreted in view of these limitations.

<table>
<thead>
<tr>
<th>Endogenous</th>
<th>Exogenous</th>
<th>Excluded</th>
<th>Policy Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDrP</td>
<td>Prices</td>
<td>Indonesian GDP</td>
<td>Education</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Expenditure</td>
</tr>
<tr>
<td>GNrP</td>
<td>Tax Rates</td>
<td>World Economic Trends</td>
<td>Health Care</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Expenditure</td>
</tr>
<tr>
<td>Investment</td>
<td>Foreign Investment</td>
<td>Cross Border Pollution</td>
<td>Infrastructures</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Expenditure</td>
</tr>
<tr>
<td>Sectors’ production</td>
<td>Exchange Rate</td>
<td>HIV/Aids</td>
<td>Micro Credit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Expenditure</td>
</tr>
<tr>
<td>Income distribution</td>
<td>Government</td>
<td>Corruption</td>
<td>Prof. Training</td>
</tr>
<tr>
<td></td>
<td>Special Allocations</td>
<td></td>
<td>Expenditure</td>
</tr>
<tr>
<td>Employment</td>
<td>Foreign Aid Grants</td>
<td>People’s Political Feelings</td>
<td>Energy Prices</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interests Rates</td>
<td>Routine</td>
<td>World’s Climate Change</td>
<td>Land Use</td>
</tr>
<tr>
<td></td>
<td>Expenditure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Debt</td>
<td>Fishery Production</td>
<td>Mineral Resources Limitation</td>
<td>Logging Control</td>
</tr>
<tr>
<td>Technology</td>
<td></td>
<td>Aggregated Demand</td>
<td></td>
</tr>
<tr>
<td>Change</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education Level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Cost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation Cost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logging</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pollution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Migrations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Boundary Chart for T21 Papua
2.1.1 Prices, Tax, and Exchange Rates (exogenous)

Prices, Tax Rates, and Exchange Rates are determined by the world economy or the central government. They may include reactions from the Indonesian economy, and are to some extent influenced by the central Indonesian government through their fiscal and monetary policies and by the Indonesian economic structure. There are few ways in which these factors may be influenced by the local conditions in Papua. Consequently, we leave these structures out of the model and consider Prices, Tax Rates and Exchange Rates to be exogenously determined.

2.1.2 Foreign Investment (exogenous)

Foreign investment has been treated as an exogenous variable with the aim of simplifying the model. In fact, foreign investment generally depends on the attractiveness of business opportunities in the region relative to the attractiveness of other regions. To represent this relative attractiveness in the model would require that we establish a reference (alternative) attractiveness. We consider that to be over and above our capacity. The assumption underlying this simplification is that various policies adapted at the regional level will not have any particular effect on the foreign investments rates. (This assumption has been modified for only one scenario).

2.1.3 Government Special Allocations and Foreign Aid Grants (exogenous)

These variables represent inflows of funds outside what are the normal government transfers to the regional budget. They are typically related to some emerging special situations or conditions, which may be seen, from the perspective adopted in this study, as random factors. It would be very difficult to define a causal structure in the model able to endogenously explain the behaviour of these variables. Moreover, these variables are not the focus of our analysis, and they do not substantially contribute the problematic behaviour studied. We decided therefore to treat them as exogenous variables.

2.1.4 Routine Expenditure (exogenous)
Within the many items of expenditure, this is the only one we decided to treat as completely exogenous. The Routine expenditure considers mainly the part of expenditure for administrative staff and services. The amount of resources allocated for routine expenditure is not considered as a policy variable, but we assumed it to grow steadily over time. In other words, we assumed no direct relationship between the type of investment decided by the government and the level of routine expenditure in the following years.

2.1.5 Fishery Production (exogenous)
Fishery production accounts only for a very small part of the regional product, and it is not a sector in which our clients desired to test any specific policies. Moreover, it would have required a considerable amount of time to model it as endogenous. Normally, in fact, to correctly portray this sector, it is necessary to estimate fish stocks behaviour in the regional sea (particularly difficult in open ocean areas). Considering the little benefit we would have had from such huge effort, we decided to assume that fishery production would have keep growing over time following the actual trends, and government policies would not have influenced it.

2.1.6 Indonesian GDP and World Economic Trends (excluded)
The measurement of the impact of that the specific policies introduced in Papua may have on the Indonesian GDP and World Economic Trends, is widely outside the scope of this study. The issues we decided to focus on, in fact, are all regional issues, and our clients are not interested on the effect that the policies locally implemented may have abroad.
In turn, the National GDP and the World Economic Trends certainly play a role on the development of the Papuan regional economy. However, the local government have almost no capacity to influence these external economic variables. We assumed therefore their effect to be constant over time, and we decided to exclude them from our analysis. Moreover, portraying these mechanisms would have probably enlarged the model to a global macroeconomic system, far beyond its initial scope.
2.1.7 Cross Border Pollution and World’s Climate Change (excluded)
Considering the geographical characteristics of the region analysed, the exchange of pollution flows with other regions may only be extremely limited. We assumed therefore that cross border pollution does not have any influence on the local situation, and that any particular activity in Papua would not create a significant outflow of pollution towards other regions. The contribution of human activities on the island to global climate change have been also considered not influential and we assumed that an eventual increase in the average temperature would not have any role in modifying policy decisions in Irian Jaya.

2.1.8 Corruption and People Political Feelings (excluded)
These variables are often very important determinant in guiding local decision makers in their choices. In this case we wanted our clients to test different policies in a neutral environment and just to concentrate on finding an optimal strategy to reach their declared objectives. We thought therefore that introducing these elements would not have been useful with respect to the purpose of the analysis, and we decided not to represent this phenomenon in the model.

2.1.9 Mineral Resources Limitations
Naturally, mineral resources are finite. This clearly implies that extraction activities cannot last forever. We’ve also observed in many circumstances the limitations of mineral resources to be a key element in driving the development of this industry. In Papua, however, considering the abundance of such resources, it has been estimated by local experts that this will not represent a problem for the next twenty years. We decided therefore not to represent the deposit exhaustion mechanism in the model.

2.1.10 Aggregated Demand
Aggregated Demand is not considered in the model as a critical element in driving production and investment choices (except for agriculture and meat production). The decision to exclude this important variable from the analysis is clearly intended to simplify the model, and it seems to us a reasonable approach, given the characteristics of
the Papuan economy. The Papuan industrial production (here also including mining and logging activities), in fact, is mainly directed to satisfy demand of other provinces or countries, and internal demand has very little impact in determining the quantities produced. Services production, besides, accounts only for a minimum part of the total production, and we assumed demand to be always enough to consume the quantities produced.

The decision to study Papuan socio-economic-environmental system separately from the rest of the country naturally implied the necessity of some special modifications to the model’s structure. In particular, to adapt the model to a regional application, we needed to redefine and calculate the movements of population, goods and money between different regions as immigration, exportation and foreign investment. We needed to represent the local government as the main decision making authority, their decision rules and limited policy options. We needed also to modify the administration’s account system and to elaborate special indicators to identify the economic benefits directed to local people only. These and many other innovative features of this T21’s application are extensively described in the model description sections.

2.2 Overview of Model’s Characteristics

The model addresses three different aspects of a nation or, as here, one of its regions; the economy, the society, and the environment, as well as the interaction between them. In reality, the model is composed by many different sectors, and each of them typically refers to economic, social and environmental factors. They are normally adapted (or created when not existing beforehand) to a specific country, and subsequently interrelated to make up the entire national structure.

What follows in Table 2 is the list of the sectors used for the Papuan application of T21. As one may easily guess looking at this table, the sectors are differentiated and named considering what are the key aspects of the region they represent.

Each of these sectors can be described and analysed separately. They are, however, interrelated, - depending on input produced by other sectors and (most of them) producing input to other sectors. They are all linked forming a structure of high degree of
complexity characterised by about 70 stock variables (several of them constituting
arrays), and more than 2500 causal loops. Consequently, such an analysis, sector by
sector, has limited value. The analysis of the model must be one that addresses the model
as a whole.

<table>
<thead>
<tr>
<th>Core Part</th>
<th>Special Sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>Dam Physical Structure and Demand</td>
</tr>
<tr>
<td>Life Expectancy</td>
<td>Dam Impact on Production Activities</td>
</tr>
<tr>
<td>Births</td>
<td>Dam Economic Costs and Revenues</td>
</tr>
<tr>
<td>Investment</td>
<td>Dam impacts on Labour Force and Forest</td>
</tr>
<tr>
<td>Industry</td>
<td>Highway Physical Structure</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Highway Impact on Prod. Activities</td>
</tr>
<tr>
<td>Services</td>
<td>Highway and Logging</td>
</tr>
<tr>
<td>Technology</td>
<td>Highway related Employment</td>
</tr>
<tr>
<td>Mining</td>
<td>Highway Economic Costs</td>
</tr>
<tr>
<td>Employment</td>
<td>Pollution</td>
</tr>
<tr>
<td>Government</td>
<td>Small Credit and Government Borrowing</td>
</tr>
<tr>
<td>Forestry and Fishery</td>
<td>Workers Migration and GNrP</td>
</tr>
<tr>
<td>Income Distribution</td>
<td>Effects on Life Expectancy</td>
</tr>
<tr>
<td>Education</td>
<td>Training</td>
</tr>
<tr>
<td>Land</td>
<td>Indicators</td>
</tr>
</tbody>
</table>

Table 2: Sectors of T21 Papua

The structure that generates the model behaviour is typically one that traverses a number
of sectors of the model offering each of these sector structures to contribute to the
creation of that behaviour. Therefore, though in this chapter of the thesis we will explain
how the different sectors of the model are structured one by one, in the chapter dedicated
to the behaviour analysis we will use a holistic approach. In particular, to do this we will
describe with the use of causal loop diagrams those feedback loops that play a central
role in generating the model behaviour.

In Figure 2 is portrayed a simple subsystem diagram of the model, exhibiting its overall
architecture and offering a qualitative idea about how the different sectors of the model
interact. Each sector has been given a specific colour to identify what kind of variable its
key variable(s) are: grey for economic variables, pink for social variables and green for environmental variables. Moreover, blue colour has been used to indicate the government sectors and the yellow for two important indicators: GNrP and Income Distribution.

Starting from the left hand side of the diagram, we see that the population is affected by births, life expectancy and migrations, mainly consisting of foreign workers immigrating with their families to find a job in Papua. The population provides labour force, and constitutes a key resource for all production activities, just as capital and land. Capital is increased through the investment flow, - local and foreign investments, that in turn is strongly dependent on the production levels. Land is used for different production activities and is a key resource in agriculture and logging. Land use can change depending both on governmental policies and internal circumstances such as food scarcity or illegal logging. Production activities, moreover, affect the land quality (through soil erosion and degradation) and produce pollution dissipated in the water, in the air, and in the soil.
The total economic benefit generated by production activities is summed up in the GDrP (the Gross Domestic regional Product)\(^2\) that has a key role in the determination of, among many other important variables, the life expectancy. The production sectors, together with technology, also define the desired level of employment, which in turn determines the workers migration flow (when labour force demand exceeds supply, there will be immigration and when supply exceeds demand there will be emigration). Technology also affects the production levels and is mainly determined by the investments introduced in each production sector.

Through a flow of taxes (direct from producers to the local government, or indirect passing through the central government), production activities influence the government budget and define what is level of public expenditures that can be sustained. The government can apply a number of different policies and distribute the available resources across a variety of activities. These will consequently affect a number of key economic, social and environmental variables, such as investment and productivity, birth rates and life expectancy, pollution and land use, in the other sectors.

Two central indicators are also portrayed in the diagram, as they are of great importance for our clients to evaluate the different policies that are tested using T21. Income distribution and GNrP (Gross National regional Product), in fact, offer synthetic measurements of how the economic benefit is distributed across the different layers of the society and how much of the benefit produced is targeted local people only.

As seen in Table 2, we differentiate between the Core and the Special sectors. We consider Core sectors those that are normally implemented in every application of T21, as they portray some common characteristics of the national system of most of countries across the world. These sectors describe the generic structure of the population, that of the economic, the land and the education systems as well as the governmental financial structures. They are normally implemented without substantial changes from one application to another, with the exception the parameter values and the initial conditions. However, since this application of Threshold21 has been the first one applying the model

\(^2\) In this study we often refer to the GDrP as the aggregate level of production in terms of value added. We use as indicator the GDrP instead of the GDP because we intend to measure only the value added produced in the region of Papua and not in the whole Indonesia.
at a regional level, many modifications have turned out to be necessary or useful also in the Core part.

On the other hand, we consider Special sectors all the structures created by the author for this specific application, in order to portray some peculiar aspects of the Papuan system or to introduce some additional policy option for the clients.

Belonging to this category is the group of Dam sectors, built with the aim of describing the actual dynamics of the Papuan electricity market and its influence on economic activities, employment and pollution, as well as to simulate one of the most likely policies of the local government: an increase in the regional hydropower capacity.

Also, the group of Highway sectors have been created to represent Irian Jaya’s road transportation infrastructure dynamics and their importance to production activities, environment, and employment. This group of sectors allows the clients to test out strategies for road construction.

To introduce more realistic options for policy makers, a government borrowing and small credit sectors have also been created. By employing these sectors, the clients can introduce increases in the public expenditure exceeding the funds currently available or finance small local businesses, and observe the effects of such policies on the overall behaviour of the system.

The pollution sector has been remodelled in line with similar sectors in other applications of T21, yet modified substantially, to consider in particular the effects of the different energetic and transportation policies that the Papuan government contemplate implementing.

The workers migration and GNrP sector describes the mechanisms underlying the movement of labour force from and to other provinces or countries. In this sector the GNrP is also determined, representing the part of GDrP benefiting to the local population. GNrP (Gross National regional Product) is in contraposition to GDrP, as it does not consider all the economic production generated inside Papua that is transferred abroad in the form of remuneration of foreign capitals invested there or of remittances from immigrated workers to their original country. In other words, the GNrP equals the GDrP less the net current transfers beyond Papua, including interest payments, profit
remittances and workers remittances. This indicator represents therefore the part of GDrP that remains within the province to be shared by the residents.

The effects on the life expectancy sector simply considers how elements as pollution and health care expenditure affect death rates, and the training sector has the only aim of introducing an additional policy option: training workers for specific activities.

The Core and Special sectors will be separately analysed and discussed in the sections that follow. In particular, while only a short overview will be dedicated to the normal Core sectors, the Special sectors, as well as the originally modified parts of the Core ones, will be described in detail. They constitute, in fact, the author’s contribution to the final version of the model.

Additional technical details of the core sectors, moreover, are reported in the T21 Papua Documentation (Barney, Qu, Pedercini, Millennium Institute 2003).

### 2.3 Overview of the Core part of the model

This section is intended to give the reader an idea about the way the Core sectors of the model work, as a way to understand the behaviour arising from the interactions of these sectors. Without specifying the sector structures in great detail, I simply describe, for each sector (or group of sectors) what we intend it to represent, what kind of structures we use to implement our intention, and how it contributes in a substantial way to the overall model’s behaviour.

To make all the sketches presented below more easily understandable, in addition to the normal stock and flow notation, the following standard has been applied:

- The names of stock variables have been written with an initial capital letter.
- The names of variables holding constants and table functions have been capitalized
- The names of auxiliaries have been non-capitalized
- A blue colour indicates inputs from another sectors
- A red colour indicates outputs to another sector
- The special brackets “< >” are used to indicate that a variable has been copied from another part of the model

2.3.1 Population, Births and Life Expectancy sectors

The Population sector has been implemented with the aim of describing the structure that governs the dynamics of the local population in Papua, and to produce a series of important inputs for other sectors.

The population has been modelled as a stock variable influenced by three main flows: birth rate (births), death rate (cohort deaths) and migration rate (net transmigration), as shown in Figure 3.

![Figure 3: Sketch of the Population sector](image)

The population stock is disaggregated by gender and into 80 age cohorts. This implies that this variable includes 160 different population groups, each with a different fertility and death rate. The birth rate is completely calculated in the births sector, while the death rates for each age and sex category is calculated based on the life expectancy and a set of demographic life tables. These tables represent the probability that each individual can die, during one year, with respect to his age, sex, and what is the life expectancy in the region. Four basic types of these tables exist, to portray the reality of populations with
different characteristics. For this application we chose the table that better fitted the death patterns observed for each age group. (To see how these tables are calculated, see Coale, A.J., and Demeny, P., Regional Model Life Tables and Stable Population, second edition, Academic Press, 1983). Finally, the migration rate is derived from the annual worker transmigration, which is calculated in the workers migration sectors, and here modified by to represent the number of relatives that normally follow each worker.

The birth sector constitutes a tree of instantaneous relationships that altogether determine the birth rate, yet that do not generate any dynamic behaviour in and by itself. There are two main determinants of the birth rate: the part of female population that is sexually active and the specific fertility of each age group within that population.

![Figure 4: Sketch of the Births sector](image)

The sexually active share of the female population consists of the married females and those having out of wedlock sex. The total fertility rate is the weighted average of two components: the consciously controlled and the unconsciously determined fertility rates. The consciously controlled fertility rate represents the average fertility rate for those women that consistently employ birth control systems. On the other hand, the unconsciously determined fertility rate represents the average number of kids that women who do not practise any kind of birth control have. The weights used to calculate this
average depend on many factors, such as the economic conditions and the literacy proportion of the population, the governmental expenditure for social services and the efficiency of the birth control systems used.

A similar kind of structure is used in the Life Expectancy sector, represented in Figure 5.

![Figure 5: Sketch of the Life Expectancy sector](image)

The life expectancy is calculated on the basis of a “normal life expectancy” derived from per capita GDrP, which is then adjusted considering four other additional factors: health care, access to clean water, nutrition and pollution. The effect of health care and access to clean water are both calculated on the basis of the governmental expenditure for health care, while the effect of pollution represents the negative effect that high pollution density may have on life expectancy. This effect function will be discussed in detail when describing the “life expectancy effects sector”. The quality of nutrition is considered a constant and set to 100% (no deteriorating effect on life expectancy). This is due to the fact that we assume that the amount of natural resources available in the region is sufficient to avoid starving and famine, which would appear in the form of increasing death rates.

2.3.2 Industry, Mining and Service
Industry, Mining and Service are the main non-agricultural production sectors in Papua. These three sectors are modelled in a similar way. Accordingly to the classic economic theory, in fact, they use the same kind of input, though in different measures, and generate production on the base of similar mechanisms. In particular in T21 the production functions are based on dynamic application of the Cobb Douglas equation, where capital and labour force are used in a multiplicative form to generate production.

I present here only the Industry sector, in Figure 6, as the other sectors are analogous to industry, and differ only for the initial values and parameters values used. The reader can refer to the T21 Papua Documentation (Barney, Qu, Pedercini, Millennium Institute, 2003) for information about what specific values have been used for the parameters and the initial values for the other production sectors.

It is important also to note that in other applications of T21 mining activities are normally considered industrial production and do not give rise to a sector of their own. We decided to model the mining sector separately as it is a most essential sector in the Papuan economy and because its characteristics, represented in the parameter values of the model, are very different than those of the Industry sector.

Figure 6: Sketch of the Industry sector
In each production sector, the central stock variable is the accumulation of productive capital, “Capital Industry” in this case. The capital is increased by the investment flow and reduced by the depreciation flow, which is a fraction of the existing capital, determined by its average productive life. The investment inflow, moreover, is a fraction, the productive share, of the amount of investments made in the Investment sector. We assumed that part of the capital investment sustained in this sector is functional to the expansion of the productive capacity, but does not directly add to the capital stock. As an example, we may think about the cost of all the accessory services needed when installing new machinery.

Given the number of persons employed in this sector (determined in the employment sector), the model calculates the capital intensity, which is the basis for determining the labour productivity. Labour productivity is the initial labour productivity in the sector, affected by a series of influences from factors we assume to have an effect on productivity. In addition to capital intensity, technology, workers education and health, pollution and transportation and energy costs play important roles in determining productivity. In the case of Papua, we added to the model the effect of secondary education on productivity, the effect of pollution, and the effects of energy and transportation costs. These effects originate in the Education, Pollution, Dam and Highway sectors, respectively.

Production is considered to be the product of the labour force actually employed in the sector and the labour productivity resulting from the factors described above.

It is very important to notice that the capital stock in each production sector is defined over a two dimensional array, to allow us to distinguish between capital from local and from foreign sources (the same formulation appears also in the Agriculture sector). This is another contribution to the production sectors offered by us. It is of key importance to identify what part of companies’ profits that is being used to remunerate foreign investors, as calculated in the GNrP sector.

2.3.3 Agriculture, Forestry and Fishery
Agricultural production is represented in a different way than industrial production. Yet, in the Agriculture sector, we still use the Cobb Douglas production function. The stock and flow sketch of this sector is presented in Figure 7.

In this sector, two stock variables play a central role for the determination of the production value: the productive capital and the agricultural land in use. The behaviour of the production capital is determined by a structure similar to the one we find governing the behaviour of industrial capital: it is increased by investments and decreased by depreciation. The labour force employed in the sector is not used to determine production, and Capital intensity (capital per ha of land) is determined by the agricultural land in use. We assumed that rural labour force for agriculture is very abundant in the region and it does not represent a possible constraint for production. Together with the technological level, soil quality, water availability and the energy and transportation costs, capital intensity is a key factor in determining the yield from agricultural production. These last two effects allow the user to consider explicitly how structural interventions and other policies regarding the electricity market or the road network may affect production.

The volume of agricultural crop production (grain, fruits and vegetables measured in tons per year) is determined by the land in use and the yield of that land.

Figure 7: Sketch of the Agriculture sector
In T21 we also consider meat production, forestry and fishery output in total agricultural production. Meat production is determined by the meat demand, which is in turn depending on the real per capita GDrP. We assume, therefore, a direct causal relationship between per capita income and meat demand, and we assume that the meat production is unconstrained.

The other two components of agricultural production, forestry and fishery, are separately modelled in the Forestry and Fishery sector, represented in Figure 8.

The fishery production is considered an exogenous variable, varying over time (the reasons underlying this decision are previously explained in the “model boundaries” section).

The production from Forestry, on the other hand, is endogenously generated, as a function of the land used as production forest and its average productivity per hectare per year.

We have introduced this endogenous perspective on production from forestry because it constitutes a business of national significance and forest protection is a critical issue to be addressed in this study. We have also added a very simple structure (at the bottom of the figure) to represent the fraction of the forestry production remitted abroad, e.g. when logging concessions are used by the government to finance highway construction (one of the policies considered in the analysis).

Figure 8: Sketch of the Forestry and Fishery sector
2.3.4 Investments

As shown in Figure 9, investments in each of the production sectors originate from two main sources: foreign investments and local (or domestic) investments.

Total domestic investments are endogenously calculated as a constant share of the non mining production, i.e. total, less mining, production. We decided to exclude proceeds from mining from the amount of funds locally invested because very little of the economic value created in this sector actually benefits local people, reducing the probability that it is reinvested in different sectors than mining.

Total foreign investment, on the other hand, is considered an exogenous variable, i.e. nominally determined as a function of time, - and in real terms affected by the current level of prices and the exchange rate. The various production sectors and activities benefit from a fixed share of the total foreign investments. Moreover, we have identified two additional factors, associated with a governmental development plan (described as part of the scenario analysis), that determine foreign investments in the Industry and Mining sector. These two factors represent the increase in foreign investments that we assumed to happen as some important infrastructure projects are completed.

A similar amendment has been made to the model in the case of domestic investment, though in this case the extra inflow of investments is endogenously determined by the
Small Credit sector as the part of the funds made available by the government that is reinvested in production activities.

Even though in the sketch in Figure 9 they are presented as simple variables, the investments in each production sector (represented in red colour) are defined over a two dimensional array, that distinguishes domestic from foreign investments.

The Investments sector also encompasses regulation and conservation cost functions that represent particular governmental policies. Although these policies are not being considered at this stage of our analysis, we have decided to keep them as they may turn out to be useful in the further development of this application of T21 to Papua.

2.3.5 Technology

In T21 technology is simply represented as a stock (Figure 10), influenced by a single flow, technological advance. The stock variable is defined as a four dimensional array, to distinguish between the technology in each production sectors; Industry, Agriculture, Services, and Mining. In each sector, technological advance is determined by the investment flow compared to the existing capital stock accumulated. We assume, in fact, that the source of technological advance in production equipment is the investment in new capital, and that the contribution of such investments to the overall improvement of technology in one sector is inversely proportional to the total capital accumulated in that sector. In other words, the higher is the technological level of the existing capital, the more expensive it is to update it or substitute it with current technology.

![Figure 10: Sketch of the Technology sector](image)
The technological advance parameter has also a crucial role in the calculation of the technological advance rate, and represents the technology cost factor associated with each of the production sectors.

The technology cost factor, associated with each of the production sectors, indicates the cost in improving the technology level within such a sector. One may compare the cost factors across sectors so as to obtain the relative costs associated with a technological advancement.

The resulting level of Technology has a very important role to play in several of the sectors beyond Production, such as in the Pollution and the Dam sectors. Moreover, it determines the level of employment:

2.3.6 Employment

The Employment sector calculates the level of employment for the various kinds of production and for governmental infrastructure construction programs. As indicated by Figure 11, the focus in this sector is the actual number of persons working in each sector, with the exception of the Agriculture sector.

![Figure 11: Sketch of the Employment sector](image-url)
It is assumed that the employment in the Agriculture sector is a fixed proportion of the total employment level in the region. This decision is mainly based on two considerations. First, it is extremely difficult to estimate the real agriculture labour force in a rural country (that also depends on how we define a person working in the Agriculture sector) and how this part of labour force contributes to production. Second, as already mentioned, agriculture labour force is not considered in the calculation of agricultural production, limiting the relevance of this variable in contributing to the behaviour of the model. Therefore we decided to simplify as much as possible the model, and we thought a reasonable estimation to assume that agricultural employment is anchored to the employment in other sectors.

The employment levels in the Industry, Service and Mining employment levels, on the other hand, have been modelled using a similar structure. The three stock variables are affected by the Net hiring rate, which compensates for the differences between the actual number of persons employed and the demand for labour. The labour demand, in turn, is calculated based on the productive capital for each kind of production and an ideal capital/labour ratio, determined by the level of the technology currently applied in that kind of production. Technology and capital are thus the most important factors in the determination of the level of employment.

As for the number of persons employed in the construction and maintenance of public infrastructures, the demand for labour generated within each infrastructure sub-sector (Dam and Highway) are simply added up to a total infrastructure labour demand, towards which the infrastructures employment stock is being adjusted by a hiring process.

With regard to annual transmigration, we start from the assumption that the migrations in the region are generated by the differences between labour demand and supply. The skilled labour supply, i.e. the sum of the secondary graduates and a fraction of primary graduates, may be compared to the total skilled labour demand. This demand has been calculated as the sum of the demand from the Industry, Services, and Mining sectors, including a fraction of the labour demand in the Agriculture sector, reflecting the fact that, also in this sector, skilled workers are in demand. Note that the term “skilled” refers to workers that have at least a secondary school degree or some specific skills obtained by way of apprenticeship or special training programs.
The imbalance between skilled labour demand and supply generates the net skilled workers migration, which may be multiplied by a constant dependency ratio (indicating how many individuals, on the average, economically depend on one worker) to obtain the value of annual transmigration. As will be explained in the paragraph on the Workers Migration sector, the number of foreign workers actually present in the region significantly affects the annual transmigration.

We have assumed that there are no constraints to the growth of the labour force in the various sectors, meaning that we assume foreign labour force to be always available to fill the current gap between labour supply and demand.

We have introduced the definition of the labour force employed for infrastructures building and maintenance as well as these endogenous considerations of migration based on labour supply and demand to explicitly account for the of annual transmigration taking place. This represents a very important social and economic problem in Papua.

2.3.7 Government

This sector as been created with the aim of representing the way the government collects economic resources from sources and how they are being spent, i.e. divided between various kinds of expenditures.
The local Papua government budget system is substantially different from a central government one. Thus in our adaptation to Papua, we had to modify completely the original Government sector of T21.

As it immediately appears from Figure 12, no stock variables have been used to represent the variables in this sector, and all the budget equations are instantaneously determined. In other words, in this system the government allocates all incoming funds immediately, using the public debt as buffer in case the expenditure would overcome the revenues or vice versa.

On the left hand side of the sketch all the government revenue streams have been listed. Some of these revenues are being endogenously generated, such as those collected by the local government in the original district (the regional district of Papua) and the share of the revenues collected by the central government destined to Papua (revenue sharing). Others revenues are exogenous functions of time, such as the general and special allocation funds allocated by the central government for general or special purposes, respectively, and aid, grant and other, representing aid funds from IFIs. All these revenues sum up to the total government revenues. The amount of revenues collected is
subsequently distributed between three main expenditure categories, - operating expenditures, development expenditures and extra expenditures.

Operating (or routine) expenditures pay for administrative staff and services. This category of expenditures takes priority over others, meaning that, in case the revenues are insufficient to cover all the expenditures, funds will primarily be used to pay for administrative staff and services, leaving some of the other indicated expenditures uncovered. Development expenditures include expenditures for health care, education, services and infrastructures. Health care and education expenditures are policy variables in the model, while Services and Infrastructures (that comprises only the maintenance of the infrastructures existing at the beginning of the simulation and the completion of the existing projects) are exogenously determined. This item of expenditure, in fact, does not consider the investments in specific infrastructure projects that we intend to test in the various scenarios, as we wanted to treat these specific investments separately. We decided to fix the share of available funds for the normal Services and Infrastructures expenditure for the future to the level actually observed in reality, which has been slightly decreasing in the last years. We made the simplistic assumption, in fact, that the government will keep the same relative level of expenditure for these two items and that as a consequence the quality of the services provided and the intensity of the maintenance made will not substantially change. This assumption well fits the historical data available. A minimum value for the share of resources destined to development expenditures has also been fixed. This represents the minimum allocation for development expenditures that the government can sustain without incurring in political problems. This value has been determined accordingly to the indications of our clients and the values for development expenditure budget observed in reality. In case the resources available are not sufficient to sustain this level of expenditures, the government will start borrowing money from foreign sources.

Extra expenditures are the sum of all costs sustained by the government for special projects, such as dam or highway construction (and maintenance), small credit initiatives and workers’ training programs.

How the extra expenditures are being determined, and how the government runs a deficit are explained in detail in the Special sectors chapter.
And finally there are the direct public investments in the production sectors. These investments are assumed to be constant, as in reality they do not show any specific patterns of growth. Moreover, we assumed that these investments have no effect on production: considering those effects was not necessary to perform the analysis of the critical issues stated. The main reason why public investments have been considered in the model is for the accounting to be correct.

2.3.8 Education

Education is a very central aspect for the development of Papua. Both primary and secondary education services exist on the island.

In the original version of T21, the education sector was structured to determine the number of primary students only. In addition, for this specific application we created a structure representing the secondary school system. Structurally these kinds of education are similar.

![Figure 13: Sketch of the Education sector](image)

Secondary graduates turned out to be a very important determinant of the migration rate (as discussed in the paragraph on Employment sector).
In Figure 13, there are four main stock variables characterizing this sector: primary and secondary students, the entrance rate (a delayed response to the indicated entrance rate) and the total secondary graduates in the population. Primary and secondary students are six stocks dimensional arrays - representing students of different grades. Each of these stocks are influenced by three rates; the entrance, the dropout, and the graduation rate.

The entrance rate is represented in the model as a first order smoothing of the indicated entrance rate, a function of the government’s expenditure in education per pupil. The dropout rate is simply assumed in the model to be a fraction of the student body, a constant fraction for the primary students and a fraction depending upon the quality of the education, indicated by the per pupil expenditure, in education for secondary students. The graduation rate from primary schools determines the adult literacy rate and the primary education index. The graduation rate from secondary schools determines the cumulative secondary graduates and the secondary education index. The primary and secondary literacy rates are of great importance in particular for their effects on labour productivity in the different production activities and on the population’s birth rate.

**2.3.9 Land**

The T21 land sector represents the total land use of the province and how this use is split between the various kinds of use made of that land. To take into account the many peculiar aspects of the Papuan territory, we have totally refurbished the model representing this sector. As portrayed in Figure 14, the total land of the province has been divided into five main categories; urban land, agriculture land, productive forest land, non-productive forest land (simply called “forest land” in the model), fallow land, and waste land. The space occupied by each of these land types, is represented by a stock variable. While as various factors may modify the land use, the total amount of land available remains constant.
Urban land is the land used for urban settlements, and it increases in response to demographic pressure that generates the need of more space for houses and business activities.

Agriculture land is the land used for agriculture production, also a result of demographic pressure that causes an increase in the desired food production, and, consequently, in the need for agriculture land. The gap between the desired and actual agriculture land is normally filled by converting fallow land. In Papua, we assumed that if this would not suffice, forest land would also be sacrificed to this end. Agriculture land is decreased by way of degradation. In fact, when the forest land decreases, the land degradation process intensifies so as to transfer land from the agriculture stock to the fallow stock. The agriculture land stock is one of the main determinants of agricultural production.

The forest land stock considers all the forest in the region that is not used for production purposes. This stock is increased by the slow transition of fallow to forest land at the “fallow to forest” rate, which considers the actual time needed for forest to regenerate. On the other hand, the forces that may erode this precious resource are many, such as illegal logging, the construction of dams, the need for agriculture land and, simply, the concessions given by the government to use this land for other purposes. If these
concessions have the aim to make the land available for timber or palm oil productions, then the land is converted into productive forest at the “forest conversion” rate. The stock of land for productive forest is a two dimensions array, distinguishing timber production from palm oil production forest. The total production forest constitutes the foundation for forestry production.

The fallow land stock is the central element of this sector and it buffers the land in transition from one kind of stock to another. The fallow land is considered a two-dimensional array by which we distinguish between cultivable and degraded land: Cultivable land can be used for agriculture, while degraded land, land formerly used for agriculture land and subsequently degraded, cannot be used for this purpose. Degraded land, however, if not used for other purposes, can naturally transform into cultivable land with a certain delay. We assumed that degraded land will be preferred when demographic pressure creates a need for an increase in urban land.

Wasteland constitutes all the land that cannot be used for any purposes. In the model, we assumed the increase in wasteland depends on soil erosion associated with the forest coverage: As less of the land is covered by forest, soil erosion increases, and more land will be wasted. In reality, wasteland can also naturally reconvert, with time, into fallow or forest land. However, considering the very long time required for this process to play out and the comparatively short time horizon we apply in our study, we have decided to disregard this reconvertable process, sure of not omitting any important dynamic process.

2.4 Special sectors: a necessary expansion of T21

The structure presented above endogenously reproduces and explains the behaviour observed in some of the most important variables in the Papuan socio-economic-environmental system. However, during our preliminary meetings with our client the need emerged for an expansion of the model to include the representation of some additional issues so as to allow the user to test a broader number of policies.

The ultimate purpose of the model, in fact, is to serve as a policy-testing tool, to help our client identify a set of policies coherent with the short and long-term objectives of our client. The model described so far enable us to test but only a very limited number of the policy options, - a shift in the expenditure between education and health care. In
particular, the model could not simulate the implementation of any of the specific policies in question by our client.

In our initial meetings with CI, we worked at the definition of a series of strategic scenarios, each containing a different set of policies that we considered important to model and subject to simulation (an accurate description of these policies is presented in the Scenarios Description and Analysis chapter). Some of these scenarios have been selected because they are very likely to be implemented by the government; others because they are considered interesting alternatives to be compared with the actual direction chosen by the executive; some because they represent extreme cases useful for qualitative policy positioning and analysis.

In particular, the policies we wanted to simulate can all be classified as belonging to five main areas:

- Infrastructures and strategic interventions in the electricity market.
- Infrastructures and strategic intervention in the road transportation sector.
- Small credit financing initiatives.
- Workers’ professional training.
- Public Debt.

Consequently, in each of these sectors, an expansion of the model was required. The basic model structure representing these important areas portrays the system at a relatively high level of aggregation. We chose the minimum level of detail that granted us the opportunity to represent the policies in question, to generate the desired outputs from the implementation of these policies for the rest of the model, and to reproduce the problematic behaviours as most significance observed in each sector.

Each special sector is related to the other sectors in a variety of ways and for a variety of purposes. Though these linkages will be described in detail, sector by sector, in the sections to follow, it is useful, at this stage, to group them into two categories so as to keep in mind the generic idea of the purpose they serve. In particular, we will distinguish relationships between the special sectors and the government sector from the relationships between the special sectors and all other sectors. The transfer of information
to the government about costs and revenues associated with the initiatives introduced constitute the first set of relationships. This information offers crucial indicators for the policymakers regarding the feasibility and profitability of each possible intervention. The second set of relationships carry the effects of the policies implemented in the special sectors over to the other sectors.

In addition to the five main areas in which we decided to expand the model, we also decided in concert with our clients to extend the model in two directions. The reason of such decision relies in the necessity of including in the analysis two very specific problems of the region; pollution on the one hand and the inequalities in the distribution of the production value between local and foreign people on the other. Pollution in the region is important in particular when we consider the emissions generated by mining activities in soil and in water.

The distribution of the surplus value of the production is also a crucial problem, because a huge part of this surplus is not destined to local people that, on the other hand, carry all the social and environmental cost of the economic activities on the island.

To properly portray these problems and the mechanisms that generate them, we introduced two additional sectors;

- the Workers Migration and GNrP Sector; and
- the Pollution Sector.

The approach used to create these two sectors is similar to what stated above for the additional five areas, both in terms of structure representation and linkages with the rest of the model.

Consequently we created 15 new special sectors (listed in Table 2) integrated into the core structure of T21 to endogenously explain the crucial issues raised by our clients and to provide a comprehensive set of policy options.
In the following section, these sectors are being described and analysed one by one. Their major structural characteristics, along with the equations that define the most important relationships in each sector will be illustrated; as well as why and how the new elements have been linked to the rest of the model.

Note
The notation used in the following sketches is the same as the one used in the description of the Core sectors. In addition, in equations, the notation “►” and a different style will be used, not to confuse them with regular text. Equations are written in Vensim syntax. The reader may refer to “Vensim Manual Version 5.0” in case there is any doubt about the meaning of the special functions used. Finally, in several variable names the words “ind”, “agri”, and “serv” are used to refer respectively to the industry, agriculture and service sectors.

2.4.1 Dam Physical Structure and Demand

We introduce the analysis of the Dam sector, with a description of the structure of the electricity market in Irian Jaya.

The main electricity producer in Papua is the state owned company PLN that shares the market with many small private producers. Given the low population density of the area, only a small part of the population is connected to the main electricity grid and many towns and villages are supplied with energy produced by diesel engines. PLN is planning investments in the sector to increase its production capacity, expand the grid and substitute the many small diesel engines with more centralised plants.

The utilisation of hydropower seems, at the moment, to be the most attractive way to expand production capacity, given the huge amount of technically suitable sites present on the island.

The Dam sector has been built with the aim of portraying the physical mechanisms of construction of hydropower capacity and power lines, as well as to determine the total
energy demand and the part of that demand that can be satisfied by the current hydroelectric production system.

![Figure 15: Sketch of the Dam Physical Structure and Demand sector](image)

In the upper left part of the sketch presented in Figure 15, the structure representing the process of construction and accumulation of hydropower capacity is portrayed. The dam construction is considered a single, generic construction process. As projects are initiated, construction is started to gain additional capacity that eventually will be made available.

To represent this process we used a simple structure that consists of two stock variables, representing the total hydropower capacity under construction and in production, and two associated flows.

The “dam construction starts” rate adds to the capacity stock under construction, and depends on the policy variable “desired construction starts”. This policy variable assumes different values in the different scenarios. To rapidly switch between different scenarios we used the variable called “scenario mode selector”. This variable acts simultaneously on many policy variables in the model, to recreate the various sets of policies described in
the scenario description chapter, without the need of manual intervention on each policy variable.

“Dam desired construction starts” accumulates in the “dam capacity under construction” stock representing the amount of capacity, expressed in Kw, that the government currently constructs. After an average period of five years, through the “dam completion rate”, capacity will be finally transferred to the “dam capacity” stock so as to contribute to electricity production.

It is important to underline the fact that I assumed there is no out flows from the stock “dam capacity”. This has been done in consideration of the normally very long lifetime of hydroelectric plants, greatly exceeding the time horizon of this study.

“Dam capacity” is principally used to define the maximum annual production of electricity from hydroelectric plants. This variable is given by the multiplication of the current capacity times the number of hours in one year (the “max utilisation period”), times the availability factor:

\[
\text{maximum potential hydropower supply} = \text{Dam capacity} \times \text{AVAILABILITY FACTOR} \times \text{MAX UTILISATION PERIOD}
\]

The plant availability fraction represents the average percentage of time over one year in which the plants are normally able to produce energy, and typically depends on the geographic location of the plants and the local climatic conditions.

“Hydro electric energy supply”, is defined as the minimum of “maximum potential hydropower supply” and “demand for hydropower”. This last variable is given by the multiplication of the “total energy demand” and the “fraction of electricity demand for hydropower”, which represents the percentage of electricity demand that is linked to the national power network and can therefore be satisfied by the energy produced in the hydroelectric plants. We assume, in this case, that the electricity demand originating from
consumers that have access to the power network is covered by hydropower. This is based on the consideration that hydropower is less expensive to produce than electricity from other sources once the plant has been constructed. Once the fixed construction costs have been sustained, in fact, the variable costs of hydropower generation are significantly lower. The PLN can therefore set a lower price for hydropower than the actual price of electricity from other sources: this will be convenient until the price set covers the variable costs of hydropower generation and until the existing capacity is not completely used.

The “fraction of electricity demand for hydropower” is represented by a stock variable, a first order delay of the “indicated fraction of electricity demand connected to power lines”. This portrays the fact that it takes time, we assumed one year in this case, for people recently connected to the power network to realise the advantages of the new system, modify their habits, and eventually utilize the public electricity service to the extent common to households and industries in that region.

The “indicated fraction of electricity demand connected to power lines” has been represented as a non-linear function, the “electricity cumulative demand distribution”, of the length of existing power lines network.

In Vensim modelling language this relationship is expressed as follows:

\[
\text{indicated fraction of electricity demand connected to power lines} = \text{electricity cumulative demand distribution(relative voltage lines length)}
\]

The electricity cumulative demand distribution function may be portrayed as in the following table.
Table Function 1: Electricity Cumulative Demand Distribution

This function saturates for an input of twelve, meaning that when the network length reaches a value twelve times higher than the initial one, we assume that the network reaches almost all of the households and companies. Such a big electricity network, in fact, would imply a density of power lines per squared kilometre in line with the values observed in most developed countries where typically almost the totality of households and economic activities are reached by the electricity network. The non-linear shape of the function that we decided to use is based on a simple assumption: we assumed that the PLN will first extend the electricity network in the most populated, and therefore most profitable, areas and only in a second time in the most remote areas of the region. The first hundreds of kilometres of power lines built will therefore connect to the network a high number of households and economic activities, with a strong effect on the potential demand for hydropower. As the most populated areas are connected, however, extending the network to the most remote users requires the use of more kilometres of power lines.
per user. The effect that each kilometre of power lines added to the network will have on the potential demand for hydropower will be therefore smaller and smaller.

Power lines are represented by a stock variable called “high/low voltage power lines” which is increased by the “power lines construction” rate. This rate depends on the variable “desired construction of power lines”, which is formulated as:

\[
\text{desired construction of power lines} = \max\left(\frac{\text{desired length of power lines} - \text{high/low Voltage Power Lines}}{\text{TIME TO BUILD POWER LINES}}, 0\right)
\]

As it appears from the above equation, “desired construction of power lines” tends to compensate the difference between the actual length of power lines and the desired one. “Desired length of power lines” is formulated as:

\[
\text{desired length of power lines} = \text{INITIAL POWER LINES} \times \text{INVERSED ELECTRICITY CUMULATIVE DEMAND DISTRIBUTION (potential hydropower demand coverage)}
\]

The idea underlying this equation is that as additional capacity is built, the government would also expand the electricity network to make the new capacity available to new users. In particular we assume that the government knows the cumulative demand distribution of electricity in the region, and builds additional power lines to maximise the utilisation of the electricity production capacity.

The other element necessary to determine the “demand for hydropower” is the “Total energy demand” that considers electricity demand both for production activities and for household. Electricity demand for production activities is separately determined in the “Dam impact on production activities” sector, while the part of demand for households depends on the “non mining production” and on the real per capita GDrP:
total energy demand =

\[(GDrP \times \text{REFERENCE HOUSEHOLDS ENERGY REQUIRED PER UNIT PRODUCED (real per capita GDrP)}) + \text{agriculture energy demand} + \text{industry energy demand} + \text{mining energy demand} + \text{service energy demand}\]

In this formulation, to determine households energy consumption, the GDrP is multiplied by the “reference households energy required per unit produced”, which is a linear function of the “real per capita GDrP”. The assumption we made in this case is that energy consumption increases as the GDrP and the per capita GDrP increase. We assumed that as the inflow of surplus value produced increases, the total amount of energy that the households consume increases proportionally. Moreover, we introduced in this formulation the per capita GDrP to capture the effect of how not only the total inflow of surplus value, but also the amount of benefit directed to each individual is important to determine energy consumption. We assumed that as the per capita GDrP increases, people will tend to consume more energy.

We decided to use the GDrP in this formulation instead of the GNrP as we considered that not only the local population but also the foreign workers in Papua represent an important part of electricity demand. The GDrP and the per capita GDrP represent in fact a better measure of the level of welfare of the population as a whole, including foreign workers.

As the hydropower becomes a substitute for the energy produced by burning fossil fuel, the air pollution decreases. This effect is represented by the function “effect of hydropower use on pollution”, which is formulated as following:

\[\text{effect of hydropower use on air pollution} = 1 + (\text{energy supply fraction from different sources} - (1 - \text{INITIAL FRACTION OF ELECTRICITY DEMAND FOR HYDROPOWER})) \times \text{"HYDRO/OTHER POLLUTION DIFFERENCE"}\]
To better understand the equation above, we can divide it into two main parts. In the first part of the equation the increase in the use of hydropower is determined. This is given by the difference between the actual fraction of electricity demand satisfied by fossil fuel energy production, the “fraction of energy supply from different sources”, and the initial one, (1 minus the “initial fraction of electricity demand for hydropower”). The difference thus determined is multiplied by the “hydro/other pollution difference” parameter in the second part of the equation, to determine the effect of the shift from fossil energy to hydropower on the air pollution. The coefficient “hydro/other pollution difference” represents indeed the intensity of the impact of an increase in the use of hydropower on air pollution, for each unit produced in all economic sectors.

*Linkages with the rest of the model*

The Dam sector is influenced in a number of ways (represented by the blue variables in the sketch) by other sectors and impacts, in a variety of ways (represented by the red variables in the sketch) other sectors.

Among the influences to be considered, two originate from core sectors of the model - the technology and non-mining production sectors. Both of these impacts are of key relevance to the determination of the total electricity demand, as described above. The other four impacts on the Dam sector considered are represented by variables defined in the “dam impact on production activities” sector, and they represent the demand for energy for the different economic activities. These inputs are also necessary for the determination of the total electricity demand.

Among the seven different kinds of impact produced by the Dam Sector, only the “fractional completion rate”, representing the fraction of the desired dam’ construction projects that has been completed, influences the sectors represented by the core, i.e. the investment sector, of the model. The “extra foreign flow investment” defined in a specific scenario is bound by the completion of the hydropower capacity expansion project, as we assumed in that scenario that the availability of hydropower is a precondition for the inflow of foreign investments. We assumed in particular that a fixed amount of foreign
funds will enter the region progressively, accordingly to the fraction of the dam’
construction projects that are completed. Otherwise, the special sectors are the ones
affected.

The environmental impact of the Dam Sector affects the pollution sector. All the
remaining impacts affect the group of dams’ sectors, and determine the economic costs of
construction and maintenance of dam capacity, electricity price and several others
important factors that will be addressed subsequently.

2.4.2 Dam Impact on Production Activities

It is of great strategic relevance for policymakers how an expansion of hydropower
capacity and the extension of the electricity grid may influence the production activities
in the various sectors. The aim of this sector is to describe these effects and the potential
benefit for the regional economy deriving from various governmental interventions in the
electricity market.

Figure 16: Sketch of the Dam Impact on Production Activities sector

The basic assumption underlying this sector of the model is that the mean through which
the electricity market influences production activities is the energy price. Price, naturally,
also includes availability aspects: electricity can be clearly available everywhere, at
different costs.

In Figure 16 is reported the structure used to represent the mechanisms through which the
amount of energy supplied and its price affect the agriculture productivity. I will explain
here only the structure used in the case of agriculture, as a similar logical scheme as been
used for all production activities.
The determination of energy price is based on the assumption that on the market exist two different prices of energy: the hydropower energy price and the price of energy generated by other sources, typically diesel engines. The latter is considered a constant in the model, and the former one a policy variable defined over four different possible values, depending on the “scenario mode parameter” (as already seen for other policy variables).

Given these two prices as well as the total energy demand and the shares of demand satisfied by the two different sources, the total expenses for the two kinds of energy sources are derived as the multiplication between demand and price of each. Then, the “weighted energy price” is simply defined as follows:

\[
\text{weighted energy price} = \frac{\text{yearly expense for hydropower} + \text{yearly expense for other power sources}}{\text{total energy demand}}
\]

The “weighted energy price” is then used to determine the “relative weighted energy price”, an indicator measuring the ratio between the actual and the initial energy price, and the “share of energy expenditure in agriculture”. This variable represents the amount of money spent for energy in the agriculture sector, with respect to the total value of the sectorial production. To determine this variable it is necessary, in addition to the “weighted energy price”, the total value of production, “agriculture production”, and the demand of energy in the sector, as appearing in the following equation:

\[
\text{share of energy expenditure in agriculture} = \frac{\text{agriculture energy demand} \times \text{weighted energy price}}{\text{agricultural production}}
\]

The demand of energy in the sector, “agriculture energy demand” in this case, is simply given by the multiplication of the sector’s production times the “agriculture reference consumption per unit produced”, and times the effect of technology on energy intensity. The reason underlying the use of technology in this formulation is that it is generally
observed that as technology increases, the amount of energy employed per each unit produced increases. I assumed in this case a linear relationship between technology and energy intensity, as given the little information available this seemed to me the simplest and more reasonable assumption.

“Agriculture reference consumption per unit produced” is represented in the model as a constant, measuring the initial consumption of energy per unit produced in this sector. The “share of energy expenditure in agriculture” represents the main element affecting the production in the agriculture sector, and particularly the productivity of capital and labour force. The reasoning behind this assumption is simple: as resources are saved by a reduction in the expense for electricity per unit produced, these can be used to increase productivity by buying more energy, for example, or increasing workers ability, buying more raw materials, etc.

It is important to notice that I did not consider a direct effect of energy price on investments. Investments are modelled as a function of production in the sector plus an exogenous component (as explained in the Investment sector’s paragraph). Creating a comprehensive function for investment, which should consider all the elements affecting the attractiveness of a certain business (including the cost of production factors), would have implied a large effort and added very little to the study of the issues at stake. The energy price, however, is an indirect determinant of investments, as when productivity of resources increases, production consequently increases and investment, as a function of production, increases as well.

The “indicated energy cost effect on agriculture productivity”, is determined on the basis of the difference between the “share of energy expenditure in agriculture” and its initial value, times a sensitivity parameter called “sensitivity agrprod to energy cost share”:

\[
\text{indicated energy cost effect on agriculture productivity} = 1 + (\text{INITIAL SHARE OF ENERGY EXPENDITURE IN AGRICULTURE} - \text{share of energy expenditure in agriculture}) \times \text{SENSITIVITY AGRPROD TO ENERGY COST SHARE}
\]
“Sensitivity agrprod to energy cost share” is a parameter used to differentiate the intensity of the effect of energy cost changes on the different production activities. In reality the formulation used to determine the effect of energy cost variations on productivity already generates effects of different intensities for the different production activities. In fact, the key element in this formulation is the incidence of energy expenditure on the total production, which is different from sector to sector depending on the energy intensity of the production activities. This parameter, therefore, has been introduced as an aggregate representation of the way other elements can affect the intensity of the original effect. Since in this case we could not identify any of these other elements, the parameter has not been in any of the scenarios projected, but its kept in the model in case in the future the client would like to test different assumptions.

The “indicated energy cost effect on agriculture productivity” is not directly used in production functions, but it is smoothed with a first order delay function before affecting productivity. This has been done to take into account the time it takes for producers to adjust their behaviour to the new prices, which I assumed in this case to be one year.

“Energy cost effect on agriculture productivity” is the stock variable that represents the final effect actually influencing productivity in the agriculture sector.

Linkages with the rest of the Model

This sector receives a total of eight inputs from other sectors, five of which from the core part of the model. These are the values of production in the four production sectors and technology, all necessary for the determination of the energy demand for production activities and the share of energy expenditure over the sectoral production. The three other inputs come all from the Dam sector: “total energy demand”, “hydroelectric energy supply” and “energy supply fraction from different sources”. They are all functional to the determination of the “weighted energy price”, the variable driving productivity changes for each production activity.

The four outputs produced by this sector, the effect of energy cost changes on agriculture, service, industry and mining productivities, are used in the correspondent production functions in a multiplicative form, to alter levels of production and, subsequently, of investment.
2.4.3 Dam Economic Costs and Revenues

This sector contains an accounting structure created to keep track of the total costs of maintenance and construction of hydroelectric plants as well as the revenues derived from selling electricity.

The only stock variable present in the sector (Figure 17) is “dam cumulative profits”, which represents the accumulation over time of the difference between costs and revenues generated by hydropower initiatives of the public electricity company. The stock accumulates two different rates: “dam profit”, the net difference between profits and costs and “interests paid on loan”, the amount of interests paid when the stock’s value is negative, which is a yearly percentage of the debt.

The way revenues generated by selling hydropower are defined is extremely simple: the policy variable “hydropower price Kwh”, representing the actual price paid per kwh, is multiplied by “hydroelectric energy supply”, representing the share of demand satisfied by the electricity produced in hydroelectric plants.

On the other hand, the determination of the total costs of maintenance and construction of hydropower capacity is more complicated. It takes into account four different items of expenditure: “dam running costs”, “dam construction costs”, “relocation costs” and “voltage lines construction costs”.

Figure 17: Sketch of the Dam Economic Costs and Revenues sector
“Dam running costs” represents the cost of maintenance and normal management of the installed capacity, and it is given by the multiplication of the existing capacity times the parameter “average cost of maintenance per Kw of capacity”.

“Dam construction costs” represents the sum of all the costs sustained to build capacity, and it is obtained as the multiplications of the parameter “average cost of capacity built” times the “dam completion rate”, times the policy variable “percentage of construction cost sustained by the government”. Using “dam completion rate” imply the assumption that the costs are sustained only in the moment part of the construction is completed. Normally, in fact, big infrastructures projects’ payments are anchored to certain stages of completion of the project. The “percentage of construction cost sustained by the government” parameter, has been introduced to allow the client to test the hypothesis of foreign investors contributing to finance the construction of hydropower capacity: the government would have to sustain, in this case, only a part of the total construction cost.

“Relocation costs” represent the cost of relocating the people originally living in the catchment’s area of a new dam, because potentially this will not be suitable to host them any longer. This variable is defined as the multiplication of an “average cost of relocation per ha” parameter, times the “forest loss for dam”, the surface of land covered with water as result of the construction of a new dam (generated by the “Dam impacts on labour force and forest” sector).

The last item of expenditure considered is the “voltage lines construction cost”, representing the total cost sustained to built power lines. This variable as well is determined in a very trivial way: it is given by the multiplication of “voltage lines construction”, the yearly amount km of power lines built, times the parameter “average cost of 1 km of voltage lines”.

It is important to notice the “dam cumulative profits” stock does not represent the national electricity company’s budget, as it does not consider revenues and costs of all its activities, nor does it represent the cost sustained by the government, which pays only a part of the total costs and does not get any revenue. It is just a useful indicator to evaluate the economic convenience of capacity investments in the sector.
The parts of costs sustained by the government for projects of capacity expansion are summed up in the variable “dam costs sustained by the government”, which only considers capacity and lines construction, as well as relocation costs.

*Linkages with the rest of the Model*

Five are the inputs from other sectors used for the determination of costs and profits, and all of them come from the dams sectors’ group. The two rates “dam completion rate” and “voltage lines construction” are used to determine construction costs, “forest loss for dam” and “dam capacity” to define the relocation and maintenance costs, respectively. The last input, “hydroelectric energy supply”, is used to determine the revenue from energy selling.

On the other hand, the outputs produced by the sector and used in other parts of the model are four: “dam construction costs”, “dam running costs”, “hydropower price Kwh” and “dam costs sustained by the government”. The first two variables are used in the “dam impact on labour force and forest” sector, to determine the labour force required for construction and maintenance of hydroelectric plants. “Hydropower price Kwh”, as already described, is used in the “dam impact on production activities” sector, to determine the “weighted energy price”. The last output, “dam costs sustained by the government” is used in the government sector to determine the total extra of expenditures.

**2.4.4 Dam Impact on Labour Force and Forest**

This sector has been developed with the objective of representing two different types of phenomena: the creation of labour demand due to the construction of new dam and the forest loss caused by the same projects. These phenomena are represented by two distinct structures, which have been aggregated in the same sector to reduce the number of sketches in the model.

In Figure 18, the lower part of the diagram represents the structure used to represent how forest loss is generated, while the upper part determines the labour force required in the hydropower sector.
The hectares of forest lost for dam construction are simply obtained by multiplying “dam completion rate” times the parameter “average forest loss per Kw of capacity built”, times the “forest cover ratio”:

\[
\text{Forest loss for dam} = \text{dam completion rate} \times \text{AVERAGE FOREST LOSS PER HYDROPOWER KW BUILT} \times \text{forest cover ratio}
\]

“Forest cover ratio” is a variable representing, as already explained while describing the Land sector, the ratio between forest land and the total land of the region. It is used in this formulation to take into account the fact that not all the surface eventually covered with water, as a consequence of building a new dam, is in effect forest land.

“Forest loss for dam” is then accumulated in the stock variable “cumulative forest loss for dam”, which is an important indicator and memory of the flora lost to increase hydropower capacity.

The way the local and foreign labour force required for construction and maintenance of hydropower capacity is determined is a little bit more complicated. The formulations used for the determination of both construction and maintenance labour forces are,
however, exactly the same. I will therefore explain the former case only, as the reader can easily understand the latter for analogy.

The main assumptions underlying these formulations are that constant shares of the amounts paid for construction (and maintenance) consist of the salaries of people involved in the construction, and that constant shares of these are for foreign workers and the rest for local workers.

The mechanism through which the demand of labour for dam construction is obtained starts with the determination of the “labour force cost for dam construction”, the total labour force cost for construction projects, which is derived as the multiplication of “dam construction costs”, the total construction costs, times the parameter “percentage of dam construction costs for labour force”. “Labour force cost for dam construction” is then shared into two components, “dam construction labour cost for local people” and “dam construction labour cost for foreign people” based on the parameter “percentage of construction labour cost for local people”. These two variables are subsequently transformed in the number of local and foreign people required for dam’ construction by multiplying them by the “initial labour productivity ind” and the “initial labour productivity mining”. The underlying idea here is that local and foreign people have substantially different of productivity, as they have different levels of instruction and of specific skills. We assumed then foreign workers productivity to be the average productivity observed in the mining sector, where most of people employed are foreign, and local people’s productivity, on the other hand, to be the one observed in the industry sector.

“Local labour force required for dam construction” is then summed up with “local labour force required for dam maintenance”, determined with a specular structure, to generate the “total local labour force required for dam”.

Linkages with the rest of the Model

The sector is affected by six elements from other sectors. The first two elements, “forest cover ratio” and “dam completion rate”, from the Land and the Dam sectors respectively, are used as above explained to determine forest loss. “Dam construction costs” and “dam running costs” are generated in the Dam economic costs and revenues sector, and are
used for the determination of the expenditure for work force for building and maintaining hydropower capacity. The last two elements, “initial labour productivity mining” and “initial labour productivity ind” come from the respective production sectors, and are used for the final determination of the number of people employed in the hydropower sector.

The dam impact on labour force and forest sector impacts on the rest of the model in two ways.

First, “forest loss for dam” is used both in the Land sector to define the level of the forest land stock, and in the Dam economic costs and revenues sector, to determinate the “relocation costs” (as already explained while describing that sector). Second, “total local labour force required for dam” is used in the Employment sector, to determine the total employment level for infrastructures building and maintenance.

2.4.5 Highway Physical Structure

Before starting the analysis of the Highway sector, it is useful to very briefly introduce the reader to the actual conditions and characteristics of Irian Jaya’s road network.

Road transportation’s infrastructures in Papua are particularly poor. Not only most of rural areas are not accessible at all by car, but also most of the linkages between the main urban centres are missing. Travelling between the eastern and the western part of the province means using an airplane, or a long boat trip. Many areas rich in natural resources, moreover, can be accessed only by river, or not accessed at all in many cases.

Conscious about the insufficiency of the feeble road network, which is undersized even with respect to the small regional economy, the government is actually carrying on a series of maintenance and construction projects to support road transportation between the main urban/economic areas. The local administration is also evaluating the project of construction of a “Trans Irian Highway”, a highway network connecting the eastern and the western sides of the province, and opening up many resources-rich areas.

The Highway sector has been built with the aim of representing the physical mechanisms of construction and degradation of highway, and the way in which the roads’ length and quality can affect the transportation cost. In the sketch presented in Figure 19, two are the
main stock and flow structures that can be identified: the one at the bottom of the diagram, representing how projects are transformed with time into real highway, and the one the top of the diagram, representing the actual level of quality of the existing roads and the elements that affect it. Both are functional to the final determination of the “relative road transportation cost”, at the right hand side of the sketch.

Figure 19: Sketch of the Highway Physical structure sector

The way process of highway construction and the actual length of the network are represented is very intuitive. “Highway construction starts” is the rate representing the yearly number of kilometres of highway the government desires to build. It is determined by the policy variable “desired km of new highway”, as well as by the time function “past highway construction” and the parameters “desired percentage of trans Irian” and “scenario mode selector”. This variable, as all the others used for the determination of the network length, is defined on a two dimensions array, to take into consideration two different kinds of roads. To simplify the model, I divided the existing roads into two categories: “high relevance” and “low relevance”. “High relevance” roads are those linking urban and economic centres, and are supposed to have a strong importance for the development of the local economies, but a small environmental impact, as they would not cross any preservation area.
On the other hand, “low relevance roads” are those created deliberately to open up new forest regions for logging and should have a strong negative effect on the environment and a small impact in terms of local economies’ development. “Highway construction starts” is therefore determined by two equations:

\[
\begin{align*}
\text{highway construction starts [highrel]} &= \text{PAST HIGHWAY CONSTRUCTION[highrel]}(\text{Time}) + \\
&\quad \text{DESIRED KM OF NEW HIGHWAY[highrel]}(\text{Time}) \\
\text{highway construction starts [lowrel]} &= \text{PAST HIGHWAY CONSTRUCTION[lowrel]}(\text{Time}) + \\
&\quad (\text{IF THEN ELSE (SCENARIO MODE SELECTOR=3,1,0)}* \\
&\quad \text{DESIRED KM OF NEW HIGHWAY[lowrel]}(\text{Time})*\text{DESIRED PERCENTAGE OF TRANS IRIAN/11000} + \\
&\quad \text{IF THEN ELSE (SCENARIO MODE SELECTOR=2,1,0)}* \\
&\quad \text{DESIRED KM OF NEW HIGHWAY[lowrel]}(\text{Time})*0.1)
\end{align*}
\]

For both equations, the two main components are “past highway construction” and “desired km of new highway” representing the projects carried on in the past (since 1995) and the projects the government desires to implement in the future, respectively. Moreover, in the equation for “low relevance” highway the “scenario mode selector” is used with a formulation similar to that used for other policy variables, with the effect of allowing the user to rapidly modify his construction policies. The “desired percentage of Trans Irian” has been introduced with the same purpose.

“Highway construction starts” is accumulated in the stock “Highway under construction”, representing the number of kilometres of new highway the government is constructing. Kilometres of new highway will eventually flow into the “total amount of existing highway” stock through the rate “highway completion rate” after an average period of five years.

As in the case of dam construction, I aggregated all the steps of highway construction into one phase of construction. The structure used here, however, is accurate enough for the purpose of the analysis, considering the long-term time horizon used.
Proceeding with the description of the sector, “Total amount of existing highway” is compared to “initial existing highway” to define “relative highway change”, which is used to determine “length effect on transportation cost”. This is determined through the table function “length effect function”, which for any given value of “relative highway change” gives a different output according to the following table.

Table Function 2: Length Effect Function

The resulting function has a hyperbolic shape, generating as a result a strong reduction in transportation cost for unit increase in the length of the highway network when the network is short, and a small effect per unit increase when the network is very long. The assumption underlying this formulation is that as the length of the network is increased, new destinations can be reached by road and existing destinations can be reached with a shorter trip, with a positive effect in the reduction of transportation costs. However, as the network becomes very dense, fewer new destinations can be reached thanks to a new road, and this can offer less potential advantages in terms of route optimisation. The function saturates when the existing network becomes 25 times bigger than the initial one.
The total quality of the highway network is represented by a stock variable, “highway quality conditions”, which accumulates “efficiency points” of each existing km of highway, measured on a scale from 0 to 100. To obtain an indicator of the average highway quality, this variable is then divided by kilometres of “total amount of existing highway”.

Two are the rates affecting this stock: “creation and maintenance” and “consumption”.

“Creation and maintenance” is modelled as a co-flow of “highway completion rate” and “programmed maintenance” components, as described in the following equation:

\[
\text{creation and maintenance} = \\
\text{programmed maintenance} \times \text{DESIRED FRACTION OF PROGRAMMED MAINTENANCE} + \\
\text{highway completion rate}[\text{lowrel}] \times \text{NEW HIGHWAY QUALITY}[\text{lowrel}] + \\
\text{highway completion rate}[\text{highrel}] \times \text{NEW HIGHWAY QUALITY}[\text{highrel}]
\]

“Highway quality conditions” will then increase both as new highways are built and from programmed maintenance conducted. The latter is obtained by multiplying the indicated programmed maintenance times the policy variable “desired fraction of programmed maintenance”, representing the amount of maintenance the government is actually willing to implement. “Programmed maintenance” is given by the difference between actual and “desired highway quality”, assuming that all maintenance work can be conducted during one year.

On the other hand, I assumed “highway consumption” to be dependent on time, and I simply assumed the consumption process to be an exponential decay process, with an “average highway lifetime” of ten years. Although in reality the number of vehicles using a certain road is relevant to its consumption, in equatorial climates natural erosion normally has the greatest role in diminishing highway quality.

The stock variable “highway quality condition” is then divided by the total km of “total amount of existing highway” to derive “actual highway quality”, an indicator of the
average quality of all the highways across the region. This indicator is subsequently compared to “initial highway quality” to determine “relative highway quality”, a dimensionless variable used as an input for the table function “quality effect function”. The output produced by this table function determines the effect of highway quality on transportation cost, represented by the variable “quality of highway effect on transportation cost”, and may be portrayed by the following table:

<table>
<thead>
<tr>
<th>INPUT</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>0.25</td>
<td>2.5</td>
</tr>
<tr>
<td>0.5</td>
<td>2</td>
</tr>
<tr>
<td>0.75</td>
<td>1.5</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1.25</td>
<td>0.75</td>
</tr>
<tr>
<td>1.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table Function 3: Quality Effect Function

As for the “length effect function”, this function has a hyperbolic shape, implying strong effects of changes in highway quality on transportation cost when the absolute quality is low, and weak effects when the absolute quality is high. The function saturates for a value of quality 50% higher than the initial one, meaning that further improvements would not benefit transportation cost.

The two effects, “length effect on transportation cost” and “quality of highway effect on transportation cost” are then multiplied together to determine the “relative road transportation cost”. This variable indicates the ratio between the actual and the initial road transportation cost. (Though these two are not determined in the model, it has been possible to obtain the “relative road transportation cost” thanks to a mathematical
simplification. In fact, if we define the actual road transportation cost as the multiplication of the initial transportation cost times the two effects of roads quality and length and divide it by the initial transportation cost, we obtain the same result as multiplying together just the two effects.

Linkages with the rest of the Model
This sector is not actually affected by any sectors of the model, but it impacts on other sectors through four main elements: “programmed maintenance”, “highway completion rate”, “total amount of existing highway” and “relative road transportation cost”.

The first variable is used in the “highway economic costs” sector, to determine maintenance cost, as well as the “highway completion rate”, which is also used to determine the forest loss due to highway construction. “Total amount of existing highway” is used in many sectors of the highways’ group, to determine costs of maintenance, logging control costs and forest loss due to illegal logging.

The key variable of the sector, “relative transportation cost”, is used in two different parts of the model: the “Highway impact on production activities” and the “Pollution” sectors. In the former case, it is used to determine transportation costs shared in the different production activities, with a formulation similar to that explained for the energy cost share on production activities. In the latter case, “relative road transportation cost” is used to define the air pollution generation rate, as I will describe in the Pollution sector’s paragraph.

2.4.6 Highway Impact on Production activities
To represent how new highway construction may impact different production activities, I used a set of assumptions similar to those introduced in representing the effect of new dam construction on production activities.

The key element to determine this effect is, in fact, the price of road transportation. I assumed that at the moment “relative road transportation” decreases, the money saved by producers on transportation would be spent on other resources to increase productivity. Figure 20 shows the structure used to represent this effect for the agriculture production sector, which is specular to those used in all the other production sectors. I will explain
here only the case of agriculture, as the reader may understand by analogy the
formulation used to represent the effects on the other production activities.

Given the two parameters “initial total agriculture transportation cost” and “initial
agriculture production”, representing the overall cost for transportation sustained in the
agriculture sector and the initial level of production in this sector respectively, the “initial
transportation cost share in agriculture” is defined simply as the ratio between the two.
This variable represents the relevance of expenditures on transportation in agriculture
with respect to the sector’s overall production. The actual “transportation cost share in
agriculture” is determined in a similar way, but “relative road transportation cost” is also
used to take into account the change in the expense for transportation due to changes in
cost. The formulation used to determine this variable is, consequently:

\[
\text{transportation cost share in agriculture} = \frac{(\text{INITIAL TOTAL AGRICULTURE TRANSPORTATION COST} \times \text{relative road transportation cost})}{\text{INITIAL AGRICULTURE PRODUCTION}}
\]

The initial and the actual transportation cost shares are then used to determine the
“indicated transportation cost effect on agriculture productivity” in the following
equation:

\[
\text{indicated transportation cost effect on agriculture productivity} = 1 + \left(\frac{\text{initial transportation cost share in agriculture} - \text{transportation cost share in agriculture}}{\text{SENSITIVITY AGRIPROD TO TRANSP COST SHARE}}\right)
\]
As indicated above, the difference between the initial and the actual transportation cost shares is multiplied by a sensitivity parameter, which differentiates the intensity of the effect in the different sectors. In some sectors, in fact, the reduction in transportation costs may have a stronger effect depending not only on transportation’s impact on the agricultural sector’s budget, but also on the characteristics of the sector itself. For example, in agriculture it is easily possible that lower transportation costs may lead to new producers gaining access to the market.

The “indicated transportation cost effect on productivity” does not directly affect the Agriculture production sector, but only after a certain delay. I assumed in this case that it takes time for producers to realise the benefits deriving from lower transportation costs and implement new strategies, and I set the average delay time to one year. Therefore, a first order delay function is used to represent this delay, determining the actual “transportation cost effect on agriculture”.

**Linkages with the rest of the Model**

This sector is affected by only element from the rest of the model: the “relative road transportation cost”, key in the determining initial and actual transportation cost shares. The highway impact on production activities impacts on the rest of the model through four elements. These are the effects of transportation cost on the different production activities, are used in their respective production sectors in a multiplicative form to obtain the value of productivity.

**2.4.7 Highway and Logging**

Logging in Papua is a central business, and illegal logging represents an extremely serious threat to the island’s primary forest. The aim of this sector is to describe how intervention on the road transportation infrastructure may affect forestland.
Highway construction can cause deforestation in three ways. First, the road itself occupies a certain area that must be previously deforested, as well as the surrounding area necessary for people and machines to work. Second, roads are necessary for illegal logging, as it would be too difficult and expensive in most cases to transport trees in other ways (i.e., where river transportation is not possible). Roads, therefore, open up new areas for illegal logging, and I assumed this to be proportional to the number of km of existing roads. Third, the government may use logging concessions around roads to pay foreign companies for road construction, as some large-scale construction projects suggest.

Figure 21 shows the stock and flow diagram of the sector and the structures actually used to represent these three components.

“Cumulative forest loss from road expansion” is a stock variable and an important indicator accumulating the yearly rate of “forest loss from highway construction”, which is composed of three elements, as already mentioned, and formulated as follows:

\[
\text{forest loss from highway construction} = \\
\text{MINIMUM HECTARES OF FORESTS CUT PER KM OF HIGHWAY}
\]
The first component, representing the minimum area lost due to the nature of the road construction’s process and the dimension of the road itself, it is simply defined as the the number of kilometres of highway built, “highway completion rate”, multiplied by a fixed amount of forestland lost per kilometre, “minimum hectares of forest cut per km of highway”.

Similarly, the last component “highway concessions” is found by multiplying “highway completion rate” times the policy variable “governmental concession per km of highway”, indicating the number of hectares the government is willing to give as payment for the construction of one km of road, times the “forest cover ratio”. This last variable has been used to take into account that not all the land surrounding the highway that is given in concession to foreign companies to pay for the road construction is actually forestland. We assumed, therefore, that the distribution of the forest is uniform across the country, and the actual percentage of forestland around all highways corresponds to the “forest cover ratio”.

“Forest loss due to illegal logging” is determined through a more complicated process. Two assumptions underlie this process: the first, as already mentioned, is that illegal logging is directly related to the size of the highway network; the second is that illegal logging is inversely related to governmental expenses on illegal logging controls. To combine these two assumptions into one, I modelled illegal logging as inversely related to the government control expenditure per km of highway. To do so, first the actual expenditure for illegal logging control per km of highway, “governmental investment for logging control per km”, is compared to its initial level, “initial control expense”. The ratio between these two parameters gives the “relative control expense”, which is used as an input to the table function “effect of control strength on illegal logging function”, which may be portrayed by the following table.
Table Function 4: Effect of Control Strength on Illegal Logging Function

This function has a hyperbolic shape, implying strong effects of changes in control intensity on illegal logging when the control level is low, and small effects when the control level is already high. The function saturates for a level of control 10 times higher than the actual, which is assumed to reduce illegal logging per kilometre to 30% of the initial level.

The output of this function is then multiplied by the parameter “initial logging areas lost per km of highway”, representing the number of hectares per year lost due to illegal logging at the beginning of the simulation, to obtain its actual correspondent, the “actual illegal logging per km”. “Actual illegal logging” is finally used to determine “forest loss due to illegal logging”, together with “total amount of existing highway”, “relative forest cover ratio” and “relative intensity of illegal logging”, according to the following equation:

\[
\text{forest loss due to illegal logging} = \sum (\text{relative intensity of illegal logging}[\text{highway stratrel}!] \times \text{total amount of existing highway}[\text{highway stratrel}] \times \text{actual illegal logging per km}) \times \text{relative forest cover ratio}
\]
Central to this formulation is the multiplication of “total amount of existing highway” by “actual illegal logging per km”, determining the gross number of hectares subject to illegal logging. The parameter “relative intensity of illegal logging”, defined over a two dimensional array, has been introduced to take into account differences in the impact on illegal logging between “low relevance” and “high relevance” roads constructed. We assumed that the former has a strong impact on illegal logging, and the latter a weak one, because of their intrinsic characteristics, as explained in the Highway sector’s section.

“Relative forest cover ratio” is also used in this formulation to take into account the fact that not all the land surrounding the highway that is illegally logged is actually forestland. The value of “forest loss due to illegal logging” thus determined is then used to determine “forest loss from highway construction” as explained at the beginning of the paragraph.

One other important structure is used in this sector to represent an opportunity cost underlying highway construction projects. “Implicit economic loss from forest loss”, shown at the bottom of the diagram in Figure 21, is a central indicator representing the amount of money the government would have received if all the forest cut for highway construction would have been given as normal logging concession. This opportunity cost refers here only to the amount of taxes on exportation lost, and not on concessions’ royalties and direct taxes on logging companies’ profits. The formulation used to determine this variable is straightforward, as indicated in the following equation:

\[
\text{implicit economic loss from forest loss} = \text{Cumulative Forest Loss from Road Expansion} \times \text{AVERAGE WOOD DENSITY} \times \text{AVERAGE EXPORT PRICE} \times \text{TAX ON EXPORTATION}
\]

The value of “cumulative forest loss from road expansion”, expressed in hectares, is multiplied by the “average wood density”, to derive the tons of wood production lost, by “the average export price”, to obtain the total value of the wood lost, and finally by the percentage of “tax on exportation” applied by the government. This indicator, being far from accurate, it gives an idea about the inflow of money into the governmental budget loss because of the construction projects implemented, an important and hidden component of their costs.
Linkages with the rest of the Model

This sector is affected by three elements from other sectors. The first two elements used, “total amount of existing highway” and “highway completion rate”, are generated in the Highway sector and are functional in determining “forest loss due to illegal logging” and total “forest loss from highway construction”, respectively. The third element, “forest cover ratio”, comes from the Land sector and is used to determine the “relative forest cover ratio” and “highway concessions”.

The highway and logging sector also impacts on other sectors in two ways. First, “forest loss due to illegal logging”, is used in the Land sector, to determine the deforestation rate. Second, “highway concessions”, is used in the Forestry and Fishery sector, to determine the “forestry production remitted abroad”, in the Land sector, to determine the “forest conversion” rate, and in the Highway Economic Costs sector, to determine the “total relocation cost”.

2.4.8 Highway related Employment

This sector represents the mechanisms through which the amount of local labour force required for highway construction and maintenance is determined. The structures used in this sector are logically similar to those used in the Dam Impact on Labour Force and Forest sector, though they are presented in a more aggregate way (Figure 22).

Three major assumptions underlie the way this sector is represented. First, I assumed that a constant share of the construction and maintenance costs consists of the salaries paid to the labour force. Second, I assumed that a constant part of the total salaries go to foreign workers, and the rest is shared between local workers. Finally, I assumed that foreign and local workers have different productivities, and that these are well represented by the productivities observed in the Mining and in the Industry production sectors, respectively. As already explained for the Dam Impact on Labour Force and Forest sector, the motivation of this last assumption originates from the fact that the Mining sector has a much higher percentage of foreign workers than the Industry sector. The productivity observed in that sector is therefore considered more suitable to represent foreign workers’ contribution to production.
Figure 22: Sketch of the Highway related Employment sector

Given these assumptions, the “total local labour force needed for highway” is simply determined as the sum of the “labour force needed for maintenance” and the “local labour force needed for construction” projects.

The “local labour force needed for construction” is determined as following:

\[
\text{local labour force needed for construction} = \frac{\text{cost of highway construction} \times \text{SHARE OF CONSTRUCTION COST FOR LABOUR} \times \text{SHARE OF LABOUR EXPENSE FOR LOCAL STAFF}}{\text{INITIAL LABOUR PRODUCTIVITY IND}}
\]

In this formulation “cost of highway construction”, the total yearly cost related to the construction of new highway, is multiplied by the “share of construction cost for labour” and by the “share of labour expense for local staff”, to determine the amount of money spent for local workers. To obtain from this amount of money the number of people actually employed, I divided it by the “initial labour productivity ind”, the labour productivity observed in the industry sector at the beginning of the simulation.
For what concerns the “labour force needed for maintenance”, I assumed that the people employed in highway maintenance are exclusively local people, given that this is a job that does not require particular skills and that foreign workers are much more expensive than local ones.

“Labour force needed for maintenance” is therefore simply defined as:

\[
\text{labour force needed for maintenance} = \frac{\text{SHARE OF MAINTENANCE COST FOR LABOUR} \times \text{actual expense for maintenance}}{\text{INITIAL LABOUR PRODUCTIVITY IND}}
\]

“Actual expense for maintenance”, the total expenditure for road maintenance, is here multiplied by the “share of maintenance cost for labour” (as I assumed in this case the share of expenditure for local staff to be equal to 1) and then divided by the “initial labour productivity ind”, to determine the number of people actually employed for road maintenance.

In this sector, with a formulation parallel to that used for “local labour force needed for construction”, the “foreign labour force needed for construction” is also determined. However, this variable does not affect any other in the model and it is solely used as an indicator.

*Linkages with the rest of the Model*

The highway related employment sector is affected in four different ways from other sectors of the model, and impacts, through the variable “total local labour force needed for highway”, on the Employment sector. This variable is used to determine the total number of people employed to build and maintain infrastructures.

Of the four elements impacting on the highway related employment sector, two come from the Highway Economic Costs sector, namely “cost of highway construction” and “actual expense for maintenance”, and are used here to determine the “local labour force needed for construction” and the “labour force needed for maintenance” respectively.

“Initial labour productivity ind” and “initial labour productivity mining”, which come
from the industry and mining sector, are also used to determine the labour force needed for construction and maintenance.

2.4.9 Highway Economic Costs
The aim of this sector is to represent the determination of the costs related to the construction and maintenance of new highway.

As appearing in Figure 23, one stock variable is represented in this sector, namely “highway cumulative costs”, accumulating over time the total costs sustained. This variable integrates the total “highway cost” as well as the eventual negative “interests paid on loan”.

Figure 23: Sketch of the Highway Economic Costs sector

“Interests paid on loan” has been represented in the model to allow the user to introduce the assumption of an opportunity cost in the determination of the total costs sustained by the government for highway construction and maintenance. This flow, in other words, represents the implicit loss for the government deriving from investing in this sector instead of investing in other financial activities. This variable, however, has not been
used in any of the scenario presented in this work, though I presume it will become useful for further analysis.

“Highway cost”, the total cost of construction sustained each year, is represented by four main components: “cost of highway construction”, “actual expense for maintenance”, “total relocation cost” and “total control cost”. “Highway cost” is simply defined as the sum of the four cost components, the origins of which is explained in the following.

“Cost of highway construction” represents the total costs for all the resources employed in the construction of new highway. It is simply obtained by multiplying the constant average “highway cost per km” times the “highway completion rate, representing the km of highway completed per year. The assumption introduced here is that the government actually pays for new highway construction only gradually, as these become functional. This assumption seems reflecting quite well what happens in most of cases for big infrastructures projects and, though certainly simplistic, I found it accurate enough with respect to the purpose of the analysis.

The “total relocation cost” is the cost sustained by the government to move people from their original region elsewhere, as their homeland has been given in concession for logging and cannot therefore host them anymore. This variable is derived by multiplying the “average cost of relocation per ha”, the same parameter used to determine the relocation costs in the Dam Economic Costs and Revenues sector, times “highway concessions”, the yearly number of hectares given as logging concessions to pay for highway construction.

“Total control cost” represents the annual governmental expenditure to control illegal logging. This expenditure is related, as explained in the Highway and Logging sector’s paragraph, to the dimension of the highway network, and is given by the multiplication between “total amount of existing highway”, the total number of km of highway, and the policy variable “governmental investment for logging control per km”.

The structure used to determine the “actual expense for maintenance”, or the annual amount of money spent by the government to maintain highways in good operating conditions, is slightly more complicated. This variable is given by multiplying the indicated “highway maintenance cost” times the policy variable “desired fraction of
programmed maintenance”, which represents the share of the indicated maintenance costs the government is willing to support.

“Highway maintenance cost” represents the indicated cost that the government should sustain to keep actual highway quality level approximately equal to the theoretical “desired highway quality” parameter. The formulation used to determinate “highway maintenance cost” is based on the assumption that maintenance costs per kilometre increase greater than proportionally to the intensity of increases in maintenance intervention. Following this assumption, I first determined the relative intensity of the maintenance intervention, the variable “relative intervention intensity”. This is the ratio between the actual required intensity of intervention to keep highway quality at the desired level, represented by the variable “programmed intensity of highway maintenance intervention”, and the parameter “normal intensity of intervention”, to which is associated a “normal highway cost of maintenance per km per year”. With normal intensity of intervention, I considered here the maintenance of the top 10 per cent surface of the road.

“Programmed intensity of highway maintenance intervention” is given by the ratio between “programmed maintenance”, from the Highway sector, and “total amount of existing highway”, the road network’s total number of kilometres.

“Relative intervention intensity” then becomes an input to the table function “maintenance cost per km of highway function” (Table Function 5), which represents the cost of maintaining one kilometre of highway as a function of the intensity of the maintenance interventions necessary.

The function used is non linear and assumes on one side a cost equal to 1/20 of the construction cost for ordinary maintenance, corresponding to the reconstruction of the last 10% layer of the road, and on the other side the full construction cost when the road must be rebuilt.
The absolute values of these costs are obtained when multiplying the output of this table function times the parameter “normal highway cost of maintenance per km per year”, representing the basic cost for an intervention of normal intensity. These relationships are represented by the “highway maintenance cost” equation, which is formulated as:

\[ \text{highway maintenance cost} = \text{MAINTENANCE COST PER KM OF HIGHWAY FUNCTION (relative intervention intensity)} \times \text{NORMAL HIGHWAY MAINTENANCE COST PER KM PER YEAR} \times \sum \text{(Total amount of existing highway [highway stratrel!]}) \]

In this equation the actual cost of maintenance per kilometre, obtained by multiplying “normal highway cost of maintenance per km per year” and the output of the “maintenance cost per km of highway function”, is multiplied by the total kilometres of
the highway network. The “highway maintenance cost” is thus used to determine the “actual expense for maintenance”, as previously explained.

**Linkages with the rest of the Model**

This sector is affected by four different elements determined in other sectors: “total amount of existing highway”, “highway completion rate”, “programmed maintenance” and “highway concessions”. “Total amount of existing highway” is used to determine “highway maintenance costs” as well as “total control costs”, and comes from the Highway sector. From the same sector also comes “highway completion rate”, used to determine the “cost of highway construction”, and “programmed maintenance”, used to determine the “relative intervention intensity”.

The highway economic cost sector also impacts on other sectors in three different ways. “Cost of highway construction” and “actual expense for maintenance” are used in the Highway related Employment sector to determine the number of people required for highway construction and maintenance. “Highway cost” is used in the Government sector for the determination of the governmental total extra expenditures.

**2.4.10 Pollution**

The pollution sector was not developed to produce quantitative levels of different pollutants, but to give a qualitative idea about how the pollution levels in Papua may evolve over time depending on the development path the government will follow.

This sector, portrayed in Figure 24, represents how the relative levels of pollution in water, air and soil with respect to the initial ones are determined, and it is based on three main assumptions.

Firstly, I assumed pollution generation to be proportional to the quantity of output produced in the different production activities. In other words, more output is produced, more resources are used, and therefore more pollution is created.

Secondly, I assumed that as the level of technology increases, the pollution generated per unit produced decreases. Underlying this assumption is the reasoning that as better technologies are available, resources are used in a more efficient way, reducing pollution generation in the production processes.
Finally, I assumed that the initial levels of pollution in each element are initially in equilibrium, in line with the initial levels of production in the different sectors. This means that if the production levels had not changed with respect to the initial ones, pollution levels as well would have remained constant. This assumption is consistent with the formulation of the pollution absorption rate as an exponential decay process, with no delays involved.

The core of the sector is the stock variable “pollution”, which represents the relative levels of pollution in the three elements. This stock is defined over a three dimensional array and separately tracks pollution levels in water, air and soil. Two flows affect this stock variable: “pollution assimilation” and “pollution generation”. As already mentioned, “pollution assimilation” is assumed to work as an exponential decay process. It is therefore defined as the “pollution” level divided by the average “assimilation half life” parameter, which assumes different values for each of the three different kinds of pollution.

“Pollution generation” on the other hand, is determined by the pollution generated in each production sector and by the “relative transportation cost”. I assumed that a reduction in
the cost of road transportation causes a shift from other forms of transportation, such as water or animal transportation, to road transportation. This consequently increases the air pollution generated per unit produced, as producers would use more fossil fuel to transport their products on wheels instead of using the slower traditional transportation forms. “Relative transportation cost” is therefore used as an input for the table function “transportation mode shift function”, which represents the effect of changes in transportation cost on the air emissions generated in all production activities, and may be portrayed as in the following table.

<table>
<thead>
<tr>
<th>Relative Transportation Cost</th>
<th>Air Pollution Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

The function has a typical inverted “S” shape, assuming strong effects of changes in road transportation cost on air pollution generation when the input move slightly around its initial value, and weaker effects while approaching the two extremes of the interval considered. The function saturates at the extremes, producing a maximum of 50% increase in air pollution generation should road transportation become completely free, and a 50% decrease should road transportation cost double with respect to its initial
value. The output generated by this function is then multiplied by the total air emissions value produced by each production activity.

The way pollution emissions are determined is the same for each of the production sectors, and I will therefore explain here as an example the industry sector, so that the reader may understand by analogy the other sectors.

“Pollution generated by industry” is represented as a function of the total production in the sector, of the “pollution generated by industry per unit produced” and of the “effect of technology on pollution”, in the form of the following equation:

\[ \text{Pollution generated by industry} = \frac{\text{industry produced} \times \text{pollution generated by industry per unit produced}[\text{element}]}{\text{effect of Technology on pollution}[\text{industry}]} \]

“Industry produced”, representing the annual production in the industry sector, is multiplied by the “pollution generated by industry per unit produced” and then divided by “the effect of technology on pollution”, to take into account how, as I assumed, technological progress may reduce pollution emissions. In this case, in particular, I assumed a direct inverse relationship between technology and pollution emission, as this seemed to me the simplest possible assumption given the information available.

“Pollution generated by industry per unit produced” is given by the multiplication of the “initial pollution generated by industry per unit produced” times the “hydropower pollution impact effect”, from the Dam sector. This formulation has been used only for air pollution, to take into consideration the effect of substituting old diesel electric generators with hydroelectric electricity. As the latter form of energy involves no fuel consumption in its production process, a larger use of it reduces the pollution generated per unit of electricity used, and therefore per unit of product created.

“Pollution generated by industry” is then summed with the pollution generated in other sectors and multiplied by the output of the “transportation mode shift function” to determine the flow of “pollution generation”, as described in the following equation:
pollution generation=
(pollution generated by industry[air]+pollution generated by agriculture[air]+pollution generated by mining[air]+pollution generated by service[air])*TRANSPORTATION MODE SHIFT FUNCTION(relative road transportation cost)

The equation above describes only how air pollution is determined: the equations for the other elements are all similar to this, with the exception of the “transportation mode shift function”, which is specific to air pollution.

The stock of “pollution” is then used to derive two important indicators: the “pollution index” and the “pollution composite index”. The first indicator simply represents the ratio between the actual and the “initial pollution” level for each of the three elements. The second indicator is derived by the first one, but is defined on one only dimension, as it uses the “relative relevance of pollution levels” parameter to make a weighted sum of the values in the “pollution index”. The idea underlying this operation is to provide the user with a simple and quick indicator of the situation of pollution in Papua. This has been made possible by giving to each of the different kinds of pollution an arbitrary weight, representative of the relative importance of the pollution levels in the different elements at the beginning of the simulation.

The indicator “composite pollution index” thus defined is also used as an input to the table function “effect of pollution on productivity function”, to determine how changes in the pollution level may affect workers productivity.

With a shape similar to the right half of an inverted parabola (Table Function 7), the function assumes little effects on productivity when pollution is low and then more serious effects when it becomes more then five times larger than its initial value.

The output of the “effect of pollution on productivity function”, represented by the variable “indicated effect of pollution on productivity”, does not directly affect productivity, but it does so with a certain delay. To represent this phenomenon I used a first order delay function.
The output of this information delay is the level assumed by the stock variable “effect of pollution on productivity”, which is then used to determine productivity in all production sectors.

Table Function7: Effect of Pollution on Productivity Function

Linkages with the rest of the model

The pollution sector is influenced in six ways by other sectors and impacts in two ways on other parts of the model. Among the influences to be considered, four are the production values of the different production sectors and are used to determine the quantity of pollution produced by each production activity. “Technology”, which comes from the Technology sector, has the same purpose. The last input is the “relative road transportation cost”, from the Highway sector, and it is here employed in determining the air pollution.

Among the two impacts produced by the pollution sector, I used the “effect of pollution on productivity” to determine the productivity for the different production activities and
the “pollution composite index”, to derive the “effect of pollution on life expectancy” in the Effects on Life Expectancy sector.

2.4.11 Small Credit and Government Borrowing

The model includes this sector to represent two different accounting processes, regarding the government debt and the small credit initiatives, both defined in part by the interest rate.

Figure 25 shows the stock and flow sketch of the sector: the Small Credit structures are portrayed in the upper part of the diagram, and the Government Borrowing’s ones in the lower part.

The Government Borrowing structure involves only one stock variable, “Gov Debt”, which measures the amount of money the government borrowed from foreign sources. For simplicity, I assumed that the government only has access to foreign financial sources. Generally, accessing local sources creates disequilibria in the financial market that I do not intend to produce or study in this phase of the analysis.
“Gov Debt” is influenced by two flows: “gov net borrowing”, representing the annual amount of money the government borrows or pays back, and “interest on gov debt”, the interest rate the government pays on the actual debt.

I formulated the equation for “gov net borrowing” to represent a specific governmental policy. In this case, I assumed that the government borrows money abroad at the moment the available funds for development expenditures are not sufficient to cover them all. The government then simply borrows the difference between the funds available and the desired expenditures. Subsequently, when the funds available rise above the level of expenditure, the government tries to pay back the debt as soon as possible. These decisional rules are compacted in the following equation:

\[ \text{gov net borrowing} = \begin{cases} \text{IF THEN ELSE} \left( (\text{Gov Debt}\times\text{prices}/\text{TIME STEP})-(\text{gov develop exp available-gov development expenditures})<0,-(\text{Gov Debt}\times\text{prices}/\text{TIME STEP}),-(\text{gov develop exp available-gov development expenditures})\right)/\text{prices} \end{cases} \]

The variable “prices”, representing the relative level of prices with respect to the initial one, is used in this formulation to transform the nominal values of the variables from the Government sector into real values, and to transform the real values of the variables in this sector into nominal values, when needed. The “IF THEN ELSE” formulation is also used to guarantee that the government does not pay back more than the sum actually due.

A simpler variable, I defined “interest on gov debt”, as the level of debt multiplied by the yearly fractional interest rate “gov interest rate”. “Gov debt” level also influences the flow of negative interests in a more indirect way. “Gov interest rate” is not a constant, but depends on “government financial reliability”, defined as the ratio between debt level and GDrP. I assumed this common macroeconomic indicator was representative of the financial reliability of the government as it gives clear information about the relative size of the debt.

“Government financial reliability” is used as input in the table function “government financial reliability function”, which determines the effect of the level of reliability on the
interest rate applied to the governmental debt. The function may be portrayed as in the following table.

![Graph of Government Financial Reliability Function](image)

**Table Function 8: Government Financial Reliability Function**

The function used is non-linear, and assumes that interest rate initially grows faster when financial reliability decreases, and then it grows slower once past the level of one. The underlying assumption here is that once government debt has exceeded total economic production value, financial reliability of the region is already seriously compromised, and further increases in debt cannot decrease such reliability much more.

The output value of this function is then used to obtain the actual “gov interest rate” by dividing “initial gov interest rate”, by the rate of interest paid in absence of any debt.

The Small Credit structure, in the upper part of the diagram, involves three different stock variables. “Government small business credit funds to be used” and “government small business credit funds used” represent the amount of money made available by the government for small credit initiatives, but not yet used, and the amount already used,
respectively. The mechanism through which money flows from one stock to the other is relatively simple.

As the government decides to make a certain amount of money available for small credit, this flows inside the stock “government small business credit funds to be used”, through the “small credit fund creation rate”. This variable is a function of the policy variable “desired amount of funds destined to small credit”, which represents the annual amount of money the government desires to devolve to small credit initiatives, and of the “scenario mode selector” parameter. The way the actual equation is formulated reflects the construction of other variables using the “scenario mode selector”, which has already been described in previous sections of this work.

The flow that moves money from the stock of the available funds to the “government small business credit funds used” is the “small credit funds concession rate”. This rate is simply the total funds to be used divided by a fixed “average time to use small credit funds”. This parameter then represents the time necessary for entrepreneurs and small companies to apply for money and for the public administration to approve requests that meet certain criteria.

After a certain interval, called the “time to refund”, money lent by the government has to be paid back. The “small credit funds returned” rate, represents the flow of money returned to the government. This rate is determined on the basis of the “small credit to be returned”, which is a pipeline delay of the “small credit fund concession rate”. In other words, this variable returns exactly the value of the input after the “time to refund” delay time. However, not all borrowers of actually return these funds; the “small credit default rate” parameter represents the percentage of funds that are not repaid. The equation of the “small credit funds returned” rate is therefore formulated as following:

\[
\text{small credit funds returned} = \text{small credit to be refunded} \times (1 - \text{small credit default rate})
\]

In contrast, the third rate affecting the “government small business credit funds used”, the “small credit missing refund rate”, accounts for the portion of credit that is not refunded
and then becomes a final cost for the government. This rate accumulates in the stock variable “small credit balance”, which has been formulated to measure the total cost of credit initiatives undertaken by the government.

I considered as costs for the government only the theoretical interests the government pays on the borrowed money and the final part of funds that are not paid back. As mentioned above, the “small credit missing refund rate” represents the latter of the two cost items, while the former is represented by the “small credit interest for gov” rate. The interests represented by this rate can be considered both real and opportunity costs, depending on the way the government chose to finance small credit. Thus to determine the amount of interest the government pays it is also important to take into account funds that are made available but not yet distributed, as I assumed that they are no longer usable for other purposes. The resulting equation for the “small credit interest for gov” rate is therefore:

\[
\text{small credit interest for gov} = (\text{Government Small Business Credit Funds Used} + \text{Government Small Business Credit Funds To Be Used}) \times \text{gov interest rate}
\]

It is also important to notice that the interest rate used in this formulation is the same “gov interest rate” used to determine the “interest on gov debt” rate.

Finally, while the “small credit balance” accumulates over time the total costs sustained by the government for credit initiatives, I also introduced the variable “cost sustained by the government for small credit” to measure the annual total cost of the initiatives. This variable is simply defined as the sum of the two rates affecting the “small credit balance”.

**Linkages with the rest of the Model**

Four variables from other sectors of the model impacts on this sector: “prices”, “gov development expenditures”, “gov develop exp available” and “GDrP”. The first three variables come from the Government sector and are used to determine the “gov net
borrowing” rate. GDrP, on the other hand, is used to determine the “government financial reliability” and comes from the Workers Migration and GNrP sector.

The small credit and government borrowing sector also affects other sectors in three ways. First, “cost sustained by the government for small credit” is used in the government sector to determine the “total extra exp”. Second, “gov debt” is used in the government sector to determine the “gov development expenditures”. Finally, “small credit funds concessions” is used in the investment sector, to determine the actual investment flows for each production activity.

2.4.12 Training

This sector has been built to represent the workers’ training process, a process through which workers acquire new skills and specialise, to eventually become part of the total skilled labour force.

As shown in Figure 26, two are the stock variables used in the representation of this sector: “workers on training”, representing the number of people actually under training, and “trained workers”, representing the total number of living workers that has been trained.

![Figure 26: Sketch of the Training sector](image)

Workers are added to the “workers on training” stock through the “training enrolment rate”, which is determined on the basis of the variable “desired number of trainees per year”. This variable is determined by the policy variable “desired number of trainees per year function”, which indicates the desired number of new trainees enrolled each year,
and by the “scenario mode selector” and the “desired percentage of training program” parameters. These are used to rapidly switch between different possible policies, with the same formulation used for many policy variables in the model, as for example “highway construction starts” (described in the Highway sector).

“Training enrolment rate” also contributes to the determination of the “total cost of training, or the cost sustained by the government to support training programs. This is derived as the yearly number of workers enrolled in the program times the “average cost of training per person”, or the average cost sustained to train each of them.

Moreover, two flows drain workers from the “workers on training stock”: the “training dropout rate” and the “training graduation rate”. The first rate, “expected dropout fraction for training” represents the flow of workers that decides to drop the training program, and I assume it is a fixed percentage every year.

“Training graduation rate” represents the flow of workers that complete the training program and become part of the stock of “trained workers”. The rate is simply the ratio between the total “workers on training” and the parameter “average time required for training”, representing the average length of all the different training programs implemented.

In conclusion, the “trained workers” stock can only be reduced by the “trained workers death rate”, representing the flow of trained workers dying every year. For simplicity, to determine this death rate I applied the “crude death rate” per thousand people to the stock of “trained workers”, as described in the following equation:

\[
\text{trained workers death rate} = \frac{\text{Trained Workers} \times \text{crude death rate}}{1000}
\]

The crude death rate does not exactly represent the average death rate of this category of people, but includes other categories (such as children, for example). However, it is surely accurate enough for the purpose of this analysis. The formulation used for the “trained workers” stock also implies an assumption that old, trained workers continue to be part of this stock, and therefore contribute to the total labour supply until they die.
This assumption seems reasonable as life expectancy in the region is quite low and few people are able to retire from work and live from their savings.

Linkages with other sectors

This simple and important sector of the model is influenced only by one other sector in the model. The “crude death rate”, from the Population sector is used as explained above to determine the “trained workers death rate”.

Notwithstanding, the training sector affects two other sectors. The “total cost of training” is used in the Government sector, to determine the “total extra exp”. The “trained workers” is used in the Employment sector to determine the “skilled labour supply”.

2.4.13 Workers Migration and GNrP

The Workers Migration and GNrP sector was built with two main objectives: to represent the dynamics of worker immigration and emigration in Papua, and to represent the mechanism through which the production’s surplus value is shared between local people and foreign people.

Traditionally, there are many workers from other provinces of Indonesia and other countries that immigrate to Papua to integrate the insufficient local labour supply. Foreign workers employed in Papua have been represented in the model as a stock variable, “migrated workers”, as portrayed in Figure 27.

This stock is affected by two flows: “net skilled workers migration” and “migrated workers death rate”.

“Net skilled workers migration” represents the net flow of foreign workers immigrating or emigrating from the province, and it is formulated on the basis of the imbalance between the “skilled labour supply” and the “skilled labour demand”. These two variables come from the Employment sector and represent the existing specialised labour force and its desired level, respectively.
The equation used to represent the “net skilled workers migration” rate also takes into account the time necessary for the imbalance between labour demand and supply to generate a migration flow, and it is formulated as following:

\[
\text{net skilled workers migration} = \frac{\text{IF THEN ELSE}(\text{Migrated Workers} + (\text{skilled labor demand} - \text{skilled labor supply}) > 0, \text{skilled labor demand} - \text{skilled labor supply}, -\text{Migrated Workers})}{\text{TIME TO MIGRATE}}
\]

The “IF THEN ELSE” formulation has been used here to ensure that the “migrated workers” stock variable would not go negative; this would mean an emigration of local workers, which I assumed unlikely given the characteristics of the local economy and society.
The “migrated workers death rate”, is simply determined on the basis of the “crude death rate”, with the same basic assumptions and the same formulation used for the “trained workers death rate”, explained above.

Apart from the workers migration stock and flow structure described here, I dedicated the rest of the sector to represent how GNrP, or the part of GDrP actually directed to local people, is determined. Two assumptions underlie the structure used in this case: first I assumed that foreign workers employed in the different sectors remit a constant portion of their salaries to their country of origin; secondly, I assumed that a percentage of the benefit generated in the production sectors proportional to the amount of foreign capital invested in each sector is remitted abroad to remunerate foreign investors.

To determine what fraction of paid salaries is actually directed to local people, I first determined what share foreigners represented in the total labour force for each production sector. The process used to determine these variables is the same for all production activities, and I will therefore only explain here the agriculture case, as the reader can easily understand the formulations used in the other cases by analogy.

Given “ag employed”, the total level of employment in the agriculture sector, the number of skilled workers employed in agriculture, “agri skilled labour demand”, is obtained by multiplying it by the parameter “agri percentage of skilled workers”. I assumed in this case that a fixed percentage of the labour force required in this sector must be specialised, without considering the possible effects of the future evolution of agriculture production techniques and tools on the type of labour force required. “Agri skilled labour demand” is then compared to the total “skilled labour demand”, from the Employment sector, to determine the ratio “agri share of skilled labour demand”, representing the percentage of the total skilled labour demand employed in the agriculture sector. The underlying assumption here is that foreign workers are distributed among different production sectors depending on the relative demand for skilled labour in each.

The variable “Agri share of skilled labour demand” is subsequently multiplied by the level of “migrated workers” to determine the number of foreign workers actually employed in the agriculture sector, i.e., the “agri skilled labour migrated”.

101
“Agri employed share of migrated workers”, the percentage of workers employed in agriculture that immigrated from outside Papua, is then defined as the ratio between “agri skilled labour migrated” and the total level of employment in the sector.

The percentages of foreign workers over the total employment levels of each sector are then used to determine the “fraction of benefit for local workers” for each production activity. The variable “fraction of benefit for local workers” is defined over a four dimensional array, to separately keep track of the values relative to the different production sectors. These are simply defined as one minus the percentage of foreign workers over the total employment. We assumed for simplicity in this case that the portion of salaries remitted abroad corresponds to the percentage of foreign workers employed in each sector. This is certainly a simplistic assumption, but given the extremely poor information available regarding the amount of remittances flowing out of the region every year, it seemed to us the most reasonable.

If “fraction of benefit for local workers” represents on one hand the portion of salaries actually benefiting local people, on the other hand “fraction of benefit from local capital” represents how much of the part of surplus value produced that is directed to reward capital investment is actually remunerating local capital.

“Fraction of benefit from local capital” is also defined over a four dimensional array to distinctly keep track of the characteristics of each production sector. For each production sector, the “fraction of benefit from local capital” is defined as the ratio of the local share of the capital stock and the total amount of capital in the sector. We assumed for simplicity that the fraction of capital remuneration remitted abroad corresponds to the fraction of foreign capital invested in the different production activities. This assumption is also simplistic, but turned out to be the most reasonable one in light of the almost complete absence of data available on this matter.

The “fraction of benefit for local workers” and the “fraction of benefit from local capital” are then used together to determine the GNrP value for each production sector, with the formulation here reported for the industry sector:

\[
\text{industry GnrP} = \text{industry produced}^* 
\]
In this formulation, the total production value of the industry sector, “industry produced” is divided into the portion of surplus value generated that goes to remunerate the capital investment and the portion that goes to remunerate workers, based in the parameter “fraction of production to pay capital”. The part of surplus value used to remunerate capital is then multiplied by the “fraction of benefit from local capital” to obtain the total capital remuneration not remitted abroad. Similarly, the surplus value used to remunerate workers is multiplied by the “fraction of benefit for local workers”, to obtain the total workers remuneration not remitted abroad. The sum of these two components determines the value of the GNrP for the sector.

The formulation used to determine the GNrP for the other production activities is identical, but for the agriculture sector. In this case the “forestry production remitted abroad”, representing the value of forestry production from logging concessions given to pay foreign companies for highway constructions, is also added to the production value remitted abroad.

The sectorial GNrPs are finally added up to determine the total GNrP. The interest paid on the public debt, “interest on gov debt”, is also subtracted in the formulation used to determine the GNrP, as I assumed the debt to be entirely financed by foreign sources.

The total GNrP is used to determine an important indicator, the “gap”. The “gap” is defined as the difference between the GNrP and the GDrP, which is simply defined as the sum of the production values in each sector, and it is useful to monitor the final destination of the eventual benefit generated by any governmental policy.

It is important to notice that the variable GNrP is not determined following the traditional macroeconomic definition, though it is coherent with it, and should not therefore be used for comparison with the GNrP of other regions, estimated with other methodologies. As already mentioned, the GNrP has been created exclusively as an indicator of the share of surplus value generated in the local economy that actually benefits local people.
Linkages with the rest of the Model

There are eighteen elements from other parts of the model that impact on this sector. First, the employment level, the capital level and the aggregated production for each of the four production sectors are used to determine the “fraction of benefit for local workers”, the “fraction of benefit from local capital” and the sectorial GNrPs, respectively. Employment levels come from the Employment sector, while the productive capital level and the aggregated sectorial productions come from the different production sectors. In addition to these, “forestry production remitted abroad”, from the Forestry and Fishery sector, is used to determine agriculture’s GNrP, and “interest on gov debt”, from the Small Credit and Government Borrowing sector, is used for the determination of the total GNrP.

“Skilled labour demand” and “skilled labour supply” come from the Employment sector and I employ them here to determine the “net skilled workers migration”. Additionally, I use “skilled labour supply” to determine the share of skilled labour demand on each sector. I use “Infrastructures employed”, also from the Employment sector, to determine the “total employment” and the “total local employment”. Finally, I use the “crude death rate”, from the Population sector, to determine the “migrated workers death rate”.

On the other hand, only three outputs for other sectors, together with many important indicators, are produced in this sector: “migrated workers”, “GNrP” and “GDrP”.

The first output is used in the Education sector, to determine the secondary education index, while the second and the third are used in the Indicators sector to determine the GDrP and GNrP growth rates. Concluding, “GDrP” is also used in the Small Credit and Government Borrowing sector, for the determination of the “government financial reliability”.

2.4.14 Effects on Life Expectancy

In this sector three similar structures are used to represent how three different elements can affect life expectancy. One of these, the “effect of pollution on life expectancy”, directly affects life expectancy, while the other two affect life expectancy indirectly by
influencing other variables in the same sector. The stock and flow diagram of the sector is portrayed in Figure 28.

The “effect of pollution of life expectancy” is formulated as a delayed value of the “indicated effect of pollution on life expectancy”. The delay used in this formulation is a first order information delay, representing the time required for the changes which occurred in the “cause” variables to have an effective impact on the system. In this case, in particular, the delay is representative of the time necessary for changes in the pollution levels to affect people’s health.

The “indicated effect of pollution on life expectancy” is the output of the table function “effect of pollution on life expectancy function” (Table Function 9), which uses as input the “composite pollution index” from the Pollution sector. This function initially assumes a small decrease in life expectancy as pollution starts increasing over its initial value, and then a greater decrease in life expectancy when pollution reaches significantly high values. Since absolute pollution levels are actually small in Papua, I assumed that for small increases over their actual value, the impact on human health would be little.
The other two effects that indirectly affect life expectancy, “actual effect of health care expenditure on access to basic care” and “actual effect of health care expenditure on clean water”, are determined on the basis of the “relative health exp pro capita”. This last variable represents the relative governmental expenditure per citizen for health care, with respect to initial levels, and is defined as the ratio between “health expenditure pro capita” and “initial health exp pro capita”. “Health expenditure pro capita” is in turn defined as the total governmental expenditure for health, “gov health exp”, divided by “price”, to transform nominal into real values, and then divided by “total population”.

The “Relative health exp pro capita” thus determined is subsequently used as an input into two different table functions, one for each of the two effects.

The first table function, “effect of health care expenditure on basic care function”, indicates how changes in the expenditure for health care may affect the population’s level of access to basic care. This function may be portrayed as in the following table.
Table Function 10: effect of health care expenditure on basic care function

These points describe a function growing at a decreasing rate that saturates for a value of the input equal to ten. I assumed that access to basic care was strongly affected by changes in the health care expenditure when this is increased or decreased slightly from its initial value. The effect, on the other hand, decreases as the expenditure is increased, and stops growing when it reaches a level ten times higher than the initial level.

The other table function, “effect of health care expenditure on clean water function” (Table Function 11), represents the assumed relationship between the level of per capita expenditure for health care and peoples' access to clean water.

This function increases at a decreasing rate as input increases, and has a similar shape to the previous one. Again, little movements of the level of expenditure around its initial value cause a relatively strong effect, which grows at a decreasing rate as expenditure approaches a level ten times higher than the initial one.
Table Function 11: effect of health care expenditure on clean water function

Both the outputs of these functions do not directly affect Life Expectancy, but only with a certain delay. To represent this delay, I used a first order delay function. The same delay time is used in the two cases, indicated by the parameter “Health care exp adj time”. This constant indicates the time necessary for changes in the health care expenditure level to have an effective impact on people’s access to basic care and clean water.

Linkages with the rest of the Model

This sector affected in four different ways from other sectors of the model, and impacts three outputs used in other part of the model.

“Prices” and “gov health exp”, from the Government sector, are used to determine the “health expenditure pro capita”. “Total population” is also used to determine this last variable and comes from the Population sector. Finally, “pollution composite index”, comes from the Pollution sector and is used for the determination of the “indicated effect of pollution on life expectancy”.

108
The effects calculated in this sector also impact on the life expectancy, in various ways. The “effect of pollution on life expectancy” is directly used to determine life expectancy, while the “actual effect of health care expenditure on access to basic care” and the “actual effect of health care expenditure on clean water” are used to determine the “access to basic health care” and the “access to clean water” respectively. These two variables are subsequently used to determine “life expectancy”.

2.4.15 Indicators

As the name of the sector suggest, in this part of the model many important indicators from various sectors are grouped, and new ones are determined.

Figure 29 gives an idea of the many different social, economic and environmental indicators the model is able to produce, in order to evaluate the state of the system and support a comprehensive policy analysis.

As most of the variables represented here are inputs from other parts of the model, I will only describe how the six additional indicators introduced in this sector are determined.

The GDrP and GNrP growth rates are important indicators of the economic development of the region, and are defined as the ratio between the actual and previous year values of the indicators, minus one. “Last year GDrP” and “last year GNrP” are defined as pipeline delays of one year length of the respective indicator’s value.

![Figure 29: Sketch of the Indicators sector](image-url)
The variable defining the length of the integration interval, “Time step”, has been used in this formulation to guarantee that changes in the “time step” would not alter the pipeline nature of the delay. The following equation represents the formulation used for the “last year GNrP”, similar to the one used for “last year GDrP”:

\[ \text{Last year GNrP} = \text{DELAY N(GNrP, 1, 2.868e+009, UNIT YEAR/TIME STEP)} \]

Of the four values defining the “delay n” function, the first is the input variable, the second the delay time, the third the initial value and the last the order of the delay.

The two indicators “capital returns to non local sources” and “salaries to non local workers” are critical for monitoring the real effect on local people of the implemented policies.

The first variable measures the amount of surplus value created that every year is remitted abroad to remunerate foreign investors. It is determined based on the total value of the production in each sector, called “sector production”, the fraction of this that is used to remunerate capital, called “fraction of production to pay capital”, and the part of production remunerating capital that is not remitted abroad, called “fraction of benefit from local capital”. The variable is determined according to the following equation:

\[ \text{capital returns to non local sources} = \text{SUM(sector production[sectors!] * FRACTION OF PRODUCTION TO PAY CAPITAL[sectors!] * (1 - fraction of benefit from local capital[sectors!])}} \]

The Vensim internal function “sum”, is a function that sums the values of all the elements in an array together, and is here used to sum up the production values in the different sectors to generate the total production value.
“Salaries to non local workers” represents the total salaries remitted abroad, and is represented in the model with a similar formulation to the one used for “capital returns to non local sources”, as the following equation highlights:

\[
\text{salaries to non local workers} = \\
\text{SUM} \left( \text{sector production}[\text{sectors!}] \times (1 - \text{FRACTION OF PRODUCTION TO PAY CAPITAL}[\text{sectors!}]) \times (1 - \text{fraction of benefit for local workers}[\text{sectors!}]) \right) + \text{forestry production remitted to abroad}
\]

In this case the total value of the production in the different sectors is multiplied by the percentage of production used to pay salaries, defined as one minus “fraction of production to pay capital”, and by the fraction of salaries remitted abroad, defined as one minus “fraction of benefit for local workers”. Unlike the previous equation, however, “forestry production remitted abroad”, which represents the value of forestry production not benefiting local people, is also considered in this formulation. Instead of dividing the value of “forestry production remitted abroad” into two components, the salaries’ remittances and those to remunerate foreign investors, I decided in this case to consider the entire value to determine this indicator, as labour force is largely the major resource employed in the rural Papuan forestry sector. In other words, I assumed that the share of forestry production remitted abroad to remunerate capital investors is negligible.

Another indicator produced in this sector is “non forestry agriculture production”, which is very useful to monitor the growth of mere agriculture sector, discounted from the surplus value generated in the forestry sector. The indicator is simply defined as the difference between the total agriculture production and the forestry production.

The last indicator defined in this sector is the “cumulative development expenditure 2010-2020”. This variable accumulates over time the value of the development expenditure from 2010 to the end of the simulation horizon. The variable “Prices” is also used here to transform the nominal values of “gov development expenditures”, from the
Government sector, into real values. The utility of this indicator resides in its capacity to give the user an idea about how different potential policies implemented today can offer different development expenditure’s budget in the future, and therefore an idea about the possibility of the government to carry on important social programs.

*Linkages with the rest of the Model*

Most of the variables in this sector come from other parts of the model, and have been described in previous sections of this work.

While this sector does not impact on any other sectors, it offers a series of useful indicators that influence the model’s behaviour through the users’ policy choices.
3. MODEL VALIDATION

Model validation in System Dynamics is an iterative and pervasive activity. It engages modellers throughout each step of the modelling process, from defining the purpose of the study until the final phase when results are analysed.

The model used for the present study, extensively presented in the previous chapter, has been subjected to various validation tests of both the characteristics of the formal structures used and the behaviour they generated. The formal validation process used in this case strictly adheres to the widely accepted series of tests proposed by Barlas (Yaman Barlas, 1996).

I will present in this chapter some of the most significant tests conducted and their results. The significance of these results in terms of model validity will be examined, and the importance of the reliability of data used will be discussed.

3.1 Introduction

The concept of model validity is tightly coupled to usefulness of the model with respect to the purpose for which it has been created.

If we try to demonstrate the complete validity of a model, intended as the perfect correspondence of our theory to the real system in all its aspects, we would certainly fail. No proof of absolute validity of a model, in System Dynamics or in any other science, is possible. Such proof could only come from a direct comparison between the model and its real equivalent, which is undoubtedly impossible for us to correctly perceive and understand.

This dilemma regarding theory verification, which has been the centre of a philosophical debate among scientists for centuries, is approached here from a relativistic and holistic point of view. The validity of the model is intended as its helpfulness in identifying the solution of a certain problem, or a preferable behaviour under certain circumstances. A model is actually valid when it can valuably support the analysis of those issues the final user is interested in, when it can improve his understanding of the mechanisms that generate them and provide sound policy recommendations.
It is exactly in this perspective that validation tests have been carried out and are reported in the following sections. The validity of the model used for the present study has been judged on the basis of its ability to improve our clients’ understanding about the real system’s behaviour and to produce important qualitative policy advice with regard to the stated critical issues. Forecasts of the actual economic, social and environmental evolution in Papua are not the objective of the model, nor is it meant to provide quantitative information about the effects of various policies. Point prediction in a highly complex system it simply impossible and no model can be proven valid in this sense.

Before reporting the characteristics and the results of the tests conducted, expect that this version of T21 successfully passed all the tests our clients and we considered important. This has clearly been a precondition for all sorts of uses of the model, and the result of continuous revision and refining of the structure. Naturally, the model did not pass at the first try most of tests. Since the beginning of the modelling process, failing tests formally or informally conducted has been an essential element in driving the construction of the model.

### 3.2 Structure tests

Structural tests have been conducted to establish, to the extent that this is possible, the level of correspondence between the model's structure and our knowledge of the actual system’s structure.

The two main categories of tests conducted are direct structure tests and structure oriented behaviour tests. The first group of tests is directed to establish the level of validity of the model’s structure by comparing its major characteristics with the information available about the system. With the second group of tests the validity of the structure is assessed through the analysis of the model behaviour under specific conditions and its comparison to what we would expect to happen in the real life under the same circumstances. The first three tests reported below belong to the first of these categories, while the last two to the second one.

### 3.2.1 Structure Confirmation Test
This confirmation test characterises the way the model has been created from the very beginning. Each part of the structure, apart and jointly with the rest of the model was submitted to our clients, who evaluated how well this was describing the reality they knew, and was eventually modified to respond to their suggestions. This is true for both the special sectors and the core parts of the model, the latter which changed substantially from other T21 applications.

It is important to reveal how the modellers had very little information about the current characteristics of the socio-economic-environmental system constituting the object of our analysis, and that we basically built the model based on that part of our clients’ knowledge that we have been able to elicit from them.

This continuous process of structure creation, discussion and revision has certainly been the most critical structure confirmation test conducted. Naturally, given the modellers’ low level of information about the system, model was not constantly compared to reality, but it was derived by combining the information gathered from multiple subjects. This stimulated our clients by clarifying their minds about the theories they used to describe the system and enlarge their mental picture of it, and forced them to incorporate their colleagues’ through the theory formalisation process. Moreover, new data was gathered in the moment it appeared clear that the information available was not sufficient to explain all of the critical behaviours observed.

It would be impossible to report here all the phases of this complex process. Certainly it has been extremely useful in many ways, for the modellers to have a clear guide in the determination of the structure to define, and for the clients to refine and share their mental models.

The model described above is the result of this process, and the high degree of confidence in the final model shown by our clients is the best way to measure how accurately we have been able to formalise their shared knowledge about the real system.

### 3.2.2 Parameter Confirmation Test

This crucial test is intended to compare the parameters used in the model with existing knowledge about the real world system. This comparison has been carried out on two levels: conceptually and numerically.
Parameters confirmation from a conceptual point of view implies that we be able to find in the real world concepts or elements with an analogous significance to the parameters used in the model. This has been consistently done during the construction of this version of T21, pushing the modellers in some cases to reformulate certain relationships and modify the structure of the model.

This process was implemented in two ways. First, the modellers regularly verified the existence of a real world correspondent before the introduction of any parameter. Second, during meetings the clients inspected the parameters used and gave us important feedback about the significance of these elements with respect to their actual knowledge.

Probably the most controversial element that we introduced in the model is the parameter called “capital elasticity” present in the various production functions. “Capital elasticity” is a parameter traditionally used in the Cobb-Douglas production function to determinate the degree of contribution to the final production of the various resources employed. The term “capital elasticity” does not evoke any real life concept, and another formulation of the same function using, for example, “effect of capital intensity on workers productivity” instead of “capital elasticity”, would have probably been clearer for non-economists. However, we decided to keep the traditional nomenclature and formulation used in the economic literature to define the Cobb-Douglas production function, for two main reasons. First, the part of our audience composed of economists had a very clear idea of the concept of “capital elasticity”, and surely found it easier to refer to the traditional equation form than any other formulation. Second, since this formulation is widely adopted, it is much easier to find solid statistic estimation of the “capital elasticity”. Conducting ad hoc surveys to estimate all the parameters used in other formulations is certainly more time and energy expensive. Regardless, a formulation of production functions that incorporates both the advantages of the traditional formulation and the intuitiveness of a System Dynamics equation form is actually under development, and it will be the object of future improvements of the model.

All the other parameters in the model have a clear and unequivocal real world meaning, though some of them may require some technical knowledge on certain topics to be fully understood.
Parameters confirmation from a numerical point of view means estimating the values of the parameters used in the model with sufficient accuracy. In other words, the modeller has to ensure that the parameters’ values are close enough to those observed in their real world equivalents. What “sufficient accuracy” and “close enough” mean in a quantitative sense is again dependant on the purpose of the analysis and the sensitivity of model’s behaviour to a certain parameter.

Regarding the first point, it is important to remind the reader that the model has been created to produce qualitative policy recommendations and not to support a quantitative analysis of the dynamics of the whole system. Therefore, more efforts have been made to correctly determine the structures that create the observed problematic behaviours than an extensive process of parameters estimation. The focus of the validity tests has been, in other words, proportionally more concentrated on the determination of the validity of the causal relationships described in the model than on the quantitative accuracy of the results produced.

Concerning the issue of the model’s level of sensitivity to changes in parameters values, it also has been observed that some of the parameters can effectively influence the model behaviour from a qualitative point of view. The sensitivity analysis conducted and reported later in this chapter had the scope of identifying these highly sensitive points and discuss what level of accuracy should be used to estimate them, to guarantee a high qualitative reliability of the results produced.

What the modellers actually did in terms of numerical parameters confirmation has been to use the most accurate data available, which has been possible thanks to the high level of collaboration offered by our clients. A team of experienced operators has been sent to Papua to gather all the information available about each of the crucial parameters used in the model. They provided critical support to our work, though they could not satisfy all of our requests for two reasons. First, data sources in developing countries are often difficult to access, and data series are frequently incomplete or simply not existing. The Papuan territory, in particular, is very difficult to travel around and an important part of the population is dispersed over many small villages lost in the virgin forest, making any survey of their habits and activities extremely difficult. The other reason why it is
impossible to answer all of our requests is the nature of many of the parameters used in
the model.
System Dynamics models generally do not describe only physical relationships for which
hard data are available, but includes “soft” relationships the modeller considers
determinant for the generation of the observed behaviour. This, naturally, is done
independently from the fact that good estimations of the relative parameters are available
or not.
Many of the relationships modelled make use of parameters that, though essential, are in
actuality difficult to estimate. Some of them, represent social elements, as for example
the “effect of secondary education on industry productivity”; others represent physical
characteristics of some relationships, as the “effect of pollution on life expectancy
adjustment time”. Data on such variables are unlikely to be present in any database, even
in a developed country. This did not dissuade us from modelling such important
relationships, but implied the use of other methods of parameters’ estimation. Where we
thought it reasonable, we used values observed in other countries for similar parameters.
In many cases we estimated them using our common sense, and submitted assumptions to
our clients, who were certainly more knowledgeable than we were about the
characteristics of the real system. This combination of hard data from the field and
common sense estimations checked with the experts in our client’s organisation gives us
a certain level of confidence about the parameters’ values chosen.

### 3.2.3 Dimensional Consistency Test

Testing the dimensional consistency of a model simply means to compare the left and
right sides of each of the equations used to verify that the same units of measure are used
for both. This process may be tedious and energy expensive, but fortunately most of
modern modelling software offer automatic dimensional consistency verification
functions, as Vensim does. The “units check” function available for this application
permits the modeller to rapidly identify and correct all the equations presenting different
units of measure in the left and the right hand side. The model used for this study has
been subjected many times to this test, to make sure that its final version would not
include any dimensional inconsistency.
3.2.4 Behaviour Pattern Test

For the model to be useful with respect to the purpose of the analysis, its structure should include the fundamental mechanisms generating the problematic behaviour object of the study. If this is true then the model must be able to reproduce the same kind of problematic behaviour observed in the real system. The scope of the behaviour pattern test is, indeed, to evaluate to what extent the model’s behaviour actually replicates the correspondent behaviour patterns seen in the real world.

It is important to notice that the emphasis of this test is placed on pattern correspondence and not on the exact duplication of the observed behaviour. Given the scope of the analysis and the expected contribution of the model, what really matters is that the model can generate the same type of behaviour observed in the real world. A very high level of accuracy in reproducing those behaviour patterns would be superfluous for policy analysis, and point prediction is not the aim of this model.

Though a failure of this test can strongly prove that a model does not include all the necessary structures to produce a specific behaviour, on the other hand passing it does not prove anything about the adequacy of the model’s structure. A modeller can use many different formulations to reproduce a determined behaviour, and the correspondence between these formulations and what is observed in the real world does not imply that the formulation actually used is correct. In other words, this test represents a necessary but not sufficient condition to prove the validity of the model.

To implement this test we used all the data series available for the variables of major interest and compared them with the model’s simulated results. Because in most cases recent updates as well as data records from the early 90’s were not available, we commonly used data series of the period 1995-2000 for our comparison. The results from such comparison have been certainly very positive, and the model can reproduce very similar pattern of behaviour to those observed in the real system. However, although the patterns of some of the variables in the model resembled their real world correspondents in long-term trends, the model did not replicate short-term fluctuations observed in reality.
As this test assumes significance in terms of model validity only when it fails, I will not show here all the cases in which the model proved able to reproduce the desired behaviour, but I will only discuss its failures of replicating the short-term fluctuations of some variables. Synthetically, I will discuss such incapacity of the structure to produce this particular behaviour and what this implies in terms of model’s validity.

The group of variables for which the model produced a short-term behaviour different from that observed in the real system represent the level of production in the various sectors and the correspondent level of employment. Data series show ample oscillations in the quantity produced from year to year, as well as in the number of people employed in each sector. Figure 30 and 31 represent measured and simulated levels of mining sector production and employment respectively. As all production sectors show a similar behaviour, though on different scales, I report here only the results observed for the mining sector, which produces by far the biggest part of the GDrP.

As can be easily observed looking at the graphs, the model's blue line produces a smooth behaviour over time that does not replicate the oscillations indicated by the red line of the data series.

![Figure 30: Time Graph for the variable “mining produced”](image)
These oscillations seem particularly amplified when looking at the level of employment in the sector (Figure 31), an amplitude of about 200% of the initial number of people employed.

Observing these discrepancies between the real and the simulated behaviours, we formulated four hypotheses to explain them, each implying different consequences in terms of model validity. Together with our clients we discussed each of these hypotheses and agreed on one.

The first hypothesis proposed is very simple: oscillations in data series are largely measurement errors, and therefore there should not be any interest in reproducing the same behaviour with the model. Though this hypothesis may seem extremely naïve, the huge amplitude of the oscillations observed actually raised some doubts about the level of reliability of the data series used. Growth in the level of employment of 200% in one year, while possibly mentioned in some questionable political agendas, is rarely observed in reality and certainly suspect.

Following the second of the proposed hypotheses, the oscillations observed in the data series really occurred, as a result of a “special” event (or series of events) in the history of
the country, such as a war or an earthquake. The model naturally does not consider the mechanism that can produce this kind of events, and their study is certainly not the object of the analysis conducted. If we could insert in the model some exogenous structures generating the effects of these events on our key variables, we could not introduce that kind of effect in the future, as the model does not explain how they are generated. Moreover, the only purpose of modelling these effects in the past would be to better fit the existing data series, which is in itself of very little utility.

With the third hypothesis proposed we introduced the idea that the oscillations observed are peculiar characteristics of the system itself, and they have some important effects on the way resources are allocated on the long run and on the country development in general. It is important for the model, therefore, to reproduce the same behaviour.

The last hypothesis proposed was somehow in opposition to the previous one. Following this hypothesis, though the oscillations are considered peculiar characteristics of the system, we assume that they are not relevant with respect to the purpose of the analysis, in consideration of their short-term character compared with the long-term orientation of the study. Clearly, the underlying assumption in this case is that the observed short-term oscillations do not affect the way resources are allocated, nor do they affect the long-term behaviour of the system. In this case, naturally, it would be superfluous for the model to reproduce such behaviour.

After a constructive and intense discussion with our clients, we all agreed that the last hypothesis is the most reasonable between those proposed, consistent with the most common orientation of macroeconomic theory. We assumed that the short-term business cycle is not relevant in the process of resource allocation in the long-term, and it is not therefore determinant for the long-term development of the country. Naturally, one can argue that intense oscillations in production levels can undermine investors’ confidence in one sector, and therefore reduce the allocation of resources in that activity. This, however, would not be related to the phase of the cycle, but to the existence of the cycle itself, which, if we assume it is a peculiar characteristics of the system, is already discounted in the actual investment flows observed. In other words, we assumed that the production cycles observed will not seriously dampen or amplify in the next twenty years, thereby not diminishing investors’ confidence.
Moreover, the analysis of the elements generating the short-term business cycle observed would completely fall out of the declared scope of the model. The purpose of the model is not explain how various type of cycles can affect the economic development of the country, but to generate sound qualitative policy recommendations.

Apart from the apparent discrepancies between the data series collected and the model’s generated behaviour in the case of production and employment levels, the model has been subjected to many other behaviour pattern tests for most of the other important indicators, and has consistently proven capable of reproducing the desired behaviour. Certainly, longer data series would have been very useful for this study, but, as already mentioned, these were not available for the region actually under analysis.

3.2.5 Sensitivity Analysis

Sensitivity basically consists of measuring the relative changes in the model behaviour happening as one or more parameters’ values are modified. This kind of investigation has two main related scopes. First, it facilitates the search of those parameters to which the model is particularly sensitive, and therefore helps the modellers to concentrate their efforts on the estimation of the values of these key elements. This activity is crucial for the validity of the model. Second, sensitivity analysis is an important tool to establish a level of confidence for the results produced by the model and therefore to establish the validity of the policy recommendations provided.

Regarding the first objective of sensitivity analysis, the modellers have regularly performed sensitivity tests every time a new parameter was included in the model or some structures substantially changed. This activity was necessary, as it represented a guide orientating the modellers and the data collecting team in their efforts to gather information. In the initial phase of model construction, the sensitivity analysis was carried out changing one parameter at the time and generally manually, thanks to the “SyntheSim” feature offered by Vensim software. This recently introduced tool allows the user to observe the results of his changes in one or more parameters on the behaviours of all model’s variables instantaneously. SyntheSim is much faster then the traditional instruments used for this kind of analysis, and both modellers and clients found it
extremely useful and time saving. Using this tool, it was easier to explain the relevance or irrelevance of a certain element in the model to our clients.

As the model started assuming a more definitive shape and it became clear which were the parameters having a strong influence on its behaviour, the objective of the sensitivity analysis gradually moved towards the second of the scopes above mentioned. At this point the question became what was the indicated level of confidence in the model’s results, given the assumed level of confidence on the parameters’ values used.

This part of sensitivity analysis was very delicate and had to be carried out with precise procedures. To perform it, we needed to randomly modify the values of many parameters contemporarily and over a certain interval of confidence with a specific distribution. Luckily, again, Vensim offers a quite complete sensitivity analysis tool, supporting many types of randomisations and probability distribution. As we started comparing the results of different possible policy scenarios, therefore, we used this tool to determine how significant the differences between various runs were.

Figures 32 and 33 can give a qualitative idea of the kind of output produced by the sensitivity analysis conducted and of its significance. For each policy scenario a large
number of parameters were varied in a certain confidence interval, with a certain probability distribution, generating a high number of simulation results, and saved together as a set in the same file. Each set of results, named “sensitivity 1”, “sensitivity 2” etc, can be used by Vensim to create a “confidence bounds” graph. This kind of graph associates a different colour to each part of the plot area depending on the actual probability that a specific variable assumes a certain value. As an example, take Figure 32, which represents the confidence bounds of the variable “gov debt”, the rainbow-like area, as resulting from one policy scenario, against the median value assumed in another scenario.

As indicated in the legend at the top of the graph, there is a 50% probability that “gov debt”, the public debt, will assume in the first scenario a series of values over time included in the yellow part of the plot area. The probability that a certain time series is comprised in a certain area of the graph clearly increases as this area is expanded, and a 75% probability is associated to the sum of yellow and the green areas. The probability becomes 95% and 100% as we also include the blue and the grey areas respectively. To have an idea of the usefulness of this kind of tool, one can notice immediately by looking at Figure 32, for example, that given our confidence bounds in the assumed parameters’ values there is no possibility that at the end of the simulation the value of debt in the first scenario can be equal to the median value observed in the second scenario. Contrarily, this is possible or even likely between 2003 and 2008. Naturally, it is even more interesting and insightful to compare directly the confidence bounds for one variable in one scenario against the confidence bounds of the same variable in another scenario, instead of against its median value. However this is not possible in Vensim, and to do this we instead visually compared various confidence bounds graphs.
As another example, Figure 33 reports the results of the sensitivity analysis conducted for the “composite pollution index”, an overall indicator of pollution level on the island. In this case the difference between the median value observed in one scenario and the confidence area for another scenario, for which we used a different colours set, also appears very clear.

This analysis was conducted for all the major indicators in the model, by varying the most relevant parameters over very ample confidence intervals and gave consistently positive results in terms of validity of the policy recommendations produced.

Specific issues regarding the level of significance of the outcomes produced for the most important indicators will be analysed in the Scenarios Description and Analysis chapter, where the results obtained from the various scenarios will be compared to derive some policy advice.
4. SCENARIOS DESCRIPTION AND ANALYSIS

As mentioned in the introductory chapter, to identify what kind of public intervention would contribute the most to solving the focus issues under analysis, I decided to proceed through an analysis of potential policy scenarios. We created, therefore, four scenarios reflecting various possible policy plans, and made a cross-comparison of the results produced to identify the most favourable one with respect to our clients’ objectives.

The elaboration of the four scenarios used for our analysis has been a long and delicate process, conducted in collaboration with Conservation International’s staff. Starting from the identification of the most probable policy options actually available to Papuan Government, we went through a series of meeting to define how these could have been transformed into various simulation scenarios. First, we needed to clarify in a more quantitative way what the various options would have actually implied in terms of government actions. Second, we defined what kind of model structure was necessary to represent such interventions. Finally, we generated a different set of values for each of the policy variables chosen to represent various policy plans. Using this approach I was able to focus our policy scenarios exactly on what our clients were most interested in, representing those hypothetical development paths they thought most significant.

Consequently, I observed a high level of engagement in the analysis from all the staff involved, as well as a natural curiosity for the results eventually generated.

Before the detailed description and analysis of each of the four scenarios, it is useful to have a quick overview of them, to understand how they relate to each other.

Of the four scenarios created and analysed, the first is called “Base Case” and represents the term of comparison for the results observed in the other cases. This scenario simply projects in the future the actual policy lines followed by the local government in the last years, and assumes the completion of the ongoing infrastructure projects. Though it does not consider very innovative policy plans, this scenario constitutes an important factor for the analysis conducted, as it represents the reference with respect to which other scenarios are evaluated.
The second scenario introduced is called “Big M”, where “M” stands for Mamberamo, a Papuan region that is characterised by an abundance of natural resources. In this scenario, we assume a full exploitation of the region, with big infrastructure interventions and huge foreign capitals inflow. This “Big M” project seems one of the public policies under discussion that is most likely to be implemented, and introduces enormous risks in terms of environmental impact as well as loss of culture and traditions.

With the third scenario created, we introduced the hypothesis of an accelerated and intensified process of roads construction. In the “More Roads” scenario, in fact, we assumed that the government undertakes a series of projects to improve the regional viability system, including the mega “Trans Irian” project, an eleven thousand kilometre highway network. This enormous infrastructure intervention would be paid by giving logging concessions around the new roads to the foreign companies contracted with building them, and is actually under consideration.

The last of the scenarios used for this study is called “Urban Development” and assumes that the government will increase expenditures on social services and education, and will try to create preconditions for the development of the small local economy. With respect to the assumptions in the other scenarios, this more softly-oriented policy plan represents a strikingly different approach to the solution of major issues the Papuan population is actually facing.

To evaluate the results of each scenario with respect to the base case, we chose a set of indicators consistent with the characteristics of the issues analysed. The seven indicators selected are able to represent what our clients considered the most significant economic, social and environmental aspects of the system under analysis.

Out of these variables, three are economic indicators: “GDrP”, “GNrP” and the Public Debt; two are environmental indicators: “pollution composite index” and “forest land”; and two are social indicators: “employment” and “cumulative development expenditure 2010-2020”.

The first economic indicator simply represents the sum of the surplus value produced in all the various economic activities: industry, agriculture, service and mining. This indicator is naturally useful to monitor the dynamics of growth of the regional economy.
The “GNrP”, on the other hand, represents the part of “GDrP” that is actually benefiting local people, and excludes all the revenues remitted abroad by foreign workers or used to remunerate foreign investors. This key indicator is necessary to understand to what extent the economic growth effectively improves local people’s wealth.

“Gov debt”, or Public Debt, measures the total amount of money the government owes to foreign financial sources. This variable is extremely useful to keep track of the actual cost sustained by the government to implement a certain set of policies. In other words, it measures the economic inheritance left to Papuan future generations.

The variable “pollution composite index”, gives a synthetic measure of the pollution levels in the air, in the water and in the land. Though levels of pollution in Papua are actually low, these are probably destined to grow in the following years, accordingly to the economic growth in the country. Keeping the situation under control from this point of view therefore becomes important and can help decision makers to orient between different interventions with different expected impacts on pollution.

The other environmental indicator is “forest land”, which represents the total number of hectares of land in the region that are covered by forest. The Papuan forest is the world’s second biggest primary forest and represents probably the most precious resource in the region. The flora and fauna’s biodiversity are impressive and could be easily compromised by the poor land management. Monitoring the state of the forest is therefore a key factor to avoid the destruction of an ecosystem of extreme value not just for Papua, but also for the entire world.

“Forest land” in not only a very important environmental indicator, but also allows us to evaluate some critical aspects of social change in the country. As mentioned in the introductory chapter, a relevant part of the population lives in remote villages dispersed in the forest, each with its own particular culture, traditions and language. These people live off of the flora and fauna offered by the forest, and its destruction would probably mean the end of their civilisations.

“Employment” is one of the two social indicators chosen and represents the total number of people employed in the production activities. This is a crucial measure of people's participation in the economic life of the country, and therefore of the general level of wealth. Particularly in developing countries, where work opportunities are rare and public
financial support for unemployed people is uncommon, creating one more employment place generates a substantial benefit for an entire family or more. When considering various policies, therefore, monitoring this variable becomes crucial for the government.

“Cumulative development expenditure 2010-2020”, the last indicator, measures the total amount of funds dedicated to the development expenditures in the indicated decade. With development expenditure I intend those costs related to education, health care and other social services, crucial factors for the development of the region. The choice to use this aggregated indicator instead of a more direct measurement of social welfare resides in the nature of the social services mentioned above. Improving the quality of these services normally requires a lot of time, because new infrastructures must be built and new personnel trained. Moreover, from the moment the quality of services is improved it takes considerable time for the population to benefit fully. These time delays are long even when compared to the time horizon of the analysis, and therefore it is difficult to capture the direct effects on the population of the increase in the level expenditure. We thought therefore that it would be more significant to use the total amount of development expenditure as an indicator of the government’s engagement in ameliorating the quality and the accessibility of social services.

Considering the kinds of issues we are interested in analyzing, we assumed these seven indicators to be well suited to monitor the current evolution of the situation in each scenario. Though occasionally other indicators will also be used to explain some particular outcomes, those indicated above represent the basic elements with which the various scenarios have been evaluated.

In the following sections each scenario will be described in detail in terms of the set of policies introduced and their significance. The results generated in each case will be analysed and explained, and the determinant of each significant change of behaviour with respect to the base case will be identified. Finally, the outputs resulting from the various scenarios will be compared and some policy recommendations proposed.
4.1 Base Case Scenario

4.1.1 Description

This scenario represents the typical continuation of the current state of affairs. The present policy lines, in terms of the relative levels of expenditure for the various activities, are projected into the future, and the ongoing infrastructure projects are continued following the original programs. In addition to these, small public investments are introduced into the hydropower sector, as it seems one of the most probable interventions the government will make, and to improve the insufficient road network. In other words, we assume that the government will not implement any major programs to change the actual situation, but simply will continue with the same style of management currently observed.

The objectives of this scenario are two. First, it is important to analyse this kind of scenario to have an idea of the possible development of the actual issues if the government will not be proactive and implement major changes, but simply has a “wait and see” attitude. The possible negative results deriving from the projection of this scenario into the future may have the effect of clarifying the need for some kind of intervention.

Second, such a “neutral” scenario is necessary to have a common basis to compare results from other scenarios. In substance, if a policy introduced in one scenario to improve a given situation gives worse results than those observed in the base case, it means that it is straight away better to do nothing. On the other hand, if the policy is successful, we can have a measure of the relative benefit obtained and the relative cost sustained to achieve it by comparison with the results of the “neutral” scenario.

To have an overview of the actual policies implemented in this scenario, we could qualitatively describe them as following:

- A small investment in Hydropower, financed by the government, but not directed specifically to support mining or industrial activities
- A relatively small investment direct to improve the existing road system based on extending ongoing projects, also financed by the government
- An increase in expenditure on Education as recently introduced by the Papuan government
- A continuation of the other government expenditures on the current relative levels

This set of policies has then been introduced in the model by setting appropriate values for the various policy variables. All policy variables have been set for the period between 1995 and 2003 equal to the estimated values observed in reality, and some of them have been modified for the future to produce the “Base Case” scenario. Table 3 shows all the policy variables that have been used to define the various scenarios and the value each of them assumed for the current one.

<table>
<thead>
<tr>
<th>Policy Variable</th>
<th>Unit</th>
<th>Base Case Scenario Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desired Km of new highway</td>
<td>Km</td>
<td>2000 high rel.</td>
</tr>
<tr>
<td>Desired construction starts function (Dam)</td>
<td>Mw</td>
<td>663</td>
</tr>
<tr>
<td>HPH concession function (Forest)</td>
<td>Ha</td>
<td>4e05</td>
</tr>
<tr>
<td>Desired fraction of programmed maintenance</td>
<td>Dmnl</td>
<td>15%</td>
</tr>
<tr>
<td>Hydropower price Kwh</td>
<td>(kw*h)</td>
<td>0.15</td>
</tr>
<tr>
<td>Desired number of trainees per year function</td>
<td>Person</td>
<td>0</td>
</tr>
<tr>
<td>Desired amount of funds destined to small credit</td>
<td>KRP93</td>
<td>0</td>
</tr>
<tr>
<td>Gov education exp share</td>
<td>Dmnl</td>
<td>0.095 =&gt; 0.19</td>
</tr>
<tr>
<td>Gov health exp share</td>
<td>Dmnl</td>
<td>0.06 =&gt; 0.156</td>
</tr>
<tr>
<td>Big M mining foreign investment</td>
<td>KRP93</td>
<td>0</td>
</tr>
<tr>
<td>Big M industry foreign investment</td>
<td>KRP93</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 3: Policy variables settings for the Base Case Scenario
For the sake of simplification, data in Table 3 have been reported in a compact way, and it is important to make some specifications not to misunderstand the given information. The first column reports the exact name of the policy variables used in the model: their meaning and the way they are used in the model have been explained in the model description chapter. In some cases, however, the values of these variables are not changed from one scenario to another in a direct way, but through the use of the “scenario mode selector” (as explained in the model description chapter). Moreover, for those policy variables that introduced a certain policy as distributed over time, for example “desired km of new highway” (in which a certain amount of new constructions are started every year) I reported in the right column the cumulative value of the policy introduced over time. This is also the reason why the units of measure reported in the central column do not contain time.

Some special comments must also be made about some of the policy variables included in the above Table, both regarding the way they have been reported and their significance in this scenario.

Firstly, some of the policy variables reported assume in this scenario the value of zero. This simply means that those specific policy options are not used in the “Base Case” but will be used in other scenarios.

Second, in the right column, in correspondence of the variable “HPH concession function”, a series of values interrupted by a vertical bar is reported. These indicate the values of the function each five years, starting from 1995. I decided to report them in a disaggregated way (and not all accumulated together as for other variables) to put in evidence the assumed trend in the dispensation of forestland concessions.

Finally, the form in which the values for “gov education exp share” and “gov health exp share” are reported indicates that these variables assume two different values during the simulation. In particular, I wanted to make evident the sudden change in expenditure for education and health care operated by the government between the years 2000 and 2001. This new policy line has been attributed to the decentralisation process occurred with particular intensity in those years, and we assumed the government in this scenario to continue with the same orientation.
The policy plans thus introduced have then been simulated over the 25 year time horizon from 1995 to 2020, and the results of such simulation are reported in the following section.

### 4.1.2 Results

As the results obtained from this scenario constitute the basis for the evaluation of those deriving from the other scenarios, their analysis cannot be based, as in the other cases, on cross-comparison. In this section, instead, the behaviour of some key variables will be analysed and interpreted, and some key mechanisms of the model that contribute importantly to the general behaviour will be explained.

In order to give a first idea of the behaviour generated by the model when projecting the actual policies in the future, Figure 34 shows the growth patterns of GDrP and GNrP.

![Figure 34: Time Graph for the variables “GNrP” and “GDrP”](image)

On the X scale time is reported, from the year 1995 until 2020, while the absolute scale on the ordinate axis measures the values assumed by the variables. Units of measure are
reported in the legend at the bottom of the graph, where a colour is also assigned to each variable and the name of the run, Base Case in this case, specified.

As clearly appears from the picture above, the model projects a steady growth for both variables, though GNrP grows slower than GDrP. Before analysing why these two variables grow at substantially different rates, it useful to understand how the model produce this pattern of growth in the economy.

The motor of growth in the economic sector is the reinforcing loop that involves productive capital accumulation. In T21, in fact, investment is defined as a function of the actual production, which naturally depends on the existing level of capital accumulated. On the other side, capital depreciates at a rate directly proportional to its level, creating a balancing loop that tends to stabilise capital growth. In Diagram 1 the two loops are presented together, constituting a very common system archetype.

![Diagram 1: Capital, Investment and Depreciation](image)

Normally, in this kind of system we observe exponential growth every time the rate of investment is bigger than the rate of depreciation, which is the normal assumption in modern economic systems.

In this application of T21, however, the mechanisms of investment and depreciation are more complex than what appears in Diagram 1. In this case, in fact, the productive capital is distinct in each sector between local and foreign capitals, and both contribute to production. The two capital stocks are also increased by different investment flows: local capital investment is driven by production, and foreign capital investment is represented as an exogenous function. Therefore, only local capital formation is involved in the
investment reinforcing loop called R1 in Diagram 1, while foreign capital investment contributes to capital growth with an exogenous flow growing linearly. This causes the total capital accumulation to grow slower than we would have otherwise expected if all the capital formation would have been involved in the R1 loop. This effect is particularly evident in the Mining sector, where foreign capital investment plays a prominent role. Moreover, the formulation used to represent the effect of the capital level on production also smooths the exponential growth we would expect from R1. The capital elasticity parameter in the Cobb-Douglas function, in fact, strongly reduces the effect of capital growth on productivity. As a result of the joint action of these factors, the type of growth the system generates is almost linear, as portrayed in Figure 34.

Many other variables are involved in the determination of labour productivity, and therefore of the level of production, but their effects are relatively weak and cannot substantially alter, under normal conditions, the pattern of growth dictated by the investment reinforcing loop.

![Figure 35: Time Graph for the variable “GNrP GDrP ratio”](image)

Looking at Figure 34 we already observed how the growth of GNrP is much slower than the one of GDrP. This is due to the fact that GNrP is defined as a fraction of GDrP, which
varies dependently on the shares of foreign capital and labour force over their total levels. If this fraction is constant, it is therefore normal for GNrP to grow consistently slower than GDrP. As shown in Figure 35, however, the ratio between the two decreases over time, before stabilising around 2005.

This means that in the first ten years of simulation the foreign shares of capital and labour force are changing. In particular, both of them are increasing, for different reasons. The share of foreign capital is increasing because the exogenous foreign investment flow is initially higher than the endogenous local investment flow. This second inflow, however, driven by the above described investment reinforcing loop, finally increases over the exogenous investment flow.

The increase in total capital, moreover, generates an increasing demand for skilled workers that cannot be completely fulfilled by the local skilled labour supply. This generates an inflow of foreign workers (their level is shown in Figure 36) that increases the share of foreign labour force employment and consequently reduces the part of salaries actually benefiting local people.

Figure 36: Time Graph for the variable “Migrated Workers”
Furthermore, though in the second half of the simulation foreign workers decrease and the share of local capital increases, the GNrP/GDrP ratio does not increase because of the effect of two additional components: the interests on public debt and the remittances from the forestry sector. Both, in fact, are subtracted from the GDrP to determine the GNrP, and contribute to keep this last indicator low until the end on the simulation time.

Remittances from the forestry sector are caused by logging concessions given in the past by the government to foreign companies to pay for road constructions. These remittances, in any case, account only for a minimal part of the difference between GDrP and GNrP.

The interest on public debt, in this sense, has a far more important role. Figure 37 portrays the bell shaped behaviour of the public debt, “gov debt”. Starting in the year 2003, according to the government’s decision rules, the local administration starts borrowing money from abroad, to sustain the desired level of expenditure. Gradually, however, the government income increase as the total production increases, until they finally surmount the total expenditures. This allows the government to start paying back the debt and the interests accumulated from 2010, and to completely cancel it around 2019.

![Figure 37: Time Graph for the variable “Gov Debt”](image)
After this overview of the main mechanisms underlying the observed behaviour in the economic sector, we can now have a look of what kind of projections the model produces for some key social variables.

Figure 38 portrays the total level of employment, which is growing producing a typical s-shaped pattern.

![Total Employment Graph]

**Figure 38: Time Graph for the variable “total employment”**

The main elements determining the growth in the general employment are presented in Diagram 2, were a conceptualisation of the relationships linking them is reported.

Capital accumulation, as already described in the previous Diagram 1, is driven by the reinforcing loop R1. As capital increases, moreover, the level of employment necessary to use the new capital, the “desired total employment”, increases, and causes a correspondent and delayed increase in the “total employment”. The total level of employment, then, contributes positively to production, and consequently closes the other reinforcing loop in the diagram, called R2.

On the other hand, investments also increase the level of technology in each sector. Technology is the crucial element in the model for the determination of the “optimal
capital labour ratio”, which represents the specific level of capital intensity that guarantees the higher profitability for the various economic activities.

As technology increases, the number of workers per unit of capital decreases, creating a negative effect on the desired level of employment. The external balancing loop B2 is thus defined, and tends to balance the effect produced by the reinforcing loops R1 and R2. The last loop in the Diagram 1, the balancing loop B3, simply represents the process of adjustment of total employment towards the desired level of total employment. This loop does not generate important components of the behaviour observed. However, because it includes a delay representing the time necessary to hire new personnel, the B3 loop could create some oscillations in the system under certain conditions.

Observing Figure 38, we can now observe how the various feedback loops described in Diagram 2 assume different relative strengths during the simulation. In particular, at the beginning of the simulation the R1 and R2 loops are dominating and driving the growth of employment. In a second phase, however, capital accumulation slows down in some sectors (as also explained in the previous description of the R1 loop), particularly in the mining sector where the foreign component of investment is determinant, and the relative force of the balancing loop B2 increases. This finally causes the total employment to grow slower towards the end of the time horizon.
Another crucial social indicator is the “cumulative development expenditure 2010-2020”. The total level of expenditure for development purposes sustained by the government between 2010 and 2020 gives a good representation of the capacity of the local administration to address the social challenges of the next decade. The behaviour over time of this stock variable is portrayed in Figure 39, in dark blue, together with the rate that affects it, “real development expenditure”, in light blue.

Figure 39: Time Graph for the variable “cumulative development expenditure 2010-2020”

Until two years before the end of the time horizon, the cumulative development expenditure grows almost linearly, integrating the slowly growing flow of real development expenditure. This last variable grows at a decreasing rate for most of the decade, since in 2019 something dramatic seems to happen, causing an extremely rapid increase of this flow for the last year of the simulation. Consequently, the cumulative expenditure increases consistently in the same period, reaching a value about four hundred million higher that it would have otherwise reached without this sudden increase in the real expenditure.
To understand the reasons underlying this sudden change, Diagram 3 proposes a simplified view of the way in which some key variables determining the level of development expenditure interact.

The governmental budget available for the various kind of expenditures, in the diagram distinct into developmental and other expenditures, is affected by two main variables: the GDrP and the amount of interests and rates of refund deriving from the existing debt. The budget available is then shared among development and other expenditures on the basis of the policy decisions made by the government. Both the expenditure for development and the other expenditures, when correctly used, should have a positive effect on the GDrP, creating the infrastructures and social preconditions for economic growth. The reinforcing loops R3 and R4 thus completed constitute the main endogenous forces driving the governmental budget growth.

On the other hand, I assumed that the government has fixed a minimum level of development expenditure under which the administration does not want to go, and this is defined as a certain percentage of the total budget (this assumption is explained in detail in the model description chapter).

Therefore, at the moment the development budget available is under the fixed minimum level, the government automatically borrows funds from abroad to sustain the development expenditure. This flow of funds borrowed accumulates in the public debt.
stock, and the interests deriving from the public debt and the rate of refunding will reduce the total governmental budget. This will finally reduce the development budget, closing the reinforcing loop R5.

In particular, in the Base Case shown in Figure 39, what happens is that the government initially incur a significant debt due to some important expenditures categorised as “other expenditures”. Development expenditures are therefore limited to the minimum share of the budget fixed by the administration and grow slowly following the pattern of growth of the GDrP. Eventually, however, the reinforcing loops R3 and R4 become stronger than R5, and generate an increase in the governmental budget that will allow the government to refund the debt as well as to sustain the minimum development expenditure desired. In the moment the debt is completely refunded, in the year 2019, all the resources used previously on interests and refund rates can be devolved to development expenditure, which as a consequence suddenly increases, as shown in Figure 39.

The time it actually takes for the reinforcing loops R3 and R4 to “take over” R5 actually depends on the effectiveness of the policies introduced, and represents a good measure of the quality of the management. Also in this perspective the stock of “cumulative development expenditure 2010-2020” can be very useful to qualitatively compare the results obtained in each scenario.

To complete the picture of future development in Papua projected by the model for the Base Case scenario, we can analyse the behaviour of some important environmental indicators.

First, it is important to observe how the total amount of hectares of forest develops over time. Figure 40 shows an almost linear decrease of the forestland in the first half of the simulation, a decrease that starts slowing down from about 2007. This goal-seeking behaviour is generated by a very simple mechanism, portrayed in Diagram 4.

Fundamentally there are four causes of forest destruction: dam construction, highway construction, forest concessions and illegal logging.

The first three of the mentioned factors are actually policy variables. Dam and highway construction, in particular, are concentrated in the first part of the simulation, and both will have almost exhausted their effects on forest loss around 2010.
Forest concessions, on the other hand, are supposed to linearly decrease in time and reach a level of zero for 2020. As the number of concessions per year given by the government decreases, illegal logging becomes the principal cause of forest loss.
As shown in Diagram 4, illegal logging is not a policy variable, but is directly dependent on the total length of the road network, “total amount of existing highway”, on the percentage of land covered by forest, “forest cover ratio”, and on the expenditure per km of highway sustained by the government to control illegal logging. This last policy variable is not represented in the diagram above as it has been considered constant. On the other hand, “total amount of existing highway” accumulates the flow of highway construction, and consequently increases illegal logging, as more forest areas are made accessible. An increase in illegal logging, then, causes a decrease in the total forest area, and consequently the percentage of land covered by forest is reduced. Naturally, as the percentage of land covered by forest is reduced, it becomes more difficult and expensive to find new areas to harvest, and the relative intensity of illegal logging consequently decreases.

The reduction in the policy variables determining forest loss, jointly to the effect of the balancing loop B4, finally causes the goal-seeking behaviour observed in Figure 40 after 2007.

![pollution composite index](image)

**Figure 41: Time Graph for the variable “pollution composite index”**
A second important environmental indicator is the “pollution composite index”, an overall measure of pollution in the air, in the water and in the land. Figure 41 portrays the development of this index over time on a relative scale taking a value of one as the initial value.

Even though this indicator shows a linear pattern of growth, except from the very beginning of the simulation, it synthesizes the behaviour of the three pollution indexes for the various elements, which actually describe different patterns. In particular, while pollution in the water and land grows linearly, pollution in the air seems to stabilise and even decrease between 2010 and 2015, until finally they start increasing again at the end of the time horizon. To understand the reasons of such behaviours, in Diagram 5 are portrayed some of the crucial relationships describing the most important mechanisms determining pollution.

Pollution is substantially created by economic production. For each unit produced, a certain amount of pollution in the various elements is released, depending on the characteristics of the various production activities. Each activity, in fact, to produce and deliver goods or services, consumes energy that must be generated somehow, commonly by diesel engines. In addition, production processes use raw materials and a part of them is constantly released in the environment. Emissions in the various sectors are related to the level of production and jointly contribute to pollution generation.

![Diagram 5: Pollution, Production and Technology](image-url)
As production grows driven by the “investment” reinforcing loop R1 (previously described) pollution consequently increases. Pollution has a negative effect on the general level of health, which in turn affects labour productivity in two ways. First, in the short run pollution increases the probability of small diseases in the population and consequently reduces the labour force efficiency at work. Second, pollution can create serious health problems in the long run, affect life expectancy and reduce the number of working days per workers. These two effects and the way they interact with production are modelled separately in the model, but are here described with one single loop (B5), for simplicity. Closing the balancing loop B5, a decrease in labour productivity would cause a decrease in production, and therefore a correspondent decrease in pollution emissions.

This balancing loop is extremely important in developed economies, but obviously plays a small role in this case, as the absolute levels of pollution in Papua are so small that the expected effects on health are very limited. Keeping in mind these mechanisms is nonetheless important, as they could be relevant for the definition of long term development plans.

On the other hand, the increase in investments deriving from the growth in production also contributes to increase the level of technology. Naturally, technologic improvement helps to use the scarce resources necessary to economic production better and more efficiently and therefore contributes to the reduction of the pollution per unit produced. Consequently, pollution emissions result diminished, with a benefit for people’s health and a following increase in labour productivity. Production then rises, causing a new flow of investments that boost technologic development, amplifying the process in the reinforcing loop called R6.

The pollution absorption balancing loop B6 is also very important in the determination of the level of pollution, though in this phase of growing emissions it does not show a particular contribution to the observed behaviour. Pollution absorption is defined as a fraction of the pollution level, and it follows the same pattern of growth of this last variable, on a lower scale, while emissions increase. The contribution of this feedback loop to the model behaviour would become more evident in case the emissions stabilise,
causing the pollution stock to follow a goal-seeking behaviour and finally reach an equilibrium point.

A last element that in the Base Case contributes strongly in the determination of the observed pattern of growth of pollution is the availability of electricity generated by hydroelectric plants. In Papua, in fact, most of electricity for economic activities is produced by diesel engines, which are extremely pollutant and inefficient. Hydropower, on the other hand, is much more environmental friendly and less expensive. An increase in the availability and use of hydropower, therefore, would cause air pollution emissions per unit of electricity produced to decrease. This is exactly what happens in this case, and explains why air pollution follows a completely different pattern of growth with respect to water and land pollution, and limits the expansion of the pollution composite index.

4.1.3 Preliminary Comments on the Results produced

As already mentioned at the beginning of this section, it is not meaningful to make a comparative evaluation of the results produced in this base case, as it represents itself the term of comparison to analyse the other scenarios. However, we can surely make some observations about the behaviour the model produced in this case.

First, the model seems to be able to reproduce and project in the future the main issues we are interested in. We observe a general growth in the economy mainly driven by foreign investments, benefiting only in part to local people. The huge shares of foreign capitals and workers over the total productive factors available, actually causes the biggest portion of surplus value generated from the exploitation of the existing natural resources to be remitted abroad. Moreover, forest erosion continues driven by illegal logging, with a consequent huge loss in terms of biodiversity, culture and traditions that the model does not quantify, but which is easy to imagine given the proportions of the forest areas lost. Finally, the development expenditure, the expenditure directed to improve social services such as education and health care, grows only very slowly over most of the time horizon, compressed by the public debt. As a consequence, obviously, the quality of life of local people is not substantially increased and a harmonic development process does not follow the mere economic growth observed.
A second qualitative observation, derived from the previous one, is that in this case none of the policies implemented appeared to change drastically the evolution of the issues under analysis. Again, this is not an evaluation of the relative merits of these policies with respect to others, but only to point out that they are not able to produce any desirable change in the problematic behaviours observed.

Finally, it appears that the indicators chosen to monitor the actual state and trends of the major variables in the model well suit our needs of control over the most problematic aspects of the system. In fact, even though in many cases additional indicators are needed to understand the causes of the various phenomena, the seven basic indicators chosen suffice to give a complete and panoramic view of the development of these critical issues.
4.2 Big M Scenario

4.2.1 Description

The key element characterising this scenario is the full exploitation of the Mamberamo region, a wide area in the centre of Papua. This area takes its name from the Mamberamo River, a huge watercourse originating in the mountainous area of the island at 3,000 meters altitude and discharging in the Pacific Ocean, north of the New Guinea Coast. The region, covered by about 8 million hectares of primary tropical rainforest, is extremely rich in mineral and timber resources. More importantly, the Mamberamo River constitutes a gigantic potential source of hydropower. These characteristics make the region particularly attracting for foreign investors, in the mining and logging sectors in particular. In the last few years, with the purpose of creating new infrastructures and developing mining and industry activities to exploit the resources in the area, foreign companies and organisations have made several intervention proposals. These proposals, typically large-scale infrastructure projects followed by massive inflow of foreign investments, are the type of intervention that we want to simulate and test in this scenario.

In this case we assume that the government decides to open up the area to foreign investments, offering land concessions to transform part of the forest into an economically productive area and to make use of the natural resources available. The government also intervenes to create basic infrastructures, as well as access roads to the area. Moreover, the government contributes to the creation of a series of big hydroelectric plants to generate the necessary electricity for mining and industry activities. As a result of these decisions, we assume a huge inflow of foreign capital to boost the economic growth in some sectors, and a full exploitation of the region. Naturally, given the characteristics of the Mamberamo area, we also expect a serious environmental impact deriving from this kind of natural resource use.

The actual governmental policies implemented could be qualitatively described as following:

- A large investment in hydropower (dam and power stations) financed jointly by foreign investors and the local government
- A correspondent investment in power lines financed by the local government
- A relative small increase in the investment in roads in that area financed by the local government

In addition to these policies, we also introduce a further assumption:

- An extra inflow of foreign capitals in the industry and mining sectors

The necessity of this exogenous input in the system derives from the fact that the model does not endogenously calculate the foreign investments, but these are treated as an exogenous variable.

<table>
<thead>
<tr>
<th>Policy Variable</th>
<th>Unit</th>
<th>Big M Scenario Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desired Km of new highway</td>
<td>Km</td>
<td>2000 high rel + 1128 low rel</td>
</tr>
<tr>
<td>Desired construction starts function (Dam)</td>
<td>Mw</td>
<td>6630</td>
</tr>
<tr>
<td>HPH concession function (Forest)</td>
<td>Ha</td>
<td>4e05</td>
</tr>
<tr>
<td>Desired fraction of programmed maintenance</td>
<td>Dmnl</td>
<td>10%</td>
</tr>
<tr>
<td>Hydropower price Kwh</td>
<td>(kw*h)</td>
<td>0.3</td>
</tr>
<tr>
<td>Desired number of trainees per year function</td>
<td>Person</td>
<td>0</td>
</tr>
<tr>
<td>Desired amount of funds destined to small credit</td>
<td>KRP93</td>
<td>0</td>
</tr>
<tr>
<td>Gov education exp share</td>
<td>Dmnl</td>
<td>0.095 =&gt; 0.19</td>
</tr>
<tr>
<td>Gov health exp share</td>
<td>Dmnl</td>
<td>0.06 =&gt; 0.156</td>
</tr>
<tr>
<td>Big M mining foreign investment</td>
<td>KRP93</td>
<td>1.2e010</td>
</tr>
<tr>
<td>Big M industry foreign investment</td>
<td>KRP93</td>
<td>6.5e09</td>
</tr>
</tbody>
</table>

Table 4: Policy variables settings for the Big M Scenario
As we expect, therefore, that the government interventions specified above attract new capital, we have to modify the values used for the exogenous investment functions. This set of policies and exogenous inputs have been introduced in the model through the same policy variables indicated for the previous scenario. In Table 4 these variables are presented and to each of them is associated the actual value assumed in the simulation. Before individually comparing the values assumed by these parameters with respect to the base case, it is necessary to briefly comment on the origin of the numbers used.

An exact and unique plan of development for the region does not actually exist, but many proposals have been created and will possibly contribute to the development of a final strategy. Consequently, we used data from various sources to define the set of policies above described, assuming values for the parameters in Table 4 as consistently as possible with the available information.

Comparing these values with those used for the Base Case scenario, we observe that most of them are significantly changed, as explained below.

Starting from the top of the table, the “desired km of new highway” has been increased by 1,128 kilometres for the low relevance roads. These new roads come in addition to the 2000 kilometres of high relevance roads built in the Base Case to make the Mamberamo area accessible by land, while it can now be reached only by river or air transportation. The additional kilometres of roads built in this scenario are considered of low relevance, as they are not built to connect two existing social and economic centres, but to open up new areas for resources exploitation.

The value of the “desired construction starts function”, indicating the number of Mw of hydropower capacity to be built, is more drastically modified, and it is ten times higher than that assumed for the Base Case. It is important to notice how the value used, which derives from a prudent evaluation of the information available, is extremely high even when confronted with the total energy demand in Papua, estimated to be around 200,000 Mwh/year. In other words, the hydropower capacity built in this scenario would be able to sustain an enormous industrial development in the area.

The “HPH concession function”, indicating the number of hectares of forestland given in concession by the government each year, also has been increased with respect to the previous scenario. In this case, starting from the year 2003, the values in the function
have been increased by 100,000 ha/year. The additional concessions represent the amount of land made available by the government for the economic development of the area.

On the other hand, the “desired fraction of programmed maintenance”, representing the level of road maintenance the administration desires to implement, has been reduced to 10% of the Base Case value. The need for this change is intuitive: since the government will sustain enormous expenses to build new hydropower capacity, it will have to cut other expenditures to avoid creating an excessive and irrecoverable debt.

For a similar reason, the price at which the electricity produced by hydroelectric plants is sold has been substantially increased. This change from 0.15 to 0.30 KRP93/Kwh was necessary to keep the national electricity company’s balance at a reasonable level. After the construction of the new electricity infrastructures, an increase in the price of hydropower is the only possible move for the state-owned company to try to recover from the huge debt created.

The following two policy variables, the “desired number of trainees per year function” and the “desired amount of funds destined to small credit”, have not been changed from their original value of zero, as they represent specific policy options that are not used in this scenario.

Similarly, the parameters indicating the share of expenditure for health care and education, “gov education exp share” and “gov health exp share”, have not been modified. They represent the general direction of the government concerning development expenditures, and in this scenario we assumed that the administration will follow the same kind of policy introduced in the Base Case.

On the other hand, the last two variables in Table 4 have been significantly modified. These parameters represent the additional exogenous components of foreign investment flowing in the mining and industry sectors as a result of the government’s decision to open up the area to economic development and to create the necessary infrastructures. It is important to observe, in this case, how these investment flows are highly significant with respect to the total size of the regional economy. The total funds invested reach the incredible level of about 18.5 billion KRP93, approximately twice the GDrP for the year 2001. Though the level of assumed investment may seem overoptimistic, it has been estimated using the best data available, including projects directly presented to the
Papuan government. We therefore considered these assumptions significant and interesting to implement considering the purpose of our analysis. All of the parameters’ values reported in Tab 4 have been used to simulate the model over the 25 year time horizon, and the results obtained are analysed in the following section.

4.2.2 Results

In this section, the results produced in this scenario will be compared with those obtained in the Base Case for our major indicators. Differences in the performances of the key variables in the model will be analysed and reasons for these behavioural changes explained. Finally, in the preliminary conclusions section, an evaluation of the set of policies introduced will be made based on their relative ability to generate a more desirable behaviour for our crucial variables with respect to the Base Case.

To have an idea of the behaviour of the key economic variables in this case, it is first useful to have a look at the graphical comparison of the GDrP patterns of growth for the current and the Base Case scenario in Figure 42.

Figure 42: Time Graph for the variable “GDrP”
As clear from the graph above, in this case the model generates a substantially higher growth in GDrP than what is observed in the Base Case, starting from the year 2003. The difference between the GDrPs in the two cases, which appears significant in light of the sensitivity analysis conducted, grows constantly until 2010, when it seems to stabilise around a value of 5 billion KRP93/Year, and slightly decrease towards the end of the simulation time.

Such a boost in production has mainly one reason: the exogenous extra inflow of foreign investments in industry and mining. Given the nature of the model, however, the impact of these additional investments on the GDrP is not only limited to the direct increase in capital (and therefore in production) in the two sectors as one may expect, but involves many other factors, as described in Diagram 6.

As a result of the increase in production, both average income per capita and life expectancy increase. The total population, therefore, begins increasing as well, creating more demand for agriculture goods that will be eventually satisfied with an increase in production, as described by the reinforcing loop R7 at the centre of the diagram. This reinforcing loop is also boosted by the increase in the number of land concessions given by the government, which augments forestry production.
The increase in total production, resulting from the increasing in foreign investments and amplified by the above-illustrated mechanism also affects labour productivity, in three ways.

First, as the production increases, the government budget increases as well, sustained by the higher inflow of taxes and contributions. The government can then use the additional resources available to increase the level of expenditure for education and health care. Better health care services lead to a higher life expectancy, and the reinforcing loop R10, which gives more strength to R7, is thus closed. The increase in life expectancy, however, not only contributes to increase the population, but also has a positive effect on labour productivity.

Similarly, after a certain delay, the increase in the expenditure for education generates an increase in the average education level of the population, incrementing workers’ productivity.

The third way in which production affects productivity is through the level of pollution. As production increases, emissions increases and pollution is accumulated faster in the air, water and land. As a result, workers health may be compromised and their productivity reduced.

The labour productivity, as resulting from the interaction of these forces, then affects the production in the various sectors again. Consequently, three additional feedback loops are closed: the reinforcing R8 and R9, and the balancing B7.

In the simulation conducted this last loop was found to be weak, as the absolute values of pollution in Papua are quite small, but it could become crucial on a longer time horizon.

The impact on the regional economy of these huge inflows of foreign investments, however, is not reduced to the effects above explained, but includes other important mechanisms, as described in Diagram 7.

As the increase in productive capital resulting from the new investment flow causes an increase in production, the endogenous local investment flow is also increased, because it is determined based on the level of production. This flow is then shared in constant proportions among the various production sectors and eventually also increases the productive capital levels in the agriculture and service sectors, initially not benefiting the extra investments.
The three reinforcing loops R11, R12 and R13 described in Diagram 7 are extremely important in the determination of the composition of productive capital in all sectors, and well account for the propagation of the effect of an investment in one sector to the others. It is important to notice, however, that the reinforcing loop R13 does not work for mining production, as we assumed this sector to be entirely financed by foreign capital. These mechanisms, in any case, are not enough to create a local flow of investment able to replace the strong extra flow of foreign investment when this starts decreasing. We assumed that the extra investments are a finite quantity of funds flowing into the local economy gradually over time, accordingly to the degree of completion of the necessary infrastructures built by the government. When these funds are totally distributed, the foreign investment flow returns to its normal value, as it would have been in the Base Case.

However, capital stocks are rather high, and their resulting depreciation rates are accordingly high. The normal foreign investment flows in addition to the local ones are not sufficient to compensate the capital depreciation and therefore cannot maintain productive capital at those levels.
This phenomenon, which acts with different intensities and timing in the various production sectors, leads to the slowdown in the economic growth observed in Figure 42 towards the end of the simulation horizon.

Figure 43 illustrates the behaviour of another key economic variable in the system: the GNrP.

Surprisingly, the values calculated for the two scenarios are quite similar, even identical at some points in time. In this scenario, contrary to what one could expect from looking at the GDrP’s behaviour, the real increase in the economic benefit perceived by local people with respect to the Base Case is quite small. The GNrP for this scenario, after a period of about ten years from 2003 to 2013 during which it reaches a value about 7% higher than the Base Case, starts slowing down its growth, until it finally oscillates around the level observed in the previous scenario. This means that the strong economic growth observed in this case is not actually transformed in a real improvement of the quality of life for local people. Why does this happen?

Diagram 8 gives an explanation of this phenomenon.
Diagram 8: GDrP and GNrP

As the extra foreign investments start flowing into the system, clearly the foreign capital stock increases, as the total capital stock does. This generates an increase in the GDrP, which have a direct positive effect on the GNrP, as we would expect. The additional inflow of foreign capitals, however, has at least two important negative effects on the system.

First, as foreign capital increases, its share over the total available productive capital increases, and the share of profit to remunerate foreign investors also increases. A smaller part of the profits goes therefore to remunerate local investors, and the GNrP results consequently decreased. This effect is partially compensated by the reinforcing loop R14, which summarises in one single loop the three reinforcing loops described in Diagram 7.

As the total capital and the GDrP increase, local investment also increases, raising the level of local capital and therefore reducing the foreign capitals’ remunerations. The R14 loop, as already discussed, is not strong enough to fully contrast the huge disequilibria in the capital composition created by the exogenous foreign investment flow.

The other way in which foreign investment affects the GNrP is through the labour demand. As the total capital increases, the demand for skilled labour force is pushed up over the level of the local skilled labour force available, causing an immigration of foreign workers, as Figure 44 illustrates. This immigration changes the composition of...
the labour force, increasing the percentage of foreign workers. Consequently, the part of
the total salaries paid that is remitted abroad by foreign workers to their original region or
country increases, causing a decrease in the GNrP.

Figure 44: Time Graph for the variable “Migrated Workers”

The huge inflow of foreign workers observed, moreover, can create extremely serious
social problems in Papua that the model is not able to measure, but that we can imagine
to occur when immigrants reach a significant share of the whole population. Ethnic
differences are indeed difficult to harmonise between various provinces of Indonesia and,
particularly in Papua, foreign workers are not totally accepted by local people.

This effect of foreign investment on the level of immigrated workers, however, is
partially smoothed by another mechanism. As the GDrP rises, the funds available to the
government increase, and consequently the expenditure in education also increases. An
increase in the quality of the education services generates, in the long run, an increase in
the skilled labour force supply, which can eventually reduce the need of a higher inflow
of foreign workers. This mechanism, though, involves long time delays and only shows
effects after many years. It takes time, indeed, to build new schools, to hire and train new
teachers and to finally obtain an increase in the quality of education. Even when the
quality of education reaches the desired level, furthermore, it takes time for students to benefit from this and to finally become skilled workers.

In addition to those described in Diagram 8, there is another crucial variable for the determination of the G NrP: the public debt. Interests and refunding rates derived from the debt, as already explained, are also subtracted from the G NrP, and can affect it significantly. Figure 45 illustrates the behaviour of the Public Debt in this scenario, compared to the Base Case. The picture of the regional assets in this graph is dramatic. While in the Base Case the debt reaches a maximum value of about 1.8 billion around 2010, in this scenario the debt keeps on growing, consistently faster, until the end of the simulation, when it reaches a stunning level of about 11 billion.

As already explained in Diagram 3, the debt grows because the government allocates a huge part of the total funds available to infrastructure interventions, and is consequently forced to borrow money to sustain the desired level of development expenditure. Payment of interest on the debt makes the funds available even smaller, and pushes the government to borrow more money from abroad, as described by the R5 reinforcing loop. This loop seems to dominate for most of the simulation, and only towards the end of the
time horizon does the R3 loop seem able to contrast it sufficiently to finally lead to a reduction of the debt. The reinforcing loop R3, describes how infrastructure expenditures improve the basic conditions for the economy to grow and can cause an increase in production and therefore in the funds available to the government. This loop, however, seems weak for the entire simulation for a simple reason: the way in which the government actually invested available funds was far from optimal and did not create sufficient benefits for production.

Two major items of expenditure exist in this scenario: dam and road construction. Dam construction, the more expensive of the two initiatives, does not have an effect on the private economy proportionate to its cost because the scale of the project is highly exaggerated. First, while most of the energy capacity built immediately generates construction and maintenance costs, it is unused for the entire simulation time and does not therefore generate any benefit for the economy. Moreover, since the quantity of energy sold is small with respect to the potential production, the public energy company may also have serious problems in repaying the costs of dams’ construction, as reported in Figure 46.

![Figure 46: Time Graph for the variable “Dam cumulative profits”](image-url)
Cumulative profits from dam reach a negative level much lower than in the Base Case, and show a tendency to recover only in the last five years of the simulation. To obtain this inversion of the trend, however, we needed to assume that the national electricity company fix a price for hydroelectric energy twice as high as in the Base Case. Though this certainly helps containing the fall of profits, it also has a profound effect on economy.

In the model we assumed that the benefit the private economy receives from an increase in the energy supply is related to the correspondent decrease in the weighted energy price paid by the companies. As the national electricity company doubles the price of the hydropower sold, the potential economic benefit for companies deriving the increase in supply suddenly disappears.

The Roads construction projects also do not generate a significant benefit for production activities, for two main reasons. First, we assumed that the new roads built by the government are of low general economic relevance: they do not connect existing economic or social centres, but are used simply to open up new areas to resource exploitation. Therefore, they do not create a strong benefit for the existing economy, but only for the new activities created in the area. Secondly, we assumed that the government cuts the maintenance expenditures on all the region’s roads to contain the public debt. This policy works in the short run, but after some years the diminishing quality of roads (see Figure 47) will make road transportation more expensive, finally undoing all the benefits deriving from the construction of the new roads.

After this overview of the economic impacts of the governmental policies introduced, we can summarise their effect on the regional economy in two major points. First, the infrastructure interventions that the government partly or entirely finances, which we assumed to be the necessary preconditions for the huge foreign capitals inflow in the Mamberamo region, have a strong negative impact on the administration’s budget and little effect on the existing economic activities. In other words, these policies create a heavy heritage for the generations to come in term of public debt, and do not significantly contribute to the economic growth in other areas of Papua.
Second, the governmental policies are not able to modify the key factors affecting the income distribution between local and foreign people. As a consequence, the economic growth observed in the industry and mining sectors generated by the foreign capital inflow in the Mamberamo region is not transformed into an increase in the quality of life of local people.

After this overview of the prospected growth of the regional economy, it is important to analyse what contemporarily happens in Papua in terms of social development. To do this I will, as I did for the previous scenario, use as a point of departure of the analysis two critical indicators: employment and development expenditure.

As we would expect when considering the strong growth in the productive capital levels for the mining and industry sectors observed in this scenario, the total employment increases more rapidly than in the Base Case. Figure 48 illustrates how, after the year 2003, the employment growth accelerates for about five years, before it starts slowing down and it returns to about its precedent growth rate around 2013. From this point in
time, the gap between the employment levels in the two scenarios is not going to change significantly, moving slightly around a value of 140,000 persons employed.

It is interesting to compare the behaviour of the employment levels observed in Figure 48, with the growth of the GDrPs in Figure 42.

![Time Graph for the variable “total employment”](image)

GDrP and employment show similar patterns of growth, in both scenarios. This is due to the fact that employment, as well as production, is strongly influenced by the capital levels in each production activity. The desired level of employment, in particular, is derived as a function of the productive capital and the ideal capital labour ratios. These last factors, in turn, are determined based on technology. As explained in Diagram 2, technology is increased by the investment rate, and as technology grows the ideal capital labour ratio for the various activities decreases. This balancing loop, called B2 in Diagram 2, partially compensates the effect of capital growth on employment, which increases only moderately slowly with respect to the productive capital and the GDrP.

Moreover, the growth observed in the total employment is not entirely going to benefit local workers, as described in Diagram 8. The huge increase in demand for skilled labour
deriving from the increase in the productive capital levels cannot be totally satisfied by the local skilled labour supply.

The increase in the level of local employment results therefore limited, as illustrated in Figure 49, while a consistent inflow of foreign workers fills the gap between labour demand and the local supply.

![Figure 49: Time Graph for the variable “total local employment”](image)

One element that positively affects both local and total employment levels is the demand for local workers derived from the huge infrastructure construction projects considered in this scenario. Though we assumed that all the specialized work force needed to build the new hydropower facilities is recruited abroad, the projects also require unskilled workers for the most basic tasks. These are presumably hired on place, being far cheaper than foreign workers, and they should be considered in the computation of the regional employment even if employed by a foreign company. For each new construction project started, therefore, a certain amount of local workers are hired, increasing the total local employment.

This contribution to the employment of local people has two major characteristics. First, it is of limited impact, if we consider that it reaches a maximum level of 30,000 people,
less than 20,000 units over the number of people hired in the Base Case for infrastructure construction. This represents an increase in the active labour force of less than 2%, which over an 18 years horizon is not really impressive.

Second, given the characteristics of the construction projects, the demand for local workers generated is not long-term oriented. In other words, workers are hired for short periods of time, and once projects are finished they are dismissed. This process may be harmful for local people whom, attracted by higher salaries tend to abandon their original jobs and their villages. After the construction projects are over, it may be difficult for them to be reintegrated into both their jobs and their original social environment.

It is finally important to notice that the local employment level in this scenario oscillates from the year 2007 around a value 5-6% higher than that observed in the Base Case. If we compare this result with the gap between the GDrPs of the two scenarios, which reaches a stunning 25%, it is easy to realise how the influence of technology and foreign worker immigration mentioned above erode most of the benefit in terms of local employment deriving from the increase in investments.

For a more complete understanding of the social development in the region, it is also interesting to observe how the development expenditure develops in this scenario, to understand the capability of the government to face the future social challenges.

Figure 50 illustrates the behaviour over time (between 2010 and 2020) of the cumulative development expenditure for the two scenarios. As is clear from the graph, the cumulative expenditure in the current scenario grows slightly faster than in the previous one until 2018, when the Base Case expenditure suddenly accelerates and ultimately reaches almost the same level. As explained in analysing the Base Case scenario results, this acceleration is mainly due to the extinction of the public debt. At the moment the government does not have to pay interest and refunding rates it can increase the share of expenditure for development purposes. This phenomenon, naturally, does not take place in the Big M scenario, as the public debt is far from being completely paid back even at the end of the simulation time. Moreover, due to the significant absolute size of the debt in this case, an important flow of funds will be diverted from the government budget to pay for interests on the borrowed capital, reducing the expenditure for other purposes.
In the period between 2010 and 2018, however, the level of development expenditure in this scenario are higher than in the Base Case because the government revenues are substantially higher, and this may have some important effects on the system.

![Cumulative Development Expenditure 2010-2020](image)

*Figure 50: Time Graph for the variable “cumulative development expenditure 2010-2020”*

The higher level of expenditure observed in this period is generated by the strong increase in the GDrP, deriving from the increase in exogenous foreign investment. As the GDrp increases, the public revenues increase as well, and since the minimum development expenditure is defined as a certain share of the total budget, it is correspondingly higher. This early increase in development expenditure may be important as many of the activities financed by such expenditure involve long delays. To invest soon in health care and education, therefore, is essential to obtain positive results before the end of the simulation horizon. Significant positive results, however, are not obtained even in this scenario, as explained below.

As described in Diagram 9, if the growth of GDrP leads to a higher level of expenditures, it also generates an increase in life expectancy and therefore in population.
Moreover, the population is also increased by the huge immigration of foreign workers which carry with them part of their families. The increase in the total expenditure is therefore not reflected in the expenditure pro capita, due to the balancing effect of the growth of population, as illustrated in Figure 51.
Moreover, it is important to notice how, as described in Diagram 9, the development expenditure pro capita, determinant for the quality of the education and health care services, also affects labour productivity and eventually production, closing two important feedback loops. The capacity of the government to weaken the B8 balancing loop while also strengthen the R15 reinforcing loop is certainly one of the key factors to transform a mere economic growth into a real socio-economic development of the region. The specific composition of the development expenditure may have an important role in this sense, but the detailed analysis of this aspect of the governmental policies falls outside the scope of the present study.

Summarising the effects of the governmental policies introduced on the major social indicators, we can derive two relevant observations. First, the policies implemented by the government do not allow local people to profit from the expansion observed in the mining and industry sectors. The necessary increase in the labour force is satisfied mainly by the immigration of foreign workers, and the resulting increase in local employment is relatively small. Second, the administration is not able to substantially increase the development expenditure, though the government budget benefits from the impressive growth of the GDrP. A significant flow of funds is drained away to pay for the interests on the public debt. Moreover, the small increase observed in development expenditure turns out to have little effect on per capita expenditure, and therefore on citizens’ quality of life, because of the increase in population resulting from the GDrP growth.

To complete the picture of the development of the system under the assumptions characterising the Big M scenario, it is interesting to observe the development of some important environmental indicators. Figure 52 reports how the forestland on the island develops over time in this and in the previous scenario.
In both cases the causes of forest loss are exactly the same (they are described in Diagram 4) though they have different intensities. The construction of both dams and highways are more intensive in this scenario, and in particular the increase in the amount of low relevance roads built has a profound effect on the forest, directly and indirectly. Directly, the construction of new roads requires a certain area of forest to be cleared for each kilometre of highway built to make room for the new lanes and the machines working on the site. Indirectly, the new roads increase the accessibility to forest areas and therefore the possibility of illegal logging.

The number of concessions for forest exploitation that the government gives is also constantly higher than in the Base Case, as already mentioned in the scenario description. However, land concessions, as well as the forest loss for the construction of highways and dams, decrease over time as the infrastructures projects are gradually completed. At the same time, due to the decrease of the forest cover, illegal logging also tends to decrease, as described by the balancing loop B4 in Diagram 4. The combination of these factors causes the forestland to follow a goal-seeking behaviour pattern towards a lower level than what observed in the Base Case. In particular, the additional forest loss at the
end of the simulation time reaches the significant value of 2.5 million hectares, about one fifth of the total forestland left.

I already mentioned the richness in biodiversity of this wonderful island and how the forest that covers it represents a precious cultural heritage for the entire planet. Though the model is not able to quantify the loss generated in terms of biodiversity and culture for each hectare of forest loss, it is possible to imagine how the cut of an additional 20% of the forestland can alter the lives of humans and other species in the region.

In addition to the serious impact observed on forest loss, the policies implemented by the government in this scenario also consistently influence the level of pollution in the region, as illustrated in Figure 53.

![Figure 53: Time Graph for the variable](image)

Pollution also grows over time in this scenario, and substantially faster than in the previous case, from 2003 until the end of the time horizon. In particular, the difference between the pollution levels in the two scenarios, well replicates the gap observed between the two production levels. As already mentioned, we assumed pollution to be strictly dependent on the level of activity in the various production sectors. Nevertheless, one could have expected pollution to grow less than proportionally with respect to
production, as investments in productive capital also increase the level of technology, which in turn decreases the pollution per unit produced. The effect of this mechanism, described in Diagram 5, is partially compensated by the fact that the economic growth observed is not uniformly distributed between all the sectors, but particularly concentrated in the mining and industry activities. Though over time the mechanisms presented in Diagram 7 tend to redistribute the investment flows and therefore to make the economic growth more uniform, initially the additional foreign investments are concentrated in these two sectors, which are also the more polluting ones. The pollution per unit produced is indeed high for mining and industry activities, and this causes pollution to grow, as GDrP grows, more than we would expect in case of a harmonic development of all sectors. The result of this phenomenon is a final level of pollution about 20% higher than in the Base Case.

As already discussed in analysing the results of the previous scenario, the growth in the pollution level in Papua should not be considered dangerous because the initial levels of pollution and the population density on the island are low. Nevertheless, what appears in Figure 53 is a precise message: this set of policies creates a strong increase in pollution emissions that can create serious problems in the long run. In the current scenario we assume most of the economic investment and the resulting production to be concentrated in a specific geographic area: the Mamberamo river basin. As a consequence, we would expect a particularly high pollution concentration in this once pristine, area. This may result in health problems for the workers employed there, but most importantly for all the tribes living along the river and using its water for all their basics needs. Mining activities, in particular, are known to release consistent amounts of chemical products in the land and in the water surrounding the extraction and treatment sites. These emissions can affect the ecosystem of the river and its effluents, and consequently the lives of the people inhabiting the basin. The model, unfortunately, does not consider the geographical distribution of pollution and cannot, therefore, measure this problem. However, from the analysis of the results of this scenario the recommendation clearly emerges for the regional administration to take into consideration also this potentially crucial aspect of the development of the Mamberamo basin area.
In summary, the effects of the policies implemented by the government on the environment of the region are not positive at all. First, the forestland is reduced much faster than in the previous scenario, due to the increase in land concessions, roads and dams construction. Second, pollution emissions are substantially increased, pushing the pollution composite index to a level about 20% higher than in the Base Case. These two effects can have a serious impact on the people, the fauna and the flora inhabiting the forest, and their combination represents a threat for the island’s ecosystem.

4.2.3 Preliminary Comments on the Results produced

After the overview conducted above on the effects of the government policies implemented in this scenario, it is possible to synthesize their main effects on the indicators chosen as following.

First, the policies implemented are economically expensive for the government. In particular, the infrastructure construction projects generate costs that greatly exceed the administration’s possibilities, creating a huge public debt. The running and maintenance costs of the new structures also play an important role in this sense, and the way the government tries to reduce them does not seem effective. Cuts in road maintenance interventions and increases in electricity prices do not stop the growth of the public debt and create some undesirable effects on the private economy. As a result, the debt starts declining only at the end of the time horizon, leaving a heavy economic heritage for Papuans’ future generations.

Second, the set of policies introduced in this scenario not only does not provide a solution to any of the critical issues analysed, but also worsens the initial situation from many points of view. The economic conditions of local people are not substantially improved, while the appropriation by foreign individuals and companies of the benefit deriving from the use of Papuan natural resources increases. Figure 54 illustrates how, with respect to the Base Case, the ratio between GNrP and GDrP (indicating the fraction of the total production that actually benefits to local people) reaches a significantly lower level.
Besides, the level of employment is not relevantly increased, as most of the additional labour demand created is satisfied by the immigration of foreign workers, a fact that by itself could contain dangerous elements for the region’s social stability. In addition, the government expenditure for development purposes is not sufficiently augmented, in particular looking at the per capita expenditure. As a consequence, the quality of education and health care services, between others, is not improved. This implies that a real improvement of the quality of life in the region is not likely to happen in this scenario.

From the environmental point of view, the situation is even worse, as the forest suffers a profound damage directly and indirectly from the new infrastructures construction projects as well as from the increase in the land concessions given by the government. Pollution also substantially increases, and if this increase is mainly concentrated in the Mamberamo area can create severe problems to the local ecosystem and humans.

Finally, it is important to notice how the differences in the results obtained in the Big M scenario and in the Base Case that have been presented here are extremely relevant in light of the sensitivity analysis conducted. In other words, the results obtained in this case
are substantially different from those observed in the previous scenario, and the significance of the qualitative comparisons made should be considered high.
4.3 More Roads Scenario

4.3.1 Description

The road system in Papua is only partially developed. Even when considering the low population density and the small size of the regional economy, the existing roads seem inadequate, and some major connections between the most important urban centres are completely missing. As a consequence, air and river transportation are in some cases the only practical solutions, and transport of people and goods are more difficult, expensive and time-consuming.

The regional government, conscious about the importance of an efficient road network for the social and economic development of Papua, has been working in the last years to create new connections and ameliorate existing ones. Many project proposals have been considered by the local administration to expand the insufficient road system, but a comprehensive action plan has apparently not been decided on yet. Among the various projects proposed, one has captured in particular the attention of the government and public opinion, for both its size and its proposed method of implementation, and seems to be among those with the highest likelihood of execution. This plan has been developed and proposed by a foreign company and consists of the creation of the so-called Trans-Irian highway network, an 11,000 kilometre highway network crossing the entire island from North to South and East to West. The project's originality resides in the fact that the foreign company proposing it has not asked for monetary compensation for services offered, but instead only for logging concessions around the new roads built.

The implementation of this project is the main element characterising this scenario, and the major point of differentiation with respect to the Base Case. The main policy change introduced in this scenario is, therefore, an accelerated and intensified road construction process, aimed at the completion of the Trans-Irian network. We also assume that the government does not sustain the construction costs for this project, and that the foreign company in charge of the works is paid exclusively with logging concessions on both sides of the new roads.

To have an overview of the policies actually implemented in the model in this scenario, I will qualitatively describe them as the following:
- An accelerated process of road construction financed by logging concessions around the road
- A small investment in Hydropower and power lines, financed by the government
- A continuation of other government expenditures at current relative levels

For the practical implementation of these policies in the model, the most important policy variables have been set to different values to reflect the government’s decisions. Table 5 reports for each of these parameters the value actually used to generate this scenario.

<table>
<thead>
<tr>
<th>Policy Variable</th>
<th>Unit</th>
<th>More Roads Scenario Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desired Km of new highway</td>
<td>Km</td>
<td>2000highrel + 11280 lowrel</td>
</tr>
<tr>
<td>Desired construction starts function (Dam)</td>
<td>Mw</td>
<td>331</td>
</tr>
<tr>
<td>HPH concession function (Forest)</td>
<td>Ha</td>
<td>+ Highway Concessions</td>
</tr>
<tr>
<td>Desired fraction of programmed maintenance</td>
<td>Dmnl</td>
<td>30%</td>
</tr>
<tr>
<td>Hydropower price Kwh</td>
<td>KRP93/</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(kw*h)</td>
<td>0.2</td>
</tr>
<tr>
<td>Desired number of trainees per year function</td>
<td>Person</td>
<td>0</td>
</tr>
<tr>
<td>Desired amount of funds destined to small credit</td>
<td>KRP93</td>
<td>0</td>
</tr>
<tr>
<td>Gov education exp share</td>
<td>Dmnl</td>
<td>0.095 =&gt; 0.19</td>
</tr>
<tr>
<td>Gov health exp share</td>
<td>Dmnl</td>
<td>0.06 =&gt; 0.156</td>
</tr>
<tr>
<td>Big M mining foreign investment</td>
<td>KRP93</td>
<td>0</td>
</tr>
<tr>
<td>Big M industry foreign investment</td>
<td>KRP93</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 5: Policy variables settings for the More Roads Scenario

To understand the significance of the values introduced, here I will briefly comment on the most relevant changes implemented with respect to the Base Case.
As we would expect from the general purpose of this scenario, the most important change implemented refers to the number of kilometres of new highway the government desires to build. “Desired Km of new highway” has been increased by a total of 11,280 kilometres. It is important to notice how the resulting total value is not only a high increase in relative terms (more than six times the original value), but also represents a high value in absolute terms. To have an idea of the scale of the project 11,280 kilometres is about ten times the distances between the North-western and the South-eastern extremes of the region. This means that the new highway network would completely cover the whole Irian Jaya, and leave only a few areas inaccessible by car. It is also relevant that we assumed that the new roads are of low economic relevance, as they do not consist of specific projects to create certain important connections between urban or economic centres. Given the method of payment the government would use it is likely that these roads would pass through the most profitable areas for logging and would also cross regions without any relevant urban centre.

Given that the road infrastructure projects would be greatly increased, in this scenario we then assumed the construction of a reduced number of new hydroelectric plants. In particular, the “desired construction starts function” has been decreased to 50% of the value used in the Base Case. The expansion of the hydropower capacity is not one of the declared targets of the government in this scenario, and we decided to reduce the amount of resources dedicated to this to redirect them to road maintenance.

The base number of hectares of forestland given in concession by the government over time does not differ from the value used in the Base Case. However, concessions given to pay for road construction play a relevant role in this scenario. Hectares of this land are not included in the policy variable “HPH concession function” as they are determined as a function of the kilometres of road built. Accordingly to the proposed Trans-Irian project, the government concede to the contracting highway construction company 5 kilometres of land on each side of the highway. This means that for each kilometre of road build, one thousand hectares of land will be given as payment for the construction. When considering the size of the project and the amount of forestland concessions given under normal conditions, it seems clear that the total additional concessions will play a fundamental role for the future of the island’s forest.
Since the improvement of the highway network and the quality of road transportation infrastructures in general are the main focuses of the administration in this scenario, we also assumed the government would increase the level of roads’ maintenance. The “desired fraction of programmed maintenance” doubled with respect to the value used in the Base Case, from 15% to 30%. The increase in the level of maintenance is necessary to generate an increase in both the quantity and quality of roads, to eventually reduce the road transportation costs and create a benefit for economic activities.

On the other hand, the hydropower price has been slightly increased from 0.15 to 0.20. We introduced this change in the price of electricity to help the public electric company to keep a better balance between costs and revenues and avoid the accumulation of a considerable debt.

As in the Base Case, the “desired number of trainees per year function” has been set to zero, meaning that this policy option is not used in this scenario. Similarly, the value used for the “desired amount of funds destined to small credit” is zero, as no small credit initiatives are introduced in this case.

“Gov education exp share” and “gov health exp share” have been both set to the same values used in the Base Case, because we assumed no change in the basic sharing among the two kinds of development expenditure. Naturally, though the relative shares are the same, the total amount of the expenditure can change, as the total government budget changes.

Finally, the last two policy variables, representing the extra inflow of capital in the mining and industry sector introduced in the Big M scenario, have been set to zero. This means that the inflow of foreign investment in all sectors will be exactly the same as the one used in the Base Case.

The policies thus introduced have then been projected over the 25 years of our time horizon, and the results of the simulation are analysed and discussed in the following section.

### 4.3.2 Results

In this section, the results generated by the model in the More Roads scenario for each of the major indicators chosen are compared with those observed in the Base Case. The
most significant differences in the behaviour of the key variables are examined and their determinants identified. The set of policies introduced are finally evaluated and briefly discussed in the preliminary conclusions session, based on its effectiveness to produce a more desirable behaviour, with respect to the Base Case.

For an initial idea of the overall economic performance of the system in this scenario, it is interesting to observe how the GDrP develops over time. Figure 55 illustrates the behaviour of this variable in the actual scenario and in the Base Case, highlighting that there is little difference between the results of the two scenarios.

GDrP in the More Roads scenario, the grey line in the graph above, seems to grow only slightly faster than in the Base Case, leading to a final value just 0.55 billions higher. Before analysing the reasons of this difference in the behaviour generated in the two cases, it is important to notice how the relative significance of this gap is small. In relative terms the two GDrPs differ only of less than 3%, after 17 years from the moment in which the various policies are applied. Moreover, the results produced by the sensitivity analysis show significant margins of superposition between the 100%...
confidence intervals of the variable in the two cases. This means that there is a significant probability that the growth observed in Figure 55, which reflects our best parameters’ assumptions, could be slower, close to the Base Case’s most probable behaviour, as illustrated in Figure 56.

As it immediately appears, the lower confidence bound of the GDrP in the More Roads scenario, in dark grey in the graph, is close to the GDrP in the Base Case. Furthermore, if we could also portray in the same graph the confidence bounds of the GDrP for the Base Case, we would observe a substantial superposition between the two. This implies that the confidence level we attribute to the difference between the GDrPs produced in the two cases is low, and that in considering this key variable alone neither of the two policy sets can strongly recommended.

However, it is still interesting to see how and why the model generates a different GDrP in this case and what economic sectors are particularly affected by the implemented policies.

![Sensitivity Graph for the variable “GDrP”](image)

It is first important to see how the enormous increase in the highway network, together with the higher level of maintenance put into practice, have a drastic impact on the road
transportation cost. In Figure 57 the “relative road transportation cost”, starting from a value of one at the beginning of the simulation, is portrayed for the Base Case and the present scenario. The difference between the two cases is striking, and the cost of transportation in the More Roads scenario ends up less than 60% of what observed in the Base Case. Naturally, this has an important effect on all production activities, depending on the share of transportation costs on the production value in the various sectors.

![Figure 57: Time Graph for the variable “relative transportation cost”](image)

The intensity of this effect on the various production activities also depends on other elements besides the impact of transportation on the cost of production. Without explicitly describing these elements, we introduced a sensitivity parameter into the model, the “highway impact on production activities sector” parameter (as already explained in the model description part), to test various assumptions about the intensity of this effect.

The sensitivity analysis conducted demonstrated a strong sensitivity of the model results to small changes in the value chosen for this parameter in the confidence interval chosen (the ample confidence bounds for the GDrP illustrated in Figure 56 are an example).
However, independent of the relative intensity of this effect, the mechanism through which it propagates throughout the system is the same. As the transportation cost decreases the labour productivity increases, as well as production. Consequently the local investment increases, with the result of strengthening the reinforcing loop R1 (described in Diagram 1).

This mechanism explains the growth of observed in the Industry, Mining and Services sectors well, but only partly accounts for the fast growth observed in the Agriculture production. Figure 58 portrays the behaviour of agriculture production over time, for the current and the Base Case scenarios. The sudden increase in agricultural production observed in this case is not driven by an increase in productivity or demand, but by the expansions of the forestry sector. In the lower part of the graph, indeed, the “non forestry agriculture production” is also portrayed (the thinner lines), indicating that there is almost no difference between the mere agriculture productions in the two cases.

This increase in forestry production, that heavily affects the total agriculture production, is generated by the huge expansion of the production forest areas. This, in turn, is caused
by the thousands of hectares of forest that the government gives in concessions to foreign companies to pay for road construction. We assumed that the new concession areas are rapidly put into production and therefore contribute to the agriculture production and finally to the GDrP.

This increase in the forestry production is relevant both in relative and in absolute terms. Logging production at the end of the simulation horizon is 30% higher than that observed in the Base Case, and accounts for 25% of the difference between the GDrPs in the two scenarios.

In reality, while this increase in forestry production increases the GDrP, it does not affect directly the GNrP, which is portrayed in Figure 59. This owes to the additional logging concessions given by the government as a payment for a certain service to foreign companies, and we assumed that the resulting production is remitted entirely abroad to remunerate the foreign companies involved in the construction projects.

![Figure 59: Time Graph for the variable “GNrP”](image_url)
Three additional factors have an important effect on the growth of the GNrP observed in the graph above: the shares of foreign capital and foreign labour force over their respective totals and the growth of the public debt.

The share of foreign capital over the total productive capital employed in the various production activities tends to decline in this scenario, as an indirect consequence of the road construction projects. As the highway network is improved, indeed, the transportation cost is reduced, increasing the production and therefore the flow of local investments. This mechanism, however, does not affect the quantity of foreign capital invested in the region, which remain the same as in the Base Case. As a consequence, local capital assumes a slightly more important role in production, creating a weak but constant and positive effect on the GNrP.

On the other hand, the observed increase in production creates an additional demand of labour force that local skilled labour supply cannot initially satisfy, because this supply is already completely absorbed by the existing activities. This generates an expansion in the inflow of foreign workers, which increase their share over the total workers employed, as a consequence augmenting the share of the total salaries that is remitted abroad. The resulting effect on the GNrP, though it is not as strong as what observed in the Big M scenario, is sufficient to overcome the positive effect generated by the increase of local investments.

Finally, an important role in decreasing the GNrP is played by the interests paid on the public debt, which reaches a significant level in this scenario (the behaviour of this important variable is separately described in following paragraphs).

As a result of the combination of the three elements described above, the level of economic surplus value benefiting local people declines almost to the same level calculated in the Base Case.

To complete the panoramic over the effects on the economic system of the new policies introduced, we have to change our focus from the private to the public economy. Figure 60 represents in particular the behaviour of the public debt over time, comparing the results obtained in the current scenario to those formerly calculated in the Base Case.
The two curves appear strongly different, as the result of the combination of various effects.

First, between 2003 and 2008 the debt in the More Roads scenario grows slower than in the Base Case, due to our assumption of a reduced expenditure for hydropower capacity. In the Base Case, however, as the dams’ construction projects are finished, the debt growth rapidly slows down and becomes negative from the year 2010, until the debt is eventually completely paid back around 2019. On the other hand, in the current scenario, the public debt keeps on growing at a slightly decreasing rate for the entire simulation time, overshooting the level of debt calculated in the Base Case around 2012 and ultimately reaching a value of almost 3 billion. The main mechanisms underlying the behaviour observed in Figure 60 are represented in Diagram 10.

The most important element causing the increase in the debt is not, in this case, the cost of highway construction, but the cost of maintenance. In this scenario we assumed that the government does not sustain any economic cost for the construction of the additional roads, as they are paid by the logging concessions given. The costs of highway maintenance, on the other hand, are strictly related to the length of the highway network,
and are completely paid by the local administration. Given the fact that road construction is a process distributed over many years, the maintenance budget grows gradually, as more new highways are completed. This generates an increasing demand for public funds and therefore increases the public debt.

As described in Diagram 10, however, the increase in the expenditure for highway maintenance generates an increase in the structures’ quality. This, together with the effect of the expansion of the network, contributes to the reduction of transportation costs, which in turn increases production and accelerates the R1 loop, as previously mentioned. The increase in production, finally, has a positive effect on the government budget, augmenting the capacity that the administration has to refund the existing debt. It is this positive effect that gradually reduces the public debt’s growth rate, generating the behaviour observed in Figure 60.

This mechanism, however, does not result strong enough to finally stop the debt growth, which eventually reaches a high level.

One last economic indicator that is important to observe in order to understand the impact of the new policies introduced on the public economy is the “implicit economic loss from forest loss”.
This variable represents the cumulative theoretical loss for the government in terms of the taxes on exportation that are not paid on the wood illegally cut or produced in the concessions given to pay for highway construction. In other words, this indicator measures the incomes the government would have had if the part of forest production above indicated would have been subjected to the normal exportation taxes. We assumed that the forestry production remitted abroad to pay for highway construction would have not been subjected to taxes, as the project’s description suggests. The behaviour of this indicator for the Base and the current cases is illustrated in Figure 61.

The loss above portrayed is extremely relevant. The additional cumulative loss with respect to what was observed in the Base Case accounts for more than the GDrP for the last year of the simulation, and is many times higher than the amount required to build and maintain the necessary new structures. Though the government is not paying a direct cost for the impressive road construction project implemented, the implicit economic cost of it is enormous. Contributing to the dramatic rise of this cost is not only the production deriving from the additional land concessions, but also the dramatic increase in the illegal
logging deriving from the expansion of the road network (as described in the following part dedicated to environmental indicators).

The above described effects of the new policies introduced on the economic development of the region can be summarised in three major points.

First, the strong reduction of the road transportation cost has a significant positive effect on the GDrP, but not on the GNrP. Foreign workers satisfy most of the increase in labour demand created and the expansion of the forestry sector does not benefit local people, as the additional production is entirely remitted abroad.

Second, though the government does not pay for the new highways’ construction, the only cost of maintenance of the new highways creates a huge public debt that does not seem to decline even at the end of the simulation time. This means that the return on public investment is not sufficient to keep the budget balance, and indicates a substantial failure of the government’s economic plan over the time horizon explored.

Finally, the cost implicitly sustained for the implementation of the Trans-Irian project is quite high. This amount of resources can be used for the same or other purposes in a more economical way if the government would have responsibly collected them, instead of leaving the full exploitation of the forest areas in the hands of the foreign companies involved in the project.

After the report and explanation, provided above, of how the new policies impact on the regional economy, it is interesting to shift the focus, in the following paragraphs, on the analysis of some major social indicators.

It is first important to have a look at how the total employment level responds to the new policies introduced. As one could guess looking at the GDrP growth in this scenario, the total employment in the region does not show any dramatic change of behaviour. Indeed, as portrayed in Figure 62, it rises only slightly over the levels calculated in the Base Case. Moreover, the effect of the growth of production on the employment level is partially compensated by the effect of technology, which similarly increases. As described by the balancing loop B2 in Diagram 2, as production grows local investments increase and
boost technological development. This reduces the ideal number of workers employed per unit of capital, and therefore has a negative effect on employment.

The increase in labour demand deriving from the expansion of the various economic activities, moreover, is of little benefit for local people, as the local skilled labour supply is already fully absorbed by the existing economic activities. Most of the additional labour demand is then satisfied by an increase in the immigration of foreign workers, which are the final beneficiaries of the supplementary salaries paid.

![Total Employment Graph](image_url)

**Figure 62: Time Graph for the variable “total employment”**

The expansion of the regional economy, however, accounts only for part of the growth in the employment level observed in Figure 62. The largest portion of it, almost two-thirds of the additional 35,000 workers, is employed for the construction of the new gigantic transportation infrastructures. This reflects our assumption that, though a big part of the labour force involved in these projects are foreign workers that are in charge of the most technical tasks, a certain amount of local people is also hired for undemanding jobs. Local workers are certainly cheaper, and can be economically used for simple tasks. We assumed furthermore that, even though hired by foreign companies, local people involved
in the roads and dams constructions and maintenances activities should be considered in the computation of the regional employment.

Given these differentiated labour force needs for the construction of new highway, not only the generic total employment results increased, but in particular the level of local employment also benefits from the additional demand for unskilled labour generated.

In figure 63, the total number of workers employed in the infrastructure construction projects is reported.

![Infrastructures Employed](image)

**Figure 63: Time Graph for the variable “infrastructures employed”**

Analysing the graph above, we can make two important observations. First, even though at first glance the increase in “infrastructures employed” (the amount of people employed in the infrastructures sector) can appear enormous in relative terms, in absolute terms it is not highly significant. The almost 20,000 people additionally employed at the end of the simulation represent only 2% of the total active workforce, a small increase if achieved over 18 years.

Second, the qualitative behaviour pattern observed in this case is markedly different from what was calculated in the Base Case or in the Big M scenario. In these last cases a large part of the infrastructures’ labour force was hired for the construction of the desired roads.
and dams and consequently was dismissed after the projects were completed. This generated the kind of behaviour represented by the blue line in Figure 63, more accentuated in the Big M case, characterised by a rapid increase of the employment as projects are started and then a gradual decrease as constructions are completed. The final equilibrium level is mainly determined by the amount of people required to run and maintain the existing infrastructures.

In the More Roads scenario, on the other hand, most of the work force hired in the infrastructure sectors is used for maintenance purposes. As mentioned above, road maintenance expenditure is particularly high in this scenario, because keeping the quality of the highway network at a high level is one of the government’s targets. Consequently, the “infrastructures employed” grows smoothly as road construction are gradually completed, and do not show any tendency to reduce. From a social viewpoint, this kind of employment has a better impact on the population than what happens in the Base Case and in the Big M scenarios. In those cases local people would have tended to leave their original villages and jobs, attracted by higher salaries. Since the kind of employment offered would be typically short-term, however, they would have soon needed to reintegrate into their initial activities and social groups, a process that may be detrimental and at times infeasible. In this scenario, on the other hand, the labour force demand is more long-term oriented, and does not create the kind of problems above indicated for the other scenarios.

However, considering that the labour demand generated by the new infrastructures projects is relatively small when compared to the total number of people employed in the region, we can conclude that the effect of the new policies on the level of employment is limited.

An important indicator to evaluate the capacity of the government to provide adequate social services is the cumulative development expenditure from 2010 to 2020. As already explained, this variable measures the total amount of money spent by the government for education and healthcare in the indicated decade, and therefore represents a good assessment of the administration’s capability to face future social challenges.
The behaviour of the variable in the current and in the Base Case scenario is illustrated in Figure 64. As the reader notes from observing this figure, the level of cumulative expenditure is mostly the same in the two cases until 2019, when the Base Case funds destined to education and healthcare suddenly increase. As explained above, this happens because at that time the government has completely paid back the public debt (including interest and the debt’s refunding rates), and can therefore use all the resources available to increase the development expenditure. This does not happen in the current scenario. In this case the debt continues to grow until the end of the simulation, and the government in 2020 is still far from being able to refund it. Therefore, the development expenditures do not increase, but remain fixed to the minimum percentage of budget we assumed to be spent for this purpose. Naturally, the total government budget is a little higher than in the Base Case, and for this reason, from 2010 to 2019, the development expenditure in the More Roads scenario is slightly bigger. However, this initial difference results small when compared to the final increase observed in the Base Case, and the cumulative development expenditure in the More Roads scenario ends up to be about 5% lower than in the reference case.
As a result of this, the quality of the social services offered in this scenario is lower than that projected in the Base Case towards the end of the simulation horizon. Figure 65, for example, reports the entrance rate for primary school in the two cases. The entrance rate represents the fraction of six years old children that has access to education services, and is dependant, in our assumptions, on the government’s spending for education per pupil.

![Figure 65: Time Graph for the variable “entrance rate [female]”](image)

Clearly, the rapid increase in the development expenditure observed in Figure 64 has a repercussion on the entrance rate, which gradually starts increasing from 2019. Though this increase may seem small and only after a long time will have effects on the education index, it is remarkable and can produce noteworthy effects on the whole system in the long run. As education increases workers productivity increases, and so does the skilled labour supply, producing an increase in the GDrP and the GNrp respectively that can activate many others beneficial mechanisms of growth. Similarly, the increase in development expenditure generates an improvement in the quality and in the accessibility of the health care facilities and of clean water, basic services for the social development of the region. This kind of development policy, however, cannot be followed in the More
Roads scenario, as the debt limits the growth of the development expenditure for a long time after the end of our time horizon.

Summarising the results of the set of policies introduced in this scenario on the social indicators chosen, we can derive two major observations. First, the effect of the new course of action on the total employment is small. The little increase in production observed generates an even less relevant increase in the labour demand, owing to the fact that the parallel growth of technology reduces the desired labour/capital ratio. The increase in labour demand, moreover, is absorbed by an increasing influx of foreign workers, and does not benefit to local people. Moreover, most of the growth observed in total employment is due to the demand for local workers for the maintenance of the new roads. This generates an increase of about 2% in the total amount of local workers employed, who are not sustained by the private economy but paid entirely by the government. Secondly, in this scenario the government finds itself unable to increase the development expenditure as much as in the Base Case. Though the difference in the expenditure levels in the two cases becomes noticeable only towards the end of the time horizon, the debt accumulated in the More Roads scenario suggests that this gap is destined to dramatically increase over time.

To conclude our analysis of the results produced by the model in this scenario, it is important to have a look at the effects of the policies newly introduced on the environment. A first good indicator of the quality of the management of the regional natural resources is represented by the amount of forestland on the island. The behaviour over time of this variable in the current and in the Base Case is illustrated in Figure 66. The immediate message this graph is giving is clear: about 50% more of forestland is destroyed in the More Roads scenario, with respect to the Base Case. The rate of forest loss seems, in this case, accelerate from 2003 and, though towards the end of the simulation it shows a tendency to slow down, it is still far bigger than in the Base Case.
The main cause of this accelerated process of destruction of the forest covering the island can be identified in the new, monolithic project of road construction implemented. Road construction affects the stock of forestland both directly and indirectly. Directly, for each kilometre of highway built a certain amount of hectares of forest is lost, as we assumed that the government would pay for road’s construction by giving logging concessions to the foreign companies in charge of the project. Though we assumed that 1,000 of hectares of land are given in concession per kilometre of highway built, only a varying share of these is actually forestland. This share depends on the forest cover: we assumed, in other words, that as the percentage of land covered by forest decreases, so does the probability that the hectares given in concession are forestland. What happens therefore when the first new highways are completed is a rapid increase in the forest conversion rate, which transforms forestland into production forest. As illustrated by the thick grey line in Figure 67, the forest conversion, after reaching a peak in 2005, gradually decreases, owing to the fact that the part of the projects left to be completed becomes smaller and smaller.

Figure 66: Time Graph for the variable “forest land”
The reduction of the forest cover also contributes to this decline in the forest conversion rate, which at the end the simulation reaches almost the same value observed in the Base Case.

As mentioned above, roads constructions also have an indirect effect on forestland.

![Graph showing forest loss and conversion over time](image)

**Figure 67: Time Graph for the variables “forest loss” and “forest conversion”**

We assumed that illegal logging is proportional to the length of the highway network, as highways are necessary both to access forest areas and transport logs. Therefore, as new roads are added to the existing networks, illegal logging increases and augments the rate of forest loss (the thin grey line in Figure 67). From 2010, however, the forest loss starts diminishing, as a consequence of the reduction of the forest cover. We also that a decrease in available forestland makes the searching for suitable logging areas more difficult and expensive, and therefore illegal logging becomes less intense.

The combination of the two rates presented in Figure 67 generates the decrease in the forestland observed in Figure 66, leaving at the end of the simulation scenario only eight millions hectares of forest left. These represent only about 30% of the initial forest, meaning that most of the vegetation on the island is lost at the end of this scenario, with possible catastrophic consequences. I mentioned earlier that forest loss represents a threat
not only to floral biodiversity of the island, but also for the many faunal species living in the forest, including human beings. The numerous tribes inhabiting the rainforest would be in danger, and with them their cultures, languages and traditions. Moreover, the dramatic reduction in the forestland projected in this scenario not only creates a menace for the people living in the forest, but also for the whole population. As the forest cover decreases, some slow but powerful, mechanisms start working. The possibility of floods and landslides increases and the process of soil erosion accelerates. In Figure 68 the rate of land degradation that transforms agriculture into fallow land is portrayed.

Driven by the decrease in forest cover, the agriculture land degradation accelerates, and is at the end of the simulation 25% higher than the value observed in the Base Case. This phenomenon does not create any specific problem over the projected time horizon, because a huge quantity of non-degraded fallow land is available to substitute the loss of agriculture land. From a long-term point of view, however, this process of land degradation may cause extremely serious problems, and eventually erode the food production capacity of the country. When the fallow land buffer is completely used,
indeed, the mechanism presented in Diagram 11 starts working, with possible detrimental effects.

![Diagram 11: Forest and Land Degradation](image)

The decrease in forest cover accelerates the agriculture land degradation, creating an additional demand for cropland. If no more fallow land is available for this purpose, this demand can only be satisfied by cutting forest, decreasing the forest cover even more. Though the conditions to make the reinforcing loop R16 work did not appear over the time horizon we took into consideration, it could have harmful consequences for the development in the region in the long run.

Consequently, the impressive forest loss projected in this scenario should not be considered a problem merely in terms of environmental degradation, but also as a potential cause of dangerous disequilibria in the island’s socio-economic system.

A last indicator that it is important to take into consideration here is the composite pollution index, indicating the overall pollution level on the island. The behaviour of this variable over time in the current and in the Base Case is portrayed in figure 69. As we would have expected given the GDnP growth pattern observed in this scenario, the pollution on the island grows smoothly and slightly faster than in the Base Case. However, the main reason of this behaviour is not the direct influence of the production level on the quantity of emissions but a more indirect mechanism. We assumed that as more highways are built and more funds are employed for road maintenance, the road
transportation cost decreases. Naturally, this generates an increase in the traffic, owing to the fact that road transportation may be preferred to other forms of transportation, because it becomes less expensive. Consequently air pollution increases, contributing to the total emissions, as we assumed that road transportation is more polluting than animal or water transportation. If we decompose the composite pollution index in the three elements that constitute it, land, water and air pollution, we discover that air pollution increases much faster than the other two forms of pollution. On a relative scale, while land and water pollution at the end of the simulation are about 2% higher than the values observed in the Base Case, air pollution results almost 16% more concentrated, as illustrated in Figure 70.

This relevant increase in air pollution, however, is only partially transferred to the composite pollution index, according to the fact that the weight given to this pollutant in the determination of the composite indicator is small. Given the initial conditions on the island and the low population density of the region, we assumed that an increase in air pollution would have been much less harmful than a similar increase in land or water pollution.

![Figure 69: Time Graph for the variable “pollution composite index”](image_url)
The slowdown in the growth of pollution, which reaches a peak around 2008, is caused by the effect of the construction of the new hydropower facilities. The additional clean hydroelectric energy produced tends to substitute the more expensive and more polluting energy produced by diesel engines, reducing the average air pollution emissions per unit produced. For a certain period of time, from 2008 to 2016, the reduction in the use of diesel generators more than compensates for the increase in total production, causing a reduction of the pollution in the air. After this transition period, however, production’s growth takes over again, driving a new rise in air pollution. This is due to the fact that, though by 2015 most of the energy demand is satisfied by hydropower, the air polluting emissions per unit produced can never be reduced to zero, as there are many industrial processes that generate air pollution independently from the form of energy actually used. In 2016, then, production reaches a level at which pollution emissions are again almost as
high as in 2008, and consequently the level of pollutants in the air starts increasing once more.

Concluding, the effects of the policies introduced in this scenario on the region’s environment are potentially dangerous.

First the forestland results are seriously compromised at the end of the time horizon, when only about 30% of its initial amount is left. This is the result of the monstrous road construction projects implemented and of the expansion of the illegal logging activities the new roads generate. It is difficult to imagine the terrible effect on the flora and the fauna of the region of this ecologic disaster, an effect that the model is not able to quantify. Such a destabilisation of the most basic environmental equilibriums, however, would certainly carry severe menaces for most of the species inhabiting the island, humans beings included.

Second, the pollution in the air grows more than proportionally with respect to the GDrP, due to the effect of the increase of traffic generated by the decrease in the cost of road transportation. Even though this increase in the air pollution does not create any problem to the population over the indicated time horizon, the acceleration in the emissions observed should be taken into consideration when establishing longer-term policy plans.

4.3.3 Preliminary Comments on the Results produced

The More Roads scenario generates the poorest global results among those analysed thus far. Most of the peculiar differences in the system’s behaviour observed in this case are, in particular, generated by the idea of financing the road construction projects with logging concessions around the new highways built, which are revealed to be highly harmful.

If on one hand the project may seem reasonable considering the government’s target of containing the construction cost of the new infrastructures, on the other hand it generates a series of important negative effects. First, the oversized highway network ends up generating high maintenance costs, which absorb an important part of the government’s budget and create a relevant public debt. Not generated by an occasional expense for
construction but by the continuous expenditure for roads maintenance, this debt represents a heavy economic heritage for future generations.

Second, the logging concessions given by the government as payment for construction of new roads represent an enormous opportunity cost for the government. Even when considering only the taxes on exportation the government would have received from the additional logging production from these concessions, the missing inflow of funds exceeds the entire GDrP in 2020.

Third, the construction of the new highway network has a devastating effect on the forestland. This occurs both directly, due to the logging concessions around the road given by the government, and indirectly from the increase in illegal logging that the new roads cause.

Finally, the impact on the private economy of the Trans-Irian project is modest when compared to its cost, deriving from both quantitative and qualitative characteristics of the project. From the qualitative point of view we assumed the new highways built to be of low economic relevance, because the target of the project is not to link existing economic and social centres. From the quantitative point of view, the project seems clearly oversized with respect to the dimension of the local economy, generating exaggerated costs with respect to its potential benefits.
4.4 Urban Scenario

4.4.1 Description

This scenario has been developed with the explicit purpose of testing policies that are radically different than those that the Papuan government is actually more inclined towards. An alternative to the most likely policy plans, analysed in the previous scenarios, has been conceptualised by our clients and simulated with the model, to see to what extent this policy plan can be considered a valid option.

The name of this scenario indicates that the fulcra of the new development strategy introduced are the urban centres and their socio-economic progress. Particular attention has been given also to the development of the production activities that are locally financed and to the support of local employment.

In all the previous scenarios we observed that the growth of the GDrP was never satisfactorily transferred to the GNrP or, in other words, into a real economic benefit for local people, for two main reasons. First, most of the companies in the region are financed by foreign capital and tend to remit most of their profit abroad in order to remunerate the overseas investors. Second, the local supply of skilled labour force turned out to be insufficient to satisfy the increasing demand, causing an inflow of foreign workers that absorbed all the benefits created by the additional salaries paid.

We decided therefore to introduce two new policies to try to counteract these forces. A small credit initiative has been implemented with the aim of increasing the number of the locally owned production activities, to rebalance the actual situation characterised by a predominance of foreign capital in the various production sectors.

Moreover, we introduced professional training courses, to increase the supply of local skilled labour and consequently reduce the need for foreign workers.

In this scenario we also considered some expansions in the hydropower capacity and an enlargement of the roads network, but with different objectives from the previous cases. In particular, we assumed that the government invests only modestly in the increase of the hydroelectric energy supply: the aim of this intervention is not to create the conditions to attract foreign investors, but simply to substitute most of the existing diesel generators with clean power. Furthermore, some road construction projects have been introduced,
with the objective of creating the missing links between the most relevant economic and social centres.

The increase in development expenditure, via funds destined to education and health care, is also one of our explicit targets in this scenario, being a key element to increase in the medium-long term the local people’s quality of life.

A final policy introduced in this scenario is the reduction in the number of logging concessions granted each year. This policy has the objective of limiting the growth of the logging sector, which merely exploits the virgin forest, in favour of other economic sectors, to respect the environment as well as the antique social groups inhabiting the most remote areas of the island.

From a qualitative point of view, these policies can be summarised as following:

- The organisation of Training Courses for local workers, to increase the skilled labour force supply
- The introduction of Small Credit initiatives for local enterprises, to reduce the dependence of production activities from foreign capital
- Targeted investments to expand the existing road network, to create the missing connections between the most relevant urban and economic centres
- A modest investment in energy production and distribution, to substitute hydropower for the more polluting and expensive diesel
- A reduction in the number of logging concessions given each year
- An increase in expenditure for education and health care

Accordingly to the new policy plan, most of the policy variables in the model have been adjusted to represent the set of decisions we wanted to test. In Table 6, in particular, to each of the policy variables is associated the value actually used to simulate this scenario, and a brief description of their significance and individual relevance is given in the following paragraphs.
<table>
<thead>
<tr>
<th>Policy Variable</th>
<th>Unit</th>
<th>Urban Scenario Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desired Km of new highway</td>
<td>Km</td>
<td>2000 highrel</td>
</tr>
<tr>
<td>Desired construction starts function (Dam)</td>
<td>Mw</td>
<td>265</td>
</tr>
<tr>
<td>HPH concession function (Forest)</td>
<td>Ha</td>
<td>4e05</td>
</tr>
<tr>
<td>Desired fraction of programmed maintenance</td>
<td>Dmnl</td>
<td>30%</td>
</tr>
<tr>
<td>Hydropower price Kwh</td>
<td>KRP93/kwh</td>
<td>0.15</td>
</tr>
<tr>
<td>Desired number of trainees per year function</td>
<td>Person</td>
<td>20,000</td>
</tr>
<tr>
<td>Desired amount of funds destined to small credit</td>
<td>KRP93</td>
<td>6.4e+09</td>
</tr>
<tr>
<td>Gov education exp share</td>
<td>Dmnl</td>
<td>0.095 =&gt; 0.19</td>
</tr>
<tr>
<td>Gov health exp share</td>
<td>Dmnl</td>
<td>0.06 =&gt; 0.156</td>
</tr>
<tr>
<td>Big M mining foreign investment</td>
<td>KRP93</td>
<td>0</td>
</tr>
<tr>
<td>Big M industry foreign investment</td>
<td>KRP93</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 6: Policy variables settings for the Urban Scenario

At the beginning of the table above, the “desired Km of new highway”, representing the length of the new roads the government desires to build, has been set to the same value used in the Base Case. This means that no additional road construction projects are added to the 2,000 kilometres considered in the first scenario, considered the minimum necessary to create the most relevant links between the major urban and economic centres.

On the other hand, the desired increase in hydropower capacity, the “desired construction starts function”, has been substantially reduced with respect to the Base Case. The aim of expanding the hydroelectric production is, in this case, merely to substitute the expensive, polluting diesel engines. The capacity increase has been set, therefore, just to satisfy the
existing demand. In this scenario only 265 Mw of capacity are built, about 40% of the value used in the Base Case.

An important element of the policy plan introduced is the reduction achieved in the “HPH concession function”. This function, which represents the desired amount of logging concessions the government desires to give, has been reduced by 100,000 hectares per year, starting in 2003. In relative terms, this reduction represents about 40% of the total concessions given in the Base Case, implying a total savings of almost two million hectares of forest.

On the contrary, the “desired fraction of programmed maintenance” has been doubled with respect to the value used in the Base Case. This policy variable represents the share of necessary road maintenance that is actually sustained by the government. This variable plays an important role in determining the efficiency and cost of road transportation. The value used here is the same as the one used in the More Roads scenario, but in this case the number of new roads built is much lower. In other words, we decided in this scenario to invest in road quality instead of quantity.

The hydropower price per Kwh has been kept at the same level as in the Base Case, because the little increase in the existing capacity programmed does not require a particular economic effort for the government. The investment made is therefore rapidly repaid even with the low price of 0.15 KRP93/Kwh, the same we applied in the first scenario.

One of the two big innovations in terms of policy options introduced in this scenario is represented by training courses for local workers organised by the government. As we can observe from Table 6, this is the first case in which the “desired number of trainees per year function” is different from zero, meaning that this kind of policy has not been used until now. We assumed that 20,000 workers, as indicated in the Table above, are enrolled over ten years, starting from 2005. We also assumed that it takes one year on the average for the 2,000 people admitted to the course each year to gain the professional skills necessary to participate in production activities. However, not all of them can successfully finish the training period, and we assumed that a fixed percentage of participants drops the course each year.
The other innovative policy introduced is the small credit initiative financed by the government. In this case the administration makes available to the local investors a certain amount of funds without applying any interest rate. The total funds used for this purpose sum up to 6.4 billion, which are distributed over 16 years, from 2005 until the end of the scenario. More precisely, every year 0.4 billion are added to the existing small credit funds, independently from the fact that these have been already completely used or not.

The “gov education exp share” and the “gov health exp share”, measuring the way the development expenditure is divided between education and health care, has not been changed with respect to the values used in the Base Case. We assumed in this case the target of the government was to increase the development expenditure as a whole, independently from how this will be actually shared among education and health care.

Finally, the “Big M mining foreign investment” and the “Big M industry foreign investment” have been left at zero, meaning that no extra exogenous flow of foreign investment are assumed to shock the system in this scenario.

The exact values reported in Table 6 have been used to run the Urban scenario, the results of which are reported in the following section.

4.4.2 Results

In this section the results generated in the Urban scenario are compared to those obtained in the Base Case, to identify the major effects of the new policies introduced. The mechanisms through which these policies influence the system are explained, highlighting the relative weight of their contribution to the observed behaviour.

Finally, in the preliminary conclusion section, a brief evaluation of the new policies introduced is given, considering their ability to produce a more desirable system behaviour.

To begin the results’ analysis, it is interesting to observe the impact of the new policy plan on the economy of the region. To have an idea of the development of the local production, the most basic indicator to monitor is certainly the GDrP, in Figure 71.
Similarly to that observed in the More Roads scenario, the total production in this case grows slightly faster than in the Base Case, reaching a final value about one billion higher. However, the production grows faster in this scenario than in the More Roads scenario, and the surplus of production generated with respect to the Base Case at the end of the simulation is twice as big. The difference between the production levels in the Urban and the Base Case scenarios, therefore, is significant, and the sensitivity analysis conducted does not show any superposition in the confidence bounds for this variable in the two runs.

![Figure 71: Time Graph for the variable “GDrP”](image)

Two elements contained in the new policy plan affect the growth of production observed in Figure 71.

First, production is positively affected by the decrease in transportation costs deriving from the better maintenance service that the government implements in this case. Even though the number of new roads built is the same as in the Base Case, the roads’ quality is substantially increased, and the final effect on the relative road transportation costs is relevant, as illustrated in Figure 72.
This reduction in the cost of transportation consequently affects the labour productivity in the various economic sectors, increasing production and therefore the GDrP.

Second, a positive effect on production is generated by the small credit initiative introduced by the government. As the government assigns funds to support the investments in locally owned production activities, these funds are gradually used, increasing local investment in industry, services and agriculture. Consequently, the labour productivity and therefore the level of production determined in these sectors are increased, as illustrated in Figure 73 for industry.

This increase in production in the various sectors finally contributes to the growth of GDrP. The growth observed in the industry sector is incredible, indicating a high level of efficacy of this kind of policy in sustaining production. This pattern of growth, however, is not replicated by the whole GDrP for two main reasons.

One reason for this phenomenon is that the small credit initiative does not boost all production sectors. In particular, we assumed that the funds made available by the government are not used in the mining sector, given that small, local companies cannot easily access this sector.
Unaffected by the credit initiative, this sector, which actually represents the single most important contribution to the GDrP, presents a pattern of growth substantially equal to what observed in the Base Case. Therefore, the increase in production observed at the end of the simulation of about three hundred million per year in the industry sector, or of about six hundred million per year in the service sector, is not going to radically change the GDrP, which reaches a level of about 25 billion per year. It is important to notice, moreover, that the mining sector, completely financed by foreign capital, it is not even indirectly affected by the increase in production in the other sectors. As explained above in analysing the results generated in the Big M scenario, that reinforcing loop R13 in Diagram 7 does not work for the mining sector, as we assumed that the share of local investment destined to mining activities is equal to zero.

Another production sector that does not particularly contributes to the GDrP growth is the agriculture sector. This sector, though initially positively influenced by the increase in investment, in the long run is not significantly influenced by the additional inflow of capital.
In fact, as explained in Diagram 12, as capital intensity in agriculture increases, the yield grows as well, reducing the amount of land needed to produce the necessary quantity of food for the existing population. The agriculture land is therefore gradually reduced, to adjust the production level to the desired one.

![Diagram 12: Agriculture and Land](image)

The balancing loop B9 results therefore extremely strong, and able to fully contrast any tentative of increasing agriculture production through investment, boosting the reinforcing loop R17. This reflects our assumption that agriculture production on the island is for local consumption only, and that the ideal level of production corresponds to the level of the local demand.

It is important to notice, finally, how the government policy of logging concessions also affects the agriculture sector. In this scenario we assumed a cut in logging concessions of about one hundred thousand hectares per year, reducing the amount of land used for forestry production. Consequently, forestry production decreases, contributing to slow down the growth of the agriculture sector, and ultimately of the GDrP. However, this reduction in forestry production, which reaches a maximum of 10% of the sector’s production calculated in the Base Case, is not relevant in absolute terms, accounting for less than 55 million per year against a total agriculture production of nearly 2 billion per year.

The combination of all the elements described above finally generates the slow but continuous acceleration in the GDrP growth illustrated in Figure 71.
After this overview of the underlying causes of the growth of production in this scenario, it is interesting to analyse the development of the GNrP, to understand how much local people will actually benefit from this growth. Figure 74 reports the GNrP calculated in this and the Base Case.

As it immediately appears, the difference in the two curves for this variable is more significant than that observed for the GDrP. In the current scenario the GNrP grows indubitably faster than in the Base Case, generating a final value more than 11% higher. In other words, the growth observed in the GDrP is in this case well transformed in the correspondent growth of the GNrP, differently from what happened in all the other scenarios. This occurs for three different reasons.

First, the small credit initiative supports the accumulation of local capital in the industry, services and agriculture sectors. This clearly increases the weight of the local capital with respect to the foreign capital invested, which is not affected by the policies introduced. Consequently, the part of production from these sectors that is remitted abroad to
remunerate foreign investors is relatively small, and this has a positive effect of the GNrP.

Second, a positive effect on the GNrP is also generated by the professional training courses financed by the government. Producing a certain amount of skilled local workers per year, these courses contribute to the growth of the local supply of skilled labour. This implies that when demand for skilled labour grows, as a consequence of the increase in the productive capital accumulated, a bigger part of this can be satisfied by local workers, increasing the benefit for Papuans from the additional salaries paid by companies. To have a clearer idea of the impact of the training courses introduced in this scenario, we will first consider the increase in the employment in the industry and services sectors reported in Figure 75.

![Figure 75: Time Graph for the variable “serv and in employment”](image)

This increase in employment, which is mainly generated by the growth of local investments deriving from the small credit funds made available by the government, can be quantified at the end of the simulation in about 43,000 workers. Moreover, we assumed that the training courses produce about 2,000 additional skilled workers per year, for ten years. These additional 20,000 skilled local workers can therefore satisfy
almost half of the observed increase in the employment. In case the training courses were not introduced, all of the additional employees required would have been foreign workers, and this would have almost completely destroyed the part of economic benefit deriving from the additional employment created that is destined to local people.

A last relevant element influencing the actual growth of the GNrP is the amount of money that the government has to pay in the form of interests and refunding rates of the public debt. As it appears in Figure 76, in the Urban scenario the public debt appears more contained and more rapidly reabsorbed than in the Base Case. Indeed, in the Urban scenario, the debt reaches a maximum level about 3.5 times smaller than what observed in the Base Case. Moreover, this is reabsorbed particularly fast and is completely paid back four years earlier than in the Base Case, in 2015.

![Time Graph for the variable “Gov Debt”](image)

The substantial reduction of the government’s expenditure for infrastructures plays the major role in containing the growth of public debt. In this scenario, while road construction has been maintained at the same level as in the Base Case, hydropower capacity creation has been substantially reduced to 40% of the value used in the first scenario.
Moreover, the other policies introduced by the government in this scenario did not seem particularly expensive. The small credit initiatives introduced do not generate a substantial cost for the government, because they consist of funds that are mostly refunded to the government. The training courses, intended to transfer only specific, basic professional skills, are short-term oriented and do not generate high costs. Furthermore, the intensified roads maintenance program implemented, considering that the initial road network is not substantially expanded, does not seem particularly expensive.

It is also important to recognize the role of the increase in the GDrP observed in this scenario in containing the growth of the debt. As the GDrP grows, the government budget increases as well, reducing the need for borrowing funds from abroad and contributing to pay back the debt sooner.

In conclusion, the policies introduced in this scenario have at least three important effects on the regional economy.

First, thanks to the small credit initiative implemented, we observe a small but constant acceleration in the GDrP growth. The total production at the end of the simulation is consistently higher than what was calculated in the Base Case, an outcome that also turns out to be significant in light of the sensitivity analysis conducted.

Second, the GNrP performs substantially better than in the initial scenario, as a result of both the training courses and the small credit initiatives implemented. Remarkably, the final economic benefit destined to local people result increased, at the end of the time horizon considered, by about 11%.

Finally, the policy plan chosen in this case proves to be less expensive than those previously implemented, with a clear positive effect in terms of debt reduction. The public debt does not reach the high peak seen in the Base Case, and is eventually reabsorbed five years earlier.

Proceeding in the analysis of the results produced by the model in this scenario, it is interesting to focus on the effect of the policies introduced on the social development of the region. A first relevant indicator to consider in this sense is “total employment”, measuring the total number of workers employed in the region. Its behaviour over time, in both the current and the Base Case, is reported in Figure 77.
As it clearly appears from this graph, the level of total employment grows in this scenario substantially faster than in the Base Case, leading to a final level about 30% higher. It is important to notice that this stunning increase in the labour force employed is more than proportional to the observed increase in production. This is mainly due to the fact that the various production sectors do not uniformly expand, but, as already explained, the additional growth is mainly concentrated in the industry and services sectors. If compared to the mining sector, these sectors are small in terms of the surplus value produced, but they employ a far greater number of workers. Due to the specific characteristics of the production processes employed, the industry and service sectors have a capital labour ratio many times smaller than what was observed in the mining sector. Therefore, an increase in the productive capital levels of these two sectors leads to a comparatively strong impact on the employment, as the one observed in Figure 77.

Moreover, as already pointed out, this increase in the labour force demand is mainly satisfied by local workers, thanks to the additional skilled labour supply generated by the professional training courses organised by the government. Consequently, the amount of
immigrated workers present on the island results much lower than what we would have expected by only looking at the growth of GDtP, as illustrated in Figure 78.

Though the number of migrated workers is increased, by about 25,000 units with respect to the Base Case, this is only a small part of the 300,000 additional workers employed. It is important to notice, moreover, that for five years, from 2003 until 2008, the level of immigrated workers in the Urban scenario is even lower than that observed in the Base Case. This is caused by the fact that the training courses started two years earlier than the small credit initiatives, and therefore they began producing an additional supply of skilled workers before the increase in production generated a supplementary labour force demand.

Finally, the social impact of the increase in the employment level is, in this scenario, particularly positive. Most of the new salaries distributed are destined to local people, and foreign workers’ decreased percentage of total employment can help reduce social tensions in the region.

Another indicator that can provide important information about the social development effect of the new policies implemented in the region is the “cumulative development
expenditure 2010-2020”. This indicator, considering the total funds allocated by the government for health care and education in that decade, well represents the capacity of the administration to provide essential social services. The behaviours of this variable over time, in the present and the initial scenarios, are reported in Figure 79.

![cumulative development expenditure 2010-2020](image)

**Figure 79: Time Graph for the variable “cumulative development expenditure 2010-2020”**

As it clearly appears from the graph above, the cumulative development expenditure grows in this scenario remarkably faster than in the Base Case, leading to a final value of about 800 million higher. This means, in other words, that in the ten years considered, the government has allocated 800 million KRP93 for development expenditure more than in the Base Case. Moreover, the population in this scenario does not substantially grow more than in the Base Case, owing to the fact that, unlike that seen in the Big M case, immigration of foreign workers and their families is minimized. As a result, both total and per capita expenditures for social services are higher, implying better education and health care services for the whole population.

Two factors mainly cause this acceleration in the growth of the cumulative development expenditure generated by the model in this scenario. The first factor is, naturally, economic growth. We assumed that the development expenditure is a fraction of what is
left of the governmental budget after paying the routine and the extra expenditure. As production increases, the funds available to the government increase, and the development expenditure accordingly grows. Moreover, the increase in the government budget also has a positive effect in containing the public debt, another important factor influencing the level of expenditure for social services. The public debt in this scenario is indeed limited to a much lower level than in the Base Case and is completely paid back earlier, around the year 2015. This implies that starting from 2015 no more resources are diverted from the government budget to pay for the debt, and therefore more funds are available for development expenditures.

As already mentioned, increasing the funds destined to social services produces relevant results in term of the perceived quality of those services only with a certain delay. This delay is representative of the time required to build the new infrastructures and hire the additional personnel required to improve education and health care services. Once the quality of these services is increased, moreover, it takes time for the people to perceive a real benefit from the occurred improvement. This is why over the indicated time horizon we hardly see any real effect of the observed increase in development expenditure on the population.

This does not mean, however, that the effects of the better social services offered are not important for the population development. In reality, they affect a number of important mechanisms of growth. One such mechanism is the R15 reinforcing loop in Diagram 9, which has a strong impact on the regional development on the long-term. As an example, Figure 80 reports the primary school’s entrance rate for females, which measures the percentage of six year old girls that have access to basic education services. In the last six year of the simulation, this percentage is substantially higher in the Urban scenario than in the Base Case, meaning that during this period a greater number of children can have access to school. Naturally, it takes time for these children to finish their primary and secondary school, become adults, find jobs and begin families, but in each of these steps of their lives their education level will play a key role. The impact of the improvement of the education services on the development of the region will be therefore relevant in the long run, and we should expect the advance of the health care system to produce a similar positive effect.
In summary, the effects of the new policies introduced on the social development of the region are positive. First, the labour force demand has been substantially increased. This increase in labour demand has been mainly satisfied by the local supply of skilled workers, thanks to training courses organized by the government. Moreover, the decrease in demand for foreign workers contributed to the reduction of immigration, with the positive effect of reducing the potential tensions emerging between local and foreign people. Second, in this scenario, the level of development expenditure that the government has been able to sustain was higher than that observed in all the other scenarios for all the eighteen years from 2003 until 2020. This implies better education and health care services, which in the long run promise extremely important effects on the development of the region.

In conclusion, across all social indicators produced by the model, we definitely observed the greatest social development progress in this scenario.
A final important element that must be considered to complete the analysis of the effects of the policies introduced on the region’s development is their impact on the environment.

A first significant indicator in this sense is the total forestland, the total area covered by forest, which provides relevant information about the government’s capacity to conserve regional biologic heritage.

In figure 81 the values calculated for the forestland in the Urban and in the Base Case are reported.

![Forest Land Graph](image)

**Figure 81: Time Graph for the variable “forest land”**

From this graph it appears clear that in the current scenario forest loss is substantially reduced with respect to the Base Case. Though the forest on the island is still seriously damaged, the level eventually reached at the end of the simulation is about 8% higher than in the initial scenario. This means a net saving of about 1.3 million hectares of forest. Considering the size of the reduction in the amount of forest concessions given by the government that we assumed in this scenario, however, we would have expected an even better performance. The reduction in the logging concessions we introduced accounted over the whole simulation time for about 1.8 million hectares. The reason why
this cut in concessions did not generate as great a benefit as we would have expected is related to the issue of illegal logging.

In this scenario, as logging concessions decrease over time, illegal logging becomes the leading cause of forest loss around 2006, four years earlier than in the Base Case. Illegal logging depends on the dimension of the existing road network and on the governmental expenditure for logging control, which are the same in the two scenarios. Moreover, the amount of forest that is illegally logged each year also depends on the forest cover. This variable, as a result of the decrease in land concessions, tends to be higher in the Urban scenario, driving the increase in illegal logging illustrated in Figure 82. The increase in illegal logging, in turn, decreases the forestland and therefore the forest cover once again. The feedback loop operating in this case is the balancing loop B4 presented in Diagram 4.

![Figure 82: Time Graph for the variable “forest loss due to illegal logging”](image)

Illegal logging in Papua as in the rest of Indonesia is an extremely serious problem, and one for which a valid solution has not yet been found. We assumed in this analysis that the main direct lever with which the government can act to decrease illegal logging is its expenditure for control.
We decided, however, not to simulate such policy for two reasons. First, until now the government has not shown a serious will to reduce illegal logging, for reasons that are beyond the objective of this thesis (personal interests and corruption seem to be the major factors favouring illegal logging at the policy level). Second, and more important, it seems that many of the control authorities in Papua are somehow themselves involved in illegal logging activities. An increase in the expenditure to sustain such “control” would not have, therefore, a deep impact on the forest loss reduction until a reform of such law enforcement institutions is implemented. In conclusion, what is necessary in this case is management with a clear consciousness of the problem as well as a substantial change in the authorities dedicated to logging control.

When assessing the environmental impact of the new policies introduced, a second important indicator to take into consideration is the composite pollution index. Figure 83 portrays the development over time of this indicator in the Urban and in the Base Case scenarios.

![Figure 83: Time Graph for the variable “pollution composite index”](image-url)
As highlighted by the graph above, the composite pollution index seems in this case to grow slightly faster than in the Base Case, to eventually reach in 2020 a value about 4.5% higher. This increase is mainly due to two factors.

First, the increase in production observed in this case contributes to the increase in pollution emissions. This effect, however, is smaller than expected as the production growth is particularly concentrated in the industry and services sectors and not the heavier polluting mining activities. A second and more important contribution to pollution emissions comes, as also observed in the More Roads scenario, by the increase in the efficiency of the road network. As more intensive maintenance programs are introduced, the roads’ quality increases, and consequently road transportation becomes less expensive. This generates an increase in road traffic and therefore in air pollution. Though in absolute terms this increase in air pollution is still small and does not cause any consequence to the population inhabiting the region over the time horizon considered, it can create important problems in the long-term. On the other hand, it is difficult to think about an balanced development of the region without considering a minimum improvement of the poor highway network. In this sense, the kind of policy introduced in this case is certainly more desirable than what is simulated in the More Roads scenario. First, this scenario aims at the improvement of the existing road network mainly in terms of quality, increasing the expenditure for maintenance on the roads linking the major urban centres. Road traffic and pollution emissions are therefore kept mainly close to the major urban centres. In the More Roads scenario, on the contrary, the construction of the Trans-Irian highway network also brings traffic and pollution into more remote and fragile wilderness areas. Second, the limited expansion of the roads network implemented in this scenario also implies a limited possibility for future growth of the road transportation. In other words, the limited highway network considered in this scenario imposes a maximum to the number of vehicles circulating per day which is far lower than with the Trans-Irian highway. This will induce Pauans authorities and private economic agents to find alternative solutions to road transportation earlier than in the More Roads scenario.
In this case, as in the other scenarios, the need clearly emerges for the government to carefully monitor the development of air pollution and to identify, where possible, valid alternatives to road transportation.

Concluding, the impact of the new policies introduced on the Papuan ecosystem can be summarized in two major points. First, thanks to the reduction in the amount of forest concessions given by the government, forest loss has been sensibly reduced. Though illegal logging slightly increases as a result of higher forest cover, about 1.3 million hectares of forest are saved in this scenario with respect to what is calculated in the Base Case.

Second, a slight acceleration in the growth of pollution is observed. Even if the effect of the increased production on pollution emissions is contained, as the economic development does not particularly interest the most polluting mining sector, the intensification of road transportation causes a noticeable increase in air pollution. However, these additional polluting emissions are concentrated in the more developed districts of the island and, unlike the More Roads and Big M scenarios, are not extended, to the wilder areas where they could be particularly harmful.

4.4.3 Preliminary Comments on the Results produced

Considering the results generated by the model for all the major indicators in this case, the Urban scenario produces overall the most desirable behaviour.

First, the policy plan introduced generates an endogenous acceleration of the economic growth that is not dependent, as in the Big M case, on the expansion of the foreign investment. On the contrary, local investment is supported in this case, particularly in the industry and services sectors, with a positive effect on the balance between local and foreign capital invested in these production activities.

Second, since the industry and services sectors employ most of the labour force, this increase in production generates a strong increase in the total employment. Due to the additional skilled labour supply created by the professional training courses introduced, most of the increase in labour demand is satisfied by local people, reducing the need for foreign workers.
Third, as a consequence of the particular characteristics of the growth of production and employment mentioned above, the growth of GDrP is also well transferred to the GNrP. This means that a relevant part of the additional surplus value produced in this case benefits local people, unlike what is observed in the other scenarios.

Fourth, the policies introduced also have a positive effect on forest conservation, saving about 1.3 billion hectares of forest with respect to that observed in the Base Case. Though much more can be done in this sense, this scenario is a good example of how forest preservation does not necessarily imply a relevant negative effect on the economic growth. Moreover, while it is true that in this scenario we observe a slight increase in the pollution index, this increase is small in both absolute and relative terms. Even if it does not represent an actual threat, however, this increase in pollution should induce the government to find alternative solutions to road transportation as soon as possible.

Finally, the fact that the policy plan introduced absorbs a relatively small amount of public resources is a positive aspect. As a result, the public debt is contained and rapidly paid back in this scenario, allowing the government to sustain a much higher level of development expenditure. This does not generate evident effects over the time horizon chosen, but it surely represents a key factor in the balanced development of the region.
5. Conclusions

The objective of the work described in this thesis was to identify a developmental path for Papua that would generate a real increase in local people’s quality of life and guarantee a proper use of natural resources. In other words, we searched for a more long-term sustainable alternative to the development plan than the one that the Government of Papua is actually undertaking.

Given the multisectoral and multidisciplinary nature of the issue investigated, (our client and) we decided to use a System Dynamics model, the Threshold21 (T21), to support our analysis. A special version of T21 has been created, portraying the specific characteristics of the socio-economic-environmental system of Papua.

In order to demonstrate that, under certain conditions, a development plan that can generate better results in terms of local people’s income and resources conservation was possible, we ran, analysed and compared four different scenarios. The first three scenarios represent some of the policy interventions under discussion that are more likely to be implemented in the near future. The last scenario was created by our client with the principle of sustaining the economic activities directly benefiting local people and preserving the natural resources.

In the following paragraphs a brief description of each scenario and the results of the policy analysis conducted are reported.

5.1 Base Case Scenario

5.1.1 Description

Of the four scenarios analysed, the first is called “Base Case” and represents the term of comparison for the results observed in the other cases. This scenario simply projects in the future the actual policy lines followed by the local government in the last years, and assumes the completion of the ongoing infrastructure projects. Although it does not consider very innovative policy plans, this scenario constitutes an important factor for the analysis conducted, as it represents the reference with respect to which other scenarios are evaluated.
5.1.2 Results
In the Base Case scenario we observe a general growth in the economy mainly driven by foreign investments, which is only moderately beneficial to local people. The huge shares of foreign capital and workers over the total productive factors available, actually causes the biggest portion of surplus value, generated from the exploitation of the existing natural resources, to be remitted abroad. Moreover, forest erosion continues to be driven by illegal logging, with a huge consequent loss in terms of biodiversity, culture and traditions that the model does not quantify, but which is easy to imagine given the proportions of the forest areas lost. Finally, the development expenditure, i.e. the expenditure directed to improve social services such as education and health care, grows only very slowly over most of the time horizon, due to pressure from the public debt. As a consequence, the quality of life of local people is not substantially increased and a well-balanced development process does not follow the mere economic growth observed. We can therefore conclude that in this case none of the policies implemented appeared to drastically change the evolution of the issues under analysis.

5.2 Big M Scenario
5.2.1 Description
The second scenario introduced is called “Big M”, where “M” stands for Mamberamo, a Papuan region that is characterised by an abundance of natural resources. In this scenario, we assume a full exploitation of the region, with big infrastructures constructions, in particular hydropower plants and roads, and huge foreign capitals inflow directed to develop the mining sector. This “Big M” project seems one of the public policies under discussion that is most likely to be implemented, and introduces enormous risks in terms of environmental impact as well as of loss of culture and traditions.

5.2.2 Results
First, the policies implemented in this scenario are economically expensive for the government. In particular, the infrastructure construction projects generate costs that greatly exceed the administration’s possibilities, creating a huge public debt.
Second, the economic conditions of local people are not substantially improved, while the appropriation by foreign individuals and companies of the benefit deriving from the use of Papuan natural resources increases.

From the environmental point of view, the situation is even worse, as the forest suffers severe damage from the new infrastructures construction projects as well as from the increase in the land concessions given by the government. Pollution also substantially increases, and if the increase in emissions is mainly concentrated in the Mamberamo area, this can create severe problems to the local ecosystem and humans.

In conclusion, the set of policies introduced in this scenario not only does not provide a solution to any of the critical issues analysed, but also worsens the initial situation from the point of view of the quality of life of local people, of the conservation of natural resources and of public debt.

5.3 More Roads Scenario

5.3.1 Description

With the third scenario, we introduced the hypothesis of an accelerated and intensified process of roads construction. In the “More Roads” scenario, in fact, we assumed that the government undertakes a series of projects to improve the regional viability system, including the huge “Trans Irian” project, an eleven thousand kilometre highway network. This enormous infrastructure intervention would be paid for by giving logging concessions around the new roads to the foreign companies contracted to build them, and is currently under consideration.

5.3.2 Results

On the one hand, the project of roads construction implemented in this scenario may seem reasonable, considering the government’s target of containing the construction cost of the new infrastructures. On the other hand, it generates a series of important negative effects. First, the oversized highway network ends up generating high maintenance costs, which absorb an important part of the government’s budget and create a substantial public debt.
Second, the construction of the new highway network has devastating effects on the forestland. This occurs both directly, due to the logging concessions around the road given by the government, and indirectly from the increase in illegal logging that the new roads cause.

Finally, the impact on the private economy of the Trans-Irian project is modest when compared to its cost, deriving from both quantitative and qualitative characteristics of the project.

In conclusion, the More Roads scenario generates the poorest results among those analysed thus far for each of the selected indicators.

5.4 Urban Development Scenario

5.4.1 Description

The last of the scenarios used for this study is called “Urban Development” and assumes that the government will increase expenditures on social services and education, will cut the logging concessions, and will try to create preconditions for the development of the small local economies. To achieve this target, in particular, professional training and micro credit initiatives are introduced, and small infrastructures interventions are realized. With respect to the assumptions in the other scenarios, this more softly-oriented policy plan represents a strikingly different approach to the solution of major issues the Papuan population is actually facing.

5.4.2 Results

First, the policy plan introduced in this scenario generates an endogenous acceleration of the economic growth through the support of domestic investment. The increase in the local investment in the industry and services sectors, moreover, has a positive effect on the balance between local and foreign capital invested in these production activities.

Second, since the industry and services sectors employ most of the labour force, the increase in production observed generates a strong increase in the total employment, and in particular in the employment of local workers. The additional skilled labour supply created by the professional training courses introduced is in fact rapidly absorbed, reducing the need of foreign workers.
Third, as a consequence of the particular characteristics of the growth of capital and employment mentioned above, the growth of GDrP is also well transferred to the GNrP. This means that a substantial part of the additional surplus value produced in this case benefits local people, unlike what is observed in the other scenarios.

Fourth, the policies introduced also have a positive effect on forest conservation, saving about 1.3 billion hectares of forest with respect to that observed in the Base Case.

Finally, the policy plan introduced absorbs a relatively small amount of public resources. Consequently, the public debt is contained and rapidly paid back in this scenario, allowing the government to sustain a much higher level of development expenditure.

5.5 Final Conclusions

From the analysis carried out on the results produced by the model for the various scenarios, we derived two important conclusions.

The first conclusion refers to the results of the policy analysis: considering the results generated by the model for all the major indicators, the Urban scenario produces the most desirable overall behaviour. We therefore strongly recommend this type of policy interventions for the development of the Indonesian region of Papua. However, some limitations on the results produced by this analysis must be highlighted.

First, the evaluation of the results produced in the various scenarios depends to some extent on the indicators chosen. We believe that the indicators we have chosen are well representative of the overall situation of the socio-economic-environmental system in Papua, but undoubtedly these reflect our particular philosophy of approach to development studies. A different set of indicators may possibly have led to considerably different conclusions.

Second, the Urban scenario has not been built through an optimisation method, but it is based on the suggestions of the field’s experts that participated in the modelling process. This approach guarantees a high degree of realism and feasibility of the proposed development plan, but also implies that further policy analysis can be conducted with the model, and theoretically better results can be found.
Nevertheless, the objective of this work, to demonstrate that a more long-term sustainable approach to development planning in Papua is possible, has been fully accomplished. Although the Urban scenario proposed is not necessarily the optimal one, in fact, it surely shows how a quicker improvement of the actual situation of the local population is possible, without huge infrastructure projects and government expenditure, and while saving a bigger share of the natural resources available. We hope that the work illustrated in this thesis can lead to a rethinking of the regional development planning in Papua.

The second conclusion does not refer to the results produced, but to the methodology used in this study. Both during the research conduced prior to the model construction and during the analysis reported in this study, the need of an integrated development analysis tool was clear. Only a model incorporating economic, social and environmental aspects of development could support our analysis and give an answer to our key questions. The Threshold 21 model demonstrated to be very well suited for this type of study and flexible enough to incorporate the particular issues affecting Papua. System Dynamics, the methodology at the core of T21, confirmed to be an excellent support for integrated development analysis, allowing the representation of strikingly different systems with the same modelling language. We therefore suggest the use of this same methodology when analysing complex and integrated development issues.
6. References

1993 Statistical Yearbook of the Immigration and Naturalization Service of USA


Barney G., Qu W., Pedercini M., *Documentation for the Threshold 21 Papua (T21)*, Millennium Institute 2003


FAO, FAOSTAT 1997, on CD-ROM


UN Population Division, *Sex and Age Annual, 1950-2050 (The 1994 revision)* (on disks)
US Department of Agriculture, *International Agricultural Baseline Projections to 2005*, AER-750, USDA/ERS


World Bank, *World Development Indicators 2000 on CD-ROM*

World bank (Web1), Overview of Poverty Reduction Strategies

World bank (Web2), PRSP Source Book

World Bank (Web3), Poverty and social impact analysis