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Patricia P.A.A.H. Kandelaars

Approved by

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Abstract

Tourism in the Yucatán peninsula has been and is still growing, which may lead to conflicts between tourism and the environment, population and other economic sectors. A dynamic simulation model has been developed to understand the dynamic relationships between economy, environment and population. In this model several scenarios are analyzed which incorporate various policies and development paths. The quality of the water, the beaches and the archaeological sites are important factors for the tourism sector. Tourism in Yucatán is also dependent on other factors which are not directly related to tourism, such as safety or popularity of other areas or countries. The main goal of this study is to obtain an insight into the dynamic interactions between the main factors influencing tourism. The results indicate that tourism shows a cyclical path, that policies to clean up the water not only have a positive effect on tourism but also on the rest of the economy. Even if the tourist sector has to pay for the cleaning up it will benefit them. The model shows that the effects of stimulating investments in tourism are not profitable for tourism in the long run.

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About the Author

Patricia Kandelaars participated in the IIASA Young Scientists Summer Program in 1996, working with the Population Project. She was awarded a Peccei Scholarship to return to IIASA in 1997 to continue her work on this topic.

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Table of Contents

A Dynamic Simulation Model of Tourism and Environment in the Yucatán Peninsula

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1. Introduction

This model is part of a Population-Development-Environment (PDE) model developed by IIASA. The PDE approach integrates the interactions between population, economic and social development and environment. Recent PDE models dealt with the small islands of Mauritius (Lutz, 1994) and Cape Verde (Wils, 1996). The next step is to develop a more elaborated PDE model for a peninsula. The Yucatán peninsula was chosen as a case study because (1) it is a region which mostly borders the sea, limiting not only trade and the migration of people but also connections by land to the rest of México; (2) it has a specific historical culture, the Mayan civilization, which has shown a sudden decrease in population (Lutz *et al.*, 1996); (3) drastic economic and demographic changes have taken place in the last twenty years such as a large population increase, mostly resulting from an increased tourism industry; (4) there may be a conflict between the economy, the inhabitants and the environment which is to a large extent due to the increase in population and tourism; and (5) there is a potential to apply this model to greater environmental, developmental or population problems of México or specific other parts, for example, the northern region with high emigration rates.

Besides modeling the population and the environment it is also important to include the economy because changes in environment and population are often related to economic circumstances. This paper focuses on tourism because it is a main economic sector in the Yucatán peninsula (Inskeep and Kallenberger, 1992). Tourism has developed over the last 20 to 30 years and is expected to grow in the future (Inskeep and Kallenberger, 1992; World Tourism Organisation, 1996). The per capita income of the peninsula is higher than in other regions of México which is mainly due to the earnings in tourism. As a result of these income differences and the economic development of the region, there has been migration from other parts of México to Yucatán. Other economic sectors which are important in the Yucatán peninsula are fisheries (Hale, 1996) and agriculture.

Tourism development and the environment are major issues in the tourism industry (Inskeep and Kallenberger, 1992). The decrease in the quality of the environment concerns not only tourists, but also the tourism industry, mainly due to the loss in income. The popularity of

tourist destinations may be reduced due to a decrease in the water quality (e.g., the algae along the Adriatic Coast in Italy) or the forest quality (e.g., the Black Forest in Germany). Other environmental factors (in a broader sense) are the tourism destinations which are overdeveloped (e.g., Spanish resorts along the Mediterranean) (Inskeep and Kallenberger, 1992).

The factors determining the number of tourists are, for example, infrastructure (both road and air transport, and accommodation), natural geographical attractions (beaches and weather conditions), historical, archaeological or architectural attractions, level of utility services, cultural attractions, and more subjective factors like safety and stability of the country. In the Yucatán peninsula tourists can be divided into two types: the beach and resort tourists and the tourists who especially come for the archaeological and cultural heritage. The first type is often referred to as large-scale and highly-developed mass tourism; the second type as ecotourism. Ecotourism can be defined in several ways. Lindberg (1991) says that ecotourism has natural attractions and (archaeological) sites that have a certain degree of solitude and that are different from mass tourism (as referred to in Nilsson, 1996; Cater and Lowman (1994) mention that ecotourism is the alternative of mass tourism.

The effects of tourism on the (local) population can either be positive or negative (based on Long, 1991). Positive economic impacts are the possibility of a higher standard of living (Hudman, 1978; Leathers and Misiolek, 1986; Crandall, 1987); more job opportunities which may keep the local population from migrating to other areas or countries (Pizam and Milman, 1986; Smith, 1988); women may have more chances of finding work (de Kadt, 1979; Samy, 1980; Dogan, 1989); tourism may diversify the economy (Runyan and Wu, 1979). Socially tourism may have positive impacts. For example, the interest in the local culture of the tourists may stimulate the cultural heritage (MacCannell, 1984; Deitch, 1989; Dogan, 1989) and the local crafts (Crandall, 1987; Greenwood, 1989; Swain, 1989); the interest in culture may stimulate the development of museums and the growth of minority language (e.g., Welsh as an element of cultural tourism) (Hunter and Green, 1995). Negative economic impacts of tourism may be, amongst other things, the replacement of traditional jobs to tourism jobs which can make the local economy dependent on tourism (Mathieson and Wall, 1982; Crandall, 1987; Wilkinson, 1989). This crowding out effect is not an effect of tourism in itself, but of failures of development in general which do not provide diversity in the economy. This principle is the same for tourists as it is for coffee, oil, or cotton (Prieto, 1996, personal communication). Negative social or cultural impacts may be the exposure to another lifestyle (Smith, 1988; Evans, 1994); the mass production of traditional products may reduce their physiological or religious value for the local people (Graburn, 1977; de Kadt, 1979); changes in tradition (e.g., changes in clothing, eating and spending leisure time); changes in values and norms (e.g., increase in criminality); loss of (historical) artifacts by sales people; changes in cultural landscape (e.g., other types of houses) (Hunter and Green, 1995). Negative environmental impacts of tourism are pollution, erosion, use of natural resources (for case studies on the Maldives and Nepal see, Brown *et al*., 1995; for over-fishing see Hale, 1996), and visual impacts such as the building of hotels or car parks (Hunter and Green, 1995). The increase in, for example, pollution may be harmful to the community and may after a period of time drive the tourists away leaving the community with a polluted environment and no tourism income (Mathieson and Wall, 1982). Edwards and Cleverdon (1982) give an extensive overview of the economic and social impacts of (international) tourism on developing countries.

The interactions between tourism, the economy and the environment are studied for various regions and countries. Most of these studies are (historical) descriptions. Ramsamy

(1994) describes the development of tourism and the environmental problems caused by it for the island of Mauritius. The distribution of the earnings of tourism from safari and beach tourism in Kenya are studied by Sinclair (1991). The demand and supply for wildlife viewing are analyzed with different methods in Shah (1995). The problems related to wildlife viewing are congestion, wildlife disturbance and eco-damage. The valuation of a national park and the possibilities of planning a greater park are also studied theoretically. Edwards and Cleverdon (1982) describe and give their forecasts of (international) tourism development. The World Tourism Organisation (1996) makes forecasts for global tourism which are described for six regions in the world.

The interactions between several economic sectors and the environment are studied using a dynamic simulation model for the northern Sporades, which is a group of islands in the Greek archipelago (van den Bergh, 1991). This study shows that tourists visiting certain fragile areas should be controlled to protect the marine system and the species living there. Tourism growth may need to be limited in certain cases.

Van Dijk *et al*. (1991) use an econometric model that has been used to forecast the demand and supply of tourism in the Netherlands. Besides the forecasting of demand and supply several scenarios are analyzed based on the model with estimated equations and assumptions.

Ong and McAleer (1995) have made an analysis of models used to study tourism empirically. One of their main conclusions is that the data used for estimation and regression is often not appropriate, because of lack of data, very small sample sizes and many omitted variables. They argue that tourism is mainly based on the expectations of potential tourists and that expectation models should therefore be used.

The factors influencing tourism on Curaçao (part of the Dutch Antilles in the Caribbean) was studied by a questionnaire (De Freytas and Arts, 1989). The primary and secondary holiday aspects were analyzed. Among the primary ones are beaches, hotel location and price, and the tropical environment; among the secondary aspects are several historical and cultural assets. It was concluded that the chances of choosing Curaçao as a holiday destiny could be increased by giving attention to making new beach facilities, cleaning the island, improving the quality of the hotels and restaurants, and giving more attention to the specific cultural and architectural heritage.

A dynamic model is used to simulate the economy and especially tourism, the environment, and the population and their interactions. Several future scenarios will be analyzed to obtain insight in the dynamic relationships between the various parts of society. It is important to study these interactions instead of making a partial model with only tourism, because of the effect of changes in tourism on other sectors, the population and especially the environment. The goal of this study is to analyze these interactions in Yucatán to see the potential effects of certain policies and how certain development paths can affect tourism and the environment on a regional scale. This analysis may be used for México as a whole or for other regions or countries in which there are problems or opportunities related to economic development (in one sector), the environment or the population. Thus, it is not necessarily to analyze problems, such as emigration in the northern region, but also to look at possibilities to develop economically without damaging the environment and possibly even improving the environment.

Section 2 gives some background information on the Yucatán peninsula and tourism. Section 3 describes the dynamic model in detail after which the results are presented in

Section 4. Section 5 gives the results of the sensitivity analysis done on various aspects concerning the demand and investments in tourism. The conclusions offer several ideas for future research.

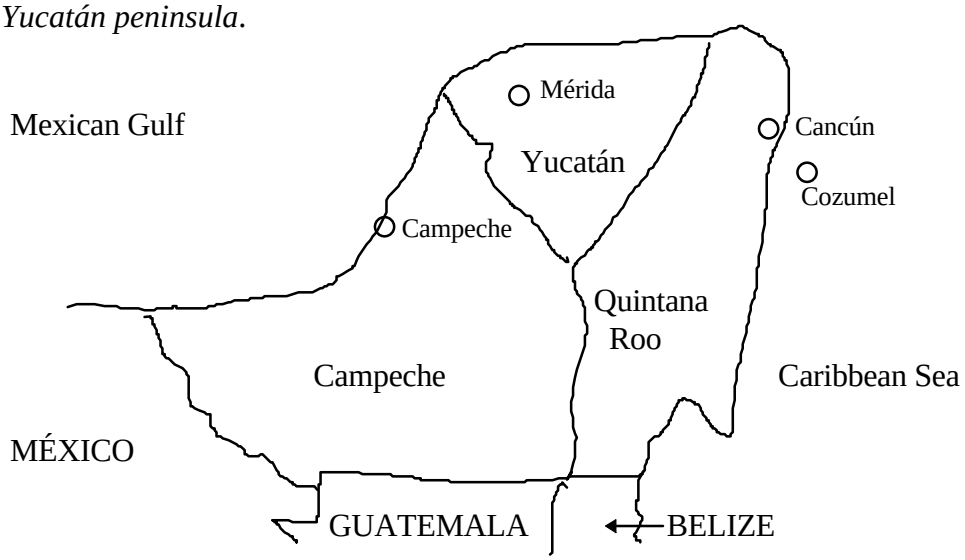
2. Peninsula, Tourism and the Environment

First, a short description of the peninsula is given, after which tourism and the environment of the peninsula will be described.

2.1. The Yucatán peninsula

The Yucatán peninsula is located in the southeast of México. This region was the center of Mayan civilization of which many archaeological sites still remain. The history of the peninsula is different from the rest of México, mainly because of the lack of communication between the peninsula and the mainland. The peninsula is mostly surrounded by the Gulf of México and the Caribbean Sea (Atlantic Ocean); the only land connection is found in the southeastern part. Figure 1 presents the Yucatán peninsula and its three states: Yucatán, Campeche and Quintana Roo. Although these three states form one peninsula they are different administrative regions without common regional policies.

Figure 1. The Yucatán peninsula.



The southeastern part of the peninsula is mainly forest, which makes the accessibility of this area not of great importance. The economy was, until the end of the 1960s, mainly based on agriculture for the local population. Only one crop, sisal, was exported until synthetic fibers came into the market. The population, presented in Table 1, earns a living from tourism, agriculture, construction (for tourism) and fisheries.

Table 1. Population in the three states of the Yucatán peninsula in 1990. Source: INEGI (1992).

	Yucatán	Campeche	Quintana Roo	Total
Population (1990)	1362940	535185	493277	2391402

2.2. Tourism

México has many beach resorts for domestic and, since the late 1940s, for international tourism. International tourism can be divided into three groups: urban (México City, Guadalajara and other cities as well), border tourism in the north, and resort tourism. Urban and border tourism are highly dependent on the domestic economy, while resort tourism is not; it made its growth path differently (Inskeep and Kallenberger, 1992).

In the late 1960s the Mexican government made a plan to stimulate tourism in several resort areas. The direct goal was to develop tourism in rural areas with tourist attractions (beach or historical sites) and where other sources of employment or economic development are scarce. Indirect goals were to stimulate the other sectors in these areas, to stimulate tourism to México, and to generate income in foreign currencies. The long-term program focused on developing five resort areas: Cancún, Ixtapa-Zihuatenejo, Loreto, Huatulco and Los Cabos (Inskeep and Kallenberger, 1992). Long (1991) analyzes the socio-cultural and socio-economic impacts of this development program for the Huatulco area.

Cancún was chosen as a tourist resort because of its geographical features: a strip of land and beach which enclose a large lagoon. In the beginning of the 1970s four main elements were planned and developed: the beach hotels, the international airport, the new urban zone and the conservation areas. A new town was needed for the increasing population of Cancún, which increased from 18,000 in 1976 to 300,000 in 1991. More striking is that in 1970 there were only 117 inhabitants (Inskeep and Kallenberger, 1992). The conservation areas were mainly designed to protect the lagoons.

The expansion of tourism in the peninsula, which was stimulated by local (regional) policy makers to develop the region, has been very fast. Especially Cancún has developed from a small village to a major resort and it still has potential to grow. The economy of the Yucatán peninsula is largely based on tourism. Other economic sectors are fishery, agriculture, local services and construction. Parts of those sectors are related to tourism, for example, the construction of hotels. The number of people occupied in agriculture has decreased rapidly, as in other regions which were stimulated by the government (see, for example, for Santa Cruz in the Huatulco area, Long, 1991). Tourism has increased from 1.3 million tourists in 1970 to 6.3 million in 1989, mostly due to the increase of beach tourism (Inskeep and Kallenberger, 1992). The share of tourism in the gross national product (GNP) was 2.8% in 1989. The number of people employed in tourism was estimated to be 1.3 million in 1989.

The tourism sector has evolved during the last 25 years, and especially over the last ten years the number of tourists has increased rapidly, mainly because of international tourism. Only hurricane Gilbert caused damage and a decline in tourism in 1988. The percentage of international tourists has increased much more than that of national tourists (INEGI, 1994; World Tourism Organisation 1994). Table 2 shows the total number of tourists

and the division amongst the national and international tourists for Cancún over the years 1981 to 1994, with a percentage of the international tourists of the total number of tourists.

Table 2. The total number of tourists (in thousands) in Cancún (Quintana Roo) from 1981 to 1994. Sources: INEGI (1994); World Tourism Organisation (1994).

	Total number of tourists	*International tourists*	*National tourists*
1981	540.8	276.8 (51.2%)	264.0
1982	643.8	336.4 (52.3%)	307.4
1983	754.7	510.2 (67.6%)	244.5
1984	713.9	499.6 (70.0%)	214.3
1985	729.9	503.0 (68.9%)	226.9
1986	869.3	641.9 (73.8%)	227.4
1987	960.6	760.5 (79.2%)	200.1
1988	838.2	657.5 (78.4%)	180.7
1989	1153.6	857.1 (74.3%)	296.5
1990	1575.7	1180.5 (74.9%)	395.2
1991	1912.1	1432.4 (74.9%)	479.7
1992	2046.6	1558.4 (76.1%)	488.2
1993p*	1973.5	1489.0 (75.4%)	484.5
1994p*	1958.1	1445.2 (73.8%)	512.9

* p = preliminary

The increase in the number of tourists has a direct effect on services needed for those tourists, for example, accommodation. Table 3 shows the number of rooms in the three main resorts: Cancún, Cozumel and Mérida.

Table 3. Growth in the tourism sector of the three main resorts. Sources: INEGI (1994); World Tourism Organisation (1994).

	Cancún (Quintana Roo)	*Cozumel (Quintana Roo)*	*Mérida (Yucatán)*
Rooms (1981) (in 000s)	5225	1725	3138
Rooms (1994) (in 000s)	18859	3350	3331
Tourists (1981) (in 000s)	541	174	559
Tourists (1994) (in 000s)	1958	321	138

The development of the Cancún area for tourism has had great impacts on the economy and the society of the Yucatán peninsula. Before, the population of Yucatán mostly lived in rural areas while now most of the people live in urban areas (Aguilar and Rodriguez, 1995). The Cancún project has attracted people from other parts of Yucatán and from the rest of México. This immigration is the main reason for population growth. The infrastructure (the international airport, regional highways, water supply, electric power and telecommunications) has been improved (Inskeep and Kallenberger, 1992).

2.3. The environment

The environment provides resources to the economic system. The marine ecosystem provides fish (shrimp, lobster, red grouper, see Hale, 1996) and the terrestrial ecosystem is used for agriculture. Besides fisheries and agriculture the natural environment supplies 'services' for tourists. For example, the beaches and lagoons, with the opportunity for several types of water sports such as diving, makes the area very attractive for tourists. Tourists not only come to Yucatán for the beaches but also to 'discover' the antique Maya culture of which many historical and archaeological sites remain, e.g., Chichen Itza and Coba, and for the natural attractions, e.g., the Sian Ka'an Biosphere Reserve and the marine reserve with a protected reef ecosystem at Cozumel.

In the early 1980s there was an environmental problem caused by the rapid growth of the area. The demand for the disposal of sewage waste was too high, which caused an algae bloom in a lagoon (Inskeep and Kallenberger, 1992). For environmental reasons a marine transportation system was not implemented through the lagoon. Not many artificial buildings have been constructed. The few that were built were damaged by hurricane Gilbert in 1988. This hurricane also damaged the beaches by erosion, but the natural processes are recovering that.

The lagoons in Cancún are very sensitive ecosystems which need to be protected. Therefore, boating in the lagoons is restricted and because of the algae problems the water is continuously monitored. According to Inskeep and Kallenberger (1992) "it appears likely that the natural beauty and ecological functions of the lagoons will be retained."

3. Modeling the Yucatán Peninsula

The Yucatán peninsula is interesting for the modeling of environment, economy, and population dynamically because of the expected growth of the tourism sector and the impacts of that growth on other economic sectors, the population and the environment.

Tourism has many different aspects of which the most important will be described here. First we will discuss the impact of tourism on employment. If tourism grows, jobs will be created mainly in the three tourist resorts of the peninsula (Cancún, Cozumel and Mérida). This increase in employment may attract people from rural areas and from other areas of México. This internal migration increases the population in addition to its natural growth rate (birth rate minus death rate). Therefore, the increase in tourism has an impact on the number of people in the Yucatán peninsula and the division of those people in the peninsula. The migration from rural to urban (resort) areas can be negative for the rural areas because it can leave the countryside without a sufficient labor force.

National and regional investments in the Yucatán peninsula are divided amongst tourism and other economic sectors. The investments in tourism might harm the country because other economic sectors are not able to grow/develop. This phenomenon is called the

'Dutch disease.' Foreign investments in Yucatán are mainly done in the tourism industry. Therefore, these investments do not harm other sectors. Another point might be that the investments and profits come and go to foreign investors which means that the local people do not benefit from it. Another dangerous issue might be the mono-economic base of Yucatán when it grows too much. The mono-economy makes the region vulnerable to economic, natural and social tragedies which will have a great impact, because there are no other sectors to lean on (Bull, 1991).

Damage to the environment caused by tourists is hard to measure; tourists use water and they might damage coral, etc. Too fast (or too large) growth might mean that the tourists do not like it any more or that the environment will be damaged too much. The effects on the culture are difficult to describe objectively, let alone to quantify. Therefore, the cultural impact is not included in the model. For practical reasons not all these issues will and can be included in the model. The environmental issues in the model are the following: 1) water quality, which depends on the water use by the population and the tourists and the investments in the clean up of the water; 2) the quality of the archaeological sites which may decrease when the number of tourists visiting those sites becomes very high; 3) the quality of the beaches which is related to the water quality and the occupancy rate of the hotels.

The population depends on the birth and death rates and on the internal migration rates. The birth and death rates are exogenous in the model while migration depends on the number of tourists. The economic sector is divided into the tourism sector and the rest of the economy, creating a two-sector model. Two linkages between the peninsula and the outside world will be included: the foreign and national investments in the region, and the tourists.

3.1. Dynamic simulation model

A simulation model is used to model the tourism sector and its interactions with other economic sectors, the population and the environment. Sanderson (1994) describes various simulation models dealing with population, environment and economy. The dynamic simulation model is used to see how developments and policies may affect the Yucatán peninsula. A dynamic model is applied to get insight into future development paths, policies and their effects on population, tourism and environment. The model does not predict future developments; it only provides possible scenarios which may be used for policy making. A dynamic simulation model tries to simulate the real situation or the real world to analyze the dynamic relations between the variables in the model. Simulation models can serve to make controlled experiments to see how the system will evolve (see Casti, 1996). By making the simulation more similar to real life and with the inclusion of different (related) decision makers the model might become a prediction tool (Casti, 1996).

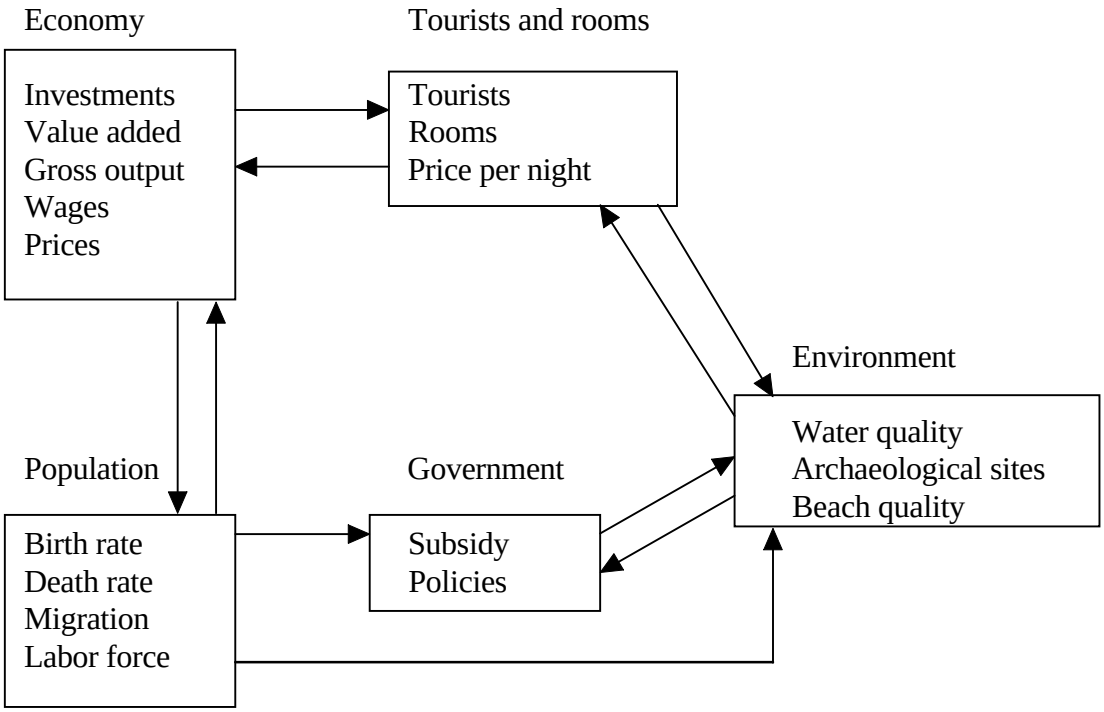
For the modeling Stella II[1] is used which consists of stocks and flows. The stocks are increased by inflows and decreased by outflows over time. For example, the population increases by births and decreases by deaths while the rest of the population remains in the 'stock.' The other variables are flow variables which depend on other flow or stock variables, or those variables are exogenous. These relationships are either based on historical data or on reasonable assumptions.

[1] Stella II is a software package for developing dynamic models and performing dynamic simulation (Peterson and Richmond, 1994). Hannon and Ruth (1994) provide a good introduction to dynamic modeling using Stella II.

The model has as a base year 1994, a time horizon of 20 years, and is run every year. The estimations of the initial conditions and the relationships between variables is based on data from the World Tourism Organisation (1994), CONAPO (1995), OECD (1995), INEGI (1992; 1994), World Bank (1994), Cinvestav (1996), and Gelting (1995).

The model encompasses six modules: the economy, the tourists, the population, the environment and the government. Figure 2 shows those modules with their interactions and main variables.

Figure 2. The general model structure.



The economy module consists of two sectors, the tourism sector and the rest of the economy, for which the price, the value added and the investments are modeled. The tourism sector consists of the number of rooms available and the demand for those rooms by the tourists. The variables for the population module are the number of people which are determined by the birth, death and migration rates, and the labor force which is a part of the total population. The environmental module consists of water use, water quality, archaeological sites and the quality of the beaches. The last sector, government, consists of policies to clean up the water which is polluted by the tourists or the population. The costs of cleaning up the water used by the population is paid by the government and can therefore be seen as a subsidy. Figure 2 presents the model structure with the interactions between the six modules and their main variables. The modules and their interactions will now be described in detail. The equations of the model are given and explained the Appendix.

3.2. Economy

The economy is divided into the tourism sector and a sector which includes the rest of the economy, say Sector 2. For Yucatán the other important sectors are fisheries (see Hale, 1996) and agriculture.

3.2.1. Tourism

The tourism sector, the main driving force of economic development in the peninsula, is described for the whole Yucatán peninsula. The gross output is the price times the number of tourists nights demanded. The price is the equilibrium price between the demand and the supply of tourist nights. The capital stock of the tourism sector is the number of rooms. The investments in rooms are regional (depending on the profit per room and the exogenous and constant national profit rate), national (depending on the GDP of México, the national profit rate and the growth in profitability of the tourism sector), and international (depending on the exogenous and constant international profit rate). At the regional and national level the total investments in the economy are divided amongst tourism and the other sectors while it is assumed that all international investments in Yucatán are made only in the tourism sector. The regional investments are determined by parts of the profits and the wages in both sectors. It is assumed that all regional investments are made in Yucatán. Thus, there is no export of capital from Yucatán. The regional investments are divided amongst the tourism sector and depend on the growth in profit per room and the national investment rate. When the profit per room increases (grows), more goes to tourism. The supply of tourist rooms depends on the price paid per room limited by the availability of rooms.

The gross output is divided amongst intermediate consumption, the labor costs (wages), the costs of cleaning the water polluted by tourists, and the profits. The intermediate consumption is a fixed part of the gross output. The profit, i.e., the capital income, depends on the occupancy rate of the rooms. The cleaning costs depend on the number of tourists. The remainder of the gross output is dedicated to labor costs. The labor needed in tourism depends on the number of tourist nights. Therefore, the wage per person is a function of the (endogenous) part of the gross output dedicated to wages and the number of people employed in the tourism sector. The profit per room and the national and international profit rates determine the amount of national and international investments.

3.2.2. The other economic sectors

The other economic sector, Sector 2 in the model, consists of the whole economy except the tourism sector. The (aggregated) price of this sector depends on the growth of the wages in this sector. The wage depends on the number of people working in this sector and the part of the gross output which goes to labor. The output depends on the labor force and on the capital in this sector (a standard Cobb-Douglas production function is used). Capital depends on investments (for details see tourism sector) and the (exogenous and fixed) depreciation rate. The profits are the gross output minus the wages and intermediate consumption. A part of the profits are re-invested in the region.

3.3. Tourists and rooms

This module consists of the number of rooms, the number of tourists, the number of days the tourists stay, and the price per night. The number of rooms depends on the investments in the tourism sector and the depreciation rate of the existing rooms. The rooms are the capital stock

of the tourism sector. The demand for tourist nights depends on the water quality, the quality of the beaches and the archaeological sites in past periods and on an exogenous factor which is the sum of all other factors, e.g., the attractiveness of other tourist areas or the safety of the region. The congestion at the beaches can be seen as a quality dependent upon the hotel occupancy rate rather than on the number of tourists. If more hotels are built, more kilometers of beaches will be available. This is the case in the Yucatán peninsula, where there are still new beach areas to develop (Inskeep and Kallenberger, 1992). In the longer term the availability of new beaches to develop will be limited. The quality of the archaeological sites depends on the number of people that visit these places. The demand for tourist nights depends on the congestion of the beaches and the sites in past years, because decisions are made on information of the near past. The price means that the demand for tourist nights equals the supply of rooms (tourist nights) which is constrained by the number of rooms. The number of rooms available depends on the price. If the price is very low, some hotels will close (some of) their rooms. If the price per tourist night approximates 0 then there will be no supply of rooms; if the price per night is very high then all rooms will be used.

3.4. Population

3.4.1. Population

The natural growth rate of the population depends on the birth and death rates (natality and mortality) which are exogenous to the model. Migration in Yucatán from other parts of México depends on an exogenous migration rate and the difference in the wage in the tourism sector and the general wage in México in the previous year. The underlying assumption is that potential migrants decide on the existing wage rate difference and will enter the peninsula one year later.

3.4.2. Labor

The population variable does not include age structure and therefore the labor force is assumed to be a fixed part of the whole population. The number of people needed to work in the tourism sector depends on the number of nights demanded. The other part of the labor force is assumed to work in the other sector, which will drive down the wages and decrease potential immigration. This means that all people who work in the other economic sectors, e.g., fisheries, agriculture, construction, and semi-formal sectors, are the remainder of the total labor force. The unemployment rate is not dealt with explicitly. It is officially around 6% (INEGI, 1994) but in reality probably much higher, because unemployed people are working in the semi-formal sector.

3.5. Environment

The environment module consists of the use of water, the quality of the water, the beaches and the archaeological sites. The environmental impact (water, beach and sites quality) means that tourism cannot grow unlimited. The environment is defined as the whole living environment, thus broader than ‘nature.’ This is done to include the quality of the beaches and the archaeological sites.

3.5.1. Water

The water quality depends on the amount of water used by the population and the tourists, the natural clean-up rate, and the effort and effectiveness of the government to clean the water. The natural clean-up rate depends on the quality of the water. The natural clean up increases to a certain point when the water quality decreases. If the water quality is 100 or 0 then there will be no natural clean up. The policy variables in the model are the cleaning up of tourist or population pollution. The interactions between the number of tourists and the population with the water are reciprocal. The population and the tourists affect the water quality by using water, and the water quality affects the number of tourists coming in, thereby affecting the migration rate and thus the population. The effects of water use per day between the population and the tourists is differentiated for a geographical and a recreational reason. The geographical reason is that tourists mostly stay at the coast, say in a strip of 25 kilometers from the coast, where the use of water has more impact. The recreational reason is that the average use of water by tourists is higher than by the population, for example, because of swimming pools at the hotels. A decrease in the water quality has a negative effect on the demand for tourist nights.

3.5.2. Archaeological sites

The quality of the archaeological sites depends on the number of tourists. This definition of quality of sites can be interpreted as the opposite of congestion. If the number of tourists at archaeological sites is very high, these sites become less attractive for two reasons. First, tourists who go to archaeological sites want relative solitude (see Lindberg, 1991). Second, the tourists might damage or pollute the sites. For the demand for tourist nights the congestion or the quality of a few years ago is important. The effect of a decrease in the quality has a delayed effect on the demand by tourists.

3.5.3. Beaches

The tourist nights depend also on the quality of the beaches, which depends on the occupancy rate of the rooms. It is assumed that tourists like to have other people around at the beach, but not too many (see Casti, 1996, for the same phenomenon but then for visits to a bar). Therefore, the number of tourists in the last period may have a positive or negative impact on the beach quality depending on the number of tourists. If the beaches are crowded or empty the demand for tourism will be less than if the beaches are nicely filled.

3.6. Government and policies

The government can impose policies to clean up the water pollution caused by the population and the tourists. The quality of the water is assumed to decrease with the use of water and increase with the natural or policy clean up. The costs of cleaning up for tourists are paid by the tourism sector. These costs are subtracted from the profits in this sector. There is an interesting interaction between the environment, cleaning up and the number of tourists. The cleaning of the water has a positive impact on the tourist demand and therefore on the price per tourist night. The gross output and the profits of the tourism sector will increase. This increase in profit may outweigh the costs of cleaning the water.

The costs of cleaning the pollution caused by the population is paid by the regional or national government. These costs can be seen as a subsidy for the population of the region,

because they (and their economy) profit from a higher water quality. The government can choose a certain percentage of cleaning up. Of course, the less the government cleans the less it costs and the less increase in the water quality.

The government can choose to clean all the water polluted by tourists but this policy may not be very effective. For example, the policy is to clean 100%, but the effective clean up is only 50%. This means that the effectiveness of the policy is only half of the expected. Here it is assumed that the policy is totally effective.

4. Scenarios and Results

Six scenarios are used to simulate the future developments of the Yucatán peninsula. First, a base scenario is made in which no policies are used and in which the development path is not changed. In the second scenario, the government imposes policies to clean up the water of the tourists. The third is a scenario in which the pollution of the population is cleaned up. The fourth is a mixture of the second and third scenarios in which the pollution of both the tourists and the population is cleaned. In the fifth scenario, Yucatán becomes less attractive due to external factors (e.g., other resorts become more fashionable). The sixth scenario involves imposing a policy to make all investments go to tourism.

Various indicators for each module give an overview of the results of the various scenarios:

1. Environmental indicators: water, sites and beach quality
2. Social indicators: population, labor force, migration rate, wages
3. Economic indicators: gross output, price, investment, profit per room
4. Tourism indicators: tourist nights, rooms, occupancy rate
5. Governmental indicators: policy percentages, subsidy

4.1. Base scenario

In the base scenario the number of tourists increases until 2005, after which it decreases until 2009 (see Figure 3). After that there is a second increase and decrease with its lowest point in 2018. This cyclical pattern is caused by three demand factors, the water, beach and sites quality, and the supply factor which is the supply of rooms. The water quality decreases over time due to the water use of the population and the tourists. In this scenario no clean-up policies are imposed. The quality of the beaches and archaeological sites depends on the tourists and the occupancy rate in previous periods. The supply of rooms is a function of the depreciation rate of rooms, which is constant at 5%, and the investments in tourism. The number of rooms increase over time until 2019 after which the investments are lower than the depreciation rate. The national and international investments depend on the profit per room and the (inter)national profit rates. If the (inter)national profit rate is higher than the profit per room, then the investors will not invest in Yucatán, but somewhere else. In the base scenario this will be the case in the years 2019 to 2023. The total regional investments depend on the wages and the profits in both sectors. The allocation of these regional investments to the two sectors depends on the change in profit per room. If the profit per room increases then more investments will go to the tourism sector, otherwise they will go to the rest of the economy. In some years (1994-2000, 2005-2006, 2008 and 2014-2016) it is more attractive to invest in tourism than in the rest of the economy due to the increasing profit per room.

Figure 3. The number of tourists in the base scenario.

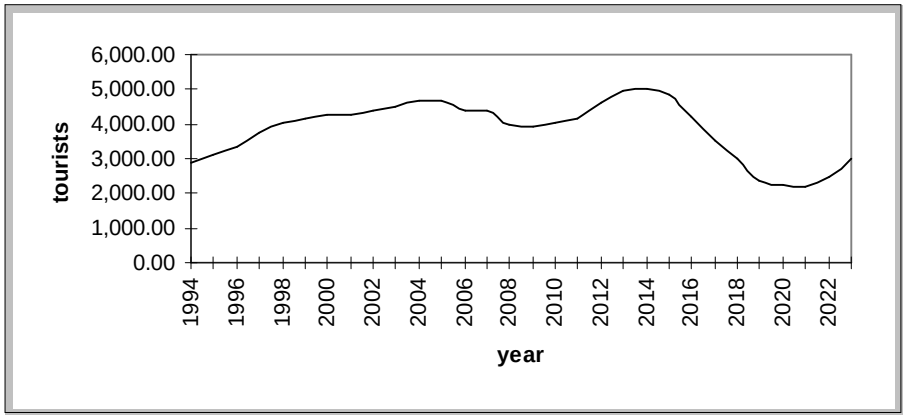
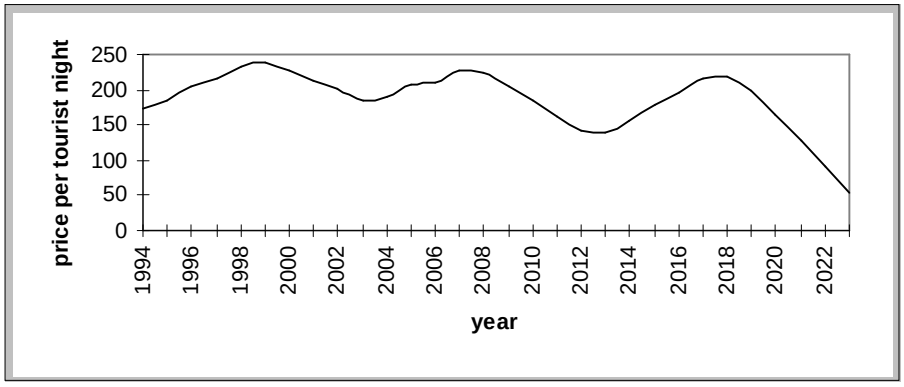


Figure 4 shows the price per tourist night which is the equilibrium price of the demand and supply of rooms. The price shows a cyclical pattern which is more pronounced than the pattern of the number of tourists. The gross output in the tourism sector is the price times the supply of rooms. The wage rate and the profits show a cyclical pattern as they are dependent on the demand for tourist nights and the price per night. In the years where the wages in the tourism sector in Yucatán are higher than in México, the immigration from other parts of México is higher than when the wages are lower than in the rest of México. It might even be possible that the migration rate becomes negative if the economy in Yucatán is in a deep recession.

Figure 4. The price per tourist night in the base scenario.



The output in Sector 2 depends on the labor force and the capital stock. As said before the capital stock increases slightly, while the labor force in Sector 2 increases strongly. Therefore, the output in physical terms increases too. The gross output, which is measured in monetary units, also increases over time, although the price paid for the output is slightly decreasing (see Table 5). The wages in Sector 2 decrease which means that the increase in the gross output in Sector 2 is outweighed by the increase in the labor force in Sector 2. The profit in Sector 2 increases due to the increasing gross output.

Table 4 shows that the water quality decreases over time. This is caused by water pollution due to the water use by the tourists and the population. Because the government does not impose any policies to improve the water quality, there is only a natural cleaning. The quality of the archaeological sites is directly related to the number of tourists visiting the archaeological sites. This is assumed to be a fixed percentage of the total number of tourists. Therefore, the sites quality also shows a cyclical pattern. The beach quality (or the beach congestion) is a function of the occupancy rate of the rooms. This can also be interpreted as the number of people on a strip of beach, considering that new rooms, i.e., new hotels, are built on a newly-developed strip of beach.

Table 4. The number of tourists, the price per room, the number of rooms, the profit per room, the water quality and the population in the base scenario.

Years	*Tourists*	*Price 1*	*Rooms*	*Profit per room*	*Water quality*	*Population*
1994	2,876.00	174.55	9,486.98	224.16	98.13	2,534.25
1995	3,092.14	186.05	9,408.41	263.80	96.33	2,682.46
2000	4,248.91	227.55	10,230.08	430.03	87.82	3,504.86
2005	4,686.09	207.05	10,818.49	410.40	79.24	4,446.27
2010	4,038.69	183.55	11,854.37	294.15	69.78	5,476.89
2015	4,821.65	178.05	12,511.64	310.06	58.43	6,583.85
2020	2,268.88	163.55	12,774.62	82.73	44.28	7,751.14
2023	2,976.38	53.05	11,198.82	58.27	33.7	8,462.90

Table 5. The labor force, the investments and the gross output of the two sectors in the base scenario.

Years	*Lab1*	*Lab2*	*Inv1*	*Inv2*	*Gross output1*	*Gross output2*
1994	143.8	1,630.17	3,957.83	4,629.63	5,622.46	38,160.38
1995	154.61	1,723.12	5,345.78	3,880.39	6,443.28	39,177.70
2000	212.45	2,240.96	7,419.63	4,851.85	10,828.60	43,705.22
2005	234.3	2,878.09	8,278.75	5,633.05	10,866.87	52,813.33
2010	201.93	3,631.89	6,704.31	7,697.16	8,302.57	62,133.92
2015	241.08	4,367.61	9,599.80	7,134.20	9,615.13	72,562.05
2020	113.44	5,312.35	859.67	7,737.00	4,156.05	83,654.10
2023	148.82	5,775.21	869.98	7,829.85	1,768.45	88,027.16

The natural increase in population is the ratio between the exogenous birth and death rates. The migration rate depends on an exogenous factor, called the base migration rate, and on an endogenous factor which depends on the difference between the wage rate in México and the wage rate for tourism in Yucatán. Migrants will come to work in the tourism sector, although not all of them will be employed there, so they will work in other economic sectors. The population will increase as can be seen in Table 4 due to migration and natural population growth.

The conclusion that can be drawn from this scenario is that although there is a potential for tourism growth because of the popularity of Yucatán, this potential is not optimally used. The main reasons are the decrease in the quality of the water and the increased number of rooms. The latter, the supply-side factor, means that the supply of rooms

is higher at a certain price. The region could do economically better if the water quality were higher and the investments in tourism were less. The number of tourists have a positive impact on national and international investments. This base scenario shows that in the case of a recession in the tourism industry, the increase in the sites and beach quality can mean that tourism will increase again.

4.2. Cleaning of water used by the population

In this second scenario, water pollution caused by the population is cleaned up. Therefore the overall quality of water decreases only because of the pollution due to water use by tourists. The government imposes a policy that 100% of the water used by the population has to be cleaned up. This percentage can be varied according to the need for cleaning or the availability of government funds. The government pays for this policy.

Because of the natural and the clean up imposed by the government, the total water quality is always higher than in the base scenario. The number of tourists shows a strongly fluctuating pattern but it is not a cyclical one as in the base scenario (see Figure 5). In this scenario the number of tourists is higher as could be expected from a higher water quality, except in 2007. The explanation for this low number of tourists is that in the first years after imposing the cleaning policy the tourists arriving increases, which has a negative effect on the beach and sites quality. Therefore, in 2007 there are fewer tourists than in the base scenario. The reduction in the quality of sites and beach have a delayed effect on the number of tourists but the effect of a higher quality is bigger. The higher number of tourists means that the sites quality decreases and the quality of the beaches might decrease too, depending on the number of rooms.

Figure 5. The number of tourists, Scenario 2 (solid line) compared with Scenario 1 (broken line).

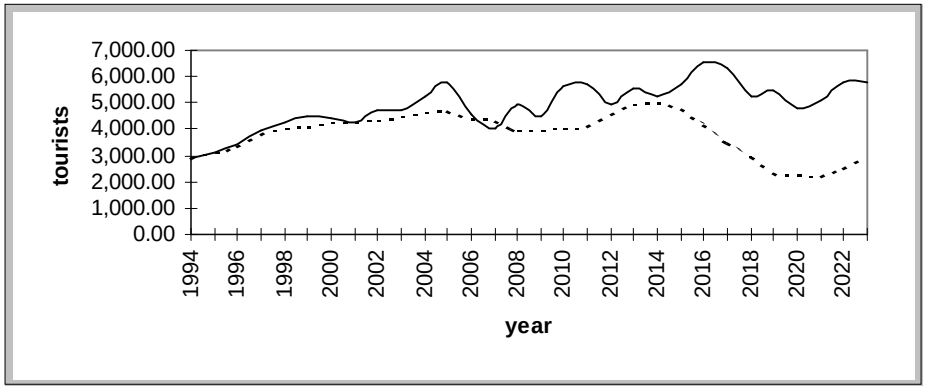
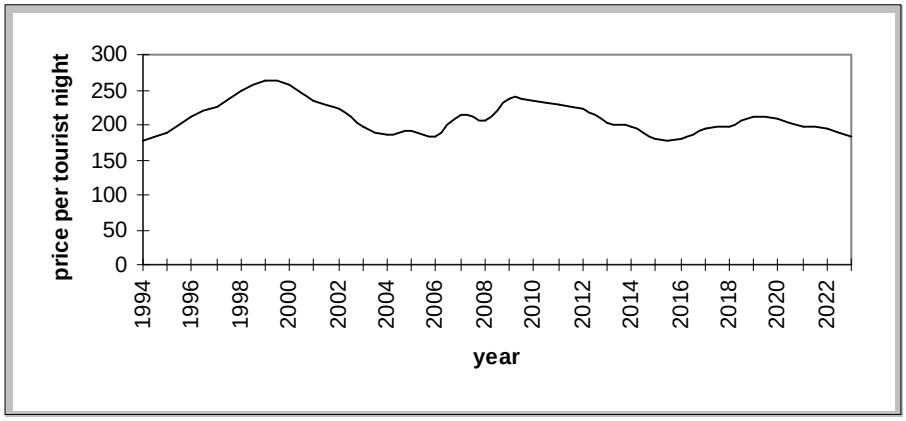


Figure 6 shows that the price per night fluctuates cyclically as in the base scenario, but here the cycle is a bit longer and in most years the price in the second scenario is higher than in the base scenario. The profit per room is the gross output minus the labor costs, the intermediate consumption and the costs of cleaning the water used by the tourists. The profit per room follows a cyclical pattern as in the base scenario but also in the second scenario the profit per room is higher, especially after 2015 when the profit per room becomes very low in

the base scenario due to the very low water quality. In this clean-up scenario the water quality is much higher (compare Table 6 with Table 4). The total national and international investments are positive during the whole period because the profit per room is always higher than the (inter)national investment rate. Consequently, the number of rooms increases faster than in the base scenario. In 2023 the number of rooms in the base scenario is 11,000 and in the second scenario there are almost 15,500 rooms.

Figure 6. The price per tourist night (Scenario 2).



The wages and the labor force needed in the tourism sector follow the same cyclical pattern as the demand for tourism. The labor force in tourism is slightly higher in the policy scenario because the overall number of tourists is higher. In the rest of the economy gross output and the prices are a bit higher than in the base scenario, because the labor force and the capital stock are mostly the same. The wages in Sector 2 are also roughly the same.

The water quality does not decrease very much in 30 years, mainly due to the clean up of the water used by the population, but also because of the natural clean up. Table 6 shows that the quality of water only decreases by 3 points while in the base scenario the quality of water decreased by more than 65 points in 30 years. The natural clean up can almost eliminate the pollution caused by tourists.

Table 6. The number of tourists, the price per room, the number of rooms, the profit per room, the water quality and the population (Scenario 2).

Years	*Tourists*	*P1*	*Rooms*	*Profit per room*	*Water quality*	*Population*
1994	2,876.00	176.05	9,486.98	226.09	99.87	2,534.25
1995	3,129.62	187.55	9,409.75	270.14	99.76	2,682.46
2000	4,376.72	258.55	10,388.38	496.33	99.13	3,505.47
2005	5,768.20	192.05	11,228.48	468.97	98.62	4,449.64
2010	5,605.27	234.05	12,258.15	496.48	98.31	5,478.05
2015	5,730.99	179.55	13,645.85	343.48	98	6,592.84
2020	4,816.43	208.55	14,867.52	290.15	97.73	7,757.47
2023	5,815.51	184.05	15,498.51	311.34	97.7	8,468.02

The government imposes the policy of cleaning the water used by the population and they also have to pay for it. The overall effect of cleaning up is positive for the profits in the tourist sector, because of the increase in the demand for tourist nights resulting from a higher water quality. More demand will give a higher price, which has a positive effect on the profit per room in that year. The higher price will give higher profits which stimulates the investments in tourism. In the long term there will be more rooms which means that the price and the profit per room may decrease. The profit per room is even more vulnerable due to the higher number of rooms and a lower price and profit.

This scenario shows that cleaning the water polluted by the population has the expected effect of a direct increase in the number of tourists. The delayed effects of the quality of the beaches and sites means that the number of tourists are not increasing constantly over time. The positive effect on tourists of cleaning the water has positive indirect effects on the prices, the profit per rooms, the gross output and the wages. Not only the tourism sector gains from the government policy but it is also beneficial to the rest of the economy. Compare for example the gross output in Sector 2 in this scenario with the base scenario (compare Table 7 with Table 5).

Table 7. The labor force, the investments and the gross output of the two sectors (Scenario 2).

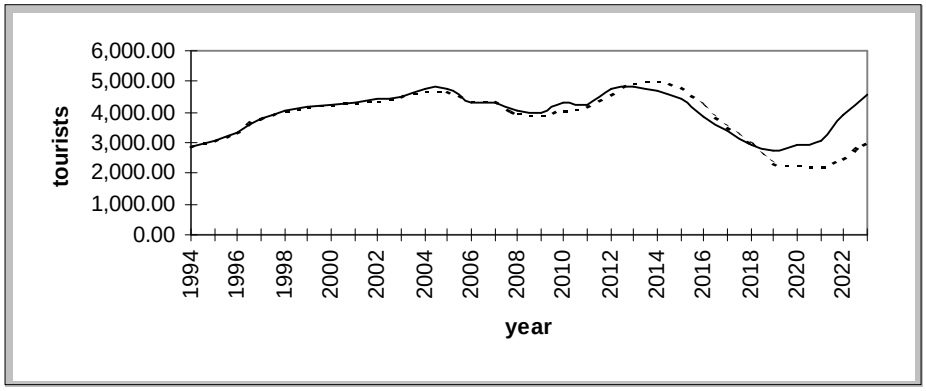
Years	*Lab1*	*Lab2*	*Inv1*	*Inv2*	*Gross output1*	*Gross output2*
1994	143.8	1,630.17	3,971.20	4,635.24	5,670.78	38,160.38
1995	156.48	1,721.24	5,393.45	3,891.05	6,573.95	39,158.71
2000	218.84	2,234.99	7,982.91	5,006.38	12,673.94	43,828.24
2005	288.41	2,826.34	8,757.67	5,757.08	12,407.18	52,171.63
2010	280.26	3,554.37	10,108.44	6,708.89	14,693.44	61,414.66
2015	286.55	4,328.44	8,140.39	9,107.65	11,524.78	72,055.17
2020	240.82	5,189.41	10,761.41	8,118.00	11,250.04	84,413.43
2023	290.78	5,636.84	11,657.41	8,730.47	11,987.87	91,520.46

4.3. Cleaning of water used by tourists

In this scenario the government chooses to clean 100% of the water pollution caused by tourists. The costs of this governmental policy will be paid by the hotel owners. The payments for the clean up reduce the profits of the tourism sector. Other percentages can be chosen depending on, for example, the level of quality, the priorities of the government and the political strength of the hotel owners.

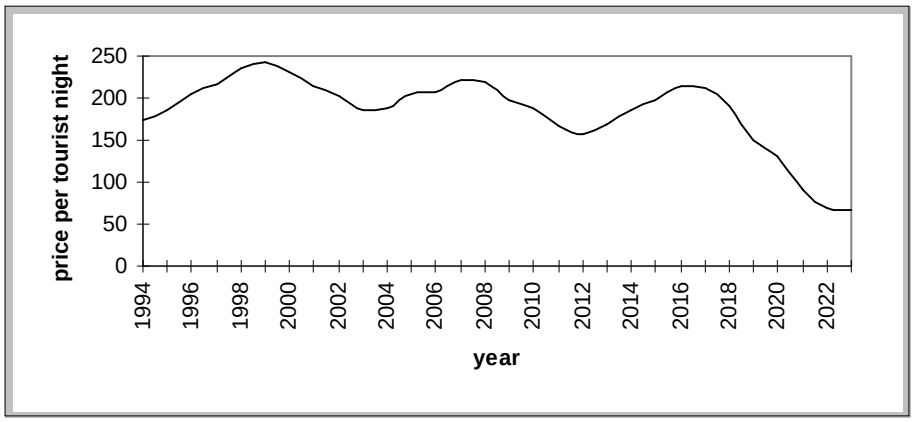
Figure 7 shows the number of tourists in this scenario and the base scenario. The pattern of both scenarios is very similar; only after 2012 the patterns are different. In Scenario 3 the decrease in the number of tourists is earlier, but the lowest point is higher compared with the base scenario. Although the water use per day is much higher per tourist than per person of the local population, the impact of the policy is not very high because on a yearly basis the water used by tourists is much lower than the water used by the population.

Figure 7. The number of tourists, Scenario 3 (solid line) and the base scenario (broken line).



The price per tourist night is shown in Figure 8 and is very similar to the price in the base scenario. The price in this scenario is sometimes lower and sometimes higher than in the base scenario, but there are only small differences. The profit per room is higher than in the base scenario until 2012, because then the profit decreases rapidly in the third scenario due to a lower price per tourist night. The profit per room is lower than in the (inter)national investments rate from 2018 to 2023 which means that during those years there is a reduction in the number of rooms because the depreciation is higher than the regional investments in tourism.

Figure 8. The price per tourist night (Scenario 3).



The population increase after 30 years is slightly lower than in the base scenario (compare Table 8 with Table 4). This is a result of the difference in wages rates between the tourism sector in Yucatán and the rest of México. In this scenario the wages are higher in the tourism sector in 1994-2010 and in 2015-2019 while in the base scenario the wages are also higher in 2020 and 2021. In the base scenario the wages are higher than in Scenario 3 in 2004-2008 and from 2016 to 2020. In the other years the wages in tourism are higher in the base scenario. Thus, cleaning the water does not have a direct positive effect on the wages in the tourism sector, although in most years there are more tourists. This is mainly due to the

lower price per tourist night in some years which makes the gross output and the wages lower. The labor force needed in Sector 1 depends directly on the number of tourists, so the cyclical pattern of tourism demand is also found in the labor force in the tourism sector. For Sector 2 the results are generally the same as in the base scenario (compare Table 9 with Table 5). The gross output and the labor force in Sector 2 are a bit lower than in the base scenario.

Table 8. The number of tourists, the price per tourist night, the number of rooms, the profit per room , the water quality and the population (Scenario 3).

Years	*Tourists*	*P1*	*Rooms*	*Profit per room*	*Water quality*	*Population*
1994	2,876.00	174.55	9,485.16	221.4	98.25	2,534.25
1995	3,096.24	186.05	9,404.87	261.34	96.58	2,682.46
2000	4,270.37	231.05	10,229.05	435.24	88.69	3,504.91
2005	4,790.96	204.55	10,825.08	412.39	80.71	4,446.58
2010	4,286.72	188.55	11,824.88	301.2	71.76	5,476.55
2015	4,444.42	197.05	12,853.77	295.61	61.07	6,583.17
2020	2,902.78	130.05	12,216.66	120.97	47.6	7,751.95
2023	4,576.85	67.05	10,720.22	126.64	37.49	8,455.85

Table 9. The labor force, the investments and the gross output in both sectors (Scenario 3).

Years	*Lab1*	*Lab2*	*Inv1*	*Inv2*	*Gross output1*	*Gross output2*
1994	143.8	1,630.17	3,939.67	4,623.09	5,622.46	38,157.81
1995	154.81	1,722.91	5,327.41	3,876.34	6,451.82	39,170.30
2000	213.52	2,239.92	7,462.86	4,863.31	11,050.69	43,694.63
2005	239.55	2,873.06	8,293.83	5,636.47	10,975.89	52,781.45
2010	214.34	3,619.25	6,900.93	7,780.05	9,052.52	61,968.13
2015	222.22	4,385.99	9,450.69	7,082.96	9,808.65	71,345.68
2020	145.14	5,281.22	861.18	7,750.65	4,228.08	82,452.01
2023	228.84	5,690.25	890.88	8,017.96	3,437.03	86,640.34

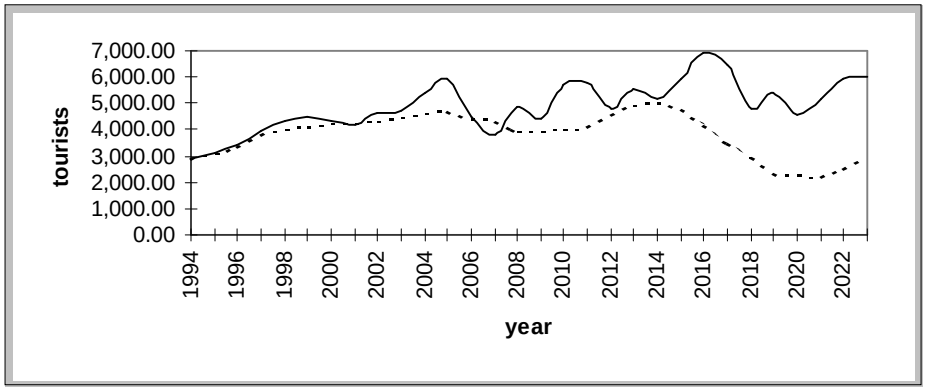
4.4. A total clean up of the water

It will not be easy to clean up the water used by the population and leave the water polluted by the tourists. Therefore, in this scenario both the water which is used by the tourists and the population is cleaned. Table 10 shows that with this policy the water quality will remain at the 1994 level. Figure 9 shows the number of tourists in this scenario and the base scenario. The patterns are the same as in Scenario 2 where only the water used by the population is cleaned. This is due to the low impact of water use by tourists. Generally the number of tourists is higher than in the other scenarios. Compared with the base scenario the number of tourists is only lower in 2007. Compared with Scenario 2 the number of tourists is lower in 2000-2002 which is a result of the higher number of tourists in the years 1995-1999.

Table 10. The number of tourists , the price per tourist night, the number of rooms, the profit per room, the water quality and the population (Scenario 4).

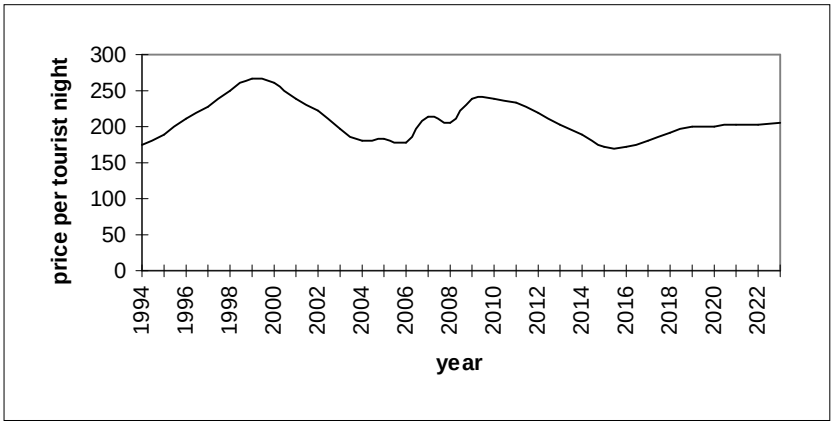
Years	*Tourists*	*P1*	*Rooms*	*Profit per room*	*Water quality*	*Population*
1994	2,876.00	176.05	9,485.16	223.33	100	2,534.25
1995	3,138.19	187.55	9,406.21	268.16	100	2,682.46
2000	4,348.42	261.55	10,387.87	494.67	100	3,505.49
2005	5,941.87	183.55	11,217.94	459.67	100	4,449.90
2010	5,684.32	239.05	12,206.33	514.55	100	5,477.88
2015	5,931.43	171.55	13,596.18	339.03	100	6,593.20
2020	4,578.23	199.55	14,728.58	261.13	100	7,756.36
2023	5,976.81	205.55	15,603.87	352.04	100	8,466.06

Figure 9. The number of tourists, Scenario 4 (solid line) compared to Scenario 1 (broken line).



The price per room is generally higher than in the base scenario (see Figure 10). The fluctuation of the price per room is similar to Scenario 2. Whether the price paid in Scenario 4 is higher or lower than in Scenario 2 depends on the number of tourists and the beach and sites quality. The profit per room shows the same pattern as the price paid and also the profit per room in this total clean-up scenario is similar to Scenario 2. The profit per room is the result of several dynamically interrelated effects. The price per night and the number of rooms determine the profit per room. The total profit and the profit per room together with the wages determine the investments. These investments are partly going to tourism, that is investments in the number of rooms, and partly to the rest of the economy. The investments in tourism increase the number of rooms which has a negative effect on the price per night because more rooms will be supplied at a lower price and also the profit per room will be less due to the increased number of rooms. Profit per room is not only related to the total profit but also to the number of rooms. The profit per room is never lower than the (inter)national profit rate which means that the (inter)national investments are never zero in the whole period. This means that the total capital stock (rooms) is higher than in all other scenarios.

Figure 10. The price per tourist night (Scenario 4).



The wages in the tourism sector follow the same pattern as gross output, which is cyclical. The wages in tourism are always higher than the wage rate in México which stimulates migration into Yucatán. This migration together with the natural population growth is higher over the 30 years than in the other scenarios (compare Table 10 with Tables 4, 6 and 8). The wages in the rest of the economy, Sector 2, decrease over time, but less than in all other scenarios. This lower decrease is caused by the higher gross output in Sector 2 (compare Table 11 with Table 5).

Table 11. The labor force, the investments and the gross output in both sectors (Scenario 4).

Years	*Lab1*	*Lab2*	*Inv1*	*Inv2*	*Gross output1*	*Gross output2*
1994	143.8	1,630.17	3,953.05	4,628.70	5,670.78	38,157.81
1995	156.91	1,720.81	5,378.58	3,887.73	6,591.95	39,148.77
2000	217.42	2,236.42	7,972.95	5,005.26	12,738.10	43,842.08
2005	297.09	2,817.84	8,673.41	5,731.93	12,215.05	52,074.88
2010	284.22	3,550.30	10,248.94	6,742.32	15,218.96	61,292.04
2015	296.57	4,318.67	8,095.68	9,074.01	11,396.40	71,876.17
2020	228.91	5,200.54	10,477.85	8,025.68	10,232.17	84,362.63
2023	298.84	5,627.40	11,984.57	8,812.94	13,759.57	90,148.24

For the water quality this is obviously the best, because all the water that is used will be cleaned. The natural clean-up rate is not used, because a natural clean up will only occur when the water is polluted. For both sectors this policy is better than no policy, but compared to the policy where only the water use of the population is cleaned, it does not make much difference. Sometimes Scenario 4 is better and sometimes Scenario 2, mostly depending on delayed effects of beach and sites quality. The overall clean up is good for the investments, because the investments over the whole time span are higher. The total number of tourists in 30 years is also higher than in Scenario 3, but for specific years the number of tourists may be less.

An interesting conclusion of this scenario is that the profits per room have increased although the hotel owners have to pay for the cleaning of the water used by tourists. For hotel owners it is not attractive to pay a tax or charge per tourist (for their use of water), but

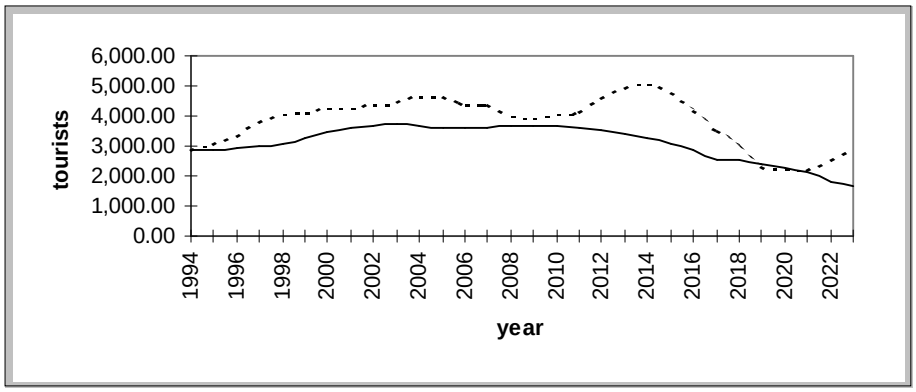
because this policy, together with the policy paid by the government to clean the water used by the population, is beneficial for their profit per room they might be interested in cooperation for cleaning the water.

4.5. Scenario with a low development path

In this scenario the development path of Yucatán is different. The attractiveness of the peninsula will not increase as much as expected, which can be caused by factors which are directly related to Yucatán, such as the safety of the region or by other factors, such as the popularity of other regions. The tourism industry in Yucatán, and in general the Mexican tourism industry highly depends on tourists from the USA. In 1994 more than 6 million tourists from the USA visited México from a total of 7.1 million foreign tourists (World Tourism Organisation, 1994). This dependency can be harmful to tourism in Yucatán and México if the American tourists decide to go to other places or resorts. It will probably not only damage the tourism industry but also parts of the rest of the economy. Therefore, a scenario is made in which the popularity of Yucatán will not increase as expected by, for example, the World Tourism Organisation (1996).

Figure 11 shows that the number of tourists is lower in Scenario 5 than in the base scenario. The number of tourists increase slightly in the first years, then stabilize, after which in 2010 a period of decrease begins.

Figure 11. The number of tourists, Scenario 5 (solid line) compared to Scenario 1 (broken line).



As presented in Figure 12 the price per tourist night does not change cyclically as in the base and clean-up scenarios (Scenarios 1-4). The price increases slightly after which it slowly decreases. The investments in tourism are very small after 2014 which is a result of the low profit per room, The profit per room is lower than the (inter)national profit rates which means that no (inter)national investments are made in Yucatán (sees Table 12 and 13). The only investments in tourism are the regional investments, but those are not enough to maintain the number of rooms (see Table 12). The decreased number of tourists and the low price give a low gross output and therefore a low need for labor in the tourism industry. The labor force in the rest of the economy is higher while the gross output is lower. This has a negative impact on the wages in Sector 2 (see Table 13).

Figure 12. The price per tourist night (Scenario 5).

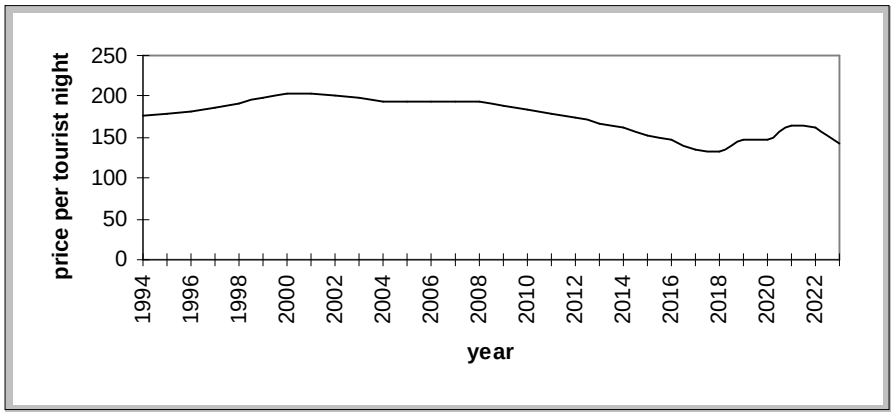


Table 12. The number of tourists, the price per tourist night, the number of rooms, the profit per room, the water quality and the population (Scenario 5).

Years	*Tourists*	*P1*	*Rooms*	*Profit per room*	*Water quality*	*Population*
1994	2,876.00	177.05	9,497.13	227.08	98.13	2,534.42
1995	2,882.71	180.05	9,420.20	233.82	96.33	2,682.83
2000	3,449.31	204.05	9,815.76	316.17	87.95	3,504.02
2005	3,615.10	192.55	10,451.98	292.12	79.49	4,444.43
2010	3,641.24	184.05	11,061.13	261.52	70.1	5,472.47
2015	3,034.92	151.05	11,585.55	162.75	58.95	6,579.73
2020	2,242.69	147.05	9,330.77	141.39	45.01	7,738.18
2023	1,637.95	143.05	8,244.80	97.51	34.54	8,441.28

Table 13. The labor, the investments and the gross output in both sectors (Scenario 5).

Years	*Lab1*	*Lab2*	*Inv1*	*Inv2*	*Gross output1*	*Gross output2*
1994	143.8	1,630.29	3,979.33	4,639.96	5,702.99	38,179.00
1995	144.14	1,733.85	5,123.44	3,832.10	5,813.15	39,319.74
2000	172.47	2,280.35	6,471.06	4,599.02	7,882.91	43,624.56
2005	180.76	2,930.35	5,925.79	6,600.00	7,796.19	51,413.75
2010	182.06	3,648.67	6,554.60	7,558.16	7,505.90	61,448.21
2015	151.75	4,454.07	793.42	7,140.77	5,134.36	73,239.72
2020	112.13	5,304.59	843.54	7,591.87	3,693.62	81,517.37
2023	81.9	5,827.00	869.31	7,823.80	2,624.26	86,757.65

Table 12 shows that the water quality in this scenario is comparable to the water quality in the base scenario (see Table 4). After 30 years the water quality has decreased by more than 65 points in both scenarios.

Table 13 shows that the labor force in Sector 1 first increases and then decreases as does the number of tourists. The gross output decreases quickly after 2015 due to a decrease

in the price and number of tourists. For Sector 2 the labor force is higher than in the base scenario, although the total labor force (a fixed percentage of the population) is lower. This is a result of the small number of people working in tourism.

This scenario shows that the other factors, not the quality of the beaches, the archaeological sites and the water, highly influence the number of tourists. By having a negative impact on the number of tourists also the price, the profits and the investments are low. This not only influences the tourism sector but also the other sectors. In Sector 2 the gross output has not decreased very much, because of the labor force in that sector, but the wages in Sector 2 are very low. It can be concluded that the dependency on the other, exogenous, factors may be dangerous for the whole economy.

4.6. Investment scenario

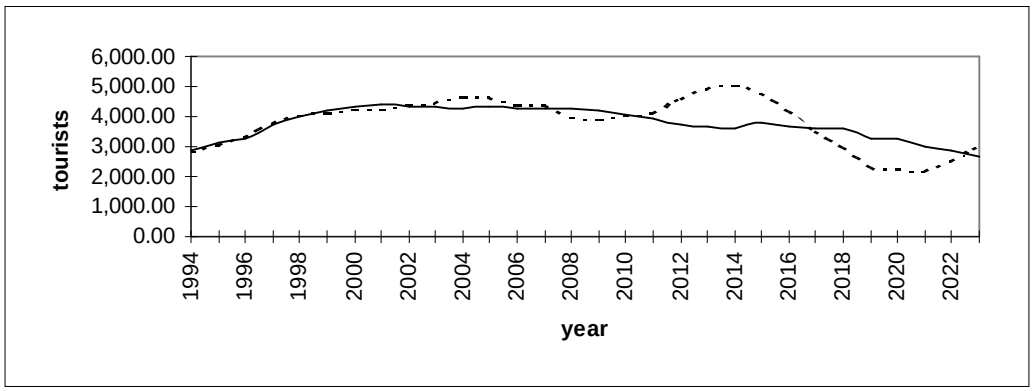
In the base scenario the national and regional investments were divided amongst tourism and other sectors. In this scenario all investments go to the tourism sector, except when the national profit rate is higher than the profit per room. In that case a part of the regional investments will go to Sector 2. This scenario shows the possible effects of an investment policy which stimulates the investments in tourism. As can be seen in Table 14 in most years all investments will go to tourism; only in some years a part of the regional investments will go to other sectors. Therefore, the number of rooms, the capital stock of tourism, increases very quickly in the first years. Then, the profit per room decreases so much that no (inter)national investments will be made, after which the investments are positive again for a decade. Until 2015 the number of rooms are higher than in the base scenario, but afterwards the number of rooms will be lower because of the quickly decreasing profits per room. These low profits per room mean that (inter)national investments are no longer made in Yucatán. The capital stock of the rest of the economy decreases rapidly in the beginning because there is only depreciation and no new capital until 2010. After 2009 investments are made in the rest of the economy which means that the capital stock and the gross output can increase again. The crowding out of the investments is an example of what is known as the 'Dutch disease' (see Section 3). As said, this scenario may occur as the result of stimulating the investments in tourism.

Table 14. The labor force, the investments and the gross output in both sectors (Scenario 6).

Years	*Lab1*	*Lab2*	*Inv1*	*Inv2*	*Gross output1*	*Gross output2*
1994	143.8	1,630.17	8,294.61	0	5,477.51	36,337.85
1995	156.43	1,721.29	8,569.47	0	6,028.69	35,423.48
2000	218.12	2,234.16	10,022.82	0	9,212.45	30,606.62
2005	215.36	2,893.53	9,815.06	0	8,058.77	26,410.70
2010	203.54	3,621.82	340.53	3,064.75	6,681.56	22,410.69
2011	195.78	3,779.58	368.16	3,313.45	6,404.82	25,863.18
2012	185.27	3,942.42	396.14	3,565.29	6,247.98	29,132.42
2013	184.92	4,097.26	11,227.57	0	6,381.16	32,434.65
2014	181.5	4,257.12	11,247.23	0	6,344.39	31,451.77
2015	190.58	4,406.24	410.78	3,697.06	6,362.79	30,430.79
2016	184.81	4,571.74	11,830.90	0	6,273.83	33,976.46
2017	180.4	4,737.18	424.59	3,821.27	5,982.57	32,736.84
2020	164.22	5,241.75	513.24	4,619.20	5,280.67	43,389.58
2023	134.61	5,762.10	588.46	5,296.18	4,237.90	53,491.23

Figure 13 shows the number of tourists in the investment scenario compared with the base scenario. This sixth scenario shows an increase in the number of tourists in the first years, followed by a period in which the number of tourists decreases slowly. The cyclical pattern as in the base scenario is not followed, which means that the total number of tourists that visit the region over 30 years is more or less the same as in the base scenario, only the division over the years varies.

Figure 13. The number of tourists, Scenario 6 (solid line) compared with Scenario 1 (broken line).



The price per tourist night shows a short increase, after which the price decreases very slowly. The price does not decrease as fast as the number of tourists; this is due to the three quality factors and the other, exogenous, factors (see Figure 14 and Table 15).

This scenario shows that it is important to keep in mind that stimulating investments in tourism is not enough to keep the peninsula economically healthy. Both the tourism sector as well as the rest of the economy do not profit from more investments in tourism and less in the rest of the economy. The investments in tourism will make the supply of rooms very high at a low price which has a negative effect on the gross output and the profit per room (see Tables 14 and 15). Because of those low profits per room the total investments in Yucatán decrease. It can be concluded that many investments in the tourism sector have a negative effect on tourism in the long term. The effects in the short term are negative for the rest of the economy while in the longer term the rest of the economy does slightly better.

Figure 14. The price per tourist night in the investment scenario (Scenario 6).

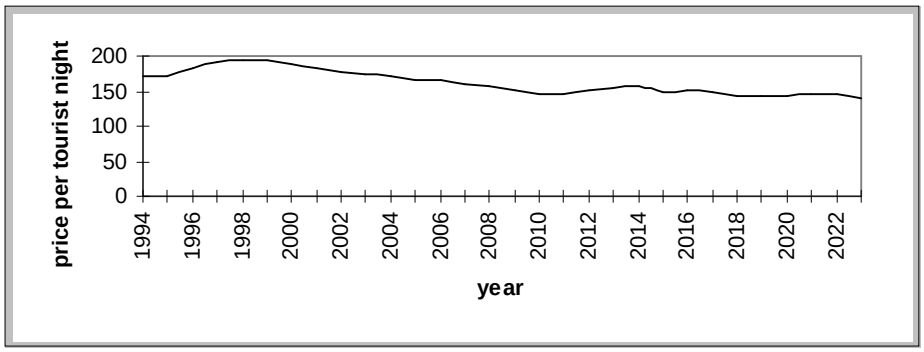


Table 15. The number of tourists, the price per tourist night, the number of rooms, the profit per room, the water quality and the population in the investment scenario (Scenario 6).

Years	*Tourists*	*P1*	*Rooms*	*Profit per room*	*Water quality*	*Population*
1994	2,876.00	170.05	9,931.18	206.87	98.13	2,534.25
1995	3,128.60	172.05	10,264.09	222.39	96.33	2,682.46
2000	4,362.45	188.55	12,172.20	299.94	87.83	3,503.26
2005	4,307.29	167.05	13,891.87	220.35	79.27	4,441.28
2010	4,070.74	146.55	15,187.38	162.8	69.82	5,464.79
2015	3,811.51	149.05	14,038.10	168.09	58.68	6,566.88
2020	3,284.49	143.55	12,039.91	162.79	44.59	7,722.82
2023	2,692.17	140.55	10,476.74	147.61	34	8,423.86

5. Sensitivity Analysis

The parameters, equations and assumptions in the basic model as described in Sections 3 and 4 are chosen because they are the most probable to occur, but most parameters or relations may be different. Especially the demand for tourist nights may react differently on, for example, the water quality. Therefore, sensitivity analysis is done to see how responsive some relations are for changes in the model. Three sensitivity runs are analyzed for beach quality, other factors determining the demand for tourist nights, and for international investments.

5.1. Beach quality

The demand for tourists depends on the quality of the beaches. In this sensitivity run the demand reacts more heavily on the beach quality. The demand for nights will be higher and fluctuates very much especially around 2010 (see Figure 15). Compared to the base scenario the number of tourists fluctuates with a higher amplitude but the number of tourists which would have visited the peninsula would be roughly the same after 30 years.

Figure 15. The number of tourists, sensitivity run 1 (solid line) compared with Scenario 1 (broken line).

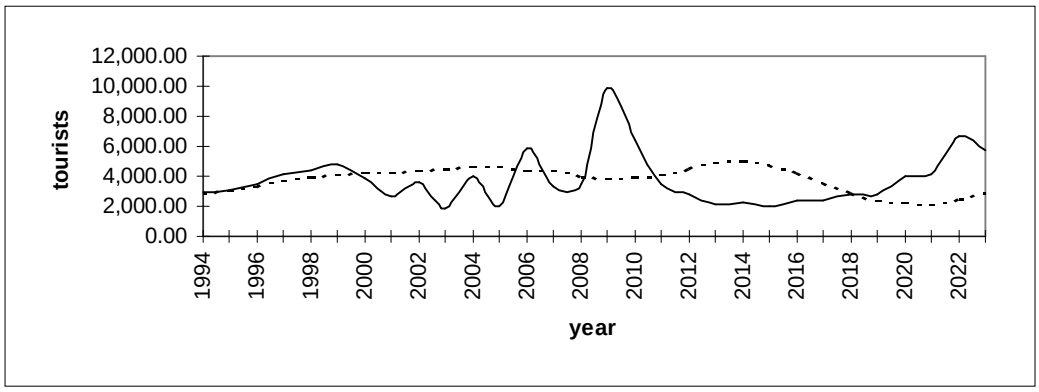


Figure 16 shows the profit per room which shows a cyclical pattern as in the base scenario. The price per tourist night fluctuates more as the effect of changes in the beach quality have a higher impact. The gross output and the profit per room also fluctuate more than in the base scenario (compare Tables 16 and 17 with Tables 4 and 5). For the rest of the economy the results in terms of gross output are a bit less, mainly due to the lower investments in this sector, which decreases the capital stock of Sector 2.

Figure 16. The price per tourist night (sensitivity run 1).

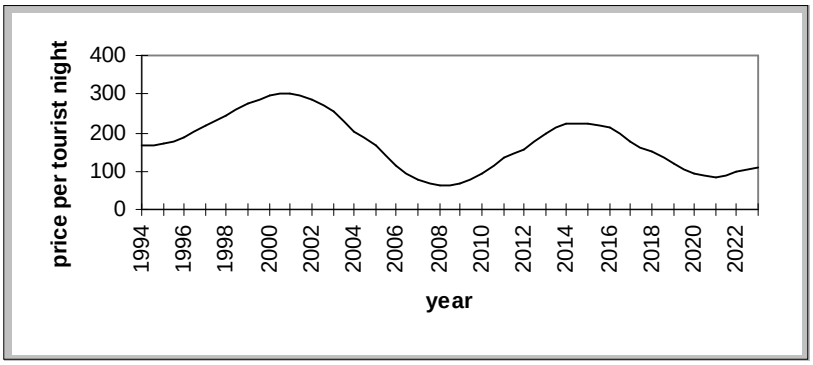


Table 16. The number of tourists, the price per tourist night, the number of rooms, the profit per room, the water quality and the population (sensitivity run 1).

Years	Tourists	P1	Rooms	Profit per room	Water quality	Population
1994	2,876.00	166.55	9,480.80	214.05	98.13	2,534.17
1995	3,075.47	171.05	9,395.45	241.25	96.33	2,682.30
2000	3,902.10	298.55	10,411.95	504.28	87.76	3,503.87
2005	2,059.30	166.55	10,442.97	111.36	79.43	4,457.23
2010	6,357.73	91.55	9,444.06	295.09	69.72	5,485.78
2015	2,050.14	225.55	9,795.94	175.86	58.62	6,594.65
2020	4,031.86	91.55	9,695.77	173.24	44.65	7,767.73
2023	5,688.68	110.05	9,946.81	301.35	33.7	8,472.85

Table 17. The labor force, the investments and the gross output in both sectors (sensitivity run 1).

Years	Lab1	Lab2	Inv1	Inv2	Gross output1	Gross output2
1994	143.8	1,630.12	3,886.96	4,599.13	5,364.78	38,149.28
1995	153.77	1,723.84	5,166.99	3,836.37	5,891.87	39,163.60
2000	195.1	2,257.60	8,071.21	5,038.74	13,047.68	44,066.36
2005	102.97	3,017.10	574.09	5,166.79	3,841.34	53,523.23
2010	317.89	3,522.16	8,015.44	5,984.86	6,518.96	59,663.36
2015	102.51	4,513.75	8,264.85	6,691.58	5,178.99	71,460.47
2020	201.59	5,235.82	7,450.64	9,135.32	4,134.11	80,734.94
2023	284.43	5,646.56	10,800.53	8,192.53	7,011.64	87,327.00

5.2. Exogenous factors influencing the demand for tourism

The exogenous factors that influence the demand for tourism are assumed to increase over time as in the base scenario, but here the reaction of the demand on the other factors will be less strong. This results generally in a decrease in demand because the other factors are stimulating demand less. The demand still shows a cyclical pattern but this pattern is generally lower than in the base scenarios (see Figure 17). Only after 2018 the number of tourists is higher due to the demand factors.

Figure 17. The number of tourists, sensitivity run 2 (solid line) compared with Scenario 1 (broken line).

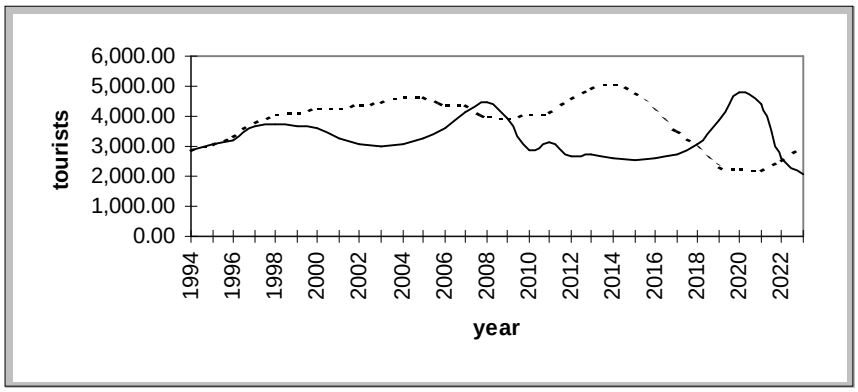
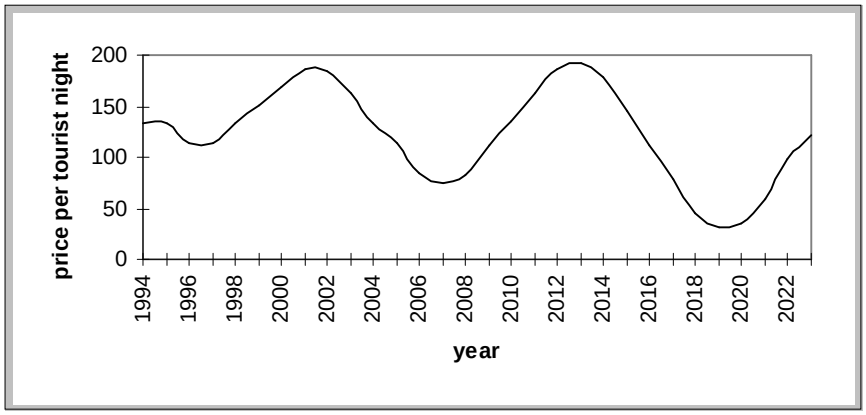


Figure 18 shows the price per tourist night which shows a cyclical pattern as in the base scenario but the price is generally lower than in the base scenario. This is due to the lower impact on the other, exogenous, factors which decrease over time.

Figure 18. The price per tourist night (sensitivity run 2).



The number of tourists is generally lower and the price per tourist night is lower than in the base scenario which means that the gross output of the tourism sector is lower. This makes the profit per room often lower than the (inter)national investment rate which means that over 30 years the number of rooms decrease by more than 2000 (see Table 18).

Table 18. The number of tourists, the price per tourist night, the number of rooms, the profit per room, the water quality and the population (sensitivity run 2).

Years	Tourists	P1	Rooms	Profit per room	Water quality	Population
1994	2,876.00	133.05	9,476.83	171.08	98.13	2,534.17
1995	3,084.22	133.05	9,361.82	189.25	96.33	2,682.30
2000	3,567.14	169.05	9,460.03	287.5	87.87	3,500.87
2005	3,292.50	113.05	9,809.35	164.81	79.54	4,437.17
2010	2,838.57	135.05	9,109.68	179.2	70.12	5,458.88
2015	2,517.63	145.05	10,297.58	142.63	59.17	6,562.46
2020	4,794.33	35.05	8,298.14	96.96	45.22	7,718.77
2023	2,052.82	121.05	7,339.97	141.34	34.55	8,419.44

The water quality is only slightly better than in the base scenario after 30 years (compare Table 18 with Table 4). For Sector 2 the lower impact of the other factors on the tourism sector are negative too. The gross output is lower, due to lower prices and a lower capital stock (see Table 19).

Table 19. The labor force, the investments and the gross output in both sectors (sensitivity run 2).

Years	Lab1	Lab2	Inv1	Inv2	Gross output1	Gross output2
1994	143.8	1,630.12	3,588.35	4,473.49	4,285.70	38,142.55
1995	154.21	1,723.40	3,829.36	4,655.86	4,595.98	39,100.51
2000	178.36	2,272.25	6,225.78	4,531.07	6,753.88	43,998.75
2005	164.62	2,941.40	574.2	5,167.77	4,168.83	51,825.80
2010	141.93	3,679.29	7,068.66	5,739.99	4,293.50	58,739.03
2015	125.88	4,467.84	728.34	6,555.08	4,090.04	68,585.27
2020	239.72	5,163.42	757.76	6,819.87	1,882.06	75,638.89
2023	102.64	5,790.97	830.6	7,475.44	2,783.14	81,812.21

The conclusion of this sensitivity run is that a lower impact of the exogenous factors on the demand has a negative impact on tourism and the rest of the economy. This is due to increasing exogenous factors. If the factors influenced the demand negatively then this scenario would be good for both sectors.

5.3. International investments

In the base scenario it is assumed that international investments depend on the profit per room and the international profit rate, and that these investments are only made in tourism and not in the other sectors of the economy. Here, a sensitivity run is done to look at what happens when no international investments are made in the region. This can be interpreted as a government policy to keep the profits in México itself, or it can be seen as a development path in which other countries are more attractive to invest.

The demand for tourist nights shows a slightly cyclical pattern, but it is more leveled out as can be seen in Figure 19. The number of rooms is more stable when there are no

international investments. This is due to less investments in rooms which keeps the price higher (see Table 20).

Figure 19. The number of tourists, sensitivity run 3 (solid line) compared with Scenario 1 (broken line).

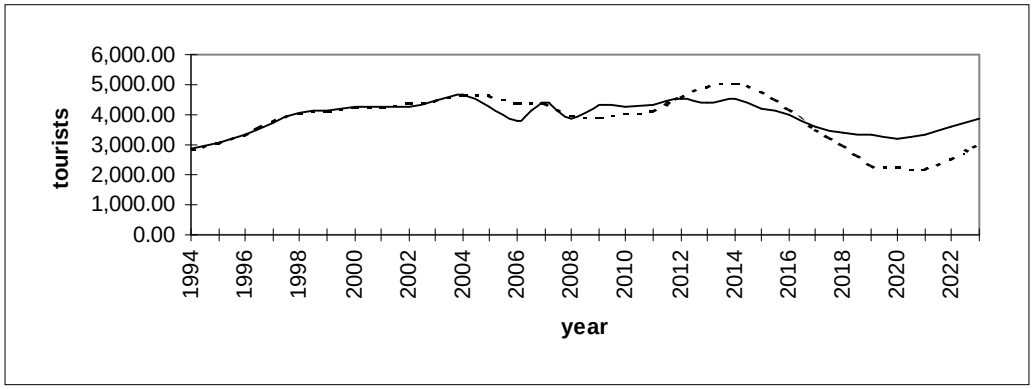
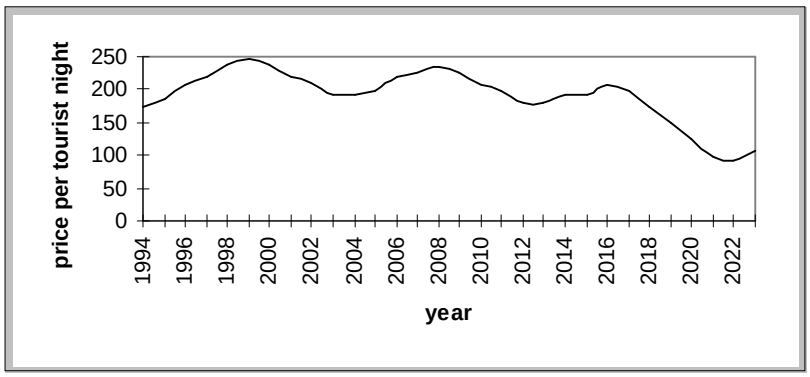


Table 20. The number of tourists, the price per tourist night, the number of rooms, the profit per room, the water quality and the population (sensitivity run 3).

Years	*Tourists*	*P1*	*Rooms*	*Profit per room*	*Water quality*	*Population*
1994	2,876.00	174.55	9,468.36	224.69	98.13	2,534.25
1995	3,092.14	186.05	9,363.65	265.47	96.33	2,682.46
2000	4,250.68	238.05	9,737.10	476.45	87.82	3,505.00
2005	4,274.60	198.05	9,958.32	388.15	79.24	4,447.18
2010	4,261.62	208.05	10,642.88	377.76	69.8	5,477.90
2015	4,185.18	193.55	11,382.27	318.65	58.47	6,588.08
2020	3,186.89	123.55	11,622.10	140.96	44.28	7,754.66
2023	3,878.02	105.55	10,221.41	180.71	33.55	8,458.59

Figure 20 shows the price per tourist night which shows the same pattern as in the base scenario. Both patterns are cyclical, but in this sensitivity run the price is generally higher. The number of rooms is lower than in the base scenario due to fewer investments. The profit per room is higher due to both the higher price and lower number of rooms.

Figure 20. The price per tourist night (sensitivity run 3).



International investments were only made in the tourism sector, so they do not affect the capital stock of Sector 2 directly. Indirectly they do. Because of the higher profit per room the national and regional investments will be higher. These go partly to the rest of the economy. For the gross output the lack of international investments is beneficial (compare Table 21 to Table 5).

Table 21. The labor force, the investments and the gross output in both sectors (sensitivity run 3).

Years	*Lab1*	*Lab2*	*Inv1*	*Inv2*	*Gross output1*	*Gross output2*
1994	143.8	1,630.17	3,687.12	4,629.77	5,622.46	38,160.38
1995	154.61	1,723.12	4,877.46	3,880.84	6,443.28	39,177.76
2000	212.53	2,240.96	6,188.51	4,897.88	11,333.00	43,733.92
2005	213.73	2,899.30	6,922.91	5,530.48	9,481.76	53,094.84
2010	213.08	3,621.45	7,955.24	6,361.70	9,930.26	62,811.84
2015	209.26	4,402.39	8,917.53	7,146.23	9,072.46	74,132.89
2020	159.34	5,268.92	893.92	8,045.28	4,409.89	85,210.00
2023	193.9	5,727.11	9,952.95	8,065.31	4,584.44	89,655.80

This sensitivity run shows that a lack of international investments does not harm tourism and the rest of the economy, because the investments in the number of rooms are not necessary for the number of tourists that are coming. On the contrary, both sectors are better off without those investments. This shows that international investments may harm the economy of the peninsula, because the supply of rooms becomes very big, which has a negative impact on the profits per room and on the other investments.

6. Conclusion and Future Research

The goal of this study was to analyze the interactions between tourism, environment, population and the rest of the economy under different policy and development path scenarios. Therefore, a dynamic model was developed to simulate those interactions and to analyze the effects of various policies and development paths. A dynamic model is used to

show the impacts over time and to include delayed effects into the model. The model has a mathematical graphic interface in which new or other variables, interactions and scenarios can be easily added and analyzed. The model can be updated when new insights, data or relationships are acquired which makes it a useful tool for future studies. The model is useful even for policy makers because it gives some insights into the effects of policies. The graphic interface, which is user friendly and easy to learn, allows users to visualize the interactions which are part of the model and change them according to their own insights.

The existing model divides the economy in only two sectors, tourism and the rest of the economy. The environmental part of the model can be further specified to obtain a more accurate model. The module for the environment is basic and more aspects could be included which may make the model more realistic, for example, the inclusion of land use and infrastructure. The population module can be refined and updated when population projections become available. This may, for example, include age structure of the population. This means that the model serves as a basic model in which many aspects may be changed and added to make it more appropriate for more detailed scenario analysis.

The results of the base scenario show that the number of tourists visiting the Yucatán peninsula follow a cyclical pattern, which is due to the water, beach and sites quality on the demand side and the number of rooms on the supply side. The price which makes the demand for and supply of rooms equal shows a cyclical pattern too. Hence, the gross output and the labor force needed in the tourism sector have the same pattern. The investments in tourism are cyclical too, but change more abruptly as soon as the profit per room becomes lower than the (inter)national profit rate. Then, the (inter)national investments become zero which makes the regional investments the only ones. The water quality in this scenario decreases over time because of the water use or pollution by the population and the tourists. The natural clean-up rate is not quick enough to clean the water used.

Three clean-up scenarios are analyzed: one in which the water used by the tourists is cleaned (paid by the tourism sector, i.e., the hotel owners); one in which the water used by the population is cleaned (paid by the government); and one in which all water is cleaned. The most striking result is that the amount of water used by the tourists is much less than what the population uses. Therefore, cleaning the water used by the population has a much higher effect than cleaning the water used by tourists. In all three scenarios the number of tourists follow a cyclical pattern. The more the water is cleaned, the more the tourists will visit the region.

The scenario in which the development path of Yucatán is lower, for example, because the popularity of other places increases, has a negative effect on tourism. The rest of the economy is not affected very much by this scenario, only the wages in Sector 2 are. This is due to the fact that in the tourism sector less labor is needed. This scenario shows the effects of the dependency on exogenous factors which cannot be influenced.

The scenario in which all investments are made in tourism shows that this has a negative effect on both tourism and the rest of the economy. All investments in tourism go to rooms which makes the possible supply of beds very high, and therefore the price and profit per room lower. The investments depend on the profit per room and with lower profits per room the investments will be lower. The impact on the other sector is even more striking: the lack of investments make the capital stock decrease and therefore also the output and price.

Three sensitivity runs were done for the effect of the beach quality and the other factors influencing the demand for tourist nights, and the effects of no international

investments. A more important impact of beach quality on demand shows that in general the demand remains the same, but more fluctuating. The prices are more fluctuating too. For Sector 2 the effects are only small. The sensitivity run in which the exogenous factors are less important for the demand for tourist nights levels out, i.e., the cyclical pattern is less pronounced. The effects are negative for both sectors, but this is due to the fact that the exogenous factors are increasing. If they were decreasing, a lower impact on the demand would be good for both sectors. The third and last sensitivity run shows that the effect of no international investments are small for the number of tourists over the whole period. More important is that the number of tourists are more stable and that the profit per room is higher which means that more national and regional investments are made. This is both positive for the tourism sector and the rest of the economy. The conclusion of this sensitivity run is that international investments are not needed when the occupancy rate of the rooms is not very high. In this case, international investments only lower the profit per room.

A general conclusion of the dynamic model to simulate policy options and development scenarios is that it gives insight in the interactions between many variables involved and that the direct and static effect is not always the only one. There are many indirect effects, such as the effects of high profits per room, which induce investments which increase the number of rooms. A higher number of rooms has a negative impact on the price and both the higher number of rooms and the lower price decrease the profit per room. Therefore, the profit per room, the price and the investments are dynamically and indirectly influencing one another.

The model integrates the interactions between tourism, environment, population and the economy which may make the analysis of policy proposals and possible development paths easier and more adequate. This model is meant to serve as a first attempt to model those interactions. In the future updating, refining and elaborating of the model is needed. The first step will be to integrate the fisheries module (see Hale, 1996) in this general model. The population projections which are currently done at IIASA will be included too. These refinements and elaborations will make the model more valuable and accurate.

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Appendix: The Equations of the Model

Economy
Sector 1: tourism sector
Sector 2: the rest of the economy

cap2(t) = cap2(t - dt) + (cap2_in - cap2_out) * dt
INIT cap2 = 4000
cap2_in = inv2/12
cap2_out = 0.1*cap2
# The capital stock of Sector 2 increases with the investments and decreases with a fixed depreciation rate of 10%. The initial capital stock (1994) is 4000.

p2(t) = p2(t - dt) + (p2_in - p2_out) * dt
INIT p2 = 1500
p2_in = if dummyd>0 then dummyd*50 else 0
p2_out = if dummyd<0 then -dummyd*50 else 0
dummyd = ((delay(wage2,1)-delay(wage2,2))/delay(wage2,2))
# The price of the output of Sector 2 depends on the growth rate of the wages in Sector 2.

inv1 = invint+invyuc1+invmex1
# The investments in tourism are the sum of the international, national and regional investments in tourism. Note that all international investments go to tourism.

inv2 = invmex2+invyuc2
# The investments in Sector 2 are the sum of the national and regional investments in this sector.

invint = if profit_perroom<intprofitrate then 0 else 5*(profit_perroom-intprofitrate)
intprofitrate = 170
# The international investments are zero if the profit per room is lower than the international profit rate.

invmex = if profit_perroom<nat_profitrate then 0 else .005*gdpmex
invmex1 = 0.5*invmex
invmex2 = invmex-invmex1
nat_profitrate = 170
gdpmex = 686406*(1+0.05*time)
# The national investments are zero if the national profit rate is higher than the profit per room, otherwise they are a part of the GDP of México. In the base scenario the national investments are equally divided amongst Sectors 1 and 2. The GDP of México increases over time.

invyuc = profit1*0.4+0.1*wage1*lab1+.4*profit2+.05*wage2*lab2
invyuc1 = if profit_perroom<nat_profitrate then 0.1*invyuc else dummyb

dummyb= if delay(profit_perroom,1)-delay(profit_perroom,2)>0 then 0.6*invyuc else 0.4*invyuc
invyuc2 = invyuc-invyuc1
# The regional investments depend on the profits and wages in both sectors. A small part of those investments will go to tourism if the profit per room is smaller than the national profit rate. Otherwise this part depends on the development in profit per room.

gross_output1 = p1*tourists*11.2/1000
Si1 = 0.2
Sl1 = 1-Si1-Sk1
va1 = gross_output1*(1-Si1)
profit1 = gross_output1*Sk1-costs_to_clean
costs_to_clean = tour_clean*10/(2876*11.2*1.5/1000000)
profit_perroom = profit1*1000/rooms
wage1 = Sl1*gross_output1/lab1
Sk1 = GRAPH(occrate)
(0.00, 0.11), (0.1, 0.12), (0.2, 0.16), (0.3, 0.213), (0.4, 0.345), (0.5, 0.37), (0.6, 0.383), (0.7, 0.403), (0.8, 0.408), (0.9, 0.42), (1, 0.428)
The gross output of Sector 1 depends on the price and the number of tourists. The gross output is divided amongst intermediate consumption (Si1), capital (Sk1), labor (Sl1), costs to clean and profits. The part which goes to capital depends on the occupancy rate of the rooms. The value added is the gross output minus the intermediate consumption. The part of the gross output dedicated to labor is divided amongst the number of workers. The profit per rooms is the profit divided by the number of rooms.

out2 = 0.01*SQRT(lab2)*sqrt(cap2)
gross_output2 = out2*p2
profit2 = va2-wage2*lab2
Si2 = 0.5
Sl2 = 0.3
va2 = gross_output2*(1-Si2)
wage2 = Sl2*gross_output2/lab2
# The output of Sector 2 depends on the labor (lab2) and the capital stock in Sector 2 (cap2). The gross output is the output times the price. The gross output is divided amongst the intermediate consumption (Si2), the labor costs (Sl2) and the profits. The value added is the gross output minus the intermediate consumption. The wages in Sector 2 depend on the part of the gross output dedicated to labor costs and the number of people working in Sector 2 (lab 2).

va = va1+va2
# The value added is the sum of the value added in both sectors.
wagemex = 15
# The wage in México.

Environment
water_qual(t) = water_qual(t - dt) + (cleaning - water_use) * dt

INIT water_qual = 100
water_use = (tourists*11.2*4+pop*365*2)/1000000
# The water quality depends on the water use and the cleaning of the water.

cleaning = nat__cleaning+tour_clean+pop_clean
nat__cleaning = (1-(water_qual/100))*(water_qual/100)*10
pop_clean = perc_pop_clean*pop*365*2/1000000
tour_clean = perc_tour_clean*tourists*11.2*4/1000000
# The cleaning is the sum of the natural cleaning and the cleaning of the water used by the tourists and the population. The natural cleaning depends on the water quality and the population cleaning depends on the percentage the government wants to clean (see government) and the number of people. The tourist clean up depends on the percentage the government wants to clean (see government) and the number of tourists.

Government
perc_pop_clean = 0
perc_tour_clean = 0
# The government can impose a policy to clean the water used by the population (perc_pop_clean) or the tourists (perc_tour_clean).

subsidy = pop_clean*10*(87/5)/((535.185+493.277+1362.940)*365/1000000)
# When the government imposes a policy to clean the water used by the population it has to pay for it. This can be seen as a subsidy which depends on the amount of water to be cleaned.

Population
pop(t) = pop(t - dt) + (pop_in - pop_out) * dt
INIT pop = 535.185+493.277+1362.940
pop_in = pop*(birth_rate+migration)/100
pop_out = pop*death_rate/100
birth_rate = GRAPH(time)
(1994, 6.16), (2009, 4.87), (2024, 4.29)
death_rate = GRAPH(time)
(1994, 3.65), (2009, 2.90), (2024, 2.84)
The initial population is exogenous. The population increases (pop_in) by birth and migration rates times the population, and the population decreases (pop_out) by the death rates times the population. The birth and death rates change over time.

labour_force(t) = labour_force(t - dt) + (labour_in) * dt
INIT labour_force = 0.7*(535.185+493.277+1362.940)
labour_in = labour_force*(birth_rate+migration-death_rate)/100
# The labor force is a part of the population. It increases with the birth and migration rates and decreases with the death rate times the labor force.

lab1 = tourists/20
lab2 = labour_force-lab1

The labor needed in tourism depends on the number of tourists. The labor in Sector 2 equals the entire labor force minus the people working in tourism. This means that there is no unemployment.

migration = if dummyc>0 then basemig+dummyc*.1/15 else basemig
dummyc = delay(wage1,1)-delay(wagemex,1)
basemig = GRAPH(time)
(1994, 3.46), (2009, 2.13), (2024, 1.31)
The migration depends on a base migration rate (basemig) which depends on the time and on the difference in the wage rate between tourism in the peninsula and in México. If the wage in tourism is higher than the wage rate in México then the migration will be higher than the base migration rate.

Tourists and rooms
rooms(t) = rooms(t - dt) + (new_rooms - rooms_out) * dt
INIT rooms = (18859+3350+747+3331)*365/1000
new_rooms = inv1/10
rooms_out = .05*rooms
# The number of rooms depends on the investments in tourism (inv1) and on the depreciation rate of 5%.

tourists(t) = tourists(t - dt) + (tour_in - tourist_out) * dt
INIT tourists = 1958+321+138+459
tour_in = dem
tourist_out = if time>0 then dummye else 2876
dummye = delay(tour_in,1)
# The number of tourists depends on the demand, the supply of rooms and the price.

occrate = min((tourists*11.2/(rooms*tourproom)),10)
tourproom = 6
# The occupancy rate depends on the number of tourists, the number of rooms and the number of tourists per room.

beach_congestion = GRAPH(occrate)
(0.00, 0.63), (0.1, 0.69), (0.2, 0.735), (0.3, 0.765), (0.4, 0.843), (0.5, 0.9), (0.6, 1), (0.7, 1.03), (0.8, 1.08), (0.9, 0.945), (1, 0.84)
The higher the beach congestion (i.e., quality) the more demand for tourist nights there will be. The beach congestion depends on the occupancy rate of the rooms. If the occupancy rate is very low tourists will not want to come.

sites_cong = max(100-5*(tourists/1000),10)
# The sites congestion depends on the number of tourists. It is defined as the quality. The less the tourists come, the higher the quality of the sites.

other = GRAPH(time)

(1994, 1.66), (1998, 2.04), (2001, 2.25), (2005, 2.38), (2008, 2.52), (2012, 2.58), (2016, 2.68), (2019, 2.74), (2023, 2.79)
The impact of factors which are not included in the model changes over time. In the base scenario the factor ‘other’ increases which means that Yucatán becomes more popular.

demvar = other*delay(beach_congestion,1)*sqrt(water_qual/100)*delay(sites_cong,3)/100
# The demand for tourist nights depends on the other factors, the beach congestion, the water quality and the sites congestion in the last period.

dem = 1/(sqrt(pr))*demvar*demand*20000
sup = 2*rooms*((exp(0.0055*(pr-50))/(1+exp(0.0055*(pr-50))))-0.5)
dem = sup
# The price makes the demand equal to the supply. The supply of rooms depends on the price and the number of rooms. When the number of rooms increases, the supply of rooms at a certain price increases too. When the price is zero, the supply of rooms will be zero; when the price is very high, the supply of rooms will be equal to the number of rooms. The demand for rooms depends on the price and the various variables (demvar, see tourists and rooms).
Note: Stella II cannot solve simultaneous equations which means that the demand, supply and price have to be solved by an iterative process within each year.