A NEW DECISION SUPPORT METHOD FOR LOCAL ENERGY PLANNING IN DEVELOPING COUNTRIES

Proefschrift

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Voor Kees Dam,
my man,
el calor en mi vida

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Preface

In 1997, two important things happened in my life that have shaped me in the past 6 years, and both things started in France. I went to France in early 1997 to do voluntary work, and while I was there I met Kees Dam and applied for a job as a PhD student (based on a fax I got from my old work). When I came back from France I got the job and started working four days a week, as I believe there are more things important in life than just work. The project I started working on was set up as a joined project between Tilburg University and Eindhoven University of Technology, although my main workplace was in Tilburg, at the Faculty of Economics.

Initially, the plan was to develop a model that could determine the optimal energy technology mix in rapidly developing areas of developing countries. In this case, the term 'optimal' was taken from a techno-economic perspective. However, after a while I realized that finding an optimal energy infrastructure was not the main problem in energy planning. Models that can calculate 'optimal' energy infrastructures already exist; the problem is that the outcomes of energy planning processes usually deviate from the solutions pointed out by these models. The question is then: Are the planners wrong or are the models? In other words: should the planners adjust their behavior to the models, or should the models be adjusted to better support the actors in practice? My personal preference for practical solutions made me choose for adjusting models to practice, as I believe this approach is more likely to directly improve local energy planning in developing countries. Consequently, a shift in focus of the research took place: from creating a new method that determines the optimal energy infrastructure, towards creating a method that better supports the *entire* energy planning process.

The first objective was therefore to find out what actually happens during the local energy planning process in order to better understand the difference between model outcomes and practice. I soon discovered that this difference can be explained by the fact that –besides the traditional energy planners– other groups in society that are not accounted for by the models also influence the planning process. In addition, most of these groups (including the traditional energy planners) have a one-sided view on the (consequences of) possible energy infrastructure options. Apparently, the interactions between these groups (i.e., the actors) steer the outcome of the local energy planning process. I learned that a method aiming to support local energy planning in practice should include other actors and other aspects in the planning process, allow for interactions between these actors, provide all actors with information throughout the entire process, and give them the opportunity to learn. This is what I have tried to incorporate in the method described in this thesis.

However, in the past six years I learned a lot more than this. I have also learned, for instance, that working on a multidisciplinary project (set up as a cooperation between two universities) brings about specific problems and requires special skills, especially in the area of communication. It took me a while to realize that people may use the same terms, but actually mean different things, or that they use different terms to express the same thing. Especially in the beginning this has led to sometimes hilarious, sometimes confusing situations. Nevertheless, it has learned me to carefully choose my words, keep an open mind, and take on different perspectives.

The multidisciplinary approach of the research project also implied that experts on the subject were not conveniently placed together in one of the two universities. In fact, most of the expert information had to be gathered outside the universities, and I would hereby like to thank all the many people that were willing to help me during my research work. In particular, I would like to mention Frank van der Vleuten, Bart Franken, and Jeroen van der Linden, who participated in the Think Tank I created to get external feedback on my ideas, and with whom I had several –sometimes eye-opening– discussions. I would also like to thank the Project Bureau Energy 2050 for supporting me during the field study in Brabant, the Netherlands.

The field study in Costa Rica could not have been arranged so easily without the help of Wim Pelupessy, who introduced me in his network of people there. Also, the valuable information and suggestions from Leiner Vargas Alfaro, Roberto Jiménez Gómez, and Mario Alvarado were indispensable in conducting the Costa Rica field study, and their open, friendly approach also made me feel at home when I was so far away from Kees. And I am forever indebted to Elsy Aburto Sanchez, who helped me conduct the Spanish interviews and cheered me up when Kees wasn't around to do so. My home in Costa Rica, as well as most of the other facilities required for the field study there, were generously provided by CINPE-UNA, while financial support came from both Ecooperation and Essent, for which I am grateful.

Of course, I am also grateful for the advice and constructive comments of the people at the two universities: Cees Daey Ouwens (Eindhoven), Johan Schot (Eindhoven), and my promoter Jeffrey James (Tilburg), who each found the right trigger to keep my motivation high. However, the advisors that were most directly involved and supported me throughout the entire period were Willem van Groenendaal (Tilburg) and Wim van Helden (Eindhoven). I already knew Wim van Helden from the course we organized together for TDO early in 1997, and I admire him for his human approach and good spirit, and the time he took to talk with me about all kinds of things. Willem van Groenendaal I first met when I started this project, and I must say that it took me a while to figure out his 'personal manual', to later discover that we actually have quite a lot in common. His capacity to look beyond his field of expertise greatly facilitated the multidisciplinary approach of my research, and his vivid examples of his experiences, among others in developing countries, eased most of the occasional tedious moments. Thanks guys, really.

As mentioned at the beginning of this preface, meeting Kees Dam has been very important to me, and I am convinced that his contribution in successfully completing this thesis is the largest of all, with his endless patience, support, and good care.

The past five years have not always been easy, but I am proud of what I have accomplished. I have learned a lot, even though there is still much room for improvement. And if I could do it all over again –knowing what I know now– I would undoubtedly do it differently. Nonetheless, I hope my work provides at least some of you with some fruitful new ideas.

Nicole van Beeck
March 2003

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Introduction: Energy Issues in Developing Countries

The choices made today will largely determine the development paths of the future….

1.1. Introduction

This thesis is about local energy planning in developing countries. Energy planning is a decision process that aims at matching future energy demand and supply, and this chapter describes the issues related to energy demand and supply in developing countries, in particular in rapidly developing regions of these countries. Section 1.2 discusses the relationship between energy demand and economic development: an increase in economic activities usually implies an increase in energy demand. Section 1.3 addresses the issues associated with the energy resources and the existing energy infrastructure in developing countries. Since the existing energy infrastructure is often not adequate to meet a substantial increase in regional demand, new infrastructure is required. The planning of new energy infrastructure is the topic of Section 1.4. And in Section 1.5 we give an overview of the energy issues in developing countries and conclude that current energy planning is not well fit to serve rapidly developing regions of developing countries, while the energy planners lack a proper tool to support them during the entire planning process. This brings us to the description of the research framework underlying this thesis (see Section 1.6), including the central question that is to be answered.

1.2. Energy Demand and Economic Development

Most economic activity would be impossible without energy. Therefore, energy is a necessary (but not a sufficient) requirement for economic development. Although it is evident from Figure 1.1 that there is a link between the energy consumption of a country and its economic development, Figure 1.2 shows that there is no simple formula to calculate tomorrow's energy demand for country X given its current Gross Domestic Product (GDP). The United Nations (1996, p. 246) state that energy demand is largely determined by per-capita income, the degree of urbanization, and the electrification rate, but the exact relationship between energy demand and economic development still remains unclear, even more so at less aggregated levels.

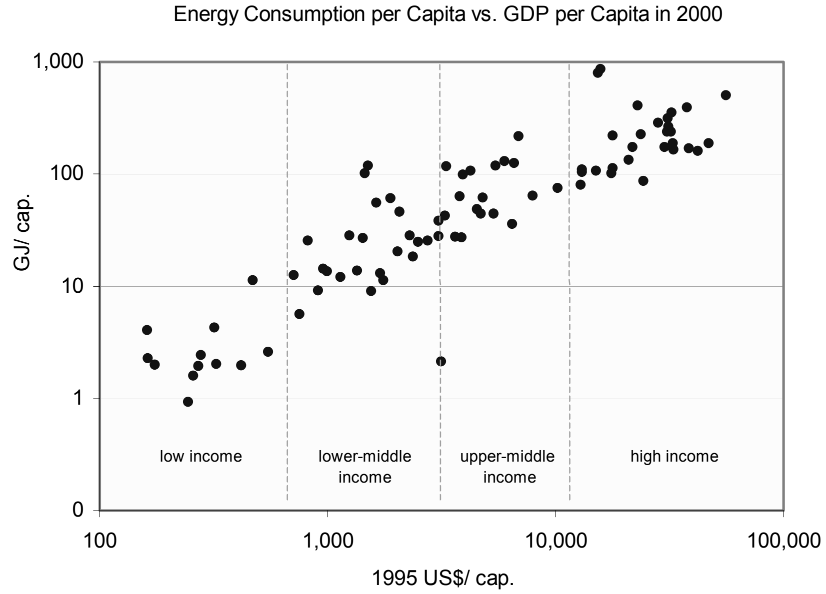

Figure 1.1. National energy consumption per capita versus the gross domestic product (GDP) per capita in 2000 for several countries. Only those countries of which data were available are included (85 countries in total). Data of included countries can be found in Appendix A. Note that both axes are logarithmic. The strong correlation between energy consumption per capita and income per capita is evident from the figure. Source: modified data from EIA (2002a).

In addition, focusing on highly aggregated national data such as GDP obscures the fact that economic growth is usually restricted to certain areas or regions within a country. These areas will experience a rapid increase in energy demand as a result of the increased economic activity, as shown in many rural areas in China (IVO, 1996, p. 6; Wang and Feng, 2000). Although the increase in regional energy demand may not always be immediately noticed at the national level, failing to meet this demand can severely hamper further regional development, and might eventually affect national development as well. So rapidly developing regions require *regional* energy planning to ensure an adequate response to an increase in energy demand.

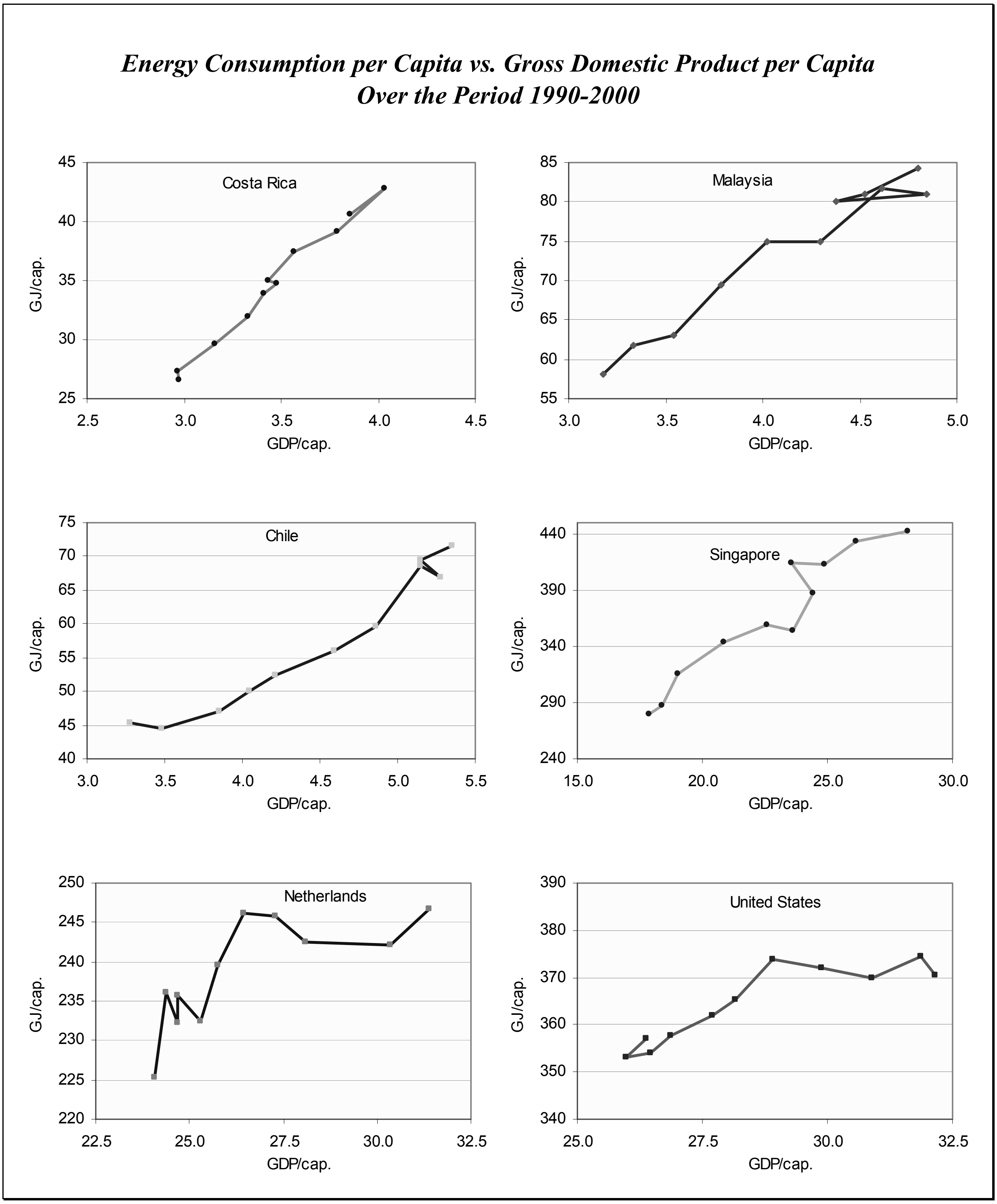

Figure 1.2. Primary Energy consumption per capita (GJ/yr) versus gross domestic product per capita (GDP, in 1995 US$) over the period 1990-2000 for selected countries. Source: modified data from EIA (2002a).

However, Goldemberg et. al. (1987, p. 6-7) argue that it would be simplistic to assume that energy use *must* increase with the level of economic activity. As an example, they refer to the episode directly after the first oil crisis, between 1973 and 1985, which showed a decoupling of energy use and economic growth in the (industrialized) OECD countries. This decoupling was attributed to structural shifts and/ or more efficient energy use. They argue that developing countries could 'leapfrog' over the long technological development path of the industrialized countries and use energy efficient technologies form the start. The United Nations (1996, Box X.1, p. 251), on the other hand, believe that the effects of income growth and demographic factors will largely offset the effect of efficient technologies, implying a positive relationship between economic development and energy consumption.

In any case, the energy infrastructure of most developing countries today is not adequate to support any substantial increase in economic activity. If such an increase in activity does occur, these countries will have to improve and expand their energy infrastructure considerably in order to meet future energy demand and sustain economic growth. And for this they will need adequate energy planning.

Another point, which is well taken by the World Bank (1994, p. 14-17), is that investments in the energy infrastructure cannot overcome a weak climate for economic activity, and do not *guarantee* economic growth. In addition, Goldemberg (2000, p. 372) states that besides investments in the energy and economic infrastructure, investments in the *social* infrastructure are equally important for development. That is why energy is a necessary *but not a sufficient* requirement for economic development. A one-sided approach of improving only the energy infrastructure will not bring about the so-desired development; the developing countries have to divide their –usually scarce– financial means among all the infrastructures (e.g., power, telecommunications, roads and railways, irrigation and drainage, sanitation and sewerage, and waste collection and disposal). This further emphasizes the importance of making the right plans and the right investment decisions regarding the energy infrastructure; the choices made today will largely determine the development paths of tomorrow.

1.3. Energy Supply Issues

1.3.1. Energy Resources

The range of energy infrastructure options that a country can choose from will largely depend on the energy resources available (including imports). Energy resources include *non-renewable* resources such as fossil fuels and uranium, and *renewable* resources such as water, wind, sunlight, and the earth's heat (see Table 1.1). Biomass can either be non-renewable or renewable, depending on the way it is managed[1]. With respect to fossil fuels and uranium, the total estimated reserves of each resource are highly disputed, partly due to the fact that new techniques make it possible to detect and exploit ever more reserves. Nonetheless, with current consumption rates the non-renewable energy resources will eventually be depleted, and data from the EIA (2002b, 2002c) and WEC (2002) indicate that for most of them this could even happen within this century.

Table 1.1.Renewable and non-renewable energy resources.

Energy Resources		**Proven Reserves** (in years, with current consumption rate)
Non-Renewable	Oil	36
	Gas	62
	Coal	211
	Uranium	100
	Biomass*	n.a.
Renewable	Water, Wind, Sunlight, Earth's Heat, Biomass*	unlimited

n.a. = data not available. *Source*: modified data from EIA (2002b, 2002c), and WEC (2002).
* Biomass can be renewable as well as non-renewable depending on the way it is managed.

The oil crises of 1973 and 1979 (both causing economic disruption at international, national and local levels) taught countries the importance of self-reliance in energy supply. Most countries will therefore use their domestic energy resources if these are known and abundantly available. However, over-reliance on one resource makes countries vulnerable to fluctuations in the availability of that resource. For instance, Feinstein and Johnson (2002, p. 5) mention that highly hydro-dependent countries such as Brazil, Columbia, Ghana, Zimbabwe, and Kenya have recently experienced problems in their energy supply due to droughts. This emphasizes the importance of using different resources in energy production. So self-reliance and diversification are essential in securing a continuous energy supply, even if this implies the inclusion of other than least-cost technologies in the energy infrastructure (Feinstein and Johnson (2002, p. 5); UNDP (1997, §1)). Nonetheless, many developing countries still heavily depend on oil imports for their commercial energy consumption, even though oil is notorious for its fluctuations in price (see Figure 1.3). The fluctuations in oil price also affect the viability of other infrastructure options; conventional infrastructures are usually based on oil, and the alternative infrastructures use the conventional infrastructure as a reference. Some alternatives are only viable if oil prices are high, so fluctuating oil prices increase the uncertainty surrounding these alternatives. In addition, high oil prices drain financial resources as well as foreign exchange reserves of oil-importing countries (World Bank (1994); OTA (1991, p. 19); Barnett (1990, p. 540)).

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[1] Biomass captures CO_2 during its growth, which is released again during the harvest. Depending on the way it is managed, biomass is renewable or non-renewable; extracting biomass from already existing resources without replacing new biomass would be non-renewable, whereas growing new biomass after harvesting will provide a continuous supply of biomass.

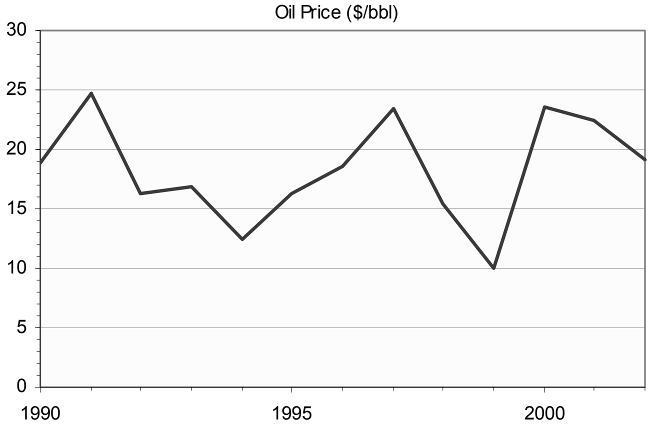

Figure 1.3. World spot prices of oil (in US$ per barrel) during the period 1990-2002. Source: EIA (2002d).

According to Feinstein and Johnson (2002, p. 5), another point of concern for many developing countries is technical know-how. Some resources require specific energy conversion technologies for which developing countries do not always have the skills and technical know-how available. So besides the dependency on fuel imports, a country can also become dependent on foreign technical know-how.

The international concern for the environment and climate change results in increasing international attention for the pollution caused by the energy sector, which is expected to increase further when developing countries attain a higher level of development, and thus a higher energy consumption. Currently, developing countries account for only 30% of the world's energy consumption, while they accommodate 80% of the world's population (UN (2001), EIA (2002c)). So if, for example, developing countries would manage to reach the same level of economic development as the industrialized countries have today, this would imply a tremendous increase in energy consumption: based on data from EIA (2000c), we calculate that the world primary energy consumption would more than triple (increase with a factor 3.5). Since world energy consumption is still heavily based on fossil fuels, this would thus imply a major increase in carbon dioxide (CO_2) emissions. This gas is emitted when fossil fuels are burned and is a major contributor to global warming. This is one of the reasons why many international lending agencies and institutions such as the World Bank, the World Energy Council (WEC), and the World Resource Institute (WRI) emphasize the importance of using energy infrastructures based on renewable energy sources and efficient energy technologies.

1.3.2. Energy Infrastructures

In this report, the term 'energy infrastructure' refers to the generation, transmission and/ or distribution of energy forms such as electricity, gas, or heat, and does *not* include any infrastructure related to the transport sector. The World Bank, in its *World Development*

Report 1994, has already demonstrated the importance of an adequate energy infrastructure for economic development. The energy infrastructures of most developing countries, however, perform poorly: costs are high, while energy supply is inefficient, unreliable, and a cause of environmental degradation (see among others: United Nations (1996); IVO (1996); World Bank (1994); OTA (1991)). According to the World Bank (1994, p. 4-7), the problems underlying the poor performance include:

- Insufficient maintenance of existing energy infrastructure, leading to low availability of installed capacity, blackouts, reduced lifetime of equipment, and unnecessary environmental pollution.
- Technical inefficiency, leading to a waste of natural and financial resources, and unnecessary environmental pollution.
- Misallocation of investments, leading to inappropriate infrastructure.
- Unresponsiveness to stakeholders, leading to inappropriate infrastructure.

Traditionally, the energy companies in developing countries are state-run monopolies that construct and operate large-scale energy generation systems and fully control the transmission and distribution of the generated energy. A centralized energy infrastructure has several advantages, most notably the economies of scale that can be reached with the large-scale systems. The large-scale systems also reduce the required back-up capacity and allow for high levels of reliability. In addition, pollution abatement measures are easier implemented (Feinstein and Johnson (2002, p. 5); Sanchez-Sierra (1991, p. 468)). An important advantage of state-run energy companies, according to Sanchez-Sierra (1991, p. 468), has been the relatively easy access of governments to funds from international lending agencies.

However, centralized energy infrastructure also has disadvantages (Feinstein and Johnson (2002, p. 5); UNDP (1997, § 2.3.1); World Bank (1994, p. 23); OTA (1991, p. 12); Sanchez-Sierra (1991, p. 468)). The focus on large-scale systems implies that new capacity is created in large increments, with large implementation periods (5-15 years), relying on long term projections of future economic conditions. These conditions can rapidly change in developing economies, frequently causing over- or undercapacity. Indeed, the central energy planners in developing countries have a hard time matching demand and supply (see also Section 1.4). But the main shortcoming put forward by the literature today is that the state-run monopolies are unable to come up with the financial resources for the necessary energy infrastructure investments. As already mentioned, a centralized energy infrastructure is highly capital intensive; the UNDP (1997, § 2.3.1) and Sanchez-Sierra (1991, p. 468) state investment cost in energy infrastructure accounting for up to 20%-25% of a developing country's total public investments, putting a substantial strain on national and foreign exchange reserves. Not surprisingly, the investments in energy infrastructure form a major component of the foreign debt in many developing countries.

The deteriorating financial and technical performance of the state-run monopolies, with declining efficiency and excessive mismanagement, have evoked a change in policy of most international lending agencies, and consequently a radical shift towards deregulation of the energy sectors in developing countries (Pandey (2002, p. 98); Turkson and Wohlgemuth (2001, p. 135); UN (1996, p. 254); World Bank (1994, p. 8-10), Sanchez-Sierra (1991, p. 468)). Many of the developing countries −whether or not urged by the lending agencies− are now in the middle of liberalizing and privatizing their energy sector in order to attract private capital and improve the efficiency and overall performance of the sector.

The United Nations (1996, p. 256) state that the reforms in the energy sector also change the way investments are made, while Turkson and Wohlgemuth (2001, p. 135) argue that because of these changes, the energy sector could move towards an infrastructure of decentralized energy systems[2]. Feinstein and Johnson (2002, p. 5) add that technological change has now 'redefined the scale at which efficiency and economy can be captured,' while the distributed energy systems, with their modular character and geographic dispersion, may offer advantages in energy security compared to the large-scale systems. Other advantages of small-scale systems include the relative ease with which they can follow demand, the step-by-step investment costs of new infrastructure, the relatively short construction time, no transmission costs or losses, and a relatively low impact on the environment. Also, a decentralized energy infrastructure easier allows for the use of locally available (often renewable) energy resources. Nonetheless, whatever energy infrastructure is constructed, it is generally preceded by the energy planning process, which is the topic of the next section.

1.4. Energy Planning: Matching Demand and Supply

Energy planning is used to match future energy demand and supply and can be done for various time-scales. For instance, energy companies generally use very detailed short-term 'engineering' models to match energy demand and supply within the next hours, days, weeks, or months. This type of planning usually only involves the already existing energy infrastructure. In this thesis, however, we focus on the medium-term (± 20 years) energy planning. This planning process involves choices concerning how the energy infrastructure will develop in the future in order to guarantee a continuous match of demand and supply. So it deals with choices concerning what energy resources and technologies will be used to expand or replace existing energy infrastructure.

In practice, the planning process for the medium term will start with an assessment of future energy demand. The demand side of the planning process involves projections or scenarios of how much energy will be demanded in the coming period, and in what form this energy is to be delivered (e.g., heat, electricity). The projections of energy demand set the

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[2] Decentralized energy systems are also called 'distributed', 'local', or 'small-scale' energy systems. The literature does not provide an unambiguous definition for these systems, but Turkson and Wohlgemuth (2001, p. 136) provide a synthesis of existing definitions from the literature by stating that these systems produce energy in relatively small amounts near to the consumer, either in isolation or connected to a distribution network.

conditions for the energy supply technologies. For instance, highly fluctuating but low energy demand will require relatively small-scale energy systems that can quickly respond to changes in demand. And systems that only generate heat are irrelevant if only electricity is demanded. So given the amount and forms of energy demanded, the relevant energy resources and technologies must be selected out of the range of possible options.

However, energy demand is not the only factor that determines the relevancy of energy technologies; the context in which technologies are to be applied is also important. The geographical or environmental context can exclude some technologies e.g., due to a lack of certain energy resources. Hydropower systems, for example, would be useless in the absence of water. But the social, technological, financial, and economical context can also influence the viability of technologies, as visualized in Figure 1.4.

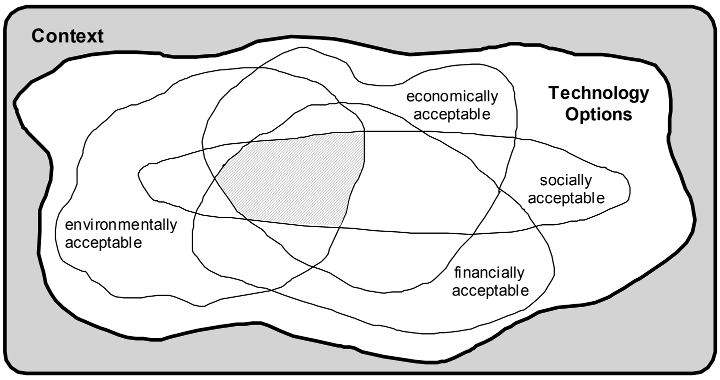

Figure 1.4. The relevancy of technology options depends on the environmental, social, financial, and economical context in which they are applied. The shaded area represents the technologies that fit well in a certain context.

The context is also reflected in the already existing energy infrastructure: the resources and technologies that are already in use influence the viability of new infrastructure, as a network of regulations, institutions, service, networks, experiences, and organizational structures is built around an infrastructure in order to reinforce the performance of that infrastructure (Smit and Van Oost, 1999, p. 56). So once an energy infrastructure is in place, it becomes increasingly difficult to switch to other resources or technologies, even if the existing infrastructure shows less desirable side effects.

Choosing the right infrastructure requires knowing what you want. But it also requires a careful assessment and weighing of the possible impacts of options *before* selecting and constructing the energy infrastructure. That is why energy planning is so important. Proper planning avoids situations in which planners are forced to make ad-hoc decisions that might later prove to be undesirable. It would be wiser to plan ahead, making well-weighed decisions about the desirability of certain development paths. Indeed, besides a proper assessment of future energy demand, the planning process should also be used to assess and compare the possible impacts of the relevant energy infrastructure options.

The World Resource Institute (1994, p. 8), however, states that energy planners in developing countries often lack knowledge on the range of energy technologies available, which limits their range of options to choose from. In addition, IVO (1996, p. 74) states that one of the main problems in energy planning is making the decision makers aware of the full range of energy technologies available. Also, developing countries lack information on the consequences or impacts of energy infrastructure options. Or as Barnett (1990, p. 539) puts it: developing countries lack 'comparative testing' of energy technologies, making it difficult for the energy planners to make informed choices. Similarly, the World Bank (1994, p. 17) states that the assessment procedures in many developing countries are inadequate, and misjudgments during the appraisal phase are frequent. Consequently, the energy planning process often leads to inappropriate energy infrastructures, as energy planners all too easily opt for the conventional technologies with which they have abundant experience.

Another problem, apart from the lack of information, results from the level at which energy planning takes place. The traditional state-run energy companies focus on the national level and tend to select large-scale complex projects (World Bank 1994, p. 86). However, as mentioned earlier, a rapid increase in economic activity is usually restricted to certain areas or regions of a developing country, which consequently experience a boost in energy demand. The focus on the national level makes it difficult for energy planners to adequately respond to rapid regional development, and the lack of an adequate response can adversely affect further regional growth. Were these regions to be served by local or decentral energy planning, the response would likely be faster and better fit to local circumstances and local concerns (World Bank, 1994, p. 73). National energy planning also tends to ignore small-scale energy technologies or local resources, as these are not easy to take into account at this level.

In addition, Turkson and Wohlgemuth (2001) and the United Nations (1996, p. 256-257) believe that the liberalization of the energy sector will also result in a need for a different planning approach, away from the centralized large-scale planning paradigm and towards more decentralized or local planning. However, little information is available in the literature on how local energy planning is done or should be done exactly.

Another issue concerns the fact that energy planning in developing countries is generally done by a select group of people from the state-run energy company. This select group determines the criteria for appraisal of the options and usually puts forward a 'best' option. However, the aspects taken into account are often restricted to financial and technical ones, sometimes extended with selected environmental impacts such as CO_2 emissions to comply with the requirements for funding of international lending agencies. Many other aspects are ignored, even though these aspects might later –during construction or operation– prove to be critical for the viability of the energy infrastructure. This is why more and more institutions, such as the World Bank, the United Nations, and the OECD, now acknowledge that participation of stakeholders or actors is necessary in order to guarantee that all relevant aspects are addressed during the planning process (see, for instance, Feinstein and Johnson (2002, p. 15); Schneider (1999); UNDP (1997, § 5.2); UN (1996, p. 257); World Bank (1994, p. 73-79), and Barnett (1990, p. 544)). The World Bank (1994, p. 17) even states that unresponsiveness to stakeholders is one of the key factors causing inappropriate energy infrastructures.

Apparently, the traditional approach to energy planning in developing countries is not well fit to serve rapidly developing areas that expect a substantial increase in energy demand. In addition, most existing energy models reflect the centralized approach to energy planning and appear to be ill-adjusted to conditions in rapidly developing regions of developing countries. So energy planners in developing countries do not have the proper instruments to support them in selecting local energy infrastructure.

1.5. Overview of Energy Issues in Developing Countries

In this chapter, we have already discussed that developing countries, in particular those with rapidly developing economies, have to deal with several energy related issues. First of all, energy is a necessary but not a sufficient requirement for development, implying that a developing country needs to invest in an adequate energy infrastructure to support further economic development, but cannot disregard other infrastructures that are equally important.

Currently, many developing countries heavily rely on only a few resources for their energy supply, which often have to be imported from abroad. Diversification and self-reliance in energy supply would make these countries less vulnerable to fluctuations in the supply or price of these resources and relieve the strain on foreign exchange reserves. However, there is a general lack of knowledge on the range of alternatives and the consequences associated with each alternative.

Also, the energy infrastructure in developing countries is usually centralized and controlled by a state-run energy company that focuses on large-scale energy systems. However, these energy companies are generally inefficient and lack financial means to invest in the highly capital-intensive, centralized infrastructure. Therefore, many developing countries are now in the middle of liberalizing and privatizing their energy sectors, in order to attract private capital and improve the efficiency of the sector.

The medium-term energy planning in developing countries, the focus of this thesis, also shows some shortcomings. Apart from a general lack of information during the planning process, energy planning is mainly done at the national level, focusing on only large-scale systems and only a few aspects. However, a (rapid) increase in economic activity is mostly restricted to certain areas *within* a country, which requires a shift from the large-scale, centralized planning towards decentralized or local planning that includes small-scale energy systems. The liberalization process might also require such a change in planning approach.

Concluding we can say that currently, energy planning is not well fit to serve rapidly developing regions of developing countries, while local energy planners do not have proper tools to support them in the energy planning process. Enough reason to look more closely at a decentralized approach to energy planning, and to investigate how a decision support method can best support the local planning process. This conclusion was also drawn by Van Groenendaal and Van Steenhoven (1996) in their project proposal underlying this research work. The framework of the research project is the topic of the next section.

1.6. Framework of the Research Project

1.6.1. Aim and Focus of the Research

This thesis is about energy planning in developing countries. More specifically, it focuses on energy planning in regions with rapid economic development that –as a result– require new energy infrastructure to meet the increase in energy demand. The reason for focusing on regions is that in the previous sections, we have seen that current energy planning is not well fit to serve rapidly developing regions: it focuses on the national level and ignores local energy resources and small-scale technologies, while only few aspects are taken into account. Furthermore, the existing energy models are not fit to support energy planners in responding adequately to an increase in energy demand in rapidly developing regions of developing countries.

This thesis will provide a new instrument that makes the energy planning process more transparent and allows the energy planners to make well-weighed decisions concerning the energy infrastructure on the medium term. A well-weighed decision implies that all relevant energy resources and technologies get a fair and equal chance in the decision process; that information is provided on the range of relevant energy infrastructure options *and* their consequences; and that a structure is provided to process new information and easily assess and compare the infrastructure options. Ultimately, the method will help steer the development of the energy infrastructure into a desirable direction. The main question addressed in this thesis is therefore:

What method allows for the inclusion of all relevant energy resources and technologies, and all relevant aspects in order to select an appropriate local energy infrastructure in rapidly developing regions of developing countries?

So the main part of this thesis will focus on designing a new decision support tool that allows for a proper identification, assessment, and comparison of relevant energy infrastructure options as well as their impacts. Note that terms such as ‘relevant’ and ‘appropriate’ need to be further defined, but this will be done in following chapters.

Apart from the main question, we can also distinguish several sub-questions, which will help in answering the main question:

I. What theories and tools already exist for supporting energy planning and what existing type of tool would best fit local energy planning in developing countries?
II. What are –in practice– the thresholds in the planning process concerning local energy infrastructure?
III. What other non-energy related theories provide useful information on steering the development of the energy infrastructure in developing countries on the medium term?
IV. What is required to make the method operational?

From a scientific point of view, this research hopes to contribute to a better insight in the complex interactions and processes associated with the selection of local energy infrastructure in developing countries. Moreover, it aims at supporting the entire energy planning process from start until finish. In addition, it attempts to build a bridge between theories of different disciplines that all have their own way of looking at the problems posed during the energy planning process. So rather than interpreting this work as an extension or innovation of one theory, this research must be seen as a synthesis of existing theories, keeping in mind that the total is sometimes more than the sum of its elements. Also, it provides a practical solution for the problem that some aspects are hard to grasp in a scientific manner and therefore usually left out of the analysis. Of course, before we can start answering the thesis questions, we need to define the ambiguous terms used in the thesis, not in the least because of the multidisciplinary nature of the research.

1.6.2. Definition of Terms

The research presented in this thesis is a synthesis of various theories from different disciplines. Throughout the years, each discipline builds up its own terminology, although many disciplines use the same terms. A complicating factor, however, is that the same term can have distinctly different meanings across disciplines. Also, different terms are used that actually represent the same phenomenon. Therefore, it is important to clearly define how terms are used in this thesis in order to avoid misinterpretations. For instance, it should be clear what we mean by ‘relevant actors’ or ‘relevant aspects’, and what ‘appropriate technology’ implies. For now, we will only define the general terms that are used throughout the thesis. Terms that need a more elaborate explanation or that are very specific are addressed in the chapter or section where they are first introduced.

Actors (also: Stakeholders)
Actors are also frequently referred to in the literature as ‘stakeholders’. In this thesis, actors (or stakeholders) are either individuals or groups of people (including companies, organizations, etc.) that represent certain interests related to the energy infrastructure, *and* are involved in or affected by the energy planning decision process or its outcome, *and* can influence the decision process.

Energy Form
The form in which energy is delivered to the end-user: electricity, heat, gaseous fuels (e.g., natural gas), liquid fuels (e.g., petroleum), solid fuels (e.g., coal), or mechanical power.

Energy Infrastructure
In this thesis, an energy infrastructure is defined as the total of buildings, energy systems, lines, pipes or other equipment, and the organizational structure that is required for the supply of energy to the end-user.

Energy Planner
A person that is involved in the process of matching future energy demand and supply. Note that an energy planner is not necessarily the same as a decision maker. Sometimes, a planner’s task is to provide a range of options from which the actual decision maker can choose. Nonetheless, during the planning process already many decisions need to be taken to arrive at this range of options.

Energy Service
An energy service is the activity for which the consumers demand energy. For instance, consumers demand gas to cook or heat their houses; they demand electricity to operate (electrical) domestic appliances or put on the lights when it gets dark. Note that energy services should not be confused with the economic term ‘services’ (as in ‘goods and services’) that is sometimes used by energy companies to refer to the support they have to offer to their customers.

Energy System
Energy conversion technology and all other equipment (hardware and software) necessary to make the technology work in practice.

Local Energy Planning
A decision process involving the establishment of goals, policies, and/ procedures in order to match future energy demand and supply on the local level and on the medium term. It includes projections or scenarios of energy demand, and the identification of (small-scale) energy systems that can supply the projected demand.

Region

The areas on which we focus in this thesis cannot not be uniquely defined in terms of –for instance– geography or population. Rather, a region is defined by way of its economic activity: there must be growth in economic activity in the region, while the existing energy infrastructure is not adequate to supply the (foreseen) increase in energy demand, implying that new energy infrastructure is required[3]. This thesis does not include the rural areas with no economic activity or energy infrastructure whatsoever. Furthermore, the region must have at least one entity with decision-making authority, such as an energy company or a municipality.

Other terms (such as appropriate technology, decision support tools, energy models, relevant actors, and actor preferences) will be defined in the chapters concerned.

1.6.3. Limitations on the Scope of Research

Similar to defining the ambiguous terms it is important to clearly indicate the limitation of scope: what is investigated, and what is left out of the research. Since most research is constrained in time, financial means, and manpower, there will always be a trade-off between the area covered and the detail in which aspects are analyzed. Carefully outlining the scope of research contributes to the efficient use of time, manpower, and money. Sometimes, however, the preliminary results force a rerouting of the research, which might affect the scope as well.

The multidisciplinary character of the research can easily lead to a broad but superficial analysis, and it cannot be expected that one person is an expert on all related disciplines. Nonetheless, we think the broad approach is necessary in order to capture the synergy that occurs between the theories of different disciplines and gain new insights. Given the constraints, we have tried to be as thorough and in-depth as possible, but unavoidably some aspects will only be touched upon and left for future research. The general limitations on the scope of research are given below. Other limitations are dealt with in the chapters concerned.

Time Scale

The focus is on medium-term planning (covering a period of about 20 years). This time period is believed to be best suited for steering the development of the energy infrastructure. For long-term periods the uncertainty about future economic, social and technological developments becomes too high, while the short-term period usually implies a direct extrapolation of past trends.

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[3] Note that most regions will also have the option of *importing* extra energy from grids that are already present.

Level of Analysis

The research focuses on regions within developing countries. Whether a region is classified under local level' or 'regional level' depends on the circumstances, because the definition for 'region' is not based on geographical characteristics. This makes it difficult to clearly distinguish between local and regional levels. Therefore, even though it is clear that 'local' refers to a smaller area than 'regional', we will use both terms interchangeably throughout this thesis.

Furthermore, although the analysis is not focused on the national level, it is sometimes worthwhile to describe the national context as well. That is, focusing on the local level contains the risk of incoherency on the national level. Without a proper national framework that sets conditions for local decision making, the sum of all the local decisions might turn out to be unfavorable for society as a whole.

No Substitution of Regional Supply Technologies

To limit the scope of research further, we will not consider the option of substituting already existing regional energy infrastructure (except, of course, in cases where existing equipment has exceeded its lifetime).

Applicability of the Method

The method described in this thesis cannot predict the future, nor does it decide for the energy planner which action or option is good or best. Although the focus is on regions in developing countries, it is not impossible that the method can also be used in regions of industrialized countries. This aspect is not investigated here, however. Furthermore, although the method is designed *for* developing countries, it is designed *by* someone from a 'Western' culture. Aspects typical for the Western (or more specifically: Dutch) culture might have influenced –unintentionally– how problems are identified and dealt with.

Testing of the Method

Given the time-constraints and the limitations in financial resources and manpower, it is impossible to actually prove that the proposed method is better than existing ones, especially since the method aims at supporting the entire planning process, which can take up to five years. So this research does not attempt to verify the method; a thorough validation of the method is left for future research. However, we will show that it is *plausible* that the method better supports the planning process than existing decision support tools do. Furthermore, to show how the method would work in practice, we will use a hypothetical (but realistic) example based on the data obtained in a field study in Costa Rica.

In the next section, we will discuss how we plan to answer the thesis questions that were posed earlier, and give an outline of the other chapters in this tehsis.

1.6.4. Research Methodology & Outline

The approach applied in this research is multidisciplinary; it uses various theories from different disciplines (e.g., economic, social, technological, historical) to support the choices made in designing the new method. An extensive survey of the literature, two field studies and many interviews with experts and stakeholders will provide the necessary data to determine how the energy planning decision process evolves in theory and practice, and how it can best be supported.

As an orientation on the subject of supporting energy planning we will start with a more detailed literature study on existing decision support tools (Chapter 2). The study will result in an overview of methods and models for energy planning and provide some general requirements for our new support method. This will help us to set up a first draft for supporting local energy planning. In Chapter 3 this draft is compared to the results of a first field study, which was conducted in Brabant, the Netherlands, to get better insight in how local energy planning is done in practice. The adjustments in the draft that follow from the field study are put into context in Chapter 4, which presents various non-energy related theories. Consequently, we will give a revised version of the decision support method in Chapter 5. As discussed in the Section 1.6.3, the actual testing of the method lies outside the scope of this research, but we will test the assumptions underlying the method in another field study, this time conducted in Costa Rica (see Chapter 6). This will lead to the final version of the new method. Chapter 7 gives an example of how the new method can be made operational, by describing the construction of a tool based on data from the field study in Costa Rica. The tool is demonstrated in Chapter 8, while the last chapter (Chapter 9) presents the conclusions that can be drawn from the previous chapters and contains suggestions for further research.

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2

Literature Study: Tools for Supporting Energy Planning

> *The way decisions are talked about is not necessarily the way decisions are made.*
>
> Bell et. al. rephrasing March in *Decision Making* (1988, p. 18)

2.1. Purpose of the Literature Study

The literature describes several constraints regarding the application of energy models in developing countries. The purpose of this chapter is to examine these constraints in more detail. However, the literature also shows that many different types of models exist, and to avoid ‘reinventing the wheel’ we will first search for elements in existing models that can be used for local energy planning in developing countries. For this, we require a characterization of model types in order to know which constraints apply to what type of model. This characterization helps us to identify useful model characteristics and will give us a better insight in the types of energy models suitable for local energy planning in developing countries. In the following sections, we first discuss energy planning as a decision-making process (§ 2.2), and how it is currently supported with decision support tools. We discuss the constraints of these tools (§ 2.3), and explain why we distinguish between methods and models (§ 2.4). An overview of the types of existing methods and models is given in Section 2.5 and Section 2.6 respectively. Section 2.7 concludes this chapter with a list of model requirements for supporting local energy planning in developing countries.

2.2. Energy Planning as a Decision-Making Process

Generally speaking, a planning process can be seen as a decision-making process, which –in turn– is defined as the process of making choices between alternatives. The decision-making process usually precedes the implementation of a selected alternative and, consequently, the operation, controlling, and evaluation of that alternative (Demkes, 1999, p. 30). However, the implementation and following steps are by definition not part of the *planning* process. The literature on decision-making divides the decision-making process into 5 main stages (see, for example: FAO, 1986, p. 18; APDC, 1985, p. 82; World Bank, 1999b):

I. Problem identification
II. Identification of alternative options
III. Assessing and comparing options
IV. Appraising options
V. Selecting an option

Energy planning in this context is the decision-making process of selecting the preferred local energy infrastructure to invest in. Adequate energy planning gives structure and support to the decision-makers and enables them to match future energy supply with future energy demand. Usually, various energy systems can be identified as alternative options to meet future energy demand, but not all of them are equally relevant i.e., not all of them meet the conditions or criteria set by the energy planners. And as explained earlier in Chapter 1, the relevancy of an option also depends on the local context in which it is applied.

In order to determine the appropriateness of the alternative options, the impacts of each option must be assessed and compared with the impacts of other options. The comparison of the impacts may pose problems, especially in situations where there is no universal measure to which all impacts can be converted. This might also cause a bias in the appraisal towards options that score well on the quantifiable impacts, as people have a tendency to favor quantifiable impacts (especially those expressed in monetary terms) at the expense of other less tangible impacts. The comparison of impacts and appraisal of the options consequently leads to the final selection of an option. So the energy planning decision-making process involves the following issues:

- Determining the future amounts and forms of demanded energy
- Identifying supply options that can meet future demand at all times
- Finding ways to identify and express impacts of options
- Finding ways to mutually compare the options
- Appraising the options
- Selecting the final energy infrastructure

For each of these issues, tools are developed to help energy planners make decisions. These decision-support tools, however, have several constraints, particularly when applied to local energy planning in developing countries. The next section will discuss the constraints of these tools as mentioned in the literature.

2.3. Constraints of Existing Energy Planning Tools

Within the context of this thesis, decision support tools for energy planning are –often computerized– models that help energy planners in matching demand and supply. According to Sanchez-Sierra (1991, p. 465), the real interest of developing countries in energy planning models began around the first oil crisis in 1973, when the high oil prices suddenly caused deterioration in the balance of trade of many oil-importing countries. Sanchez-Sierra states that most early models were based on linear programming techniques that helped determine the least-cost option for the required expansion of the generation capacity. These models were not specifically designed for developing countries; in fact, they were first developed and used in the industrialized countries, and passed on to developing countries when the latter showed interest as well.

Today, the situation clearly has improved: many types of models are available, each providing support in its own way. However, as already mentioned in Chapter 1, most models still reflect the commonly applied centralized approach to energy planning, while the literature on supporting *local* energy planning in developing countries proves to be rather scarce. This section discusses the constraints of existing models as mentioned in the literature. However, it is important to keep in mind that no tool can determine what decision is ‘good’ or ‘best’. This depends on the (ethical) viewpoint of the model users and on the values accounted for in the analysis. So models cannot determine the desirability of the solutions they provide; the decision-makers ultimately determine what the ‘best’ options is. In addition, it is impossible to capture every aspect of reality in a model. At best, models provide a (highly) simplified representation of parts of reality. Apart from these universal limitations of models, Biswas (1990) and Van Beeck (1999; 2000, p. 4-6) mention several other constraints related to the use of decision support models in general and energy models in particular:

- *Context-related issues are not addressed*
  An important drawback of most models is that they mainly focus on financial and technical aspects, and are not designed to include the interest of actors other than the investor. Van Groenendaal (1998, p. 133) and Arrow et. al. (1996, p. 63) argue that in reality, different parties are involved in the decision process, each having their own objectives. Therefore, the outcome will always be some compromise. Focusing only on the (financial) interest of the investor easily leads to exclusion of relevant aspects in

decision making, or –at the other end– the rejection of the model itself. Biswas calls this: “the lack of understanding the decision making process”. This lack of understanding results in models that do not satisfactory reflect the real situation, so that decision-makers do not get adequate support in answering the questions actually posed. An example is the cost-benefit analysis, an analyzing technique that is heavily promoted by the World Bank. But even the World Bank (1994, p. 85-86) admits that this appraisal technique is not widely applied in practice, even though it is well established and documented. The narrow focus on only few aspects is partly due to the fact that many context-related[1] issues are often ‘intangible’ and cannot easily be incorporated in a formal analytical framework. However, simply ignoring these context-related issues may well threaten the viability of the energy systems, or lead to the implementation of undesirable ones.

- *Impacts need to be quantifiable*
  Biswas states that models only model what can be modeled, implying that unknown aspects cannot be taken into account. Many models, however, only include aspects that can easily be modeled (i.e., the quantifiable aspects). The result is an overemphasis on financial and technical aspects. Indeed, in the strive for optimal solutions, many model developers use a least-cost approach, which has resulted in a systematical exclusion of not readily quantifiable impacts. In particular many social and environmental aspects of energy systems –even though they are well known– are not incorporated in models because they cannot be quantified in a satisfactory manner. This does not mean, however, that these aspects are not important. Also, the focus on quantified aspects can easily give a false sense of scientific accuracy; there is no guarantee that the outcome reflects the aspects that really matter. It also creates a bias in the appraisal of options, favoring those options that score well on quantifiable impacts. Certainly, the world would become less complex if all things could be reduced to certain numbers or certain amounts of money. However, Van Groenendaal (1998, p. 133) is right when he argues that in reality hardly any problem can be reduced to a logically consistent model with a unique solution. Furthermore, most models work with *predefined* indicators, which are used to assess the impacts of options and compare them mutually. These predefined indicators merely reflect what the model developers perceived to be important at the time, while they make the model inflexible towards adjustment to local conditions and concerns that arise during application of the model.

- *Technology is treated as a black box*
  Many energy models, especially those developed from an economic perspective, represent ‘technology’ in a highly aggregated manner i.e., treating it as a black box. These models are unable to distinguish between different energy systems, even though these systems have distinctly different impacts on the environment and the society in

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[1] The context in this case refers to the interrelated technological, economic, environmental, political, social, cultural, and institutional factors in a society or group.

which they are applied. Comparing between options and selecting an appropriate energy infrastructure requires knowing what is hidden inside the black box.

- *Local resources and small-scale energy systems are neglected*
  Since most energy models reflect the commonly applied centralized approach to energy planning, they focus on the national level. By doing so, they often ignore small-scale technologies and local (renewable) resources, largely because these options depend on local conditions, which are not easily incorporated in national models. Nonetheless, local resources may offer several advantages to national resources: they do not require an infrastructure for transport, and many of the local resources are renewable, free to use, and relatively clean. As mentioned in Chapter 1, small-scale energy systems also offer several advantages compared to large-scale systems: their modular character allows for flexible expansion and step-by-step investment costs (putting less strain on budgets and foreign capital); they generally have a short construction time; they are easier adaptable to local circumstances; and a transmission grid for the generated energy is usually not necessary.

As stated in Chapter 1, most of the support tools for energy planning are not specifically designed for developing countries. So in addition to the more general constraints of (energy) models listed above, there are also other constraints that are related to application of models *in developing countries* (see, for example: Biswas, 1990; IVO, 1996; Van Beeck, 1999; Van Beeck, 2000; World Bank, 1994):

- *Lack of information on the range of options*
  In general, energy planners in both developing and industrialized countries have only limited information available; they lack information on the range of technology options, especially concerning the unconventional technologies. However, planners in industrialized countries have easier access to new information than their colleagues in developing countries. The costs of gathering reliable up-to-date information can be considerable in developing countries, resulting in decision-makers opting for the well-known or 'proven' technologies even if potential benefits of other technologies are believed to be higher (IVO, 1996, p. 33). Many models reflect this conservative attitude by providing information on only a few widely applied energy technologies. Nonetheless, for well-weighed decisions on the future development of the energy infrastructure, it is necessary to assess all relevant infrastructure options, including the less familiar (but commercially available) ones. Providing information on the range of options is just as important in cases where the energy planner is not the same person as the decision-maker. In those cases, the planners will usually have to present the real decision-makers a list with alternatives (and consequences) to choose from.

- *Applicability to developing regions is low*
  The models that focus on the national level often use aggregated data and extrapolations of past trends, and cannot account for the specific characteristics of regions with rapid economic development. In developing countries, many data become unreliable if used at a less aggregated level, while the conditions that are normally assumed constant in models (e.g., elasticities), are rapidly changing in these regions.

- *Uncertainty is high*
  According to Pandey (2002, p. 102), an important difference between industrialized and developing countries is that the latter, in particular those with rapid development, generally face much greater uncertainty. Especially in the areas of infrastructure development, economic development, regulations and policies, prices of goods and services, and demand for goods and services. Uncertainty complicates the use of models, in particular forecasting ones. A good example is a survey of the World Bank (1994, p. 17) revealing that energy demand was consistently overestimated –on average– by 20 percent over a 10-year period, leading to overcapacity and overestimated revenues.

- *Poor data availability and reliability in developing countries*
  Most existing models require a considerable amount of (quantified) data in order to perform their analysis. Data collection is always time-consuming, but even more so in developing countries. Biswas (1990) states that many data in developing countries simply do not exist, while the data that do exist are not easily available due to poor or non-existent management of data, rivalry between ministries and/or institutions, unnecessary classification of data as ‘secret’ or ‘confidential’, and official apathy. In addition, there is no guarantee that the obtained data are indeed reliable. This lack of reliable data poses a severe constraint on the use of almost all models in developing countries.

Not every constraint mentioned above applies to every model; there are many different types of models and each model has its own characteristics. Also, some constraints relate more to the *method* that is applied than to the *model*, although most models are associated with a particular method. The distinction we make between methods and models is discussed in the next section (§ 2.4). In order to know which constraints apply to what type of method or model, we present an overview of the method types (§ 2.5), as well as an overview of the characteristics of energy models (§ 2.6). These overviews help us in determining which method types and model characteristics are suited for local energy planning in developing countries.

2.4. Methods versus Models

Until now, we have used the terms ‘method’ and ‘model’ interchangeably, which is common usage in many disciplines. However, for the sake of clarity and to avoid confusion in terminology, in the remainder of this thesis we would like to make a distinction between methods and models. The reason for this is that we want to distinguish between the conceptual framework for structuring the decision process on the one hand, and the way things are calculated (operationalized) on the other. So in the remainder of this thesis, we use the term ‘method’ for a conceptual framework, while the term ‘model’ refers to the (computerized) calculation procedure or format that is used to facilitate the use of the method in practice. Models, from this perspective, are thus *part of a method*, as visualized in Figure 2.1.

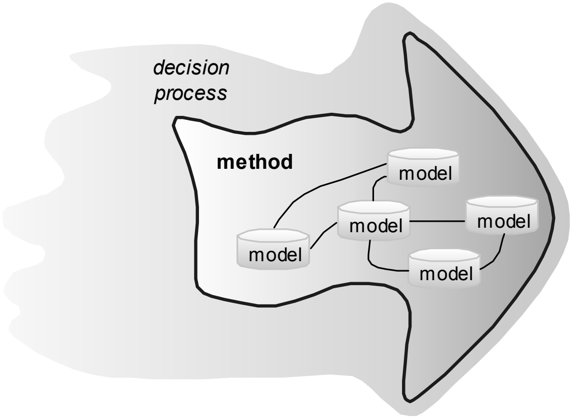

Figure 2.1. Distinction between method and models as tools that support the decision-making process.

So the proposed distinction implies that both methods and models can support energy planning. Note that the term ‘decision support tool’ does not imply a distinction, and can refer to either a method (including its models) or a single model. Usually, the conceptual framework (method) consists of a transparent, logical structure that divides the decision process into several concrete steps. This way, different alternatives and their consequences can be systematically analyzed and compared in an explicit and efficient manner. The (computer) models can then facilitate the actual implementation of the method steps. Since models are part of a method, the assumptions underlying a particular method also hold for the models. Next, we discuss different method types for decision-making (§ 2.5), followed by an overview of the characteristics of different energy models (§ 2.6).

2.5. Method Types for Decision Making

According to Bell et. al. (1988, p. 16-18), the literature commonly cites two types of methods for decision-making: *descriptive* methods and *normative* methods. Bell et. al. add a third type of method, which they call the *prescriptive* method[2]. Each type of method addresses a different question:

- The descriptive method focuses on the question how and why people think and act the way they do, so how people actually make decisions. This type of method is based on empirical analysis and is validated by the extent to which the methods correspond to observed choices. Most descriptive methods have a background in psychology and behavioral science.

- The normative methods attempt to capture how ideal decision-makers might behave, and propose rational, logically consistent procedures for decision-making. So normative methods deal with how people should make decisions. Validation is determined by theoretical adequacy i.e., the degree to which the methods provide acceptable idealizations or rational choice. Traditionally, statistics, mathematics, and economics provide the disciplinary background for the normative methods.

- The ‘prescriptive’ methods –as defined by Bell et. al.– are concerned with the question of how to improve the quality of real decision-making; how can real people be helped and trained to make good or better decisions? These type of questions are often addressed in operations research and management science. Bell et. al. state that good advice or support has to be tuned to the needs, capabilities, and ‘emotional makeups’ of the individual decision-makers. If decision-makers interact and depend on each other for the final outcome, the required support becomes even more complex. The pragmatic value –i.e., the ability to help people make better decisions– serves as a validation of a method. However, Einhorn and Hogarth (1988, p. 137-138) state that it is not easy to prove that a particular prescriptive method has improved the quality of decision-making.

Demkes (1999, p. 25-30) describes another way to categorize methods, in particular methods related to investment decisions. He mentions three categories of methods:

- The rational or (bounded) rationality methods
- The political methods
- The chaos methods

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[2] Bell et. al. acknowledge that it is common in economics to use the terms ‘normative’ and ‘prescriptive’ interchangeably, but they prefer to treat the terms quite distinctly, and we follow their line of thinking here.

The methods based on *rational behavior* have a normative approach and a background in neo-classical economic theory. They provide optimal solutions, but the conditions that have to be met are very strict. These conditions or presumptions include: there is only one single decision-maker or a perfectly cooperating group; alternatives are limited and consequences are known;
consequences of alternatives are measurable and comparable; preferences and valuations are consistent and choices are rational; and uncertainties are quantifiable (Arrow, 1996, p. 62).

In practice, the strict assumptions of rational methods are hardly ever met. Therefore, the concept of 'bounded rationality' was introduced, first by Herbert A. Simon in 1955. People, and therefore decision-makers, have limited capacities and cannot overlook the complexity of a problem, nor the range of all possible alternatives. Available information is not always complete, and not always correctly interpreted. Also, the actions following from the available information are not always appropriate. So people can behave rational, but only within certain (mental) boundaries. Bounded rationality also acknowledges that there are costs associated with searching and processing information. As a result, decision-makers stop searching for more information as soon as they are satisfied with the obtained solutions, instead of searching until an optimal solution is reached. This strategy is referred to as satisficing behavior.

Demkes states that methods with a *political* approach are descriptive of nature and provide a representation of the subjective manner in which the real decision process evolves. In general, different stakeholders are involved in the decision process, and their (often) conflicting aims can harm the process. Political methods help identify and minimize potential conflicts in an early stage, and take into account the role of power and political behavior in the decision process. The stakeholders do not necessarily act rational, and the decision process usually involves negotiations to reach a final solution. Uncertainty can influence the process and affect the role and power of stakeholders, depending on their capabilities to deal with it. Stakeholders can directly influence their role and power by withholding or sharing information. However, obtaining complete information is perceived to be unattainable, so optimal or 'best' solutions are rare in political methods.

The *chaos* methods are descriptive and used when alternatives are unclear, participants spend a fluctuating amount of time and effort on the process, and choices are inconsistent and not well-defined. However, Demkes believes these methods provide little structure to the decision-process and thus are not suited to help decision-makers choose between investment alternatives.

Generally, each of these method types make use of models, and these models can, in turn, be divided into several types or categories. The characteristics of energy models are discussed in the next section.

2.6. Characteristics of Energy Models

An overview of the different types of energy models can give us information about which model characteristics are useful in supporting local energy planning, thus prevents us from 'reinventing the wheel' (although the latter –in another context– can be a valuable learning experience as well).

When examining energy models, there are general characteristics that are shared by all models. For instance, any model will always be a simplification of reality, and will only include aspects that could be modeled *and* were perceived as important at the time of construction. Furthermore, Grubb et. al. (1993, p. 432-433) mention that any model dealing with future situations unavoidably makes use of estimates and assumptions, which may or may not turn out to be valid under the circumstances in which the model is applied.

When characterizing energy models, there are many ways to do so. For instance, Hourcade et. al. (1996, p. 283-286) characterize models according to three main dimensions, namely the *purpose* of the models, their *structure*, and their *external assumptions*. Grubb et. al. (1993, p. 432-446), on the other hand, use six dimensions to classify energy models, including 1) top-down vs. bottom-up, 2) time horizon, 3) sectoral coverage, 4) optimization vs. simulation techniques, 5) level of aggregation, and finally 6) geographic coverage, trade, and leakage. Yet other authors use distinctions based on, for instance, the applied mathematical techniques, the degree of data intensiveness, the degree of model complexity, or the model flexibility.

The characterization of model types outlined in this thesis is a synthesis of the ways mentioned in the literature[3]. Based on this literature, we will use 10 ways of characterizing energy models:

I. The Perspective on the Future
II. The Specific Purpose
III. The Model Structure: Internal & External Assumptions
IV. The Analytical Approach: Top-Down vs. Bottom-Up
V. The Underlying Methodology
VI. The Mathematical Approach
VII. Geographical Coverage
VIII. Sectoral Coverage
IX. The Time Horizon
X. Data Requirements

In the following sections we will discuss each of these ways in more detail. It should be noted, however, that this list of ways is not meant to be exhaustive and does *not* imply that ways are independent of each other. In fact, many models will have the same combination of

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[3] The literature on energy model characterization used here include: Vogely (1974), Meier, (1984), APDC (1985), Munasinghe (1988), Kleinpeter (1989), World Bank (1991), Grubb et. al. (1993), IIASA (1995), Kleinpeter (1995), Hourcade et. al. (1996), World Bank (1999a, and 1999b), and Van Beeck (1999).

characteristics. For example, the underlying methodology generally often implies a certain analytical and mathematical approach, which also has consequences for the model structure. Nonetheless, we believe that these ten ways of characterization will help discriminate between the different models mentioned in the literature so that better insight is gained in what they stand for. Appendix C gives concrete examples of the characteristics of some existing models.

2.6.1. The Perspective on the Future

The first way to characterize energy models is according to the model's perspective on the future i.e, how the model addresses the future. Hourcade et. al. (1996, p. 283-284) identify three perspectives of energy models:

- *To predict or forecast the future*
  Forecasting models are usually only applied for analyzing relatively short-term impacts of options because the model outcomes are based on an extrapolation of past trends. A prerequisite for such an extrapolation is that critical development parameters (e.g., elasticities) reflected in historical data remain constant in the future. This approach is mostly found in short-term econometric demand models and requires an endogenous representation of economic behavior and general growth patterns. Other examples of forecasting models are the technically detailed models that determine how much energy has to be generated to match demand at the short term (e.g., hours or days). Note that forecasting models cannot capture or predict discontinuities in trends.

- *To explore the future (scenario analysis)*
  Scenario analysis explores the future by constructing a limited number of 'intervention' scenarios, which are then compared with a 'business as usual' reference scenario. The intervention scenarios are only relevant in the context of the reference scenario and rely on assumptions rather than parameters extracted from past behavior. Generally, these assumptions include economic behavior, physical resource needs, technical progress, and economic or population growth. Economic behavior is usually represented or simulated either by a 'maximizing utility' approach or in terms of technology adoption processes. Sensitivity analyses are essential to examine the effects of small changes in the assumptions. The scenario analysis approach can be used in the so-called 'bottom-up' models as well as the 'top-down' models[4].

- *To look back from the future to the present ('backcasting')*
  The purpose of backcasting models is to construct visions of desired futures by interviewing experts in relevant disciplines. After a desired future is constructed, the model helps to look back from the future to the present to determine the required

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[4] See Section 2.6.4 for an explanation of bottom-up and top-down models.

changes needed to accomplish such a future. This approach is often used in studies on alternative energy futures. This perspective can also be used to assess the long-run (economic) consistency of alternative scenarios in exploration studies. This way, a ‘bottom-up’ approach can be linked to a ‘top-down’ approach.

2.6.2. Specific Purposes

Models are usually developed to address specific questions and are therefore only suitable for the purpose they were designed for. The World Bank (1991) –among others– warns that incorrect application of a model may result in misinterpretations and wrong conclusions. These mistakes cannot be ascribed to poor model functioning; they are the responsibility of the model users. So the second way to characterize energy models is according to their specific purposes, which include energy demand, energy supply, impacts assessment, and appraisal of options.

- *Energy Demand Models*
  The demand for energy depends on economic conditions. Energy demand models focus on either the entire economy or a particular sector of the economy, and help to determine future demand. Demand models usually regard demand as a function of changes in population, (per-capita) income, and energy prices. Other factors that can influence energy demand include (among others) the degree of urbanization and the electrification rate of a region or country. Not all models include all forms of energy demand. In fact, many models focus exclusively on electricity. On the other hand, some models that address ‘energy’ as a whole, cannot differentiate between different forms of energy and thus do not deal with the fact that not all energy forms are suited for certain purposes (e.g., supplying heat is useless for operating electrical appliances).

- *Energy Supply Models*
  The purpose of supply models is to help select proper energy technologies that can supply the demanded energy. They generally allow for a detailed description of different technologies and mainly focus on technical aspects, but often also include financial aspects to rank technologies in order of least cost. More detailed supply models distinguish between the different forms of energy (electricity, heat, fuels) that need to be supplied.

- *Impact Assessment Models*
  Impact assessment models assess the consequences of selecting certain options. The consequences (impacts) are caused by the energy systems, but may also be a result of certain policy measures. Almost all models include indications of (monetary) costs and benefits as impacts. Other impacts may include changes in the economic situation (e.g., employment), changes in the social situation (e.g., distribution of wealth), or changes in

health and the environment (e.g., avoided deaths, emissions, solid or liquid waste, biodiversity).

- *Appraisal Models*
  Appraisal models help decision-makers to compare (the impacts of) the options and most models will also rank the options in order of preference. Appraisal is generally done according to one or more preset criteria, of which efficiency (technical as well as financial) is the most commonly used. Even if the analysis includes only one option, the appraisal step will have to consider the alternative of *not* selecting the option, and the consequences associated with that choice. A very important aspect in appraisal is the sensitivity of the outcomes to (small) changes in the input variables. The sensitivity analysis might result in the choice for less (or more) stringent criteria, and this, in turn, can influence the scores of an option on other criteria. For instance, relaxing a 'reliability' criterion from 100% to 90% may reduce costs considerably. For the planner it is important to know how the scores on other criteria are affected if one of the criteria is altered.

Although models exist that focus on one aspect only (such as utility expansion models or environmental impact models) most models today combine several specific purposes in an integrated approach. Demand-supply models and impact-appraisal models are common examples of integrated models, but an integrated approach is also required to study energy-economy-environmental interactions. Some models are constructed as a modular package, which enables the planners to use only those modules (sub-models) that are relevant.

2.6.3. The Model Structure: Internal and External Assumptions

Besides the perspective on the future and the specific purpose, models can also be categorized according to their structure, more specific the assumptions on which the structure is based. When constructing a new model, developers have to make decisions concerning the assumptions that will be embedded in the model structure (implicit or internal assumptions) and those that are left to be determined by the user (i.e., external or input assumptions). Hourcade et. al. (1996, p. 284-285) distinguish four independent dimensions to characterize the structure of models: the degree of endogenization; the description of the non-energy sector components of the economy; the description of energy end-uses; and the description of energy supply technologies. Each of the four dimensions has a range from 'more' to 'less' and each energy model can be ranked somewhere on that range.

- *The degree of endogenization*
  Endogenization means the attempt to incorporate all parameters within the model equations as a way to minimize the number of exogenous or external assumptions.

Predictive models have a high level of endogenization regarding consumer or market behavior, while exploring and backcasting models use external assumptions in order to better incorporate the discontinuities in historical patterns of behavior.

- *The description of the non-energy sector components of the economy*
  Non-energy sector components include investment, trade, consumption of non-energy goods and services, income distribution, and more. The more detailed the model's description of the non-energy sectors, the more suitable the model is for analyzing the extent to which energy policy measures or energy technology investments affect the entire economy.

- *The description of energy end-uses*
  The more detailed the model's description of energy end-uses, the more suitable the model is for analyzing the technological potential for energy efficiency and for differentiating between alternative energy supply technologies.

- *The description of energy supply technologies*
  A detailed description of supply technologies is needed to analyze the differences in impacts of these technologies as well as the technological potential for fuel substitution. Most models with an economic background, however, represent 'technology' in a highly aggregated manner, treating it as a black box. This makes these models less suited for analyzing different supply technologies.

Assumptions or parameters that are not embedded in the model, the *external assumptions*, will have to be determined by the model users. According Hourcade et. al. (1996, p. 286), external assumptions commonly include assumptions about:

- *Population growth*
  Other things being equal, a growth in population increases the demand for energy, but there is no straightforward formula to determine the exact amounts (and forms) of energy demanded if the population increases. Furthermore, energy demand also depends on, for instance, per capita income. Assumptions are needed to describe the link between population growth and increased energy demand.

- *Economic growth*
  Economic growth generally causes an increase in activities that require energy. This does not imply, however, that energy demand must increase as well; an increase in energy efficiency might offset the increase in demand. Again, there is no simple formula to determine the relationship between the economic growth and energy demand. Note that another consequence of economic growth is that it generally reduces the economic lifetime of energy-using equipment.

- *Energy demand*
  Energy demand is influenced by structural changes in an economy (different sectors have different energy intensities), but also by the choice of technologies, the level of energy efficiency, and the rate of electrification. In addition, per-capita income and the degree of urbanization affect the demand for energy.

- *Energy supply*
  Energy supply will always be related to certain amounts (and forms) of demanded energy. The supply options are determined by availability of resource as well as by the energy technologies that are commercially available. Assumptions usually concern aspects such as the conversion efficiency or the capacity factor of technologies.

- *Price and income elasticities of energy demand*
  Elasticities measure the relative change in energy demand, given relative changes in energy prices and in household incomes. Higher elasticities imply larger changes in energy demand when incomes change.

- *Existing tax system and tax recycling*
  Taxes can have large impacts on the total costs of energy systems, from a financial as well as an economic perspective.

If *all* the parameters of a model are determined exogenously, the model would be no more than a calculator, albeit an extremely flexible one. On the other hand, there always has to be at least one external parameter to get a specific outcome. In practice, energy models will lie somewhere between these two extremes, depending on the number of equations they use.

2.6.4. The Analytical Approach: Top-Down vs. Bottom-Up

The forth way of model characterization concerns the analytical approach i.e., whether the model can be characterized as top-down or bottom-up. The terms top-down and bottom-up are often used in the literature, so we will discuss these types of models in some more detail. The early top-down models typically showed a high degree of endogenization and included a description of other sectors, while the early bottom-up models better described energy end-use and energy supply technologies. Today, attempts are made to combine both approaches into a ‘hybrid’ model (such as the MACRO/MARKAL model), but this proves to be difficult. Nonetheless, many top-down models now use simulation, a technique that used to be restricted to bottom-up models only.

The distinction between top-down and bottom-up models is particularly interesting because the two model types tend to produce different outcomes for the same problem[5]. Hourcade et. al. (1996, p. 281-289) and in particular Grubb et. al. (1993, p. 432-446) provide useful information on this subject. According to Hourcade et. al., the differences in outcomes of top-down and bottom-up models stem from the distinct manners in which they treat the adoption of technologies, the decision-making behavior of economic agents, and the actual operation of markets and economic institutions over a given period of time.

Grubb et. al. (1993, p. 433-437) state that the top-down approach is associated with –but not exclusively restricted to– the 'pessimistic' *economic paradigm*, while the bottom-up approach is associated with the 'optimistic' *engineering paradigm*. Therefore, the latter is also referred to as the *engineering approach*. The economics paradigm regards 'technology' as a set of techniques by which inputs such as capital, labor, and energy can be converted into useful outputs. More efficient techniques will require fewer inputs for the same output, although the distribution of input shares may vary. For instance, an efficient technique can either use very little energy, or use very little of other inputs. So a purely economic top-down model has no explicit representation of technologies, but uses elasticities or other aggregated parameters that implicitly reflect the technologies. Stated otherwise, technology is treated as a black box, and the technically best techniques are identified by observing market behavior.

The engineering paradigm, on the other hand, gives a detailed description of the various techniques available in order to identify possibilities for improvement. This paradigm disregards market behavior: the best technologies are the state of the art that scientists and engineers can deliver, regardless of whether the technologies are profitable or commercially available. This implies a gap between the 'best' technologies from an economic top-down viewpoint and the 'best' technologies in the engineering paradigm, since the latter tends to ignore existing constraints in applying new technologies, while the economic paradigm is based on market behavior, which usually lags behind the technical possibilities. According to Grubb et. al. (1993, p. 434-435), the constraints in applying new technologies include hidden costs, costs of implementation measures, market imperfections, macro-economic relationships (multiplier effects, price effects), and macro-economic indicators (GNP, employment). These constraints determine actual market behavior and therefore, models that are based on actual market behavior automatically include the existing constraints. However, advocates of the engineering approach argue that appropriate policy measures would substantially reduce the constraints associated with state-of-the-art technology, making existing consumer behavior no longer an adequate measure. So the bottom-up models are, generally speaking, more optimistic about the technological possibilities than the top-down models.

Top-down models generally use aggregated data to examine interactions between the energy sector and other sectors of the economy, and to determine the overall macro-economic performance of the economy as a whole. For this, the behavioral relationships need to be endogenized as much as possible. Past behavior can then be extrapolated into the future, which makes top-down models suitable for predictive purposes on the short term.

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[5] However, the 'hybrid' models that combine the two approaches imply that differences in outcomes are more likely the result of differences in external assumptions than in model structure (see Pandey, 2002, p. 102).

In contrast, most bottom-up models exclusively focus on the energy sector, and use highly disaggregated data to describe in detail the energy end-uses and technological options. Accorsing to Hourcade et. al. (1996), the bottom-up models that use a normative method provide an estimate of the technological potential: they examine the effects of using only the most efficient technologies. Bottom-up models combined with a descriptive method, on the other hand, provide practical estimates of the technology mix resulting from decisions that are based on factors such as complex preferences, intangible costs, capital constraints, attitudes to risk, uncertainty, and market barriers. As a consequence, descriptive bottom-up models are typically less optimistic than normative ones. In a sense, the descriptive models tend towards forecasting the future, and can be seen as an attempt to bridge the gap between the engineering paradigm and the economic paradigm, while prescriptive bottom-up models tend more towards exploration.

Concluding we can say that the distinction between top-down and bottom-up models can generally be typified as the distinction between aggregated and disaggregated models, or as the distinction between models with a maximum degree of endogenized behavior and models with a minimum degree. Furthermore, top-down models are generally used for prediction, while bottom-up models are mainly used for exploration. Top-down models –due to their forecasting nature– can only be used if there are no discontinuities in historical patterns, while bottom-up models are only suited if interactions between the energy sector and the other sectors are negligible. The different aspects associated with top-down and bottom-up models are summarized in Table 2.1.

Table 2.1. Characteristics of top-down models and bottom-up models.

Top-Down Models	**Bottom-Up Models**
• Use an 'economic approach' • Give pessimistic estimates on 'best' performance • Can not explicitly represent technologies • Reflect available technologies adopted by the market • The 'most efficient' technologies are given by the production frontier (which is set by market behavior) • Use aggregated data to forecast the future • Are based on observed market behavior • Disregard the technically most efficient technologies available, thus underestimate potential for efficiency improvements • Determine energy demand through aggregate economic indices, but vary in addressing energy supply • Endogenize behavioral relationships • Assume there are no discontinuities in historical trends	• Use an 'engineering approach' • Give optimistic estimates on 'best' performance • Allow for detailed description of technologies • Reflect technical potential • Efficient technologies can lie beyond the economic production frontier suggested by market behavior • Use disaggregated data to explore the future • Are independent of observed market behavior • Disregard market thresholds (hidden costs and other constraints), thus overestimate the potential for efficiency improvements • Represent supply technologies in detail using disaggregated data, but vary in addressing energy consumption • Assess costs of technological options directly • Assume that interactions between energy sector and other sectors are negligible

2.6.5. The Underlying Methodology

The fifth way of characterization is the underlying methodology, which is usually related to –but not the same as– the types of methods discussed in Section 2.5. The model methodology reflects the way model developers approach a posed problem in order to solve it. The overview of methodologies given below is based on the model methodologies mentioned in among others APDC (1985), Grubb et. al. (1993), IIASA (1995), Kleinpeter (1995), and Hourcade et. al. (1996). The model methodologies include:

I. Econometrics
II. Macro-economics
III. Economic equilibrium
IV. Optimization
V. Simulation
VI. Spreadsheet
VII. Backcasting
VIII. Multi-criteria methodologies

In principle, each methodology can be used separately, but in practice, models will use a combination of methodologies and the distinction between them is not always clear-cut. For instance, many econometrics or macro-economic models also use optimization techniques, while spreadsheet models often make use of optimization or simulation methodology. Note that the literature commonly associates simulation, optimization, and spreadsheets with bottom-up models, but some economic top-down models now also use optimization and simulation techniques. The econometric, macro-economic, and economic equilibrium methodologies are generally only applied in top-down models, although exceptions exists here also.

- *Econometric Models*
  Econometrics is defined as "applying statistical techniques in dealing with problems of an economic nature" (Kleinpeter, 1995, p. 177). Econometric methodologies are methodologies that apply statistical methods and rely on aggregated data of past behavior to predict the future in terms of required labor, capital, or other inputs on the short- or medium-term. Early energy (demand) models were purely based on econometrics, but today the econometric methodologies are usually part of macro-economic models. Econometric methodologies are also frequently used to analyze energy-economy interactions. A disadvantage of econometrics is that it cannot represent different technology options. In fact, it does not represent specific technologies at all. In addition, economic behavior must be stable in order to base variables on past behavior. Finally, Munasinghe (1988) as well as the APDC (1985) state that econometric models require skilled and experienced model users (econometricians), and many high-quality data. Furthermore, long-term effects can only be addressed by increasing the aggregation level, to reduce the fluctuations over

time. The APDC (1985) mentions another methodology similar to the econometric one, namely ‘trend analysis’. Trend analysis also extrapolates past trends of economic activity and energy consumption, but has less stringent data requirements. Nevertheless, trend analysis also requires highly aggregated data and does not allow for feedbacks of energy-economy interaction. It cannot capture structural change and does not explain determinants of energy demand.

- *Macro-Economic Models*
  The macro-economic methodology focuses on the interactions between the sectors of an economy and on the economy as a whole. It is often applied in energy demand analysis when taken from a neo-Keynesian perspective (i.e., output is demand determined). These models often use Input-Output tables to describe transactions among economic sectors and assist in analyzing energy-economy interactions. The Input-Output approach can be used only when the assumptions of constant returns to scale[6] hold, as well as the possibility of perfect aggregation. Macro-economic models are often developed for exploring purposes, using assumptions and scenarios that do not necessarily have to reflect reality. Often, macro-economic models do not concentrate on energy specifically but on the economy as a whole, of which energy is only a (small) part. Therefore, macro-economic models are not always seen as energy models. Similar to the econometric methodology, the macro-economic methodology has the disadvantage that it does not represent specific technologies and requires a relatively high level of expertise. Also, effects of intertemporal preferences and long-term expectations are not taken into account, resulting in a rather static representation of technical change.

- *Economic Equilibrium Models*
  Where econometric and macro-economic methodologies are mainly applied to study the short- or medium-term effects, economic equilibrium methodologies focus on the medium to long term. They are used to study the energy sector as part of the overall economy and focus on interrelations between the energy sector and the rest of the economy. Economic equilibrium models are sometimes also referred to as resource allocation models. There is a distinction between partial equilibrium models on the one hand, and general equilibrium models or optimal growth models on the other. Partial equilibrium models only focus on equilibriums in parts of the economy, such as the equilibrium between energy demand and supply. General equilibrium models are particularly concerned with the conditions that allow for simultaneous equilibriums in all markets, and the determinants and properties of such an economy-wide set of equilibriums. According to Slesser (1982), general equilibrium models simultaneously consider all the markets in an economy, allowing for feedback effects between individual markets. Economic equilibrium methodologies are used to simulate very long-term growth paths and do not systematically rely on econometric relationships

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[6] Constant returns to scale imply that if the production capacity is doubled, output is doubled as well.

but are instead benchmarked on a given year in order to guarantee consistency of parameters. They rely on (neo-classical) perfect market equilibrium assumptions; output is determined by supply and markets ‘clear’ (there exists no structural unemployment). The disadvantage of these models is that they do not provide adequate information on the time path towards the new equilibrium, implying that transition costs are understated.

- *Optimization Models*
  Optimization methodologies are used to optimize energy investment decisions endogenously (i.e., the results are directly determined by the input). The outcome represents the best solution under given constraints. Utilities or municipalities often use optimization to derive their optimal investment strategies. Furthermore, optimization is used in national energy planning for analyzing the future expansion of the energy infrastructure. Optimization methodologies assume that all acting agents behave optimal and rational under given constraints. According to DHV (1984), disadvantages of this methodology are that optimization models require a relatively high level of mathematical knowledge and that the included processes must be analytically defined. Optimization models often use linear programming or integer programming techniques[7].

- *Simulation Models*
  According to the World Energy Conference (1986), simulation models are descriptive models that aim at reproducing a simplified operation of a system. A simulation model is referred to as static if it represents the operation of the system in a single time period; it is referred to as dynamic if the output of the current period is affected by parameter values of previous periods. Simulation models are especially helpful in cases where it is impossible or extremely costly to do experiments on the system itself. A disadvantage is that simulation models tend to be rather complex. They are often used in scenario analysis.

- *Spreadsheet Models (Tool Boxes)*
  Although spreadsheet models all make use of spreadsheets (as the term suggests), this term may cause some confusion because other models also frequently use spreadsheet programs to apply certain methodologies. With spreadsheet models we mean highly flexible models that, according to Munasinghe (1988, p. 30) are more like software packages to generate models than models per se. The World Bank (1991, p. 6-9) refers to spreadsheet models as ‘tool boxes’ that often include a reference model, which can easily be modified according to individual needs and local circumstances.

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[7] See Section 2.6.6 for an explanation of linear programming and integer programming.

- *Backcasting Models*
  The backcasting methodology is used to construct visions of desired futures by interviewing experts in the fields and subsequently looking at the developments paths required to accomplish such futures. This approach is often used in studies on alternative energy futures. For instance, the Dutch interdepartmental research program Sustainable Technological Development (STD) used backcasting models to explore the (technological) requirements for certain desired futures (STD, 1998).

- *Multi-criteria Models*
  The multi-criteria methodology is used when criteria other than economic efficiency need to be included in the analysis. This methodology allows for inclusion of quantitative as well as qualitative data in the analysis. However, this approach is not yet widely applied in energy models. Two examples of application can be found in studies conducted by Georgopoulou (1997; 1998).

2.6.6. The Mathematical Approach

The sixth way to characterize models concerns the mathematical approaches or procedures applied in the models (see, for example: IIASA, 1995; and Kleinpeter, 1995). Commonly applied techniques include linear programming, mixed integer programming, and dynamic programming. Of course, combinations of techniques are also possible. Mathematical techniques that only recently have been applied to energy planning (mostly on an experimental, small-scale basis), such as multi-criteria techniques and fuzzy logic, are not addressed here.

- *Linear Programming*
  Linear programming (LP) is a practical technique that can be applied to find the combination of activities that maximizes or minimizes a defined criterion, subject to certain constraints (Slesser, 1982). All relationships are expressed in fully linearized terms. Linear programming is commonly applied to find the most profitable (optimal) production level given certain prices for the inputs and outputs. The LP technique is a relatively simple technique that gives quick results and demands little mathematical knowledge of the user, but can only deal with activities and criteria that can be expressed in linear equations[8]. Other disadvantages are that all coefficients must be constant and that LP results in choosing the cheapest resource up to its limits before any other alternative is used (World Bank, 1991). Also, LP models can be very sensitive to input parameter variations. This technique is used for almost all

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[8] That is, if x_1 and x_2 are inputs and y is the output, the technique is only applicable if their relationship is of the form $y \leq ax_1 + bx_2$.

optimization models, and applied in national energy planning as well as long-term energy (technology) studies.

- *Mixed Integer Programming*
  Although Mixed Integer Programming (MIP) is similar to linear programming, it allows for greater detail in modeling technical properties and relations of energy systems than linear programming does. Decisions such as Yes/No or (0/1) are admitted as well as non-convex relations for discrete decision problems. MIP can be used when addressing questions such as whether or not to include a particular energy conversion plant in a system. By using MIP, variables that cannot reasonably assume any arbitrary (e.g., small) value –such as unit sizes of power plants– can be properly reflected in an otherwise linear model. (World Bank, 1991).

- *Dynamic Programming*
  Dynamic programming is a method used to find an optimal (growth) path. The solution of the original problem is obtained by dividing the original problem into simple subproblems for which optimal solutions are calculated. Consequently, the original problem is then optimally solved using the optimal solutions of the subproblems.

2.6.7. Geographical Coverage

The seventh way of characterization is the geographical coverage, which reflects the level at which the analysis takes place, an important factor in determining the structure of a model. There are several levels on which a model can focus, including the global, international, national, regional, local, and project level. Given the somewhat flexible definition of ‘region’ in Chapter 1, local models can cover the same geographical area as regional models, so they are treated as equals in this thesis. Bottom-up models usually focus on the regional/ local level, describing local conditions and technology options in detail.

National models treat world market conditions as exogenous, and often encompass all major sectors within a country simultaneously, addressing feedbacks and interrelationships between the sectors. Examples of national models are econometric demand models for the short term and general equilibrium models for the long term. International models focus on international regions such as Europe, the Latin American Countries, South-East Asia. Sometimes, these models are also referred to as ‘regional models’, but to avoid confusion we will use this term exclusively for regions *within* countries. The global models describe the economy or situation of the entire world using highly aggregated data.

The project level is a somewhat special case; it usually refers to a subnational level and focuses on a particular site or issue. However, the project level can also encompass a project on a national scale, such as the one Van Groenendaal (1998) describes in his book on the introduction of natural gas as an energy source on Java.

In general, the higher the level of analysis, the more aggregated the data will be. Also, the description of the energy sector will be more rudimentary at a higher level, because usually all major sectors and macro-economic linkages are included in the model, which leaves little room for a detailed treatment of the energy sector. Local and project models, on the other hand, generally require disaggregated data in order to describe in detail the different energy technologies and their effects on the local level, but cannot easily address effects on the society as a whole.

2.6.8. Sectoral Coverage

The eighth way of characterization is the sectoral coverage. A model can focus on only one sector (as many early bottom-up models do) or include more sectors. How the economy is divided into sectors is crucial for the analysis. Usually, models use data based on the so-called ISIC classification, which already implies a division into particular sectors.

Multi-sectoral models can be used at the global, international, and national level, and focus on the interactions between these sectors. At lower levels a multi-sector analysis becomes more complicated due to data constraints. Single-sectoral models only provide information on a particular sector (in our case the energy sector) and do not take into account the macro-economic linkages of that sector with the rest of the economy. The rest of the economy is represented in a highly simplified way. Nearly all bottom-up models are sectoral, but not all sectoral models use bottom-up methodologies. For instance, top-down partial equilibrium models focus on the long-term growth path of a distinct sector.

2.6.9. The Time Horizon

The ninth way of characterization concerns the time horizon that the models take into account (i.e., whether they focus on the short, medium, or long term). No standard definitions exist as to what is a short term or a long term; the terms mentioned in the literature are rather arbitrary and often overlap. For instance, Grubb et. al. (1993, p. 437) mention a commonly noticed period of 5 years or less for the short term, between 3 and 15 years for the medium term, and 10 years or more for the long term. However, in Chapter 1, we have already set the medium-term period for energy planning to approximately 20 years (and we will continue to do so).

The time horizon is important because different economic, social, and environmental processes take effect at different time scales. Thus, the time horizon determines the structure and objectives of the energy models. Long-run analyses may assume economic equilibrium (i.e., resources are fully allocated or markets ‘clear’), while short-run models may need to incorporate ‘transitional’ and disequilibrium effects (e.g., unemployment).

2.6.10. Data Requirements

The last, tenth, way of characterization concerns the data requirements of the models. Models require certain types of data. We have already discussed the aggregated and disaggregated data, where the long-term global and (inter)national top-down models require highly aggregated data with little technological detail, and the local bottom-up models require disaggregated data with great detail in representing energy supply and demand. Also, we have discussed the fact that most models require impacts to be quantified in order to include them in the analysis. Some models even require aspects to be expressed in monetary units. However, data are not always available or reliable, especially in developing countries. In this case it is important that the energy model is flexible enough to handle ordinal or qualitative data as well.

2.7. Requirements for Supporting Local Energy Planning: A Preliminary Method

As discussed in Section 1.6.1, the intention of this thesis is to construct a new decision support method that allows for the inclusion of all relevant energy resources and technologies, and all relevant aspects in order to select an appropriate local energy infrastructure in rapidly developing regions of developing countries. The need for such a new method became apparent in Section 2.3, where we discussed the constraints of existing models as listed in the literature. A general constraint of most existing tools is that they do not address context-related issues, which can (partly) be explained by the fact that these models are unfit to include different types of actors and they ignore their interests and preferences. In addition, many issues are left out of the analysis because most tools can only handle quantified data. Also, many (economic top-down) models treat technology as a black box and are unable to take into account local resources or small-scale technologies. In addition, the focus on rapidly developing regions in developing countries implies that the uncertainty concerning future developments is rather high, while many developments will show a discontinuity with past trends. Most models are unfit for such situation, while the poor availability of reliable data constraints the use of existing models further. Given these constraints, and given the main aim of this thesis, we use the following guidelines for the new energy planning support tool we want to construct:

- The method needs to structure the decision process and make it more transparent.
- The method must be applicable to rapidly developing regions in developing countries, implying that models cannot use simple extrapolation for determining the future.
- The method must be able to account for the interests and preferences of participants.

- The method must allow for inclusion of context-related aspects, implying that models can handle technical and financial aspects as well as economical, environmental, and social ones.
- The method must be able to differentiate between technologies; moreover, it must provide a structure to compare them.
- The method must be able to address all relevant energy systems, including –if applicable– fossil fuel energy systems as well as renewable energy systems.
- The method must be able to address different forms of energy demand in order to select proper energy technologies.
- The models of the method must be flexible with respect to the input data in order to easily adapt to local circumstances, and to allow for inclusion of aspects that cannot be easily quantified.

In addition to the guidelines listed above, *information* is a crucial factor in supporting any decision-making process; how much people know determines their range of alternatives. So the method should also serve as an awareness-raising tool. However, providing information alone is not enough; a structure to *process* the information is also required. This way, the energy planners can broaden their range of alternatives with new options that were unknown or seemed less evident at first.

Notice that the guidelines distinguish between 'methods' and 'models', as discussed earlier in Section 2.4, so for our new method we will also make such a distinction. Concerning the method as a whole, we believe that energy planners are best supported through a logical, transparent structure. Given the method types discussed in Section 2.5, this tends towards a choice for a normative method, because it implies a predefined format with steps that planners must follow to reach a good outcome. However, normative methods require a single decision-maker (or a perfectly cooperating group), while energy planning in practice usually involves many actors. Also, the energy planners are not always the ones that make the decisions, implying that these planners have to provide a range of promising alternatives instead of the 'best' option. Another threshold of using normative methods is that they can easily lead to situations in which energy planners 'are doing it wrong' if they do not exactly follow the rules of the method, even if the circumstances impede a proper application of the method in the real world. We believe, as Bell et. al. (1988) and Simon (1988) do, that energy planners generally have good reasons for not using normative methods, and that it is better to adjust the method somewhat in order to provide real support in practice, than trying to change humanity.

Also, we believe that decisions made by the actors are not (always) rational, even when accounting for certain boundaries. And we believe that the decisions are influenced by the role that actors play in the planning process, and the power they have.

All this implies that the new method can best be a prescriptive type of method (as defined by Bell et. al. (1988)) that aims at improving the quality of decision-making by using a structure as in a normative method, but without having to comply with strict rules such as 'behave rational'. The method thus serves as a handhold or heuristic for energy planners. Also, some aspects of political methods appear to be useful in constructing a new method for local energy planning, in particular concerning the subjective aspects in decision-making, the participation of different actors in the decision process, and the conflicting aims that might exist. The chaos method is believed to provide too little structure to support the planning of the future energy infrastructure.

One of the guidelines for the new method concerns the inclusion of the interests and preferences of all relevant actors[9], but to be able to include these interests and preferences, we have to know what the actors want. Therefore, we propose to let the actors participate in the decision-making process. Furthermore, we propose to use the interests and preferences of the actors as a basis for assessing the impacts of the options. The aspects that the actors put forward as important can be translated into ‘indicators’, and the scores on the indicators then represent the impacts of the energy infrastructure options. This ensures that all relevant aspects (including context-related ones) are addressed in the analysis. In addition, to ensure that the proper energy forms are taken into account, we propose to take the energy services (i.e., the purposes for which people demand energy) as a starting point of the analysis. Other stages ore issues in energy planning were already addressed in Section 2.2, including the determining of future energy demand, the identification of supply options, an assessment of the impacts of options, the appraisal of the options, and the final selection of an energy infrastructure.

We now have enough input to present a *preliminary* method for local energy planning in developing countries, and Figure 2.2 shows an outline of this method, including the method steps and the associated models. The method steps give structure to the entire energy planning process, while the models facilitate the completion of the method steps. Note that we identify four different types of models, in line with their specific purpose: a demand model, a supply model, a model for impact assessment, and an appraisal model. With the overview of the model characteristics discussed in Section 2.6, we can systematically analyze which model characteristics are useful in supporting local energy planning in developing countries.

What is clear beforehand is that all models must be suited for local level analysis, the focus of our research. Also, as discussed in Chapter 1, the sectoral coverage will only include the energy sector and does not include transportation fuels. Furthermore, the time horizon is set at the medium term (approximately 20 years). Furthermore, we plan to implement the models using a spreadsheet methodology, leaving many assumptions external to be more flexible with regard to available data and adjustments to local circumstances. Another reason for choosing a spreadsheet methodology is that most people are familiar with the working principles of spreadsheets, which facilitates the application of the models. The other characteristics are more model-specific and will be discussed per (sub)model below.

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[9] In this thesis, as defined in Chapter 1, actors (or stakeholders) are individuals or groups of people (including companies, organizations, etc.) that represent certain interests related to the energy infrastructure, are involved in or affected by the energy planning decision process or its outcome, *and* can influence the process.

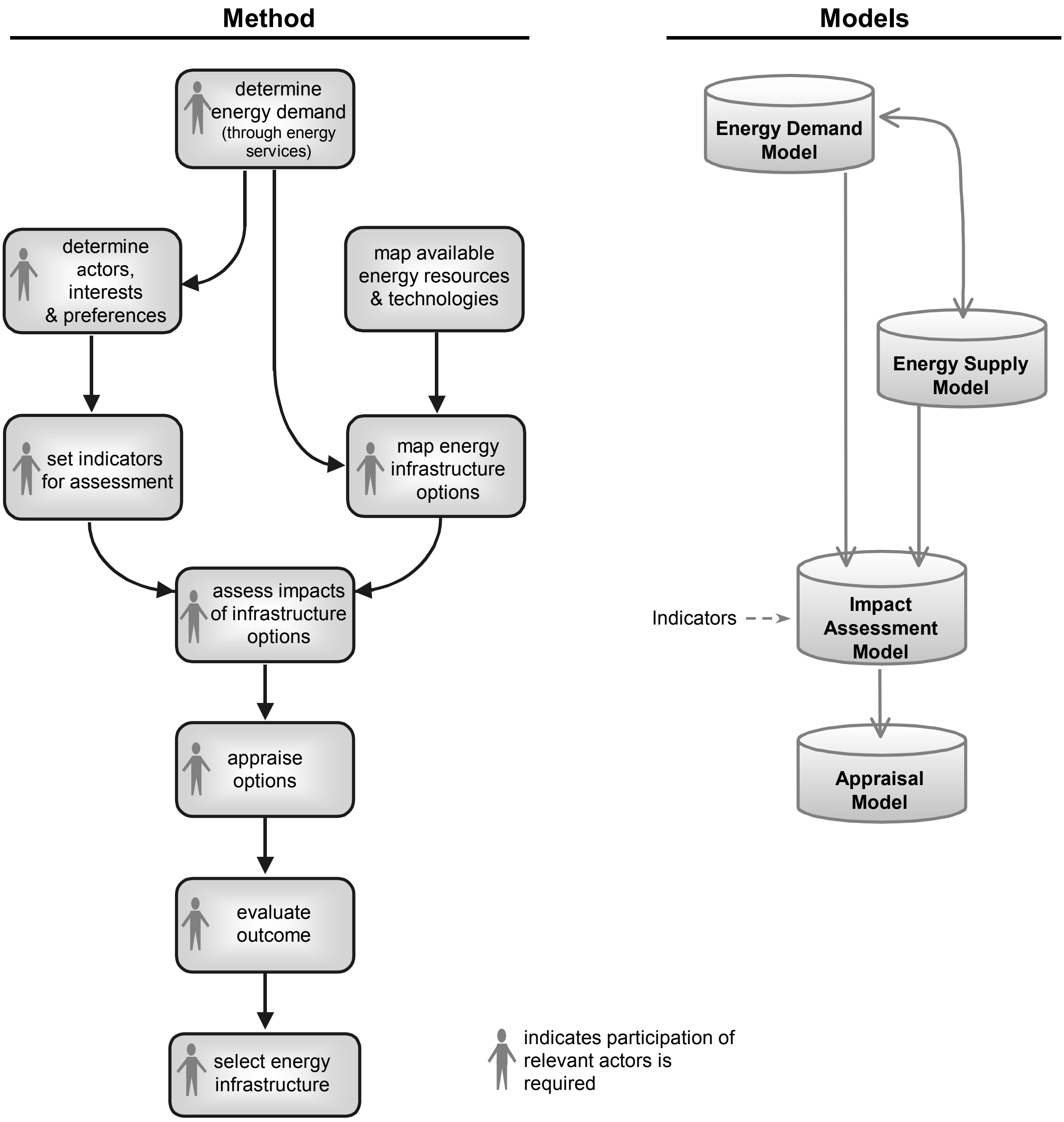

Figure 2.2. The steps of a preliminary method to support the energy planning decision process, and models to facilitate the steps. Derived from Van Beeck et. al. (2000).

The model-specific characteristics per (sub)model include:

I. *Energy Demand*
Demand models frequently use forecasting techniques to project future energy demand. However, in regions with rapid economic growth, historical data do not provide a satisfactory forecast due to the discontinuity in trends. Therefore, scenario analysis is more suited to explore the future. Past experiences in regions with similar development patterns can hereby serve as a basis for the scenarios. Furthermore, it is important to know the energy services that end-users desire, because these energy services are directly related to the forms of energy (e.g., heat, electricity, gas) that the energy technologies have to supply. Therefore, we need a model that can address the demand for these different forms of energy. A detailed, disaggregated analysis of energy demand calls for a flexible bottom-up approach.

II. *Energy Supply*
Since the focus of the new support method is on selecting appropriate energy systems that are commercially available, the supply model must have a descriptive bottom-up approach to allow for a detailed description of all the relevant energy resources and technologies without being too optimistic about their actual application.

III. *Impact Assessment*
The impact assessment model must be able to include all relevant aspects, even if these aspects cannot (easily) be quantified. This rules out techniques such as cost-benefit analysis as overall appraisal method, although these techniques can still be useful in some parts of the assessment. Thus the impact model must be flexible in handling quantitative (ordinal, numerical, monetary) as well as qualitative data. Since most existing impact models are an integrated part of other models, they cannot be easily modified to include other (qualitative) criteria. However, models that have a modular setup do not have this constraint because each module can be operated (and thus be adjusted) separately from the others.

IV. *Appraisal*
The appraisal model is not a model in the sense that it contains calculation procedures; it is meant to provide a transparent structure to appraise and compare the impacts of the different options. The structure will help the actors to identify which options are desirable or appropriate. However, since the actors usually have conflicting interests and preferences, the preferred option may differ per actor, and it will often be impossible to identify one option as the most appropriate.

The set of models used in the method for local energy planning can best be a modular package so that each model can –when needed– be separately operated and adjusted to local circumstances. The package should at least include models for energy demand, energy supply, and impact assessments. The models will require a bottom-up approach to allow for a detailed description of the energy forms demanded and the resources and supply technologies needed.

As far as the mathematical approach is concerned, we have to find an approach that can handle the different data types and does not require planners to have special skills or expertise. Most probably, the mathematical approach will be a combination of techniques. The method types and model characteristics used in the preliminary method for local energy planning are summarized in Table 2.2.

Table 2.2. Overview of the method types and model characteristics suited for supporting local energy planning in developing countries.

Method:
A prescriptive method, with elements of political methods.

Models:	*Demand Model*	*Supply Model*	*Impact Model*	*Appraisal Model*
Perspective on Future:	Scenarios	n.a.	n.a.	n.a.
Purpose:	Determine future energy demand	Map energy supply options	Determine impacts of options	Provide structure to appraise options
Structure:	Many external assumptions	Many external assumptions	Many external assumptions	n.a.
Analytical Approach:	Bottom-up	Bottom-up	Bottom-up	n.a.
Methodology:	Spreadsheet	Spreadsheet	Spreadsheet	n.a.
Mathematical Approach:	–to be determined–	–to be determined–	–to be determined–	n.a.
Geographical Coverage:	Regional/ local	Regional/ local	Regional/ local	n.a.
Sectoral Coverage:	Energy sector (no transport)	Energy sector (no transport)	Energy sector (no transport)	n.a.
Time Horizon:	Medium term (20 yrs)	Medium term (20 yrs)	Medium term (20 yrs)	n.a.
Data Requirements:	Quantified	Quantified	Very flexible, all data types	n.a.

n.a. = not applicable

This chapter has now answered the first sub-question of the thesis about the existing theories and tools for energy planning. The literature study has provided us with information on method types and model characteristics from which we used those that we believed fit for a preliminary method (including 4 models). However, since the literature on *local* energy planning was scarce, we still don't know how local energy planning in these regions evolves in practice. In order to make the preliminary method compatible with everyday practice, we need to know more about how energy planning really evolves at the local level, what specific constraints exist at that level, and what can be done to solve them. This requires a descriptive analysis, which is the topic of the next chapter.

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3

Field Study: Local Energy Planning in Brabant, the Netherlands

3.1. Purpose of the Field Study

The literature on supporting local energy planning in developing countries proves to be scarce, especially when focusing on rapidly developing regions[1]. This chapter contains the results of a descriptive field study that we conducted in 1999 on local energy planning (see also Van Beeck (1999)). The purpose of the field study was to get a better insight in how local energy planning really evolves in practice, and whether the preliminary method presented in Section 2.7 is indeed fit for supporting planners in rapidly developing areas. We examined whether the planning process follows the steps of the method described in Figure 2.2, as well as the bottlenecks that occur during the process. The results are subsequently used to adjust the preliminary method.

The field study focused on the planning of local energy infrastructure at new building sites in Brabant (also referred to as Noord-Brabant), a province of the Netherlands. The study consisted of in-depth interviews with local actors and experts in the field, as well as an analysis of policy documents, reports, Internet sites, and other literature concerning the planning of local infrastructure in the Netherlands, and Brabant in particular. Most actors interviewed were found using the snowball-technique of asking one person to point out other

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[1] There are many reports on so-called ‘rural electrification projects’, but these projects usually concern isolated communities with little economic activity, and do thus not comply with our requirement of regions with increasing economic activity.

relevant persons or groups, who in turn point out others, etc. Appendix E contains a list of the interviewed people, while an overview of all the consulted literature is given at the end of this chapter. Note that the data presented in this chapter reflect the situation in 1999. However, the Dutch energy sector is currently in the middle of a liberalization process and many changes occur in a relatively short period of time. So the actual situation may indeed be different from the situation in 1999. These changes are not taken into account here.

Although we realize that the Netherlands is *anything but* a developing country, we believe that some elements in the planning process are universal and also hold for regions in developing countries, such as the planning stages or certain bottlenecks. And choosing a region in the Netherlands offered several advantages for us, in particular given the constraints in time, manpower, and budget. For instance, information was easily accessible, up-to-date, and relatively reliable. Also, communication problems were limited, so that actors in the planning process and experts in the field were easily addressed and interviewed. All this allowed us to gather the necessary information in only a short period of time at relatively low costs. Nonetheless, the real value of the new method can, of course, only be determined when testing it in a region of a developing country.

The region of Brabant was chosen because it showed a rapid increase in economic activity in the previous years, while there were many new building sites planned in the province. The new building sites offer one of the few opportunities in the Netherlands for *local* planning, as energy planning generally occurs at the national level due to the highly centralized energy infrastructure. The national energy infrastructure is highly developed and very much based on fossil fuels, but the new building sites offer the opportunities to deviate from the conventional choice for energy infrastructure.

In Section 3.2, this chapter will first give a description of the context in which local energy planning in Brabant takes place, followed by an overview of the main actors involved in the planning process, their aims and their interests in Section 3.3. After that, we will discuss the key issues and bottlenecks in the process (§ 3.4), followed by a discussion of the necessary adjustments to the preliminary method (§ 3.5).

3.2. Description of the Context

This section describes the context in which local energy planning in Brabant, the Netherlands, takes place. First we will give some general information on the region and country of focus (§ 3.2.1), followed by an explanation of VINEX locations, the new building sites in the Netherlands (§ 3.2.2). Finally, the general policies and issues regarding energy planning at VINEX locations are discussed in § 3.2.3.

3.2.1. General Information on the Netherlands and Brabant

The Netherlands, with a total surface of 41,526 km^2, is inhabited by 15.6 million people. It has no mountains and is divided into twelve provinces, which are in turn divided into numerous municipalities. As Figure 3.1 shows, the province of Brabant is situated in the south of the Netherlands. The province accounts for 12% of total Dutch surface area, and contains a total of 2.2 million people, which is 15% of the total Dutch population (see Table 3.1). Brabant traditionally has strong agricultural and industrial sectors, although the service sector is gaining importance. Note in Table 3.1 that local economic growth in Brabant in 1998 (6.8%) exceeded national growth (5.6%), although the unemployment rate was slightly higher.

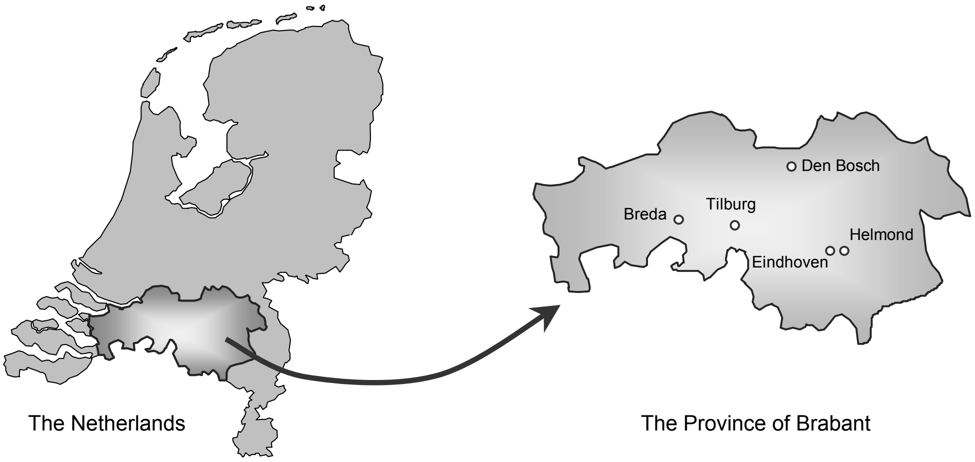

Figure 3.1. The province of Brabant situated in the south of the Netherlands.

Table 3.1. General information on the Netherlands and Brabant. Source: CBS (2002).

Netherlands	1998	Brabant
41,526	Total surface area (km^2)	5,082 (12%)
15.7	Total inhabitants (million)	2.32 (15%)
377	Inhabitants per km^2	456
352	GDP in 10^9 euro	51,175
5.6 %	Growth in GDP	6.8%
25.8	GDP per capita (1.000 euro)	22.0
4.1%	Unemployment rate (1997)	4.4%
99.9%	Electrification rate	99.9%
14,011	Installed electrical capacity (MW)	1,750
3,300	Electricity demand per household (kWh/yr)	3,300
1,945	Gas demand per household (m^3/yr)	1,945

Source: CBS (2002). EnergieNed (1999).

The electrification rate in the Netherlands and Brabant is high; practically all households are connected to the national grid. Electricity production is mainly based on fossil fuels, of which natural gas accounts for 60.6% of national electricity production, coal accounts for 25.9%, oil for 3.5%, uranium for almost 4.4%, leaving 5.7% for other energy sources (Scheepers et. al., 2001, p. 6). Natural gas is also supplied directly to end-users, mainly to be used for heating purposes (space and tap water heating, and cooking). So most households are connected to an electricity grid as well as to a natural gas grid, which makes an electricity-gas infrastructure the conventional energy infrastructure. Box 3-1 gives a short overview of the development of the Dutch energy infrastructure.

Box 3-1. Development of the Dutch energy infrastructure. Source: Daey Ouwens et. al. (1987), Correljé (1998).

Development of the Dutch Energy Infrastructure

The Dutch energy infrastructure (excluding the energy for transport) is based on the generation, transmission, and distribution of electricity, and on the exploitation, transmission, and distribution of gas. the development of the electricity infrastructure started in the 1880s with isolated small private plants, which became (still isolated) municipal utilities around 1910-1920. In the 1930s provincial utilities started to emerge that tried to take over the municipal production capacities, meanwhile establishing regional grids. Most regional grids were consequently merged into one national grid in the 1940s to limit the required back-up capacities. With increasing plant capacities and amount of electricity production, the need for central planning became unavoidable, and in 1971 a national institution (SEP) for the planning and control of central electricity production was established. The capacities of power plants continued to increase (up to 600MW and more per unit), along with a centralization of the organizational structure, and by the mid-1980s a shift to internationally operating companies was already expected. Only a handful small-scale systems could survive the competition of scaling up, but only because they served a specific purpose (e.g., gas turbines used during peak demands or for district heating). Daey Ouwens et. al. mention four factors that important in explaining the ever increasing scales in the electricity sector:

- Economies of scale: better technical efficiencies and lower investment costs per unit are achieved as scales increase. Also, large-scale systems are easier to monitor and control as a whole.
- Once the thought of scaling up was seen as the best direction to go, an organizational, technological, and research structure emerged that aimed at achieving an optimal performance for large-scale systems, which made it very difficult for small-scale systems to develop.
- The use of nuclear energy –once thought to be a promising alternative in the Netherlands– favors large-scale production (due to reasons of controlling safety and risks). To be compatible with nuclear plants, the fossil fuels based systems would also have to scale-up.
- The centralized systems more easily allow for establishing a monopoly than the many dispersed small-scale systems, and would allow for internationalization.

The development of the gas infrastructure in the Netherlands began in 1948, when the first resources of gas were discovered in northeast of the Netherlands (Correljé, 1998). The development of the infrastructure was centrally organized and proved relatively uncomplicated, as by the end of 1968 –after only 20 years– practically the entire country was connected to a gas grid.

Energy planning in the Netherlands is highly centralized, but VINEX locations offer one of the few opportunities in the Netherlands for *local* planning. The next section will explain what these VINEX locations are.

3.2.2. New Building Sites: VINEX Locations

In the Netherlands, the national government plans and designates –in consultation with regional and local governments– special sites for the development of entire new-to-build town districts in order to meet the demand for living space of a growing population. These new building sites are called "*VINEX locations*" referring to the policy document in which the government clarifies the plans (VROM, 1992). The Dutch General Advisory Committee (AER, 1997) states that in the Netherlands, starting in 1995, more than 600,000 new houses will be built within the VINEX framework. Approximately 50,000 of these new houses will be built at VINEX locations in Brabant, near the cities of Eindhoven, Helmond, Breda, Tilburg, and Den Bosch (see Figure 3.1). Only few houses are built by private persons; the majority of the houses is built by property developers on request of the government or housing corporations.

The field study on local energy planning in Brabant focuses on the decision process regarding the energy infrastructure at VINEX locations. These sites offer one of the few opportunities in the Netherlands to make relatively unrestricted choices regarding the energy infrastructure. In almost all other cases, the choice is restricted to a few (conventional) options due to the already well-developed and highly centralized national energy infrastructure. For new building sites, however, many options –including renewable energy systems– are still open, in particular at the early stages of the planning process. There are basically three options for the energy infrastructure at VINEX locations: the conventional infrastructure with gas and electricity supplied to the households; an option with electricity and district heating; and an all-electric option. These options refer to the energy forms delivered to the end-users. However, an infrastructure option is also determined by how the particular forms of energy are generated (e.g., centrally or regionally, using renewable or non-renewable resources) and what type of technologies are used. So there is usually a wide variety of infrastructure options to choose from. However, the decisions made early in the process restrict the range of options available at later stages, emphasizing the importance of making the right choices from the start. And this requires planning.

3.2.3. Energy Planning at VINEX Locations

In Brabant, the total energy planning process at VINEX locations –from a green pasture to the actual start of constructing the energy infrastructure and houses– takes about 5 years. The process involves, among others, decisions regarding the level of ambition, the forms of energy delivered to the customers (heat, electricity, gas), the energy sources and technologies used to produce the proper forms of energy, the scale of energy generation (central or decentral), the way the houses are built, and the distribution of costs and benefits.

Since the 1990s, *sustainable building* has become a central theme in governmental policies concerning housing development. Sustainable building is a way of building that minimizes the impact on the environment, among others by using environmental friendly materials and measures that reduce the demand for space, energy, and water (ECN, 1997, p. 91-92).

The energy measures that are included in the sustainable building concept follow the so-called '*Trias Energetica*', a logical order in taking energy measures at new building sites, as shown in Figure 3.2 (Provincie Noord-Brabant, 1999).

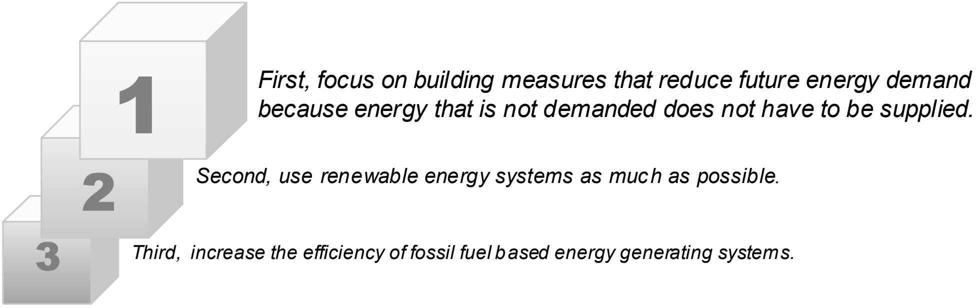

Figure 3.2. The principles of the Trias Energetica.

The Trias Energetica first aims at reducing the projected energy demand of future buildings by applying measures such as isolation, thermal collectors, and heat recovery. The remaining demand should as much as possible be met with renewable energy systems, to benefit from their unlimited supply and relatively low environmental impacts. Only then should the remaining part be supplied by –highly efficient– fossil fuel based systems. It is interesting to note that the Trias Energetica does not include consumer behavior; it only focuses on the –relatively easy to control– "technical" part of the planning process, even though consumer behavior determines for a large part actual energy consumption.

The effect of the sustainable building measures is expressed in the *Energy Performance Coefficient* (EPC), which reflects the degree of sustainability of a new building (Novem, 1998a; Novem, 1998b). The lower the EPC value, the lower the projected energy demand of a building[2]. The EPC will affect the development of new energy infrastructure, because a reduction in (projected) energy demand of a new district implies reduced energy revenues for the energy companies that construct the energy infrastructure in that district, and this affects the viability of the energy infrastructure options.

In 1995, the Dutch government introduced a standard for the EPC, the so-called *Energy Performance Norm* (EPN), which limits the projected amount of energy that newly-built houses may use for space heating, ventilation, supply of hot tap water, lighting, and cooling purposes (MEZ, 1995). The EPN has become more stringent in recent years, starting at 1.4 in 1995 and 1.2 in 1998 to 1.0 in 2000 (ECN, 1996). The housing constructors (usually property developers) are free to choose the measures with which the EPN can be reached.

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[2] Note that when calculating the EPC, the size and type of the building (e.g., apartments, row houses, villas) are also taken into account.

Another −still voluntary− measure for sustainability is the *Energy Performance on Location* (EPL), which reflects the projected amount of CO_2 emissions at an entire new building site, including the buildings *and* the energy infrastructure (CE, 1998a; CE, 1998b; Novem, 1998a; Novem, 1998b). So unlike the EPC (that is mainly focused on energy for heating purposes[3]), the EPL includes all forms of energy consumption, including electricity. And unlike the EPC, *higher* EPL values imply a *better* score on sustainability (i.e., less CO_2 emissions). The EPL values range from 1 (worst) to 10 (best), but are related to the EPC values: a conventional local infrastructure (gas and electricity) with an EPC value of 1.0 corresponds to an EPL value of 6.

At the time of the field study (i.e., 1999), important issues dominating energy planning at VINEX locations were (and currently still are) the liberalization and privatization processes in the energy sector. Through liberalization, the consumers will be able to freely choose between energy companies for their energy supply. In 1999, the electricity market was only partially liberalized; only large consumers were allowed to freely choose an energy company (Kers, 1999). In the near future (originally intended after 2007), the electricity market will be fully liberalized. The gas market will also be liberalized in the near future, although some market barriers will remain for new entrants.

Now that we have described the context in which local energy planning at VINEX locations takes place, we want to know more about concrete cases of local energy planning, in particular the actors that are involved and the issues that play a key role in the process. The next section will address the main actors and their interests and preferences concerning local energy planning, Section 3.4 will discuss the key issues.

3.3. Main Actors, Interests, and Preferences in Local Energy Planning

The local energy planning process for VINEX locations in Brabant involves several actors, and to adequately describe current practice in local planning it is important to know who are involved in the process, what their interests are, and who takes certain decisions. To obtain this information, we interviewed people that represented the main actors involved in local energy planning at VINEX locations. Additional information was obtained from interviews with experts, policy documents, and from (confidential) reports of consultancy firms that were written at the request of particular actors. Also, official and unofficial meetings between actors were attended to get better insight in the issues that play a key role in local energy planning in Brabant.

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[3] The EPC and EPL only include electricity that is used for lighting and for operation of pumps or ventilation, not the electricity needed to operate electrical appliances such as radio or TV, or for cooking and such.

The field study of Brabant identified the following groups, organizations, or institutions as relevant actors in the planning process:

- National Government
- Regional Government: Province of Brabant
- Local Governments: Municipalities in Brabant
- Energy Companies
- Property Developers
- Consultancy firms

- Support Organizations
- Future Residents

The last two actors, support organizations and future residents, are separated from the upper six actors to indicate that their role in the process is –at present– less significant. We will discuss the actors and their role in the planning process in more detail below. The interests and preferences that we attribute to a particular actor are a synthesis of the statements made during the interviews by the persons that were believed to represent that actor. So the interests and preferences of actors described below are not necessarily an exact copy of the interests and preferences of each individual that was interviewed. In addition, it is important to note that currently these actors are rethinking their roles and adjusting their strategies as a result of the liberalization of the energy sector. Much is still uncertain and the roles and strategies of actors may change in the future.

3.3.1. National Government: Regulatory and Policy Framework

In the Netherlands, the national government is not directly involved in local energy planning. However, adequate local decisions or actions do not necessarily result in a desirable situation for the society as a whole. So in order to get an adequate and compatible set of local policies that serve the entire society, the role of the national government is to provide a broad regulatory and policy framework within which other actors operate. The Dutch national regulatory framework relating to energy and sustainable building consists of a mixture of policy plans, regulation, standards, voluntary agreements, subsidies and taxes, and information supply. Table 3.2 lists some examples of the instruments that the national government uses with respect to energy and sustainable building.

The development of VINEX locations offers an excellent opportunity for the government to implement measures for sustainable building and unconventional energy systems at VINEX locations. Probably the most important and powerful instrument for the national government to promote sustainable building and sustainable energy is the EPN (Energy

Performance Norm) enacted in 1995 (MEZ, 1995). With this standard the government aims at achieving a 25% reduction in energy demand in 2000 compared to 1990 (AER, 1997).

However, measures for sustainable building and sustainable energy are not the only ones that affect the development of VINEX locations. Other issues also influence decisions, such as the liberalization of the electricity sector, which affects the roles and strategies of the different actors.

Table 3.2. Examples of instruments used by the Dutch national government to provide a regulatory and policy framework for energy and sustainable building issues.

Instruments	***Examples***
Policy Plans	*Third Note on Energy (1995)* In this policy document, the Dutch government aims to improve energy efficiency with 33% in 2020 (an annual improvement of 1.5% since 1995), while 10% of energy supply has to be sustainable by then (AER, 1997). This document also initiated the liberalization of the energy sector and the use of the EPN for new buildings.
Regulations	*Energy Distribution Law (1996)* This law prohibits the municipalities and provinces to put any restrictions on the distribution of electricity, gas, or heat (ECN 1997, p. 7-10).
Standards	*Energy Performance Norm (EPN)* Standard for the maximum projected energy demand of a specific type of building, enacted in 1995 when the value was set at 1.4. The EPN was lowered in subsequent years, resulting in a value of 1.0 since 2000.
Subsidies & Taxes	*CO_2 Reduction Plan* Subsidies to reduce CO_2 emissions *Regulating Energy Tax (REB)* An eco-tax on fossil fuels (above a certain threshold of consumption) in order to reduce energy consumption and promote the use of renewable energy.
Voluntary Agreements	*Energy Performance on Location (EPL)* Measure for the amount of CO_2 emissions at new building sites (including buildings *and* the energy infrastructure), reflecting the degree of sustainability.
Information Supply	*National Package for Sustainable Building (1995)* List with measures and actions that contribute to sustainable building.

3.3.2. Province of Brabant: Administrative Intermediary

In the Netherlands, provinces are an intermediary between the national government and (large) municipalities (Moerkerken, 1999). The province translates national policies into concrete consequences for municipalities, while at the same time giving feedback to the national government about regulations and policies that do not work properly at the local level. In addition, the province constructs regional development plans concerning the general infrastructure and the environment. Any plans made at a lower level (e.g., by municipalities) must comply with the regional plans. Also, the province issues permits for large companies (for constructing buildings or for activities that affect the environment), it enacts regional environmental regulations, monitors the compliance of the larger companies to voluntary agreements, grants subsidies, and promotes the transfer and diffusion of knowledge. According to Moerkerken (1999), provincial support is usually restricted to the larger municipalities because there are too many small municipalities to support all of them. The smaller municipalities are assumed to get their support from the larger ones.

Traditionally, the provinces are shareholders of the regional gas distributing companies, but this is changing rapidly as a result of liberalization. So in general, the role of the province in local energy planning is limited to determining the conditions for regional development, and supplying the large municipalities with information.

3.3.3. Municipalities: Implementation of Policies

In the Netherlands, the people that work for the municipality are either municipal *officials* or municipal *councilors*. Councilors represent a political party and are appointed for a period of 4 years; local officials usually have a contract for unlimited time. Municipalities usually do not have a special energy department, partly because energy is always one among many aspects, partly because the municipalities (especially the smaller ones) simply do not have the capacity and means for such a department. According to Zijdeveld (1999), Biemans (1999), Klaassen (1999), Schalk (1999), and Van Eupen (1999), energy will generally not be a central theme in municipal policies because other *non-energy* aspects are equally important, such as the livability of a district, the comfort of the houses, safety issues, parks and public gardens, water management, waste disposal and recycling, traffic and transport, architectural style, and freedom of choice for future residents. This is one of the reasons that municipalities prefer a flexible energy infrastructure, so that it is easier to adapt to future developments in society (Projectgroep 'Energiebesparing Meerhoven', 1995).

The municipalities in the Netherlands have a rather high degree of autonomy and play a crucial role in the implementation of national (and regional) policies. The municipalities are therefore the key actors to ensure that sustainable building measures and sustainable energy systems are implemented at VINEX locations (Van Huffelen, 1999; Hamers, 1999). For each location, the municipalities make detailed infrastructural and environmental plans that usually also contain the aim to be self-sufficient, implying that local demand (e.g., for energy or water) is as much as possible met by local supply (AER 1997, p. 5-9). This aim favors a decentralized approach in energy planning. Some municipalities, however, want to go beyond the implementation of national and regional plans. Their ambitions reach higher, they want to serve as role models for other municipalities. For example, the five largest municipalities in Brabant (Eindhoven, Tilburg, Breda, Den Bosch, and Helmond, see Figure 3.1) have signed an ambitious agreement to voluntarily aim at developing VINEX locations with an EPL of 7, implying that these locations will have a higher degree of sustainability (less CO_2 emissions) than average. For this purpose they have formed a 'B5 Platform' to exchange experiences and ideas (Van Huffelen, 1999; Visser, 1999).

The municipalities are one of the actors for which the liberalization of the energy sector has considerable consequences. While municipalities traditionally let the energy companies develop the energy infrastructure (after all, both were serving public interest), municipalities now deal with energy companies that are mainly concerned with competitiveness and profit. On the other hand, municipalities now also have a new powerful instrument: a tender or bidding procedure (Van Huffelen, 1999; Visser, 1999). By using this procedure, the municipalities can determine the terms of reference for the development of local energy infrastructure and choose the energy company that offers the best proposal. This new instrument does, however, require the municipalities to adjust their role, from watchdog towards initiator of the energy planning process.

If municipalities want to implement measures related to sustainable building and energy, it is important that they determine a certain level of ambition regarding the energy infrastructure before any decisions are taken. Otherwise, they can easily be dominated or overpowered by energy companies, even more so if the latter act in conjunction with property developers in a joint effort to promote the ‘less risky’ conventional options (Biemans, 1999; Van Eupen, 1999). To give the municipal ambitions a more formal basis, they can be put down in an official policy document, a so-called ‘energy policy plan’ (Gemeente Breda, 1996; Gemeente Breda, 1998; Gemeente Boxtel, 1996; Gemeente Helmond; Gemeente Tilburg, 1998).

The municipalities generally lack the necessary information to determine realistic level of ambitions and policy plans, so they contract consultancy firms to provide them with this information. The latter thus play an important role in supporting the municipalities during the initial stages of the planning process. The municipalities can usually get subsidies from Novem (a semi-governmental support organization) to contract the consultancy firms (Hamers, 1999; Vrins, 1999). Besides the subsidies from Novem and the support from consultancy firms, the municipalities get support from a special energy bureau for Brabant (Project Bureau Energy 2050). However, there is a difference between large and small municipalities regarding the support from these organizations or the granting of subsidies. The position of small municipalities is generally weaker; they get less (and less easily) subsidies; less space to develop new building sites; and less support from consultancy firms or other process supporters (Dörfel, 1999; Schipper, 1999; Wirtz, 1999).

So municipalities can influence the local energy planning process by using the tender procedure, by setting more stringent standards for the EPC value than the norm, and by voluntarily choosing to comply with a certain value for the EPL. In addition, they can also influence the development of the energy infrastructure through local subsidies and taxes, through the issuing of (building and environmental) permits, and by setting limits to the costs of houses. A complicating factor in the planning process, which can easily lead to internal conflicts, is the fact that many municipalities are still shareholder of local energy distributing companies, a remains of the pre-liberalization period.

3.3.4. Energy Companies: Energy Supply & Competitiveness

The energy companies play an important role in the development of any new energy infrastructure because they are responsible for the development and maintenance of the infrastructure, as well as for the production and reliable supply of energy. In 1999, energy companies in Brabant could be divided into four groups[4]:

I. Electricity production companies that produce electricity on a large scale and supply it to the (inter)national transport grid.
II. Electricity distributing companies that develop new electricity distribution infrastructures and distribute electricity to the end-users. Recently, these companies are also involved in the production of electricity with small-scale (< 50 MW) systems, such as cogeneration units fueled by gas or biomass, wind turbines, or solar systems.
III. Gas companies that develop new gas distribution infrastructures and distribute natural gas to the end-users. They are often part of the electricity distributing companies.
IV. District heating companies that develop new district heating infrastructures and distribute heat to the end-users. Like gas companies, they are often part of the electricity distributing companies.

The first group of energy companies is not relevant for local energy planning, as they are only involved in large-scale production of electricity that is supplied to the national transport grid. The other energy companies, however, play an important role in local energy planning, not in the least because they have a lot of experience and knowledge, in particular on fossil fuel systems. Recently, most energy companies have also begun experimenting with unconventional systems such as renewable energy systems.

Similar to the municipalities, the liberalization of the energy sector has also affected the energy companies. Before the liberalization, the electricity companies served public interest, but now they have to act commercial and survive competition (De Jong, 1999; Krikke, 1998; Kers, 1999; Leentvaar, 1999; Van Gestel, 1999). They have to adopt different roles and look for new strategies; competitiveness and profit are now the most important criteria. The changes and the uncertainty surrounding the liberalization process have resulted in energy companies showing risk avoiding behavior. Many of them are now reluctant to start or continue experiments with less proven technologies (such as renewable systems) (Van Gestel, 1999; Krikke, 1999). They also show a tendency to wait with new investments and only want to initiate new projects if there is a clear demand. So the energy companies focus mainly on proven technologies that guarantee an almost certain profit and a long-term, reliable supply.

One exception is, however, the ‘green electricity’ that energy companies now sell on a small-scale basis. Green electricity is produced with renewable energy systems such as wind turbines, PV solar systems, and biomass power plants. And even though the energy companies (initially) sold green electricity at a higher price than regular electricity, it has been

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[4] Due to the liberalization process, the structure of energy companies is changing rapidly. However, it lies outside the scope of this research to discuss the changes in detail.

able to find a niche market in the liberalized electricity sector. Apparently, consumers are willing to pay more for electricity if they know they are helping to reduce the adverse impacts on the environment. So in local energy planning, energy companies focus on competitiveness, following a strategy of low (production) costs, low risks, and/or at obtaining a niche market.

3.3.5. Property Developers: Profitability

Property developers are the actors that actually construct the new-to-build houses before selling them to private persons or social housing corporations. The property developers have to comply with several national and regional standards and regulations regarding construction procedures, the environment, and the safety of new-to-build houses (Lambrichts, 1999). Two important governmental documents are the Construction Act (containing standards for construction, including the EPN), and the National Package for Sustainable Building, a list of concrete measures that contribute to sustainable building. The property developer's role in the energy planning process is usually limited; the process only indirectly affects them, as some building measures relate to reducing energy demand. However, for a long time property developers resisted any energy saving measures in new buildings (such as isolation) because they had to pay for the additional cost (AER 1997, p. 5-9). However, at the end of the 1990s, the demand for houses in the Netherlands was so high that people bought houses regardless of the higher prices caused by the energy saving measures. So most property developers now have a more cooperative attitude towards sustainable building measures. Nevertheless, they will always prefer to use conventional techniques instead of new ones because of the lack of experience and the risks associated with the latter (Lambrichts, 1999). So unless municipalities clearly express their ambitions regarding sustainable building, property developers will try to convince the municipalities to opt for conventional techniques.

3.3.6. Consultancy firms: Specialized Knowledge & Models

The consultancy firms belong to the group of organizations that support the local energy planning process. However, they fulfill an important role in the process and are therefore treated separately. The role of the consultancy firms is to provide the expertise and the information that are required to make well-weighed decisions. The bureaus generally conduct studies on realistic level of ambitions for VINEX locations –generally expressed in a value for the EPC or the EPL– or on the range of technology options available to attain a certain level of ambition (Vrins, 1999; G3 Advies, 1996; G3 Advies, 1999; Gastec, 1996; Ecofys, 1996). The consultancy firms sometimes also provide support during the negotiations between different actors, during which they can serve as an intermediary, or mediate in conflicts (Vrins, 1999). The actual support that actors get from consultancy firms depends on the size of the project (small projects or small municipalities generally get less support) or the policy of the consultancy firms; some bureaus –mainly those that work for municipalities– focus on obtaining a collective support base among the actors for a particular option, others (mostly ones that work for energy companies) concentrate more on a detailed assessment of the options with the help of computer models.

Based on Vrins (1999) and an examination of the (confidential) consultancy reports, it appears that consultancy firms generally use bottom-up energy models to facilitate their studies, and these models often only include financial costs, technical performance, and CO_2 emissions as criteria for appraisal of options. According to Vrins (1999) and Hamers (1999), discussions arise frequently between actors as to whether the assumptions used in the models are correct. For instance, it is not uncommon that energy companies doubt the assumptions used in reports for the municipalities. Consultancy firms can significantly influence the process by focusing on certain options and leaving out others, or by using assumptions that affect the viability of options.

3.3.7. Support Organizations: Auxiliary Actions

Besides the consultancy firms, there are two other support organizations active in Brabant: Novem, a Dutch semi-governmental organization that provides subsidies and information on energy and the environment, and the Project Bureau Energy 2050[5]. The project bureau promotes the use of sustainable energy in Brabant (Van Huffelen, 1999; Visser, 1999). The support organizations serve as an intermediary for the municipalities, energy companies, property developers, and small- and medium enterprises, and they support the process by lobbying, bringing people together, mediating in conflicts, stimulating new initiatives, and –in the case of Novem– granting subsidies for studies and projects.

3.3.8. Future Residents: Informed, But Not Included

Sustainable building implies the implementation of measures that may affect the future residents' freedom of choice. For instance, an all-electric energy infrastructure will imply that households use electricity for cooking instead of gas, which is the traditional way to cook in the Netherlands. Ultimately, the future residents will have to use the new equipment and often pay for the extra costs. Therefore, public support is needed, and for an adequate support base, communication is the first step. Future residents need to be well informed on items that affect heir lives. However, at the time of the field study, only one-way communication took place from –on the one hand– municipalities, energy companies, and property developers to –on the other hand– the future residents. The latter thus do not participate in the energy planning

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[5] The Project Bureau Energy 2050 is financed by the province and the originally largest energy company in Brabant, PMG (which in 2000, has merged into a new energy company Essent).

decision process[6]. Disregarding the preferences of future residents can result in resistance and/or adverse effects of policies or decisions. Preferences of future residents include, among others, comfort, freedom of choice, reliable and easy-to-use equipment that requires little maintenance, reliable supply of energy, and of course, low prices of energy and houses. Another issue important to future residents is the living environment of the VINEX locations. Generally, the municipality is thought to be the designated actor to take into account the preferences of the future residents. In general, the municipalities already apply the ‘Not More Than Otherwise’ principle, which states that future residents should not have to pay more for energy from an alternative energy infrastructure (e.g., electricity and district heating) than they would with a conventional one (i.e., electricity and gas).

3.3.9. Overview of Actors, Interests, and Preferences

Table 3.3 gives an overview of the main actors that we identified in the field study of Brabant, as well as the interests and the preferences that we extracted from the interviews with actors. Note that the preferences of future residents are also included in the table, although this actor is generally not included in the energy planning process. The municipality is thought to represent their interests.

Table 3.3. Interests and preferences of relevant actors in energy planning for VINEX locations in Brabant.

Actors	**Interests and Preferences**
National Government Regulatory & policy framework	• Sustainable development → Sustainable building → Sustainable energy • CO_2 reduction
Municipality Implementing national & regional policies	• Sustainable development, CO_2 reduction • Flexible energy infrastructure • Self-sufficient new building sites (water, energy) • Reliability of energy supply (not explicitly mentioned) • Future residents: Not More Than Otherwise (NMTO) principle
Energy Company Competitive & profitable in energy supply	• Competitiveness • Profitability • Use of proven techniques (low risk and uncertainty) • Reliable supply of resources and energy • Low maintenance of equipment
Property Developers Profitable in constructing houses	• Competitiveness • Profitability • Use of proven techniques (low risk and uncertainty)
Consumers Informed but not included	• Low prices of houses and energy • In-house comfort & pleasant living environment • Easy-to-use equipment (low maintenance, fast response) • Freedom of choice • Reliable energy supply

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[6] There were some interest groups such as the Women’s Advisory Commission that could express their preferences during the planning process, but their influence was relatively low.

3.4. Key Issues in Energy Planning for VINEX Locations in Brabant

The field study of Brabant shows that the energy planning generally follows the steps described in Section 2.7, although not as straightforward as assumed by Figure 2.2. However, we distinguish two important other stages in the process that are specific for this case: the determination of ambitions and the implementation of these ambitions.

As noted earlier, the municipalities –when using a tender procedure– play a key role in local energy planning; they determine the conditions with which new energy infrastructure for VINEX locations has to comply (e.g., building measures, values for the EPC or EPL), so they are the main initiators of the energy planning process. The energy planning process begins with the municipalities determining their ambitions, and they generally need the help of consultancy firms and energy companies to do this.

When implementing the ambitions, the municipalities are confronted with the ambitions or interests of other actors, mainly the energy companies and property developers. The field study of Brabant shows that the actors are mutually dependent on each other and generally have to negotiate to reach a final outcome. Therefore, the outcome of the local energy planning process at VINEX locations is usually different from the ambitions or preferences that the actors initially had. Especially the municipalities often experience difficulties in implementing their ambitions in practice. But even the determination of realistic ambitions appears problematic. Based on the information obtained during the field study of Brabant, we have identified several thresholds that the municipalities –as initiators of local energy planning– encounter, which we will discuss below. First we will address the thresholds that play a role in determining the municipalities' ambitions (§ 3.4.1), and consequently the thresholds that play a role in implementing the ambitions (§ 3.4.2).

3.4.1. Key Issues in Determining the Level of Ambition

The municipality's ambitions concerning the energy infrastructure at VINEX locations are usually expressed in a value for the Energy Performance Coefficient (EPC) and/or a value for the Energy Performance on Location (EPL). Determining realistic values is, however, not an easy task for municipalities. They generally lack knowledge on the range of options and the feasibility of measures to attain certain EPC or EPL values. Therefore, they will need the support of consultancy firms to analyze and provide information on the options and consequences. These consultancy firms, in turn, will need the cooperation of energy companies to obtain essential data on current energy demand and supply. So the consultancy firms as well as the energy companies can already influence this stage of the process through the information they provide. The property developers are usually excluded at this stage of the energy planning process to avoid a situation in which the municipalities face too powerful opposition from a coalition of energy companies and property developers that jointly lobby for an 'easier' conventional option.

In theory, the level of ambition may be based on energy considerations only, but in practice the determination of the level of ambition is affected by trade-offs with other non-energy aspects that are equally important. Also, thresholds in the process hamper ambitious plans. During the field study of Brabant we identified the following trade-offs and thresholds:

- *Non-Energy Aspects*
  Energy aspects that play a role in local energy planning at VINEX locations include sustainable building measures, CO_2 reduction, values for the EPC and/or the EPL, infrastructure investments, reliability of energy supply, flexibility of the chosen infrastructure, and (extra) costs for future residents. However, municipalities consider energy as only one among many aspects; besides the energy aspects, other *non-energy* aspects affect the decision process. Non-energy aspects concerning VINEX locations include the livability of the district, the comfort of the houses, safety issues, space for parks and public gardens, water management, waste disposal and recycling, traffic and transport, architectural style, and freedom of choice for future residents. So creating an "optimal" energy infrastructure in terms of technically and financially efficient systems may not always result in desirable VINEX locations. On the other hand, the VINEX locations are one of few opportunities to introduce unconventional energy systems into the existing –fossil fuel based– energy infrastructure. And including energy aspects at the beginning of the general planning process for VINEX locations results in a wider range of options for the energy infrastructure. In addition, the municipalities should keep in mind that, whatever decision they make, most 'final' choices cannot easily be reversed, while the consequences of the choices will affect society for as long as the lifetime of the energy infrastructure, and sometimes even longer. So even though energy cannot have the highest priority, and an "optimal" energy infrastructure is often undesirable, more options remain open the earlier energy is taken into account in the process.

- *Motivated People*
  Motivated people are essential in setting (and attaining) high ambitions. Motivated people are often the initiators of new and ambitious plans, and they mediate in conflicting interests between departments.

- *Internal Support Base*
  An internal support base within the municipality is essential for incorporating energy aspects into the general decision process regarding VINEX locations. Since none of the municipalities has an energy department, energy is often the responsibility of a the 'environmental coordinator.' Usually, energy issues do not have priority in any of the departments, and that is why it is important that the internal support base throughout the municipal departments is large enough to support the energy ambitions. An internal support base also contributes to the consistency of municipal actions. Without a sufficient support base, ambitions are easily frustrated during the implementation phase, as Box 3-2 illustrates. A repetitive threat to the municipality's internal support base are the elections

after every four years: new councilors can shift the priorities and policies of previous councilors. However, by giving ambitions a formal status in policy documents, and through communication and information the municipalities can improve the internal support base for energy related ambitions.

Box 3-2. An example of the lack of internal support base.

Lacking Internal Support: Municipal Councilors vs. Municipal Officials

During the field study of local energy planning in Brabant, a municipality had very ambitious plans: putting a solar collector on every roof of the new-to-build houses of a VINEX location. The municipal officials had arranged everything: a consultancy firm had given them the necessary information and had shown the plan was feasible; they knew where to get subsidies, and had arranged a substantial discount if the solar collectors were to be ordered en masse.

However, at the start of the actual construction of the houses, the municipal councilor –doing the honor of 'placing the first stone'– gets into conversation with the property developer of the site. The latter remarks that he believes the planned solar systems restrict the freedom of the future residents because they can't refuse the systems if they don't want them. Wouldn't it be better, the property developer suggests, to let the future residents make their own choice after the houses are built? The councilor ponders a while and then decides that the property developer is right: the freedom of choice for residents is important, and it would be better to delay the whole solar system plan and let the future residents decide whether they want one or not. So despite the careful preparations of the officials, the deal was suddenly off, and an opportunity lost to get subsidies, since most subsidies do not apply to private persons. In addition, the benefits of buying the solar collectors with discounts, and of installing them in bulk during the constructing of the houses had vanished……..

- *External Support Base*
  External support, like internal support, is essential during the determination of the municipal level of ambition. The principal actors in determining the municipality's ambition are the municipality, the consultancy firms, and the energy companies. Of course, the municipality ultimately decides which ambitions it will pursue, but without the support of the two other actors the determination of a realistic level of ambition becomes difficult. In fact, if an ambition is determined without the support of at least one energy company it is likely to be unattainable in practice.

- *Conflicting Interests*
  Often, the reluctance of the energy companies to cooperate in setting high ambitions is a result of conflicting interests (which can easily turn into conflicts) concerning, for instance, the feasibility of certain ambitions, the assumptions used to identify and appraise relevant energy technologies, or the distribution of costs and benefits among the actors.

- *Process Support*
  Process support for determining the municipal ambitions is provided by consultancy firms, and to a lesser extent also Novem, and the Project Bureau Energy (PBE) 2050. They can help bring actors together and create a broad support base (internal as well as external) that increases the feasibility of ambitions. In addition, most consultancy firms

use bottom-up spreadsheet-like computer models to give information on the feasibility of options and on their consequences. However, the role of these models is modest in practice, as the support base for an option appears to be more important. Without a sufficient support base, the assumptions and the options used in the models are an easy target for discussion, and can easily lead to disputes between actors.

- *Technological Development*
  Ambitions are often considerably less ambitious by the time they reach the implementation stage as a result of technology development. Therefore, some municipalities, such as Tilburg, use a "sliding scale" when setting ambitions, with maximum and minimum boundaries within which the level of ambition varies (increases) throughout the years. The level of ambition which is actually implemented will lie somewhere between the minimum and maximum boundaries depending on the technological development that has taken place (as well as on the changes in society and policies).

- *Intangible Aspects*
  Some parts of the process are very difficult to control or even influence, even though they can affect the process considerably. These intangible aspects are generally only known to (a few) insiders and can easily lead to rigid viewpoints and severe conflicts. Examples of intangible aspects include historic relations between actors or individuals, the fact that –traditionally– the province and many municipalities are shareholders of energy companies, political considerations and aspirations, as well as the lust for power of some individuals.

We will now address the thresholds that the municipalities encounter when trying to implement their ambitions.

3.4.2. Key Issues in Implementing Municipal Ambitions

Once the municipality has determined its ambitions, the next step is to implement them. During the implementation phase, the municipalities have to deal with several actors, of which the energy companies and the property developers are the most important ones. The tender that reflects the ambitions of the municipality compels the energy companies to make proposals that comply with the conditions of the tender. Often, energy companies will form a consortium with, for instance, property developers and banks to improve their offer and provide more service. Also, the energy companies get support from the consultancy firms in writing their proposals, in particular regarding technology options and building measures.

The municipality then has to choose an energy infrastructure from the proposals before the property developers and contractors can start constructing the buildings and the energy company can construct the energy infrastructure. However, before this stage is reached, the municipality can encounter several thresholds during the implementation of ambitions. These thresholds partly arise due to the fact that the ambitions of municipalities generally do not coincide with the interests of the energy companies or the property developers. Not surprisingly, the preferred energy infrastructures of actors also differ. Nonetheless, the actors are mutually dependent, so they will usually have to negotiate with each other to reach a mutually supported outcome. Some of the thresholds of the implementation stage were also present during the determination of ambitions, others are specific for the implementation stage. The main thresholds during implementation of municipal ambitions include:

- *Motivated People*
  Motivated people are essential when implementing ambitious goals. Motivated people are often the driving forces of the process that keep negotiations going, come with creative solutions to solve conflicts, and inspire other individuals.

- *Internal Support Base*
  At the implementation stage it is even more important that the internal support base within municipalities is large enough. This base is influenced by the political climate, elections, available knowledge and perceptions, communication, and internal conflicts.

- *External Support Base*
  For the successful implementation of their ambitions the municipalities need the cooperation of energy companies and property developers. Since the interests and preferences of these actors –and thus the preferred energy infrastructure– generally do not coincide, while the actors are mutually dependent, they will usually have to negotiate and compromise to reach an outcome. Apart from differences in interests and preferences, there is also a difference in knowledge of the actors. And a proper external support base will also improve the sharing of information.

- *Conflicting Interests*
  High ambitions of municipalities easily conflict with the interests of the energy companies and property developers; the energy companies and property developers prefer conventional options consisting of proven technologies and standard procedures with which they have abundant experience. They are not eager to invest in new technology, which usually involves substantial risks as well. In addition, they often do not agree on the assumptions that the consultancy firms use to point out feasible but high level of ambitions for the municipality.

- *Process Support*
  As mentioned before, process support is offered by consultancy firms, Novem, and the Project Bureau Energy 2050, but the role of the consultancy firms in the process is by far the most important one. The consultancy firms often use models to help the

municipalities or energy companies determine the ‘best’ options. However, the field study of Brabant shows that, in practice, the role these energy models in finding commonly acceptable, appropriate options is modest. Generally, the outcomes of these models only serve as a starting point for discussion because different models and assumptions are used per actor. The outcomes of these models usually ‘prove’ that the preferred option of an actor is in fact the ‘best’ option. However, if the other actors do not support this particular option, the assumptions used in the models are an easy target for discussion. Only if the support base for a technology option –including the assumptions– is large enough among the actors, a model is useful for a detailed study. Also, many consultancy firms tend to focus only on technical-financial or architectural aspects that can rather easily be represented in models. However, in doing so they neglect other important aspects such as the livability of a district or a house. For example, a north-south orientation of the houses improves the viability of solar systems, but many future residents will perceive an entire district with such houses as monotonous and less desirable to live in. Nonetheless, consultancy firms can also play an important role in establishing a broad support base among the actors, by acting as an intermediary. Novem also offers support through the granting of subsidies, but the application for subsidies is often complex and time consuming, while the subsidies often only apply to selected programs that do not always fit into the plans of the municipality. In particular small municipalities appear to encounter this problem.

- *Intangible Aspects*
  The intangible aspects at the implementation stage are not much different from those at the determination stage. The consequences, however, are usually larger since the decisions that are taken affect the physical environment directly. However, intangible aspects have less influence if initiatives get a formal basis by incorporating them in governmental policy plans. Also, supplying sufficient information helps to establish a support base, and contributes to the motivation of individuals.

- *Distribution of Costs and Benefits*
  The distribution of costs and benefits among the actors may differ for the different alternatives. The investors (i.e., energy companies and property developers) do not always receive the benefits of the investments, which reduces their willingness to cooperate. For example, municipalities usually do not have the financial means to support their ambitions, while they often apply the Not More Than Otherwise (NMTO) principle to protect the future residents. This implies that the energy companies or property developers (or both) pay the extra costs for e.g., renewable energy systems or sustainable building measures. Consequently, the competitiveness and profitability of the latter two actors is reduced, which explains their reluctance to cooperate. To avoid conflicts in the implementation stage it is therefore important to reach agreement in advance on who pays which costs.

- *Housing Market*

  The situation on the housing market determines to a large extent the willingness, especially of the property developers, to cooperate in initiatives that deviate from normal procedure. If the demand for houses is relatively high, the property developers are more willing to invest in unconventional techniques, as any extra costs can be passed on to the future residents.

- *Land Policy*

  The municipalities often do not possess the land on which they are planning a VINEX location. Property developers are usually the owners, so the municipalities either have to buy the land or get the property developer's permission to develop a VINEX location on his land. The property developers often agree to a deal in return for the right to construct the buildings at the site (or another site). So the property developers do possess power to influence the decision process by refusing to close a deal. This weakens the municipality's position when demanding, for example, special building measures.

- *Market Liberalization of the Energy Sector*

  The market liberalization of the energy sector poses problems at the implementation stage of the municipality's ambition, although the exact impacts were still uncertain at the time of the field study. The AER (1997) anticipates a shift from energy optimization towards cost optimization. Economic lifetimes of equipment are believed to decrease and this may lead to decreased attention for energy efficient technologies and/or renewable energy. Also, because of the uncertainty associated with the liberalization process, the energy companies in particular show risk avoiding behavior, and a tendency to wait with new investments. Also, they don't initiate new pilot projects –or even abandon existing ones– with less proven technologies such as renewable energy systems. Furthermore, the energy companies are forced to shift from a role in which they serve public interest towards a commercial role in which competitiveness and profit are the most important aspects. Municipalities also have to adjust their strategies and adopt new roles as they are now allowed to use a tender procedure, and thus act as initiators of local energy planning by setting the conditions for the local energy infrastructure.

- *Consistency in Conditions*

  The municipality's consistency in policies and conditions concerning the energy infrastructure influences the uncertainty perceived by the other actors[7]. However, since compromises appear to be inevitable in order to reach agreement among actors, adjustments of the conditions seem unavoidable.

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[7] In economics, this uncertainty regarding the consistency and stability of regulation and policy is commonly referred to as 'regulatory risk'.

3.4.3. Discussion of the Issues in Local Energy Planning for VINEX Locations

The field study of VINEX locations in Brabant shows that local energy planning is not a simple straightforward process. Many actors are involved and many issues play a role, which is illustrated in Figure 3.3. The main actors include the municipalities, the energy companies, consultancy firms, and –to a lesser extent– the property developers. The municipalities plan the VINEX locations and initiate the energy planning process by setting the conditions with which the new energy infrastructures must comply. The energy companies construct and maintain the energy infrastructure, and supply the energy to the end-users, while the property developers construct the houses at the VINEX locations. In addition, the consultancy firms fulfill the information needs of the actors, and all actors operate within the regulatory and policy framework set by the national and (provincial) government. An important issue that influences the energy planning process is the liberalization of the energy sector, which forces actors to adopt new roles and adjust their strategies. Also, the uncertainty associated with market liberalization (concerning regulations and actors' strategies) results in risk avoiding behavior, a tendency to keep options open by waiting with new investments, and abandonment of pilot projects with less proven technologies.

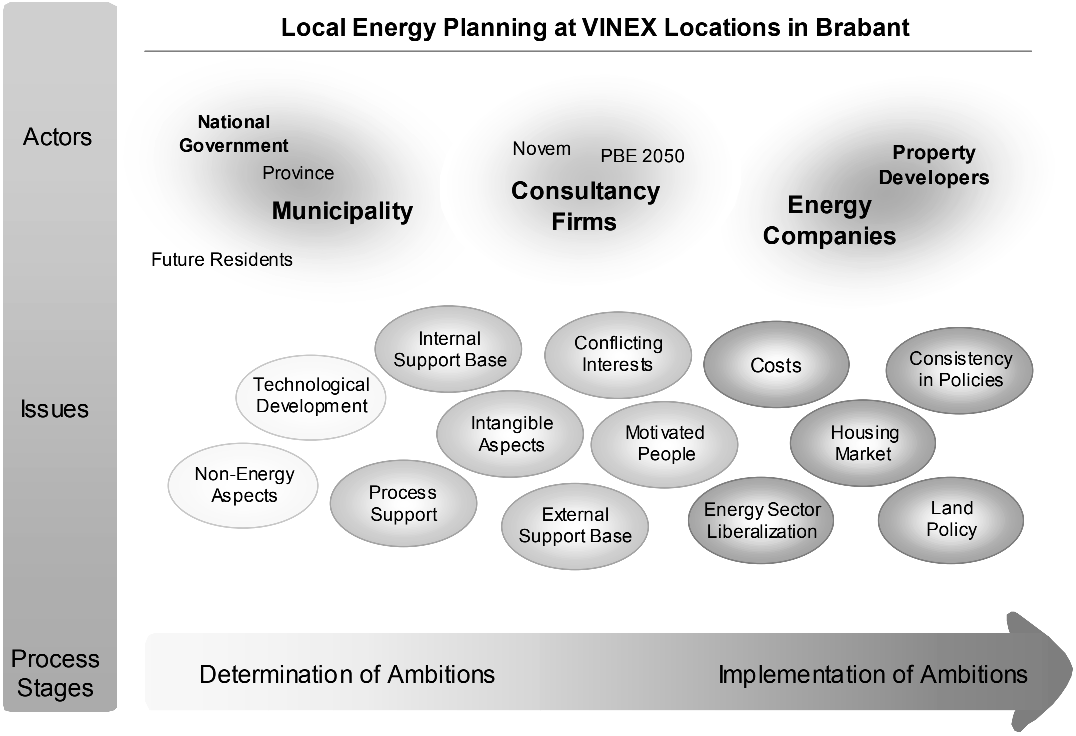

Figure 3.3. Actors and Key Issues in Local Energy Planning for VINEX locations in Brabant.

When planning a new VINEX location, the municipalities have to implement the national policies and regulations concerning sustainable building. In addition, the municipalities can use the tender procedure to set conditions for the new energy infrastructure, which makes them the initiators of the local energy planning process. However, this requires that the municipalities determine a –realistic– level of ambition regarding the energy infrastructure. In general, the municipalities lack the information to do this; they need the help of consultancy firms to point out the options. The consultancy firms use bottom-up spreadsheet-like models to identify relevant options and assess possible consequences, but they need data of energy companies to do this. So both the consultancy firms and the energy companies can influence the determination of energy ambitions through the information they provide. In addition, there are non-energy aspects and thresholds that impede high level of ambitions of municipalities, as outlined in Figure 3.3.

When implementing the ambitions, the municipalities not only have to deal with the energy companies, but also with the property developers. All these actors have different interests and preferences regarding the local energy infrastructure, but at the same time they are mutually dependent: the municipalities depend on the consultancy firms to provide them the information on realistic ambitions and infrastructure options, while the consultancy firms depend on the energy companies for data on energy demand and supply. Municipalities depend on property developers for the use of their land, but the property developers have to comply with regulations concerning building measures and depend on the municipalities to get building permits. The energy companies depend on the municipalities with respect to the conditions set for new energy infrastructure, while they also have to ensure that the new energy infrastructure is compatible with the techniques applied by the property developers. Often, the energy companies also require the support of the consultancy firms to determine the options (and consequences) that comply with the conditions set by the municipalities.

The mutual dependencies force the actors to negotiate and make compromises in order to find a mutually supported outcome. Trade-offs have to be made, and thresholds and conflicting interests arise either during the implementation of the municipal ambitions or during the determination of the ambitions, as Figure 3.3 illustrates. So the final energy infrastructure will rarely be ‘optimal’ from a technical or financial point of view. At best, the outcome will be ‘appropriate’ and supported by all the actors.

This also explains why the current models are mainly used at the beginning of the planning process. These models point out one or more ‘best’ options for one particular actor, but the included aspects are limited to those perceived as important by that one actor, and the aspects usually need to be quantified. Not surprisingly, these ‘best’ options are usually the preferred options of the actors. However, since different aspects and assumptions are used per actor, the preferred options of actors differ. So the actors each present their preferred energy infrastructure at the beginning of the negotiations, only to find out that compromises are necessary to reach a mutually supported outcome. Current models do not intend to include more actors or aspects that are not easily quantified, and the field study of Brabant shows that these models are therefore not well fit to support the *entire* energy planning process.

The field study of Brabant also revealed that actors state their interests and preferences in rather ambiguous terms (e.g., infrastructure need to be ‘flexible’), but during the planning process the actors usually learn to express themselves more clearly. Through the interactions during the process, actors also learn about the interests and preferences of other actors, and about unnoticed consequences of certain infrastructure options. The interactions and learning generally cause changes in the preferences of actors (e.g., goals become less ambitious but more realistic), in the options included in the analysis (e.g., not only conventional fossil fuel options, but also renewable options are included in the analysis), or in the aspects taken into account during the assessment of the options (e.g., not only financial and technical aspects are taken into account, but also aspects such as safety, risk, comfort, reliability, or sustainability). Again, current models are not well fit (not intended) to support these repetitive changes or feedback loops, and are therefore mainly used at the beginning of the energy planning process (or at the end, to work out the ultimately selected energy infrastructure in more detail).

The aspects of local energy planning brought forward by the field study in Brabant and discussed in this chapter requires us to make some adjustments to the preliminary method of Section 2.7. We will discuss these adjustments in the next section.

3.5. Required Adjustments to the Preliminary Method

The field study of energy planning at VINEX locations in Brabant was conducted to determine how local energy planning really evolves in practice, and what specific constraints occur at that level. The results of the field study first of all emphasize the importance of issues that we mentioned when discussing the preliminary method in Section 2.7. For instance, the field study clearly shows that there is not just one decision-maker: many actors are involved in the energy planning process, while the planners are not always the actual decision-makers. The actors usually have different interests and preferences, but at the same time they are mutually dependent, and they have to negotiate and make compromises to reach a (mutually supported) outcome. But conflicting interests are not the only reason that financially or technically optimal solutions are rare: trade-offs that have to be made and thresholds that occur during the process also prevent such optimal outcomes. At best, options have a broad support base among the actors and can be referred to as appropriate rather than optimal. So the field study shows that because of mutual dependencies, it is important to include all relevant actors in the process, *and* to assess all relevant aspects to reach a broadly supported appropriate outcome.

The field study of Brabant also shows that most actors lack knowledge to make proper decisions, and that the support of current energy models is limited; they are only used at the beginning of the planning process and provide little or no support during the further stages of the process, when actors have to interact and negotiate in order to reach a final outcome. In addition, the models are unfit to incorporate the repetitive changes in preferences of actors, the options included in the analysis, and/or in the aspects accounted for in the impact assessment. These changes are a result of learning: the interactions give actors insight in each other's preferences and interests, and provide new information about alternative options or unsuspected impacts.

So interaction and learning appear to influence the outcome of the energy planning process considerably. Although the field study shows that local energy planning in Brabant generally follows the steps of the preliminary method presented in Section 2.7, it does not yet explicitly address interaction and learning. So if we want to develop a method that supports the *entire* energy planning process, we have to take these issues into account somehow.

The other outcomes of the Brabant field study may seem fairly straightforward to most people, but they do provide us the necessary feedback on the assumptions made for the preliminary method. The main finding is that the setup of the preliminary method is realistic, but to fully support the entire energy planning process, the method must be adjusted to explicitly allow for interaction and learning.

We have now answered the second sub-question of the thesis (about the thresholds in the planning of local energy infrastructure, see § 1.6.1), and can start making the adjustments to the preliminary method. Complicating factor is that the literature on energy planning does not contain information on how to incorporate interaction and learning, not to mention at the local level. Therefore, we searched beyond the field of energy planning to find additional theories containing valuable concepts that can help us construct the new method. The valuable non-energy related theories are discussed in the next chapter.

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4 Additional Input from Non-Energy Related Theories

4.1. Introduction

The field study on energy planning in Brabant shows that current energy models do not account for interactions and learning, and are therefore not well fit to incorporate the recurrent changes in actors' preferences, or the changes in the options and aspects included in the analysis. As a result, the support of the current energy models is restricted to the beginning of the energy planning process. Since we want to support the entire energy planning process to improve the quality of decision making, we will need to incorporate interaction and learning in the new method. However, little can be found in the energy planning literature on how to include these aspects. Therefore, we decided to examine literature of other disciplines not directly related to energy. In particular, the literature concerning theories on technology development and technology management appear promising in this respect, which have been applied in fields such as information technology, biotechnology, transportation technology, or agricultural technology[1]. These non-energy related theories contain valuable insights or concepts that help us to explicitly incorporate interaction and learning in our new method. More specifically, we use the quasi-evolutionary theory (a variant of the theory on evolutionary economics) to provide a broad theoretical framework for our new method. This theory is particularly suited to help explain how the development of the energy infrastructure

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[1] See, for instance, Jelsma (1995), Rip et.al. (1995), Broerse (1998), and Weber et. al. (1999).

evolves, how it can be influenced, and what the role of learning is. Note that other theories stemming from a neo-classical economic framework (such as bounded rationality, transaction cost, and experience curve theories)[2] could be equally fit to explain developments in the energy infrastructure, but we prefer the use of the quasi-evolutionary theory because it is easy to comprehend and stresses the social factor more than the economically oriented theories do.

Another issue stressed by the results of the Brabant field study is that energy planning rarely results in 'optimal' outcomes, due to the fact that many actors influence the planning process, each having different interests and preferences. Mutual dependencies force the actors to negotiate and compromise to reach a final outcome, which is 'appropriate' rather than optimal. The concept of appropriate technology provides useful theoretical support when diverging from the traditional wish for an optimal solution.

At a more concrete level, approaches such as Technology Assessment and Participatory Technology Development, which are used to manage technology in society, provide handholds for the actual construction of the new method for local energy planning.

So this chapter will address the additional non-energy related theories that provide a framework for the new method. In the following sections, we will first give a brief description of quasi-evolutionary theory and its principles (§ 4.2), followed by an explanation of the concept of appropriate technology (§ 4.3). In sections 4.4 through 4.6 we will discuss the more concrete approaches to manage or influence technology development, and we will conclude with an overview of the valuable inputs of non-energy related theories for the new method (§ 4.7).

4.2. Quasi-Evolutionary Theory

The quasi-evolutionary theory provides a useful basis for addressing processes of learning and interaction during local energy planning. The theory is developed by among others Rip (1989) and Schot (1991), and combines aspects of evolutionary economics (as developed by authors such as Nelson, Winter, and Dosi) with sociological work of, for instance, Callon and Bijker[3]. But the theory also shows overlap with ecological-economic theories and contains aspects of theories on history of technology, philosophy of technology, and economics of innovation (Rip et. al., 1987, p. 16; Meppem and Gill, 1998)[4]. Initially, the theory was used to describe the early stages of technology development, but the growing perception that technology development is a continuous process of modification has led to application of the theory at

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[2] A more detailed discussion of the concepts of bounded rationality and transaction costs lies outside the scope of this thesis. A further explanation can be found in, for example, Simon (1982), Williamson and Masten (1995; 1998), and IEA (2000).

[3] See for instance: Nelson (1987), Nelson and Winter (1977; 1982), Dosi (1982), Callon (1986), and Bijker et. al. (1987; 1992).

[4] See also: Rosenberg (1982), Freeman (1982; 1991), Rip and Van den Belt (1988), and Schot (1990).

other stages of the development cycle as well. Note that energy planning largely deals with technologies that are already commercially available, and which are thus at the end of their development cycle.

The quasi-evolutionary theory is based on the notion that technology and society influence each other, and how this is done is explained in § 4.2.1. We will then explain how quasi-evolutionary theory sees technology development (§ 4.2.2), followed by the roles that actors play in the development of technologies (§ 4.2.3). The influence of learning is discussed in Section 4.2.4, while Section 4.2.5 deals with the effects of technology development. Section 4.2.6 addresses the appraisal of technology effects, and the last section on quasi-evolutionary theory (§ 4.2.7) gives an overview of the useful inputs of this theory for the new method.

4.2.1. Technology Influencing Society Influencing Technology

Technologies are not only the objects you can *touch*. Those are merely the physical appearances of technologies. A technology involves more; it also consists of the values, ideas, knowledge and activities that make it possible for the objects to operate in society (Schot, 1991, p. 12). The fact that technologies affect society is trivial for most people. For instance, the difference is clear between on the one hand the rural community where it takes many hours every day to prepare and cook food on a wood stove, and on the other hand a city where it takes five minutes to prepare ready-made food in a microwave, while television is spreading today's news. Indeed, the availability of energy and telecommunication technology has drastically changed the lives of many people.

However, the fact that society influences the development of technologies is less evident for most people. Fischer (1992) gives an often-cited example of this fact by describing the development of the telephone. Initially developed for taking over the purpose of the telegraph (i.e., transporting short business messages), the telephone soon became an instrument for maintaining social relationships, even despite the attempts of the telephone companies to avoid this kind of 'misuse'. However, the desire in society for social communication was so strong that the telephone companies eventually made adjustments to better serve this type of application. Another more recent example of society's influence on technology development is the replacement of 'unwanted' technologies (such as building materials containing asbestos or cooling equipment containing CFCs) with less harmful technologies. And the development of nuclear power is another example. In the Netherlands, for instance, nuclear power was initially thought to be a viable alternative for fossil fuel power plants, but the strong and continuous resistance in Dutch society practically led to a standstill in its development. Akrich (1995) states that technology development is also influenced –though less apparently– through the views that technology developers have of the future users, their behavior, and their needs (the so-called *user representations*).

So technology development is not an autonomous process; societies influence technologies as much as technologies influence societies. Technology development and societal change are thus entangled. The process of mutual influencing or interaction between technology development and societal change is called the *co-evolution*[5] of technology and society (Rip and Kemp, 1998). This entanglement also implies that effects of technologies are not predefined; they are only *possible* effects.

Collingridge (1980, p. 11) explains that the reason why it *seems* that technology develops autonomously is because the effects of technologies are usually only detectable after a widespread implementation of these technologies, while the processes preceding the widespread implementation are often unknown or unclear to most people. Also, the influence of only one individual –or even a group– on the development process is often small. Many actors are involved in the process, which makes individual commitment and initiative necessary, but not sufficient to bring about substantial changes in the development. The roles of actors in the development process of technologies will be addressed in Section 4.2.3, but we will first discuss the development process itself in more detail.

4.2.2. The Technology Development Process

A traditional –logical– representation of the development stages that a technology generally goes through during its lifetime is a linear process with 5 consecutive stages (see Figure 4.1). Starting with the creation of ideas and knowledge, the development process leads –through R&D– to a product or system that is consequently introduced onto the market. After diffusion, the development process ends with the effects caused by a widespread application of that technology product or system in society (Smit and Van Oost, 1999).

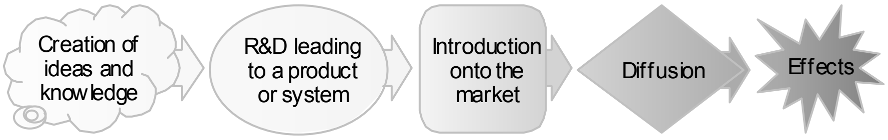

Figure 4.1. A linear representation of technology development. Source: Smit and Van Oost (1999, p. 58).

This linear *deterministic* representation of technology development ignores the interaction and feedback that occur *between* the development stages, or between the development process and society. So this deterministic view ignores the influence that actors in society have on the development process; it sees technology development as an *autonomous* (but not necessarily a neutral) process, and society simply has to adapt to whatever the effects imposed by a technology.

The quasi-evolutionary theory, on the other hand, acknowledges that society influences the development of technology and vice versa. This is what we called 'co-evolution' in the previous section[3]. The effects of a technology therefore depend on the *social context* in which it develops (Rip et. al., 1987, p. 17). The social context consists of the economic market,

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[5] Strictly speaking, co-evolution and quasi-evolution are different (but related) concepts. However, in this thesis we will use these terms interchangeably.

institutional factors (such as regulations, formal and informal relationships between actors, and political structures), as well as social and cultural factors. Societal change and technology development are thus interrelated processes that co-evolve and in which actors play an important role. This view on technology development is referred to as the (societal) *constructivism* perspective[6], and is based on the actor-network theories of authors such as Callon (1986) or Latour (1987). The actors in society interact through formal and informal institutional, organizational, and economic relationships, and they can influence –but *not* control– the development of a technology through collective actions. Nonetheless, other elements of the social context, such as regulations and market forces, will also influence the development.

The co-evolution of technology development and societal change implies that many variations of a certain type of technology are created, and that the actors in society 'select' the promising ones for further development. This continuous process of introducing technology variations and subsequently selecting some of them occurs on a trial and error basis; there is no guarantee beforehand that a particular variation will be successful in society. The continuous introduction of new variations, of which some will prove viable and some will not, results in a 'development tree' with branches that are either dead ends or continue in a certain direction (see Figure 4.2). Each branch can be seen as a development process on itself, progressing through (some of) the development stages presented earlier in Figure 4.1. The actors in society select the branches that they believe to be promising, step by step creating a certain development path.

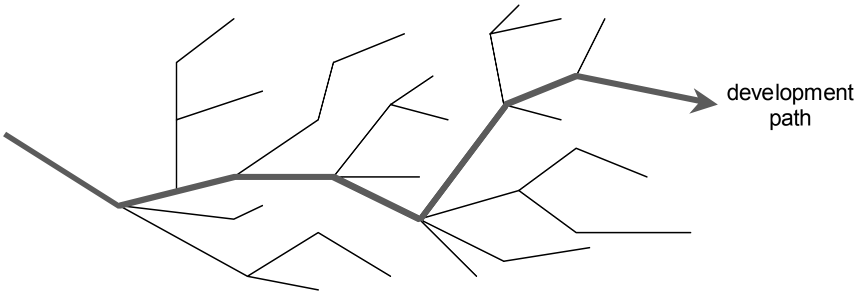

Figure 4.2. Technology development as a quasi-evolutionary process of variation and selection. Source: Schot (1991, p. 68).

So the quasi-evolutionary theory sees technology development not as a rational, linear, and deterministic problem-solving process, but as a 'trial and error' *search process* characterized by many uncertainties (Rip et. al., 1987, p. 16). From the outside, the development path may seem a deterministic, autonomous process, but Rip et. al. argue that the internal search processes within parts of society make technology development a *socio*-technical process.

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[6] This view is not to be mistaken with that of *social* constructivism, which is based on theories such as those from Bijker (1992). This view also considers technology development and social change as interrelated processes, but assumes that the actors –each from their own viewpoint – determine the development of a technology by giving *meaning* to it.

As Figure 4.2 shows, the accumulation of viable branches i.e., the development path, moves into a certain –only vaguely defined– direction. Once a certain path is established, however, it becomes difficult to radically change its direction, implying that the development of technologies depends on decisions made in the past, while the decisions made today will provide a direction for the future. For instance, past decisions have led to a situation in which European households are connected to a 220V electricity grid, while American households use 110V. This has substantial consequences not only for the generation units used by the energy companies, but also for the electrical appliances used by the end-users. The dependency on past decisions and procedures is referred to as *path dependency* of technology development, and it restricts the range of technology variations. In addition, decisions regarding future developments are often based on heuristics and procedures that have proven to be successful in the past. These heuristics and procedures direct the development of technologies into certain *technology trajectories*, but these trajectories are no guarantee that technologies will become successful (Schot, 1991, p. 92-93). Nevertheless, the further a technology trajectory progresses, the more the technology becomes *entrenched* or *locked-in* in a society; society continuously (re)organizes itself to allow for an optimal performance of the selected technologies (see also § 4.2.5). This lock-in or entrenchment process complicates the introduction of new technologies that substantially differ from those developed in the trajectory. For instance, electric vehicles use a technology that substantially differs from the widely-used combustion engine, and although the first electric vehicle was already used at the end of the 19th century, the disappointing results of more recent initiatives for a widespread application of electric vehicles can largely be explained by the entrenchment of the combustion engine.

At a meta-level, *technological paradigms* or *regimes* emerge, consisting of a set of formal and informal rules, heuristics, and cognitive structures existing within firms, research institutions, regulating bodies, or other parts of society. These paradigms or regimes support and improve the entrenchment of certain (new) technologies, while ignoring developments that do not fit in (Schot, 1991, p. 149-151). So the technological regime also restricts the range of technology variations. A study conducted by Daey Ouwens et. al. (1987, p. 122-147) provides a good example of this for the Dutch electricity sector: the ever-increasing scales in the sector have now made it very difficult to introduce new small-scale energy systems.

The variation and selection processes that occur in technology development (creating the ‘development tree’ of Figure 4.2) are *mutually dependent*, as opposed to the processes in Darwin’s evolutionary theory. Therefore, the theory is termed *quasi*-evolutionary. For example, technology developers often anticipate what society wants, and pre-select technologies that they believe are viable, thereby influencing the selection process. The developers’ expectations of the needs and desires of society can also lead to new variations and new directions. There is thus a direct link between the variation and selection processes. Expectations about future developments can be very powerful in directing strategic decisions and R&D investments, and often lead to self-fulfilling prophecies when expectations become reality as a result of the granted attention and money (Weber et. al., 1999, p. 46; Smit and Van Oost, 1999). Another direct link between variation and selection exists through, what Johan

Schot (1991, p. 90-91) calls, a *technological nexus* that consists of formal and informal communication between producers and users of technology. Schot states that a technology nexus serves as an important platform for actors in learning about each other's *and* their own needs and wishes. And as we will see in Section 4.2.4, learning is an integral part of the process of technology development.

The mutual dependency between variation and selection makes technology development a very complex process that is virtually impossible to control. However, it *can* be influenced, for instance by making the process more transparent and explicit, which is exactly what approaches such as technology assessment and participatory technology development attempt to do (see Sections 4.4 through 4.6).

The actors in society play an important role in the further development of technologies through the selection of technology variations. So it is time we look more closely at how quasi-evolutionary theory sees the roles of actors.

4.2.3. The Roles of Actors in Technology Development

In previous sections we have seen that quasi-evolutionary theory is based on the notion that technology development and social change are entangled; technologies change society, but at the same time the social context determines which technologies are viable. The groups in society that are involved in and/or affected by the development of technologies (i.e., the actors) form an important part of the social context[7]. Actors have the power to induce technical change, although they will never be able to completely control the development of a technology. So even though path dependencies and technology regimes exist, actors –and the way they interact– can influence the development of technologies, as well as the effects that the technologies have on society. Generally, the literature distinguishes four types of actors (Smit and Van Oost, 1999, p. 96-98):

- Technology developers (e.g., scientists, engineers, inventors, manufacturers)
- Technology users (e.g., consumers, employers)
- Technology regulators (e.g., governmental bodies, trade associations)
- Other stakeholders (e.g., special interest groups)

Weber et. al. (1999, p. 39) also add a fifth meta-actor, the network manager, that facilitates and modulates the interactions among the other actors, although the literature often attributes these activities to the technology regulators (Schot, 1991, p. 160-161). Technology users are not necessarily restricted to the ones using the technology, but also include the ones that

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[7] The social context, as discussed in 4.2.2, consists of the economic market, institutional factors (such as regulations, formal and informal relationships between actors, and political structures), as well as social and cultural factors.

experience the effects of a technology. Rip et. al. (1987) call the latter the *societal actors*, which try to ‘avoid, reinforce, or pass on’ certain effects of a technology.

According to Rip et.al. (1987), particularly the government can play an important role in technology development, through i) promoting the gathering and distribution of information; ii) promoting (societal) learning; and iii) specifying aims that serve public interest. However, as already shown in the Brabant field study (Chapter 3), the government –with its hierarchy, many departments, and internal differences– does not always act as a unity. Rather, it acts as a combination of ‘subactors’, each with different views and interests. Jelsma (1995, p. 158), for instance, warns us that the government is generally not well suited to coordinate learning processes, because the internal differences obscure the impartiality of the government as an actor, which undermines its credibility. So internal support within organizations or groups is just as important as external support, a point that is also well taken by Rip et. al. (1987).

The views and interests of actors can change over time due to changed circumstances, new information, new insights, or due to learning (Smit and Van Oost, 1999). This makes the actors important objects of study in the assessments of technology development. At each stage of the development process, decisions must be made that will not only affect the range of viable technologies, but also the future effects on society. Many of the decisions are made implicitly, which makes it difficult to influence them. However, Rip et. al. (1987) believe that by making the decision process more explicit, many consequences of choices can be assessed in advance, so that undesirable choices can be avoided. For well-weighed decisions, actors will need to learn about each other’s as well as their own interests and preferences, and gain (better) insights in aspects and options regarding technology development. How learning influences the development of technologies is discussed in more detail in the next section.

4.2.4. The Influence of Learning

Evolutionary theory sees learning an integral part of the process of technology development. Learning is requirement to better embed a new technology in society (Jelsma, 1995), and occurs trough feedback and *articulation* processes between or within actors. Articulation implies that actors develop and make explicit their views on what they need and desire. Three types of articulation can be distinguished (Smit and Van Oost, 1999, p. 84):

- *Demand articulation*, in which (future) users of a technology learn to specify their needs and wishes. This type of learning is important because users initially often do not know what they want or expect from a technology. Through interaction with developers or by using prototypes, the users learn what they want and need.
- *Technical articulation*, in which scientists and engineers (i.e. technology developers) learn to specify the requirements for a technology. This type of learning is important because at early stages of development, the technology is still flexible; developers can thus relatively easily make adjustments to meet social requirements. After a

technology has been materialized into a product and is put on the market, the degree of flexibility –along with the available options for adjustment– decreases drastically (see § 4.2.5). The social requirements can be obtained through interaction with (future) technology users, where technical articulation and demand articulation co-evolve. However, scientists and engineers often apply their own representations of users (i.e., the views that developers have of the future users, their behavior, and their needs) as a less time-consuming way to determine the technology requirements, even though their user representations might not be correct. The risk of misrepresenting users' needs and desires is particularly present in new technologies, because the future users do not yet have a clear idea of what to want or expect from that new technology.

- *Social and political articulation*, in which the society as a whole, including the government, learns to specify what is wanted. This type of learning plays a role when more and more effects of a technology become apparent or can be anticipated, and society has to decide if and how it wants to apply a new technology. For instance, a society can regulate the use of a technology (e.g., genetic manipulation), or promote its use through subsidies or providing information (e.g., renewable energy systems).

For actors in society, feedback and articulation are important processes to learn to determine the desirability of a particular technology development. According to Smit and Van Oost (1999, p. 48), these feedback and articulation processes have always taken place, but mostly in an implicit and subconscious manner. They state that, in order to influence technology developments into desirable directions, these learning processes must be made more explicit and conscious. A complicating factor is that effects of technologies are not always immediately apparent; they take time to be noticed. But as time evolves, technologies also become less flexible (see § 4.2.5). We will discuss approaches that aim at influencing the development of technologies in Section 4.5 and Section 4.6.

So, learning is important to make actors aware of their own interests and preferences, and those of other actors. And learning influences the development of a technology to better embed it in society. Jelsma (1995) states that learning processes require openness and access to information as well as a network between actors in order to acquire collaborative decision-making. So the interaction between, for instance, experts and the public must be more than just one-way 'communication'. Jelsma also states that a constructive dialogue will only take place when all actors have access to the information they need *and* have an interest in participating and interacting. He mentions two constraints to social learning. First of all, learning is constrained by uncertainty, as actors do not automatically make better-weighed decisions when more information is provided. Similarly, Smits and Leyten (1991) remark that an increase in information about technologies and consequences usually increases the complexity of decision making –even if the information is combined with a structure to process it– and can therefore lead to more uncertainty.

The second constraint of learning that Jelsma mentions is the strategic behavior of actors, as a way to improve their role or power base. This implies that most learning processes need to be *coordinated* to be constructive. Moreover, coordinated learning processes do not exclude the existence of controversies or conflicts. In fact, learning processes have a risk of being counterproductive, as Jelsma (1995, p. 157) illustrates:

> "Controversies are not problematic per se, but they are a risky way of learning. Unless controversies are managed in such a way that they yield useful outcomes, and that frustration and alienation of important actors are avoided, the learning may be counterproductive. If actors emerge from a controversy with adverse attitudes and negative experiences, … [this] can block cooperation for years."

Most actors, however, are aware that they depend at least partly on others to achieve their goals, so in their (strategic) behavior they are considerate with each other. According to Jelsma, social learning can be enhanced when decisions can be reversed (e.g., with flexible technologies), but he acknowledges that technologies usually require some inflexibility (i.e., entrenchment or lock-in) to make them robust.

According to quasi-evolutionary theory, learning is thus essential in the development of technologies. However, as we already mentioned above, the development of technologies can only be influenced into desirable directions when effects are either anticipated or known. How the (possible) effects of technologies can be assessed is the topic of the next section.

4.2.5. Assessing the Effects of Technology Development

In the previous section we saw that learning is necessary to embed a technology in a society. Rip et. al. (1987, p. 19) state that this integration is essential for technologies in order to perform optimally in society. The degree of integration is thus directly linked to the viability of a technology. The integration of technology in society was earlier referred to as *entrenchment* or *lock-in*. Rip et. al. add that the integration process of a technology may also affect other sectors of an economy. For instance, the fact that electricity is now supplied to many households has caused a tremendous increase in consumer electronics. This, in turn, has reinforced the use of electricity. So from this point of view, entrenchment is not something to avoid. The integration or entrenchment of a technology in a society comprises of several aspects (Smit and Van Oost, 1999, p. 56):

- A physical infrastructure, such as roads, pipe-lines, and service stations
- Regulations and institutions, such as traffic rules, standardized equipment, licenses
- Adjustments to organizational structures
- Cultural adaptations e.g., in values, beliefs, or behavior
- Actors acquiring skills to handle and operate new technologies

Rip et. al. (1987, p. 19) explain that once the integration of a technology is well underway, the vested interests and the investments made will not easily be put aside for radical new inventions; new technologies will be evaluated using the existing infrastructures as a reference, which favors technologies that are compatible with the existing infrastructures. So if at the end of the development process –after entrenchment has well advanced– society perceives some effects of a technology as undesirable, it cannot simply replace the technology. Due to entrenchment, replacing a technology requires adjustments to at least some of the aspects listed above. Especially the radically new technologies that deviate substantially from existing ones meet many barriers when trying to establish a place in society, even if they are desired. Nonetheless, as Rip et. al. (1995, p. 8) remark:

> “That entrenchment occurs, and certain paths will be followed, is inevitable. The point is that some paths are better than others, and that these should be actively sought and shaped.”

So assessing the effects of technologies to avoid undesirable effects should ideally be done at the early stages of development, when the technology is still flexible and can easily be adjusted. However, in the early stages little is known about the possible effects. Only *after* implementing a technology in society, more becomes known about the actual effects, but by then the social entrenchment diminish the adjustments that can be made. The trade-off between the flexibility of a technology and the knowledge on effects is called the *control-dilemma*, or the *Collingridge-dilemma,* referring to the author who first described this trade-off. This dilemma is visualized in Figure 4.3.

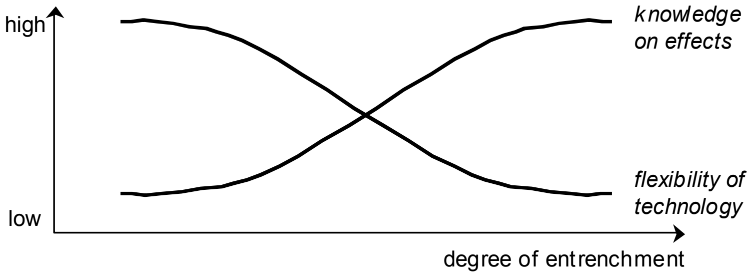

Figure 4.3. The control-dilemma of Collingridge: The more becomes known about the effects of a technology (as a result of progressing integration), the less flexible the technology becomes regarding adjustments. Source: Smit and Van Oost (1999, p. 96).

The control-dilemma implies that there is no best point in time to do an assessment study on effects. This, in turn, has led to different assessment approaches, each focusing on different stages of the development of a technology (see also § 4.5).

We are still discussing the concepts associated with quasi-evolutionary theory. This section has dealt with the effects of technology development. The next step is to look at the evaluation or appraisal of these effects; when effects can be anticipated or become known, society has to decide whether these effects are desirable or not. This is the topic of the next section.

4.2.6. Appraisal of Effects

The appraisal or valuation of technology effects is often time-consuming and complex. Daey Ouwens et. al. (1987, p. 7) as well as Correljé (1999) mention that one of the reasons is that the (future) effects of technologies are not always easy to identify –not to mention quantify. Also, as we have seen in Section 4.2.1, technologies in their early stages of development can only be appraised on the basis of *possible* effects because a technology –and thus its effects– co-evolves with society. Another complicating factor in appraisal is the fact that actors each have their own interests, needs, desires, beliefs, and views (e.g., on what should be seen as a relevant effect). What is seen as relevant is often related to *who* is affected; an actor that experiences some clearly negative effects of a technology likely considers these negative aspects relevant, while other actors that only benefit from the technology may not even know about the existence of any negative aspects. So the bias in distribution of effects can easily lead to overlooking important effects if not enough groups are included in the assessment study. But even if all groups would be affected equally, and even if actors value effects the same way, there will still be differences between actors with respect to the priorities they attach to the effects. Finally, learning will also influence the appraisal of effects, as it may change the priorities, preferences, and needs of actors.

Not surprisingly, actors often appraise technology options in completely different ways, so simply mapping the effects will not support the actors much in reaching a final outcome. According to Daey Ouwens et. al. (1987, p. 7), a final outcome can only be reached if there is consensus among the actors, or if the actors accept the existence of different solutions. However, Rip et. al. (1987, p. 25) state that, although the support of some actors is crucial for the viability of a technology, it may be necessary sometimes to ignore the lack of support for certain technologies in order to break down an existing technological regime.

We have now addressed the main concepts of quasi-evolutionary theory, so we will conclude with an overview of the useful inputs from this theory for the new method we want to develop.

4.2.7. Useful Inputs from Quasi-Evolutionary Theory

As discussed in Section 3.5, the preliminary method we developed (see § 2.7) has to be adjusted to better account for interaction and learning. The quasi-evolutionary theory appears to provide a good theoretical framework to do so. This theory evolves around technology development, and we believe that technology development as explained by the quasi-evolutionary theory shows strong similarities with our notion of energy infrastructure development.

For instance, the quasi-evolutionary theory argues that technology development *can* be influenced, and is as much a social process as a technical one. In Chapter 1 we argued that undesirable developments of the energy infrastructure can largely be avoided through a proper assessment of the options during the energy planning process. We also argued that this requires the inclusion of all relevant aspects and all relevant actors, which makes the planning process also a social process. A process that needs support.

Another similarity concerns the concept of variation and selection, which can also be applied to the development of the energy infrastructure: the range of energy technologies (variations) that can be used in an energy infrastructure is continuously changing, while the energy planners select only certain technologies to be included in the energy planning process, and thus make a chance of being implemented at the end of the planning process.

The concepts of entrenchment and path dependencies explain why it is often difficult to deviate from the conventional energy infrastructure options, but the quasi-evolutionary theory provides handholds to improve the integration of less conventional options, which usually requires a joint effort of actors in society. This stresses the importance of including all relevant actors in the process.

The concepts of entrenchment and path dependencies also show that an embedded energy infrastructure cannot easily be replaced if it proves undesirable at some time. This stresses the importance of making well-weighed decisions already early in the development process i.e., during energy planning, when the range of options is widest. Well-weighed decisions also require that all relevant actors are included in the process, because the differences in viewpoints of actors result in a different appraisal of the effects of technologies, and these differences need to be accounted for before irreversible decisions are made.

For well-weighed decisions, actors have to learn about technology options and their possible effects, and about the interests and preferences of other actors. The quasi-evolutionary theory shows that an important aspect of learning is the articulation of an actor's needs and preferences regarding new energy infrastructure. Learning also involves feedback on the consequences of certain preferences or choices, requires interaction between actors, and the possibility to adjust initial preferences and statements. Just like the quasi-evolutionary theory sees technology development as a continuous process of modification, so can the development of the energy infrastructure be seen as a continuous process of modification, with energy planning as a driving process for change. So any method that wants to account for learning requires an iterative setup to capture the recurrent changes. Furthermore, the constraints of learning (uncertainty and strategic behavior) require a coordinated learning process, inducing the need for a transparent structure and possibly a meta-actor guiding the process. Finally, learning implies that it would not be appropriate to predefine the criteria about what is 'positive' and what is 'negative' with respect to energy infrastructure options: new insights may reveal that 'positive' aspects have a 'negative' side effect and vice versa. So defining the criteria for assessment should be left to the actors involved in the process, who can adjust the criteria when needed. This line of thinking touches upon the concept of appropriate technology, another useful non-energy related theory, which is discussed in the next section.

4.3. The Concept of Appropriate Technology

In many cases, the main indicator for choosing the “best” technologies has been –and often still is– the criteria of efficiency: either technically or financially. However, there is a growing awareness that pure technical-financial considerations do not guarantee successful adoption of technologies in developing countries. In fact, the problems with implementing the “best” technologies strengthen the thought that other criteria also need to be included in the analysis to determine the viability of a technology. The example of Philips’ V2000 video standard, which was supposed to be superior to the now widely applied VHS standard of Sony is still illustrative in this respect. A more recent example is the struggle of Apple to survive on the computer market. Although their computers are generally thought to be superior to those of Microsoft, the latter is currently dominating the market.

The concept of ‘appropriate technology’ aims to incorporate additional indicators in order to determine whether a technology is viable or not. Two schools of thought can be found in the literature on appropriate technology. On the one hand, Appropriate Technology (with capital A and T) is synonym for Intermediate Technology as conceptualized by Schumacher (1975), implying that technologies are characterized by low capital costs, are labor intensive, and use local materials and labor. In addition, the technologies are easy to use, maintain and repair. Of that same school, McRobie (1981), sees Appropriate Technology more as a development strategy, and his definition involves technologies that are characterized by low capital costs; satisfy self-expressed local needs; make optimal use of local resources; are easy to understand and access for all social levels; are compatible with user attitudes, values and purposes; are compatible with the environment; are economically self-sustaining; have optimal reliability and dependability; are flexible and adaptable; and promote self-sufficiency. Throughout the years, many additional requirements have been added to the definition list of Appropriate Technologies. Carpenter (1987) mentions that in 1979, Chowdhury identified as many as 145 criteria to define Appropriate Technologies. In that same year, Diwan and Livingston (1979) commented that there is no single best definition of Appropriate Technology.

The problem with this type of Appropriate Technology is that it *predefines* beforehand the criteria to which technologies must comply in order to be “Appropriate”. This implies that technologies are evaluated *outside* the context in which they will be applied. In other words, it contains a high degree of “We will tell you what is good for you”. Another problem with the concept of Appropriate Technology is that it was –and often still is– associated with second-rate technologies, especially by developing countries for which they were initially intended (Carpenter, 1987, p. 29). As a result, the acceptance of the “Appropriate” technologies is often low.

The other school of thought on appropriate technology acknowledges that the context determines which technologies are viable and which are not, and that technologies should thus be assessed within the context in which they are applied (see Das, 1981; Betz et. al., 1984; Carpenter, 1987). The context, in this case, consists of economic, cultural, social, institutional, environmental, and other factors present in a society or group, all of which can be referred to as “local circumstances”, even though this obscures the fact that context plays a role on national or international levels as well. Long and Oleson (1980, p. 1) define this type of appropriate technology as “the technology that is appropriate to a particular situation faced by a given group of people, with consideration given not only to economic circumstances and available resources but to value priorities”. So, from this perspective it makes no sense to preset criteria for appropriate technologies because their appropriateness can only be assessed by taking into account the conditions at the place where they will be applied.

For the new decision support method we are developing, the ‘context’ school of thought on appropriate technology appears to best support our ideas presented in Section 2.7, as we proposed to use the interests and preferences of actors to construct indicators, implying that local circumstances largely determine which technologies are appropriate. How actors can obtain an appropriate outcome of the energy planning process is the topic of the next section.

4.4. Influencing Technology Development Is Possible

The quasi-evolutionary theory shows us that –through anticipation, interaction, and learning– it is possible to influence (but not control) technology development, and thus the effects on society. However, the influence of just one individual or actor will be limited; collective action is required. And even then the outcome will be uncertain, as several aspects of society have to change as well. Furthermore, the development process is complex. To quote Rip et al. (1995, p. 4):

> “Stimulating the development of technologies with desirable impacts (and a minimum of negative impacts) is not a clear cut problem, of course. First of all, which impacts do we want to consider and in whose interest?

Rip et. al. (1995, p. 4) continue by saying:

> “… goals evolve across the course of lengthy development and implementation projects. Therefore, even if clear values are present and shared, it is often impossible to identify an optimum strategy beforehand. This implies that experimentation and societal learning must be an integral part of management of technology in society.”

The traditional deterministic approach to manage technology in society is the so-called *two-track approach* of promotion and regulation: on the one hand, developers create new technologies, while on the other hand, the government sets limits to the (negative) impacts that those technologies have on society (Rip et. al., 1995, p. 2-3). However, there are also approaches that do account for the co-evolution between technology development and societal change. Rip et. al. (1995, p. 4-5) state that these approaches generally comply with the following requirements:

- Consider the (possible) effects of technologies already at early stages of development
- Involve users and other impacted communities
- Make learning an integral part of management

In addition, Smits and Leyten (1991) mention that –instead of providing answers– management approaches for influencing technology development should focus more on the processes of negotiation and consensus that precede the ultimate selection of options. Also, the approaches should aim at broadening the decision process to include more actors, and on supporting the actors in building their opinions by providing information *and* a structure to process this information.

Furthermore, Akrich (1995) advises not to overrate the rationality of the choices made. She believes that choices are often made instantly, only to be rationalized afterwards. However, according to Akrich, this does not mean that the ad-hoc decisions are purely arbitrary. She is convinced that each decision can be justified at the local level by the configuration at a given point in time, implying that an internal process of appraising options has taken place.

In the following sections we will discuss two important approaches for influencing the technology development: Technology Assessment (TA, see § 4.5) and Participatory Technology Development (PTD, see § 4.6). Both approaches aim to avoid or alleviate negative effects of technologies by improving decision-making.

4.5. Using Technology Assessment to Influence Technology Development

Technology Assessment (TA) is a collective term for several sub-approaches, and focuses on the national level at the medium to long term. Literature on TA mainly concerns industrialized countries; assessment studies in developing countries are rare[8]. The general characteristic of Technology Assessment is that it supports decision making by systematically identifying, analyzing, and evaluating the possible technological developments and their impacts on society. TA takes into account the social context in which the technologies are (or will be) used. Furthermore, TA generally promotes the awareness of both positive and negative impacts of new technologies, and helps to articulate the needs so that actors can anticipate (and consequently aim to avoid) negative societal effects of a technology (see for instance: Daey Ouwens et. al., 1987; Smits and Leyten, 1991; and Smit and Van Oost, 1999,

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[8] The author found one TA study in a developing country done by Lemmens (1987), of the sugar industry in Kenia.

p. 13). The result of a technology assessment study is usually a variety of *possibilities* –as opposed to predictions– on future developments and future effects of a technology. The actual developments and effects depend on the choices made by the actors during the development stages of a technology. However, there are several constraints for applying TA, of which the first two are related to the control-dilemma of Collingridge as discussed in Section 4.2.5 (Smit and Van Oost, 1999):

- Many (indirect) effects only occur after the technology is widely used, such as the exhaust emissions of cars.
- Some effects only become apparent after considerable time, such as global warming due to greenhouse gasses, or the carcinogenic characteristic of asbestos or cigarettes.
- Future developments are difficult to predict because of the quasi-evolutionary aspects of technology development.
- Effects are valued differently by the various groups in society due to differences in interests, values, and moral beliefs.

These constraints have led to several sub-approaches of technology assessment that each support different stages of technology development. For our case of local energy planning, the following approaches appear to contain valuable aspects: Constructive TA (CTA), Interactive TA (ITA), and a more recently developed practical tool for applying CTA called Strategic Niche Management (SNM). We will address each of these approaches in a separate section below.

4.5.1. Constructive Technology Assessment

Constructive technology assessment (CTA), is believed to be an important instrument to induce technical change (Daey Ouwens, et. al., 1987; Smits and Leyten, 1991; Rip et. al., 1995; Schot, 1991). According to Callon (1995), CTA is based on three hypotheses:

I) Technology development results from a large number of decisions made by numerous heterogeneous actors. These actors negotiate on technical options and in some cases reach mutually satisfactory compromises.

II) Technological options can never be reduced to their strictly technical dimension. The design and introduction of a technique are inseparable from social restructuring and role distribution, implying that the appraisal of technological options is a matter of political debate (i.e., the co-evolution of technology and society).

III) Technological options bring about irreversible situations (e.g., sunk costs, changed ecosystems). Future decisions will increasingly rely on decisions taken in the past (i.e., path dependencies exist).

Furthermore, there are four important characteristics of CTA (Broerse, 1998; Smit and Van Oost, 1999). The first one is the *creation of a network* through which actors can interact and exchange information. In fact, this is the starting point of any process supported by CTA. The second important characteristic of CTA is the *improvement of learning* (articulation) during the development of new technologies. Throughout the development of a technology, actors learn about their own needs and wishes, and about those of other actors. Also, they learn what the social and technical requirements of a technology should be. The learning processes require that CTA provides a support structure that is flexible enough to follow the decision processes, in particular the modifications or delays in choices. The third characteristic of CTA is the *promotion of the reflexive capacities* of the actors. *Reflexivity* implies that actors recognize that technology development is not an autonomous process, but instead is co-produced with societal change, and that technologies reflect cultural aspects and user representations. Reflexivity is needed to avoid actors falling back to old positions and preconceived opinions.

The CTA approach focuses on the integration of new technologies in society. More precisely, CTA *broadens* the decision making process at the R&D phase of technology development, and is therefore expected to result in a minimization of mismatches, wrong investments, and possible social conflicts during the entrenchment phase of a technology. Broerse (1998, p. 14) and Smit and Van Oost (1999) emphasize that "broadening" not only refers to the inclusion of more aspects and criteria in the decision-making process, but also refers to the inclusion of more actors, especially those that will experience the effects of new technologies. This way, new needs and values can already be accounted for during the early stages of technology development, and the entrenchment of (new) technologies in society is promoted.

Note that 'constructive' does *not* imply 'conflict avoiding'. On the contrary, involving more actors increases the chance of conflicting interests. However, through CTA, all the stakeholders are in a position to participate in the development process, and can thus take responsibility for the construction of technology *and* its effects. Moreover, Schot states that broadening the development process results in "being able to notice earlier and more clearly that social effects are coupled to specific technical options, and that designers design not only technological but also social effects." This brings us to the fourth important characteristic of CTA: the *anticipation* of the technology effects. A backbone of CTA is that it helps to anticipate possible societal problems caused by technology-under-development (Smit and Van Oost, 1999, p. 13). Consequently, CTA enables the actors to make constructive suggestions for the adjustment of that technology. These suggestions should preferably be carried out in the design phase of the technology because the possibilities for adjustments are largest then.

Schot emphasizes that anticipation does *not* imply the *prediction* of effects, but instead the acknowledgement that different possibilities exist, and that their effectuation depends on the choices that will be made. These choices –in turn– are based on learning, which makes the outcomes of a CTA-supported process inherently uncertain.

A drawback of CTA, according to Broerse (1998, p. 13), is that broadening decision-making makes it a very time-consuming process, which usually requires a considerable amount of money. However, Daey Ouwens et. al. (1987, p. 2) believe that through CTA, a society can learn faster and more easily about the (dis)advantages of new technologies, so that ad-hoc regulatory measures to compensate for negative impacts can be kept to a minimum, which also saves time and money.

4.5.2. Interactive Technology Assessment

The basic characteristic of *interactive* technology assessment (ITA) is that it aims to explicitly incorporate the views of all actors. Grin et. al. (1997) state that if TA wants to have a significant effect on actors' decisions, the actors must recognize at least some of their own views in the assessment. Hence the need to include all actors. According to Grin et. al., most TA approaches do not systematically include all the relevant actors in the process. Interactive Technology Assessment, on the other hand, is believed to be an adequate tool for this.

The main aim of ITA is the same as for all TA approaches: to influence the development processes of technologies so that they develop into desirable directions. More specifically,
ITA strives for a synthesis of the views of al the actors involved; it is based on a repetitive evaluation of the actors' arguments. These arguments make explicit the actors' preferences and beliefs in order to allow them to be discussed. Grin et. al. (1997) state that ITA is especially appropriate for structuring unstructured problems, in particular the following cases:

- Inventing creative innovations
- Getting a detailed insight in the possibilities and constraints of certain development trajectories
- Bridging the gap between political objectives and the views of actors that have to implement these policies

This does not imply, however, that the ITA approach is a guarantee for complete agreement of all actors on all aspects, and neither can it replace the decision processes on technology development. Also, for obvious reasons, the number of actors that can be involved in an ITA study is not unlimited, so it can never give a full representation of the real world. The ITA approach can best be seen as an additional analytic tool to influence the decision processes on technology development. Note that the concepts of ITA are similar to the political methods discussed in Section 2.5. Grin et. al. state that ITA can even be seen as a social experiment that gives a creative and innovative analysis without the interference of power aspects. The information and new ideas gained from an ITA study can then be used to influence the real world, which of course does have to deal with power.

4.5.3. Strategic Niche Management

Recently, Weber et. al. (1999) developed a tool called Strategic Niche Management (SNM). The SNM tool does not have a rigid approach; it involves a set of overlapping and interrelated activities, and must be seen as a handhold rather than a standard. Actors can use this handhold for the practical application of CTA; it helps them to generate new ideas, and to introduce new technologies on the market. Weber et. al. (1999, p. 9) define SNM as:

> "… the creation, development and controlled breakdown of test-beds (experiments, demonstration projects) for promising new technologies and concepts with the aim of learning about the desirability (for example in terms of sustainability) and enhancing the rate of diffusion of the new technology."

The work on SNM focuses on the transport sector, but the tool can in principle be used for any technological innovation. Weber et. al. (1999) argue that a successful innovation is not so much determined by the technical characteristics, but by the socio-economic context; by the mental frameworks, individual behavioral patterns, and by institutional and organizational patterns. This view –as we have seen– is common in quasi-evolutionary theory. The existent frameworks and patterns in a society make it very difficult to replace dominant technologies. Only small modifications can be easily integrated in society, thereby restricting future choices to those that are in line with the existing systems (see also Section 4.2 on path dependencies and technological regimes).

The SNM tool provides support in setting up new experiments, and helps create technological and market *niches*. Technological niches are financial and organizational 'spaces' that protect the development of a technology before it is introduced onto the market, in order to increase the viability of that technology. The 'spaces' can include subsidies, exemption from taxes, or exemption from normal profitability criteria, among others (Smit and Van Oost, 1999, p. 64). Technological niches are thus different from the market niches, which are special (small) segments of the market that serve a specific type of consumer. Niches are essential for the integration of desirable –but unconventional– technologies in society.

Weber et. al. (1999, p. 17-18) identify three key-processes in the formation a technological niche. First, the expectations of the actors need to concur. According the Weber et. al., expectations can be very powerful if they are mutually shared, credible, and concern solutions for societal problems that existing technologies cannot solve. Second, actors need to learn about the problems and needs of other actors (and their own), and about the potential of the technologies under consideration. This is necessary to reduce uncertainties and broaden the perception of actors. The third process involves the formation of a network between actors. Weber et. al also note that actors with vested interests can be very helpful in expanding a niche, so preferably, they should be part of the network. However, these actors also tend to be 'defensive' with respect to radically new technologies, and are usually reluctant to engage in projects concerning such technologies.

The SNM tool was the last sub-approach of Technology Assessment that we believed to contain valuable inputs for our new method. In the next section we will give an overview of the useful inputs from Technology Assessment approaches.

4.5.4. Useful Inputs from Technology Assessment

Technology Assessment (TA) is used to manage the development of technologies, and can help us to expand the theoretical basis for the new method we want to develop to help manage the development of local energy infrastructure. For instance, both the Constructive Technology Assessment (CTA) approach and Strategic Niche Management (SNM) mention the creation of a network, implying that the energy planning process should be broadened to include actors other than the energy company. These approaches also stress the importance of learning and reflexivity, implying that the new method should have an iterative setup and a transparent structure that prevents actors from falling back to preconceived ideas. The anticipation of (possible) effects, a backbone of CTA, also requires that all relevant actors are included in the energy planning process, as the differences in viewpoints of actors point out different (possible) effects of technologies. Finally, Interactive Technology Assessment (ITA) also stresses the importance of including all relevant actors in the process, and suggests a repetitive format to extract the needs and preferences of actors. We will now turn to the other approach for influencing technology development: Participatory Technology Development.

4.6. Using Participatory Technology Development to Influence Technology Development

Participatory technology development (PTD) is, contrary to TA, a local-level approach that is often applied in developing countries, in particular by NGOs (Non Governmental Organizations) and consultants. The bottom-up approach is not well documented in the literature, but Broerse (1998) provides useful information in her dissertation concerning the use of PTD in the bio-technical innovation process in developing countries. Additional information was obtained from ETC, a consultancy firm specialized in energy projects in developing countries (De Winter, 2000).

The PTD approach, according to Broerse (1998, p. 193-194), is mainly used by NGOs outside the formal R&D system, which might explain the little amount of information that was readily available. PTD is applied in particular with respect to local farming in developing countries. It focuses on the development of farming technologies and the development of local capacities, including the socio-cultural structures necessary to sustain the development processes.

An important advantage of the PTD approach is that it actually proved successful in developing countries. Important contributor to the success of PTD, according to Broerse (1998), include the fact that local farmers get to play an important role in the decision-making process, and that learning is promoted.

Broerse (1998) poses six key success factors for the introduction of new technologies: i) interaction with and understanding of the users; ii) commitment of actors to a mutually shared vision; iii) existence of trust-relationships and coalition building; iv) mutual learning; v) consolidation of a new innovation network; and vi) support and guidance from an intermediary. Also, external 'expert' knowledge is complemented with local knowledge and inputs. However, Broerse adds that the use of PTD is limited to the local level, and that it operates in a more or less isolated way, thus ignoring the development of new technologies and national policies. So although not much information is available on PTD, this approach supports our ideas on the importance of including all relevant actors and allow for learning to take place.

In the sections above, we have addressed the approaches to influence technology development, we have explained the concept of appropriate technology, and we have discussed the quasi-evolutionary theory. It is time we present an overview of the valuable aspects of these theories, concepts and approaches for constructing the new method.

4.7. Valuable Inputs from Non-Energy Related Theories

The non-energy related theories discussed in this chapter provide several useful inputs for the new method we want to develop. First of all, the quasi-evolutionary theory on technology development provides a good underlying framework to explain how the development of the energy infrastructure evolves. Following the lines of thought of the quasi-evolutionary theory (§ 4.2), the development of (new) energy infrastructure is seen not as a purely technical process, but also as a social one. In fact, the energy infrastructure and society co-evolve: new infrastructure is adapted and selected to integrate in society, while society is adapted to allow for an optimal performance of the selected infrastructures.

Energy planning can be seen as the beginning of the development process of new energy infrastructure. Initially, energy planners have a wide range of energy technology variations from which they can select the ones for the new energy infrastructure. However, the more the energy infrastructure develops into a particular direction (e.g., fossil fuel based centralized infrastructure), the more the range narrows. Not necessarily in the number of variations, but in the differences between the variations. The variations become less 'extreme' and show more and more of the same characteristics (e.g., one particular fossil fuel, only large-scale plants). The further the energy infrastructure develops along a certain development path, the more it becomes entrenched in society, and the harder it becomes to change the direction of its development. This path dependency hampers, for instance, the introduction of small-scale renewable energy systems in an otherwise well developed fossil fuel based centralized energy infrastructure. So the development of the energy infrastructure is a process of continuous modifications, especially in a rapidly developing region, and energy planning initiates each new modification.

The concepts of entrenchment and path dependencies also show that an embedded energy infrastructure cannot easily be replaced if it proves undesirable at some point in time. This stresses the importance of making well-weighed decisions already in the early stages of the development process i.e., during energy planning, when the range of options is widest. Well-weighed decisions also require that all relevant actors are included in the process, because the differences in viewpoints of actors result in differences in appraisal of the effects of technologies, and these differences need to be accounted for before irreversible decisions are made.

The quasi-evolutionary theory further explains that for well-weighed decisions, actors have to learn about technology options and their consequences, and about the interests and preferences of other actors. They also have to (learn to) articulate their own needs and preferences regarding new energy infrastructure. Learning also involves feedback on the consequences of certain preferences or choices, it requires interaction between actors, and the possibility to adjust initial preferences and statements. So if the new method wants to account for learning, it requires an iterative setup to capture the recurrent changes. Furthermore, the constraints of learning (uncertainty and strategic behavior) require a transparent structure and possibly a meta-actor to guide the process.

In addition, allowing for learning requires the method to be flexible with respect to the criteria or indicators that are used to determine the appropriateness of options. In the preliminary method (§ 2.7), we already proposed to use the actors' preferences and interests as a basis to construct indicators, and this idea is supported by the 'context' school of appropriate technology discussed in § 4.3. The context school on appropriate technology states that the appropriateness of technologies is defined by the context in which they are applied. So we reject the use of *predefined* criteria, even if this implies that the definition of appropriateness remains rather vague. In fact, the same reasoning holds for the terms 'relevant actors' and 'relevant technologies'. So the relevancy of actors and technologies is determined from within the context in which they are situated.

The actor types mentioned when discussing the quasi-evolutionary theory (§ 4.2.3) require some adjustments before they can be applied to energy infrastructure development. In our case, the technology developers will likely be presented by the energy companies. Strictly speaking, the energy companies are also the *users* of the energy technology used in the infrastructure, but we will use the interpretation of Rip et. al. (1987) who state that this type of actor (which they call 'societal actor') experiences the effects of the technologies, while trying to avoid, reinforce, or pass on some of these effects. The technology regulator will likely include the governmental bodies, but also the consultancy firms or other support groups that act as (independent) mediators of the process. The other actors will likely be the same, i.e., special interests groups and such.

Technology Assessment (TA) approaches provide us handholds to manage the development of local energy infrastructure. For instance, both Constructive Technology Assessment (CTA) and Strategic Niche Management (SNM) mention the creation of a network, implying that the energy planning process should be broadened to include actors other than the energy company. These approaches also stress the importance of learning and reflexivity, implying that the new method should have an iterative setup and a transparent structure that prevents actors from falling back to preconceived ideas. The anticipation of (possible) effects, a backbone of CTA, also requires that all relevant actors are included in the energy planning process, as the differences in viewpoints of actors point out different (possible) effects of technologies. A backbone of SNM is that it uses niches to integrate unconventional technologies in society. In our case, local energy planning that is based on SNM theory may offer a way to create niches, for instance to introduce small-scale renewable energy systems into a centralized fossil fuel based energy infrastructure. This does require, however, a joined effort of all relevant actors, and thus the inclusion of these actors in the planning process. Finally, Interactive Technology Assessment (ITA) also stresses the importance of including all relevant actors in the process, and suggests a repetitive format to extract the needs and preferences of actors.

A disadvantage of the TA approaches is that they are intended as instruments for strategic policy making on the long-term, while the new method requires decisions that lead to concrete actions on the medium term. Furthermore, TA studies are usually time-consuming and expensive if done in detail, while this amount of time and money may not be available in a rapidly developing region of a developing country. So we need to look for shortcuts in assessing (anticipated) effects. In addition, TA is typically applied in industrial countries, so little experience is available on, for instance, special requirements for developing countries. Here, the PTD approach can be helpful, even though there was not much information available in the literature on this approach. PTD is a bottom-up approach that already proved successful in managing small-scale technologies in developing countries, albeit those were not energy technologies. Like the TA approaches, the PTD approach also stresses the formation of an actor network and the importance of learning as key factors to success.

Finally, as already explained in the introduction of this chapter, we do not deny that in principle, the development of technologies can be explained within a neo-classical framework, using concepts such as bounded rationality, experience curves, and transaction costs, but generally speaking these concepts do not explicitly address the social aspects involved in the decision processes, tend to have rather rigid conditions for which the theories hold (e.g., rational behavior), and usually require a background in economics to be understood. So we believe that a quasi-evolutionary framework for our method better fits the practice of energy planning in developing countries.

We have now answered the third sub-question of this thesis, regarding the non-energy related theories that can provide useful information on how our new method –through supporting energy planning– can help steer the development of the energy infrastructure on the medium term. With the additional input from these theories, we have a sound theoretical framework within which the new method can be placed. So it is time to present in full the new method for local energy planning in developing countries. This will be done in the next chapter.

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5

A New Decision Support Method for Local Energy Planning in Developing Countries

> *"Would you tell me, please, which way I ought to go from here?"*
> *"That depends a good deal on where you want to get to," said the Cat.*
> Lewis Carroll, *Alice's Adventures in Wonderland* (1982, p. 57)

5.1. Guidelines for the New Method

In the previous chapters, we have shown that there is a need for support on local energy planning; most support is currently focused on national planning and does not adequately address regions that require new energy infrastructure. In addition, most planning models used at the local level only support the early stages of the planning process because these models do not account for learning and interaction, and ignore the needs and views of relevant actors, thereby neglecting relevant aspects.

The new decision support method discussed in this chapter aims to improve the quality of decision making by supporting actors engaged in or affected by local energy planning in selecting an appropriate mix of energy technologies for the development of local energy infrastructure. This way, the method can help the actors in steering the development of the energy infrastructure into a desirable direction.

The new method has an eclectic approach, using theories and concepts from different (non-energy related) disciplines in order to support all stages of the planning process. The method focuses on the *process* of energy planning rather than the outcomes of that process, while energy planning is regarded as much a social process as a fulfillment of technical and/or economic requirements. In addition, the method must be seen as a heuristic rather than a normative set of strict rules. Based on the literature reviews in Chapter 2 and Chapter 4, and the field study of Brabant discussed in Chapter 3, we use the following guidelines for designing the new method:

- Support the entire process of local energy planning in developing countries
- Provide information on energy infrastructure options and the associated consequences, and provide a framework to process the information
- Include different forms of energy demand
- Include all relevant local energy resources and small-scale energy technologies
- Include all relevant actors in the energy planning process, and consider their interests and preferences when assessing the impacts of the energy infrastructure options
- Identify trade-offs and conflicting interests
- Provide a structure to systematically compare the energy infrastructure options
- Allow for learning and interactions between actors
- Use flexible models that can easily adapt to local circumstances and allow for inclusion of aspects that cannot easily be quantified.

In Section 2.7 we already constructed a preliminary method that incorporates most of the guidelines. However, if we want to include learning and interaction, we will have to adjust the method somewhat to make it more iterative. In the next section (§ 5.2) we will start with an outline of the new method and then discuss its steps in more detail. Section 5.3 will address the limitations of the method, while Section 5.4 discusses how the method can be tested and made operational for use in practice. Finally, in Section 5.5 we will summarize the main aspects of the new method.

5.2. A New Decision Support Method for Local Energy Planning

5.2.1. Outline of the New Method: The Triple-i Approach

In this section we will give a short outline of the new decision support method for local energy planning in developing countries. The following sub-sections of Section 5.2 will treat each method step in more detail. The method steps and associated models are visualized in Figure 5.1. The method starts with determining future energy demand. Next, the relevant actors are determined, as well as their interests and preferences. Simultaneously, the relevant energy resources and technologies need to be mapped, so that the energy infrastructure options can be designed. Also, the interests and preferences of the actors need to be ‘translated’ into indicators, which are then used to assess the impacts of the infrastructure options. Consequently, the actors appraise the scores on the indicators (i.e., the impacts) of the different options, after which the actors mutually evaluate the outcomes. Any changes in preferences, indicators, or options result in a repetition of steps until a final appropriate energy infrastructure can be selected.

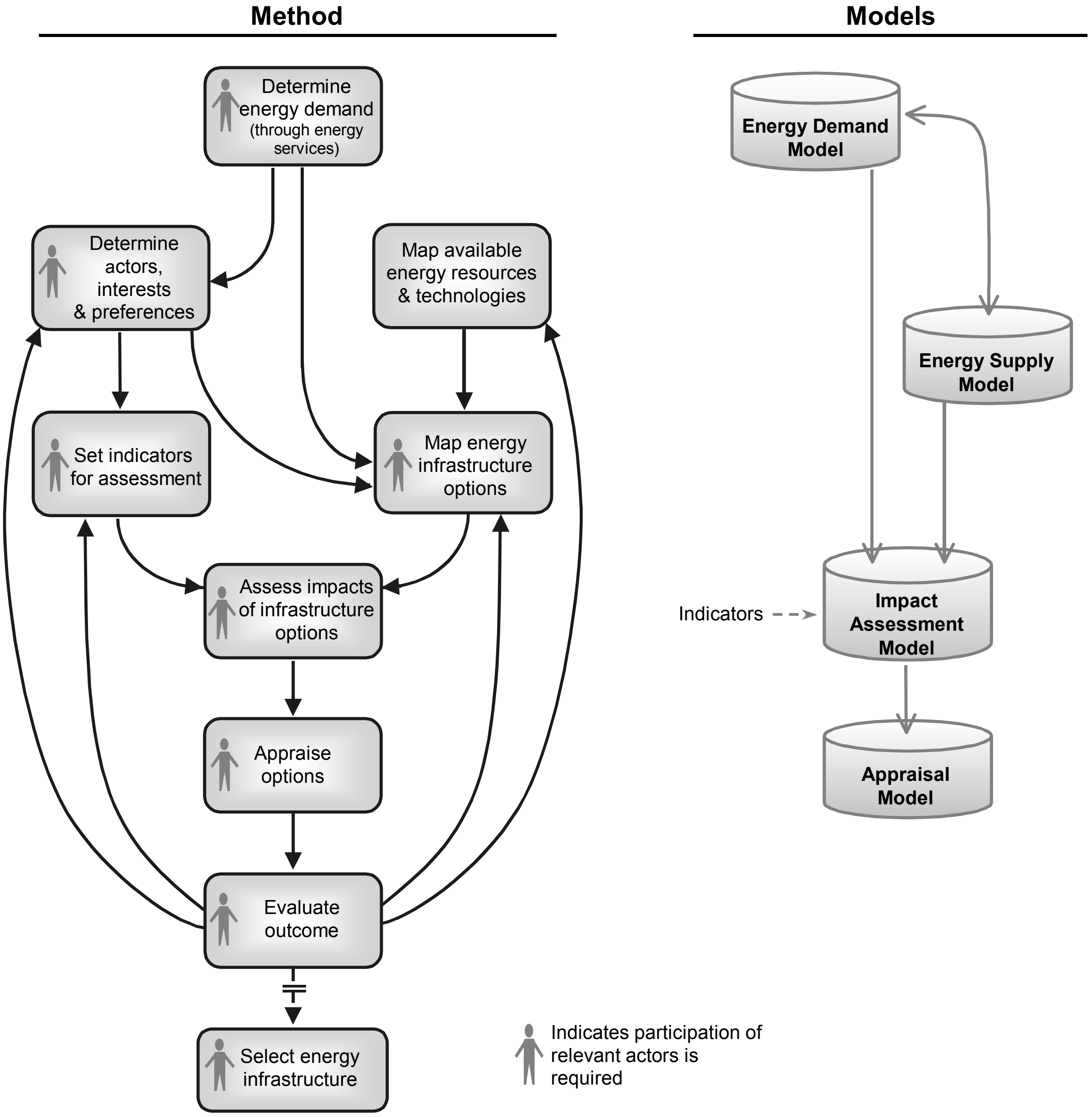


Figure 5.1. Steps of the new decision support method, and the models that facilitate the steps.

The steps of the new method do not deviate much from the steps of the preliminary method described in Section 2.7; we continue to distinguish between the method (providing a framework or handhold for the planning process) and the models (used to facilitate the steps of the method), which was previously visualized in Figure 2.2. Also, we still require the active participation of actors during most steps of the method. However, in order to explicitly include interaction and learning in the method, we have introduced more feedback and forward loops between the steps. At first sight, the method visualized in Figure 5.1 seems to represent a logical straightforward process, but this is merely to make the structure of the method more transparent; the figure clearly shows how the planning process can be divided into several steps. However, as we have seen in Chapter 4, energy planning should not be interpreted as a straightforward process of completing consecutive steps in a strict order. As a result of interactions and learning, new steps are initiated before previous steps are completed, and series of steps are repeated several times. The method therefore has a dynamic structure with a cyclic or iterative character, and the loops between the steps are repeated until a satisfactory outcome is reached. This iterative aspect is visualized in Figure 5.2, where the method steps are placed along the path of an inward spiral. This reflects the notion that normally, the iteration process will start at a general (largely qualitative) level and advances to a more concrete and detailed (more quantitative) level as more becomes known on options, interests, and mutually supported outcomes. The infrastructure options included in the analysis will initially deviate much from each other, but at the end will likely be variations of only one or two infrastructure options.

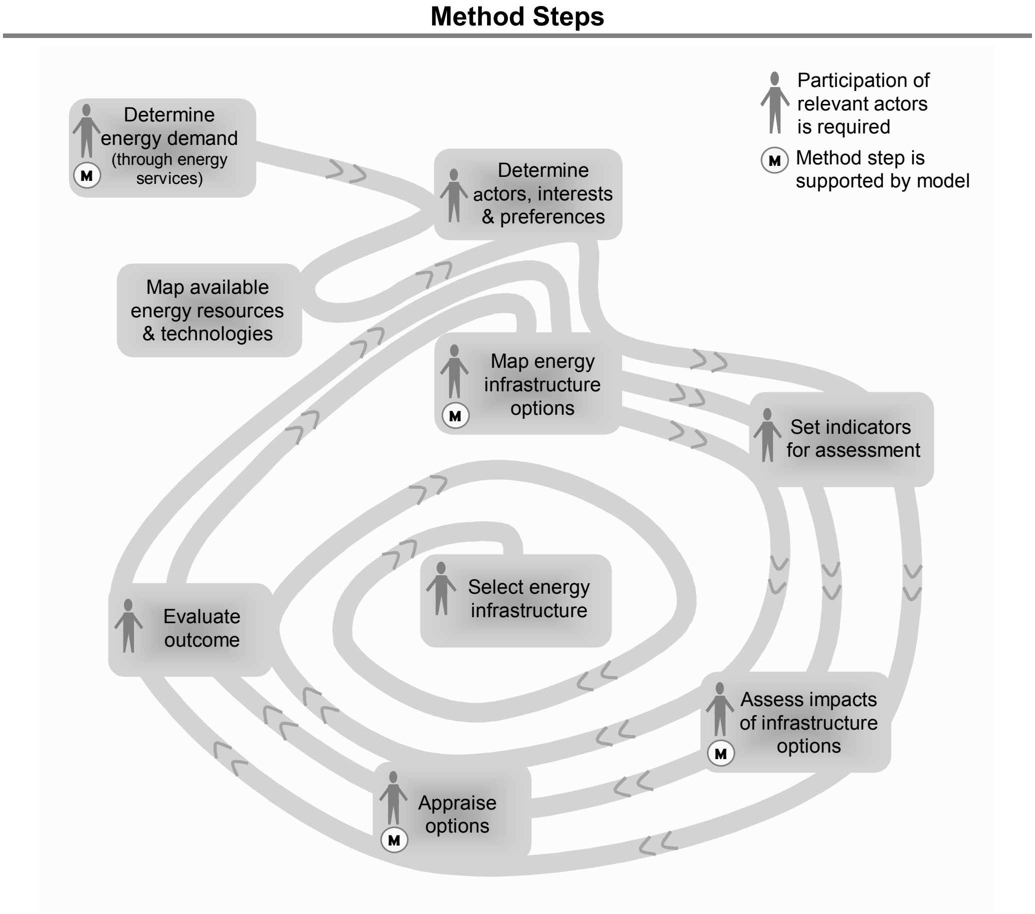
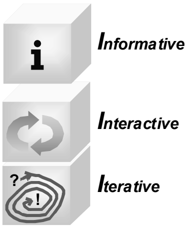


Figure 5.2. The new decision support method as an iterative or cyclic method with repeating steps.

Note that in Figure 5.2 the method steps with a 🧍 symbol explicitly require the participation of actors (the other steps may be completed by only one actor, such as an independent mediator). If the Ⓜ symbol is included in a method step, this indicates that this step is supported by a model.

So the new decision support method helps actors select appropriate local energy infrastructure by providing information on the energy infrastructure options and their consequences, using the actors' interests and preferences as a basis for the impact assessment. Furthermore, the method promotes the interaction between the relevant actors and has an iterative character so that the actors are allowed to learn about the needs and views of other actors, articulate those of their own, and adjust their preferences throughout the planning process. In short, the new method has a *triple-i* approach: it is informative, interactive, and iterative. In the next sections we will discuss each steps in more detail. If a step requires the participation of actors or is supported by a model this is denoted in the section heading by the symbols as used in Figure 5.2.



5.2.2. Step I: Determine Energy Services and Energy Demand 🧍 Ⓜ

The first step of the method is to determine the future amount and forms of energy demanded by the end-users (i.e., households, industry, small and medium enterprises, etc.). To do this, we need to know for which purposes the end-users demand energy. For instance, people want electricity because electricity allows them to watch TV, or listen to the radio, or put on the lights when it is dark. Similarly, people want heat to boil water or to heat their houses. These purposes are called *energy services*[1]; they are the underlying reason why end-users demand energy. Related to energy services are the *energy forms* (e.g., electricity, heat, or fuels such as gas or petroleum), which the end-users can use to fulfill the desired services. Each energy form can usually provide more than one energy service. For instance, electricity can be used for lighting, cooking, and heating, while fuels can be used for cooking, heating, and transportation purposes. The energy forms require an *energy infrastructure* to reach the end-users: resources need to be exploited, energy technologies are needed to covert energy resources into the proper forms of energy, and a transmission or distribution grid is needed to supply the energy forms to the end-users. The approach that starts with the energy services and works back towards the energy resources is also referred to as the 'energy services-to-sources' analysis (OTA, 1991), and is shown in Figure 5.3. Generally, there is a variety of energy resources and technologies to generate the required energy forms, although the technologies do not all generate the same forms, and each technology has its own characteristics.

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[1] Note that the term 'energy services' should not be confused with the more economically oriented term 'services' that utilities sometimes use to refer to the products or support they have to offer.

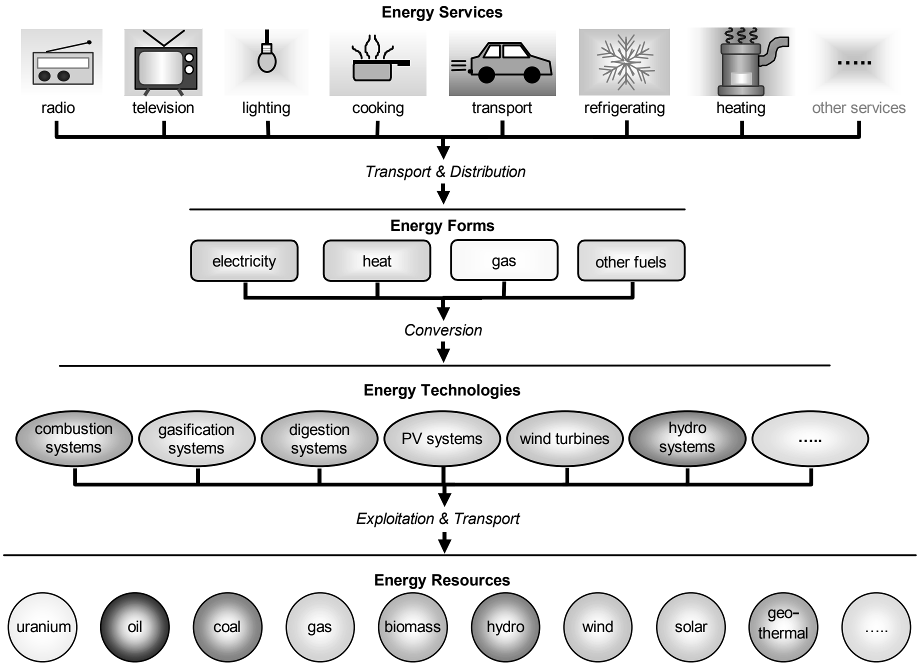

Figure 5.3. Structure of the 'energy services-to-sources' analysis.

Once the desired energy services are known, the energy planners have to determine which energy forms will be delivered to the end-users to fulfill these energy services. Consequently, the resources and technologies with which the forms are generated have to be selected. However, the range of resources and technologies to choose from is limited by decisions previously made. For instance, options that involve an entirely new energy infrastructure will have a hard time competing with those options that use already existing infrastructure due to lock-in aspects, although there are exceptions.

Thus, the demand for energy is in fact the desire for certain energy services, which can be provided by different forms of energy. The energy forms, in turn, are a result of the conversion of energy sources by different energy technologies.

But how, then, can demand be determined? At the local level, usually little information is available on energy demand, not to mention on the desired energy services. If an energy company already supplies energy to the region, it usually has data on past consumption of certain energy forms. However, a strong economic development in a region prevents simple extrapolation of these data to forecast future demand, as explained in Chapter 1. The energy services, and consequently the amount and forms of energy demanded, can also be determined through a field survey, but this is generally a time-consuming and expensive way to collect data, while the obtained data only provide information on recent consumption, not on future demand.

As discussed in Section 2.6.1, a good alternative that is often used to explore future energy demand when uncertainty is high, is the use of *energy demand scenarios* that represent 'extreme' socio-economic developments and associated energy demand. Experts and stakeholders can help construct the scenarios, while national and regional studies on socio-economic development and energy demand –if available– can be used as a handhold.

Existing energy demand models might be helpful in constructing the scenarios by providing insight in the consequences of assumptions (e.g., population growth, growth in energy demand per client) or help in performing a sensitivity analysis to determine the robustness of the assumptions. Sometimes, historical data of other (foreign) regions that showed similar development paths in terms of economic growth or energy per capita can also provide a handhold for constructing scenarios. But undoubtedly, many assumptions need to be made, as the regional development process and associated demand are inherently uncertain. Consequently, the actors have to determine the desirability and likelihood of the scenarios, and focus on the most likely scenarios to determine the developments in future energy demand.

Note that the use of scenarios to determine future energy demand implies that the actors, besides selecting an energy infrastructure, also have to choose a socio-economic development path. However, there is no guarantee that the regional development will actually follow the chosen path, although a joined effort of actors can very well steer the direction somewhat. After future demand scenarios have been determined, the next step is to determine the relevant actors, and their interests and preferences, which is the topic of the next section.

5.2.3. Step II: Determine Relevant Actors, Interests, and Preferences

After demand has been determined, the next step of the method is then to determine the relevant actors. Actors, as defined in Section 1.6.2, are individuals or groups of people (including the government, companies, non-governmental organizations, etc.) that are involved in or affected by (the results of) the decisions process regarding new energy infrastructure *and* have the ability to influence this process.

If the new method wants to addresses all the aspects that the actors perceive as important, it has to somehow account for the interests and preferences of these actors. This is the reason why the method does not use predefined criteria; instead, it translates the interests and preferences of actors into indicators, which are then used to assess the impacts of energy infrastructure options (see also § 5.2.6).

Determining the relevancy of actors is an important issue when applying the method. The relevancy of actors depends on the local circumstances, and an unambiguous rule for relevancy is difficult to give. By definition, the actors are relevant if they have an interest in energy planning *and* can significantly influence the process. However, not every individual can be included in the decision process because it would make the process endless and unmanageable. The number of actors can be limited if individuals with similar interests organize themselves in groups, which generally also increases their influence. To further limit the number of actors, the interests of individuals or groups can also be represented by other actors. However, if too few actors determine which energy technologies are used, this may lead to resistance from those that can not participate in the process, especially when they are (or will be) significantly affected by the chosen energy infrastructure. The resistance, in turn, can result in time-consuming efforts to invalidate objections to the construction and use of the energy infrastructure, or result in expensive adjustments or compensation payments. Practice will have to show which actors are relevant, keeping in mind that this may change over time; new actors may turn up during the planning process, while a particular direction of development may make other actors less relevant. Nonetheless, at least one actor must have decision-making authority for the planning process to have any effect. Sometimes, the actors already involved in the process can represent new groups by adding the interests of the latter to their own interests. Actors that are often –but not always– involved in local energy planning include the energy companies, municipalities, national government (providing a regulatory framework), and investors (often the same as energy companies). Most actors (but not all) can be traced by using the snowball effect: obvious actors are asked to point out possible other actors, who in turn –when asked– point out yet others, and so on.

To determine which aspects are perceived as important, we need to know the interests and preferences of the relevant actors. The actors each have their own interests and preferences regarding local energy infrastructure, which may cause conflicts. If ignored, conflicting interests can severely hamper the planning process (Jelsma, 1995, p. 157). Also, trade-offs often have to be made between preferred aspects that cannot be obtained simultaneously. Therefore, it is important to spot possible conflicting interests and trade-offs in advance. Also, the actors need to be made aware of the fact that they form part of a network. Callon (1995, p. 309) describes a network as the group of unspecified relationships among actors. And Weber et. al. (1999, p. 38), and Jelsma (1995, p. 157-160) stress the importance of network formation in enhancing constructive interaction and learning, reducing uncertainty by sharing expertise and experiences, managing conflicts, and avoiding frustration or alienation of important actors. Also, it might be helpful to use an independent mediator (see § 5.4.2).

As with the number of actors, the number of interests and preferences included in the analysis must be limited for the method to be practical. Actors have to select the most important aspects they want included in the analysis, although they can always change their set of important aspects at a later stage. Before we go to the translation of the interests and preferences into indicators (Section 5.2.6), we will first discuss the step of mapping relevant energy resources and technologies, and consequently mapping the energy infrastructure options.

5.2.4. Step III: Map Relevant Energy Resources and Technologies

Energy resources that can be used for the local energy infrastructure include renewable and non-renewable (depletable) resources that are locally available. Water, wind, the earth's heat, and the sun are all renewable resources, while the non-renewable energy resources encompass uranium and the fossil fuels such as crude oil, natural gas, and coal (see § 1.3.1). Biomass is only renewable as a resource if managed in a "sustainable manner" (i.e., given enough time to recover between harvests). The local circumstances in a region determine for a large part the relevancy of the energy resources; resources that are relevant in one region might prove irrelevant in another. For instance, a lack of water will limit the use of hydropower systems, while a lack of wind will make wind turbines less relevant. The geographical and climate conditions are not, however, the only aspects that determine the relevancy of an energy resource in a particular region. A clear-cut unambiguous definition of relevant resources is difficult to give, but the following considerations can be used to determine the relevancy of energy resources in a region:

- Local circumstances such as geographical and atmospheric conditions (e.g., local availability of resources)
- Whether a resource is technically exploitable
- Whether there exist technologies to convert the resources into the proper energy forms
- Whether actors accept the use of the resources (and the technologies associated with them), and are able to exploit the resources

Consequently, we need to determine the relevancy of energy technologies that can convert the resources into the proper forms of energy. Considerations in determining the relevancy of energy technologies can include:

- Whether the energy technologies can generate the proper amounts and forms of energy demanded
- Whether technical know-how is available to construct and operate the energy systems
- Whether a service network is available for maintenance and spare parts to guarantee supply at the longer term

Again, these considerations should not be interpreted as strict rules; the actors ultimately have to determine what is relevant and what is not. Note that relevant technologies are not the same as *appropriate* technologies[2]. Relevant resources and technologies form the start of the planning process. The appropriate technologies, on the other hand, are a subset of the relevant technologies and are the outcome of the planning process; they reflect what actors perceive as important, and are usually the result of learning, negotiations, and compromises. Appropriate technologies thus cannot be seen separate from the social context in which they are applied. So appropriate technologies are always relevant, while relevant technologies do not necessarily have to be appropriate.

A detailed description of different energy resources and associated energy conversion technologies can be found in Appendix B. If we want to apply the ‘energy service-to-source’ strategy adopted in Section 5.2.2, we have to make an overview of the resources and technologies available, and the energy forms they can produce. Out of the range of alternatives, the energy planners can then choose those resources and technologies that can provide the proper amount and forms of energy to fulfill the desired energy services. The range of energy resources and technologies included in the analysis should reflect –at first

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[2] The definition of *appropriate technologies* used in this thesis is given in § 4.3.

glance– the variety of interests and preferences of the actors. This brings us to the next section: mapping the energy infrastructure options.

5.2.5. Step IV: Map Energy Infrastructure Options

With the relevant energy resources and technologies known, we can start mapping the energy infrastructure options. Besides energy resources and technologies, the local energy infrastructure generally also consists of a distribution grid to supply the energy forms to the end-users. However, for micro-systems such as solar collectors or PV panels placed on or near buildings, a distribution grid is not required because these systems are located at the place where the energy is consumed.

Generally, there is a large number of infrastructure options that can be constructed with the available energy resources and technologies. In order to limit the number of infrastructure options, but include those that reflect the variety of interests and preferences among the actors, the method initially makes use of ‘extreme’ *energy supply scenarios*. These extreme scenarios represent the outer boundaries of the range of energy infrastructure options available. The supply scenarios will often –after several iterations– evolve from extreme general options to detailed variations of one or two particular options. One infrastructure option that should not be overlooked is the possibility of *importing* the proper energy forms from outside the region, especially in situations where a distribution grid is already available.

Existing supply models might be helpful in matching the supply scenarios with the different scenarios for energy demand, for instance by determining how much resource input is needed per energy infrastructure to produce the proper amount and forms of energy, keeping in mind characteristics such as the conversion efficiency of the technologies, capacity factors, and distribution losses.

5.2.6. Step V: Set Indicators for Assessment

When demand scenarios have been determined, the relevant actors have been identified, and the infrastructure options have been constructed, the next step is to construct the indicators for the impact assessment. To include context-related issues in the impact assessment, the latter must consider the aspects that the actors perceive as important. That is why we determined the interests and preferences of the actors in one of the first steps: they are used to construct the indicators. This is also the reason why the indicators cannot be predefined before the relevant actors are identified.

As the field study in Brabant shows (see Chapter 3), most actors formulate their interests and preferences in rather ambiguous terms, even though they will usually learn to better articulate them throughout the planning process. For instance, a preference for a ‘flexible’ energy infrastructure can mean a lot of things and is usually not restricted to one dimension (i.e., economic, technical, social, etc.). So we need to find measurable indicators that properly reflect the interests and preferences of all the relevant actors. The scores on these indicators then represent the impacts of the energy infrastructure options.

But how can we translate the interests and preferences into proper indicators? In the literature, it is common to make a distinction between technical, financial, economic, environmental, social, and sometimes also political, institutional, and cultural indicators (Van Pelt, 1993). However, many aspects of the energy infrastructure are multidimensional (such as ‘flexibility’) and cannot be forced into one category, which makes such a distinction rather artificial and less useful for our method. As a guideline, the actors can start with general indicators, and work towards more detailed indicators in the following iterations of the process, when more information is available and learning has progressed. An exception can be made for the indicators that reflect conflicting interests, as discussions and negotiations between actors will likely focus on these indicators, which therefore require more attention and detail. Van Pelt (1993, p. 42-43) mentions three general guidelines that are useful for setting indicators:

I. *Comprehensiveness*
The set of indicators should be comprehensive in the sense that it covers all relevant aspects, and not just those that can be quantified or for which information is easily available.

II. *Limited Number of Indicators*
In general, people are only able to consider no more than about eight indicators at a time. More indicators would make the appraisal step too disordered for the actors. Therefore, the number of indicators included in the impact assessment should be limited, and this is usually done by using general indicators that are build up out of sub-indicators.

III. *Independence*
To avoid double counting (i.e., a positive score on one indicator automatically implies a positive score on another indicator) the indicators should be independent.

The last guideline of independence is not useful per se. Tversky and Kahneman (1988) showed that the way decisions are framed or formulated influences the outcomes of decision processes (and showed that this effect cannot be explained within the theories of rational choice). Using the same line of reasoning, we pose that the way indicators are framed influences the appraisal of the scores on these indicators. This implies that it is not necessary to have entirely independent indicators, as dependent indicators can still shed a different light on aspects of energy infrastructures (e.g., conversion efficiency and CO_2 emissions).

Without intending to predefine indicators, a database of commonly used indicators, the preferences they represent, and the different ways to measure the scores on these indicators can be helpful and speed up the process. Examples of possible indicators and ways to measure them can be found in Appendix D. Once the indicators are set, the actors can assess the impacts of the different energy infrastructure options, which is the topic of the next section.

5.2.7. Step VI: Assess Impacts of Infrastructure Options

A well-weighed choice for a particular energy infrastructure can only be made if all the relevant infrastructure options *and* their consequences are known and taken into account. The consequences (i.e., the impacts) are represented by the scores of an option on the indicators that were set in the previous step of the method. These scores can be measured in various ways (see Appendix D), so for consistency it is important that the scores of all options on a particular indicator are measured the same way.

Furthermore, to facilitate the comparison of the options, the scores should be quantified as much as possible, and preferably in monetary or numerical units, as these measures are usually very powerful and convincing in decision making. However, quantifying impacts in practice often proves difficult or at least time-consuming, as reliable data are generally hard to obtain, especially in developing countries and at the regional level. Therefore, the method allows for other types of measures to assess the scores on the indicators. In this thesis, we distinguish between four classes of measures, in order of increasing quantification:

I. Qualitative or nominal measures.
II. Ordinal measures
III. Quasi-quantitative measures
IV. Quantitative or numerical measures

The first class of measures consists of *qualitative* or *nominal* measures, which result in nominal (or *discrete*) scores. Nominal scores can be divided into categories, but cannot be ranked in a particular order e.g., in terms of more/less or better/worse. In addition, nominal scores (as well as the scores of al other measurement classes) are mutually exclusive. Examples of nominal measures are the gender of persons, or their place of birth (Babbie, 1998, p. 141-143). An example related to energy planning is the color of an energy system. The use of qualitative measures can complicate the comparison of options, as the appraisal of the scores on these measures is merely a question of personal taste, which allows little room for discussion.

The second class of measures is the one of *ordinal* measures. These measures have (mutually exclusive) scores that can be ranked in a logical order (e.g., better/worse or lower/higher), but the distance between two scores cannot be quantified in a meaningful way (Babbie, 1998, p. 141-143). For instance, we can rank schools according to their level of education, but the exact difference between levels of education cannot be quantified; the ranking of education levels can only be done on an ordinal scale. Ordinal measures can be used for indicators that cannot be quantified within reasonable time: given a certain ordinal scale, the actors have to assign scores that express their opinions on how well an option performs on a particular indicator. Only if actors feel they lack information to make a 'sensible' judgment, or if discussion arises on the assigned scores, a more detailed study on measuring an indicator is required. The range within which the ordinal scores must lie can be chosen rather arbitrarily, although the literature provides some rules and guidelines (Baarda and De Goede, 1990, p. 148-149). The ordinal measures can also be used to perform 'quick-scans' on the scores of the indicators: actors and/or experts can make 'educated guesses' on what they think are reasonable scores of options. This way, indicators that receive similar scores for all options can be separated from the indicators that reflect conflicting interests. The latter can then be addressed in more detail.

The third class of measures that we distinguish is the class of *quasi-quantitative* measures. These measures consist of a combination of quantitative data and ordinal ranking. We use this class of measures in situations where general indicators are divided into several sub-indicators that have different measuring units. In such cases, an overall score on the general indicator is difficult to calculate. The same applies to situations where one indicator can be measured in different ways, but the actors cannot agree upon which measure to use. The quasi-quantitative measures let actors assign ordinal scores, but quantitative data are available to base the scores on. The scores assigned by an actor can then represent those quantitative data that the actor perceives as relevant. For instance, the general indicator 'environmental impacts' can be divided into several sub-indicators such as emissions, water quality, deforestation, and biodiversity. An actor will often not be interested in all the sub-indicators; if an actor is only interested in water quality and deforestation, the overall score on the environmental impacts indicator will be based on those sub-indicators only, ignoring the sub-indicators 'emissions' and 'biodiversity'. So for quasi-quantitative measures, quantitative data are available to the actors to determine the scores, but the scores are in fact ordinal.

The last class of measures that we distinguish consists of *quantitative* or *numerical* measures[3]. Quantitative measures imply that differences in scores can be quantified and have meaning, while the distances between consecutive values on a scale are constant (Babbie, 1998, p. 141-143). Examples of quantitative measures are the monetary values to express costs and benefits, or CO_2 emissions expressed in tons emitted per year.

To improve communication, the indicators can be defined uniquely, using only one measure per indicator. Van Pelt (1993) explains that one way to achieve uniquely defined indicators is to split up 'ambiguous' general indicators into unique sub-indicators that only highlight one aspect of the general indicator. Actors then have to assign relative weights to these unique sub-indicators. Subsequently adding the sub-indicators will result in an overall score on the general indicator. However, this approach implies that the unique indicators can all be converted to a universal measuring unit, which is not always the case. In addition, this approach would result in a substantial increase in the number of indicators, which –in turn– would make the assessment more complex and time-consuming. Moreover, actors may not be interested or able to assign weight to all unique indicators, which complicates the calculation

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[3] The literature divides quantitative measures into *interval measures* and *ratio measures*. The latter have a true zero point (e.g., age), where the former lack such a point (e.g., the temperature measured in degrees Celsius), see among others, Babbie (1998, 141-143).

of general indicators. Therefore, we prefer to limit the number of indicators (thereby speeding up the process) by allowing actors to assign ordinal scores to general indicators, taking for granted that it is not immediately clear which aspects of a general indicator are emphasized by an actor. Note that using general indicators does not imply that these indicators do not need to be defined properly. To avoid miscommunication as much as possible, definitions are mandatory, even if they are less specific.

An impact assessment model can help the assessment by quickly calculating the scores on quantitatively measured indicators or –in the case of quasi-quantitative measures– by providing (quantitative) data related to a (sub-)indicator. Particularly when scores have to be recalculated as a result of subsequent iterations, models can speed up the process. Note that our method does not exclude the use of existing models or procedures, which might be helpful during the impact assessment to calculate scores on particular impacts[4].

The impact assessment results in an overview of how well each infrastructure option scores on each indicator. The next step in the process is then to compare the different options, which is explained in the next section.

5.2.8. Step VII: Compare and Appraise Options

After the scores on the indicators (i.e., impacts) are determined, the actors can start comparing and subsequently appraising the infrastructure options. The method presents each actor all scores on all indicators, in order to give them an overall picture of the issues at stake. This way, an actor can become interested in indicators (e.g., those with extreme scores) even though these indicators did not reflect any of the actor's interests and preferences at first.

When comparing the options, most actors will get a general idea of the options they are willing to accept and those they would certainly reject. The criteria that actors use in appraising the options are left implicit. So the actors do not need to express at which maximum or minimum threshold scores they will reject an option. According to Georgopoulou et. al. (1997; 1998), actors usually experience difficulties in expressing these threshold scores, especially during the first few iterations. In addition, an actor generally does not have a threshold for indicators that the actor is not interested in. Nonetheless, although the appraisal is done implicitly, the actors do have to make explicit the outcomes of their appraisal, but this is done during the evaluation step (see § 5.2.9). And even though the comparison and appraisal are largely done implicitly, an appraisal model can help the actors by providing a structure with which the impacts of the options can be systematically compared, as shown in Figure 5.4 by the so-called (spider)web diagrams. These web diagrams are largely based on the spider model described by Nijkamp et. al. (1997) in a study on the transport sector. It provides a structure that gives actors an overview of all the scores on all

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[4] Examples of procedures to determine economic impacts, for instance, can be found in Belli et. al. (2001), Julius and Mashayekhi (1990), Van Groenendaal (1998), EDRC (1997), and Duvigneau and Prasad (1984).

indicators even if the latter are measured in different units. Also, the web diagram can easily handle changes in scores.

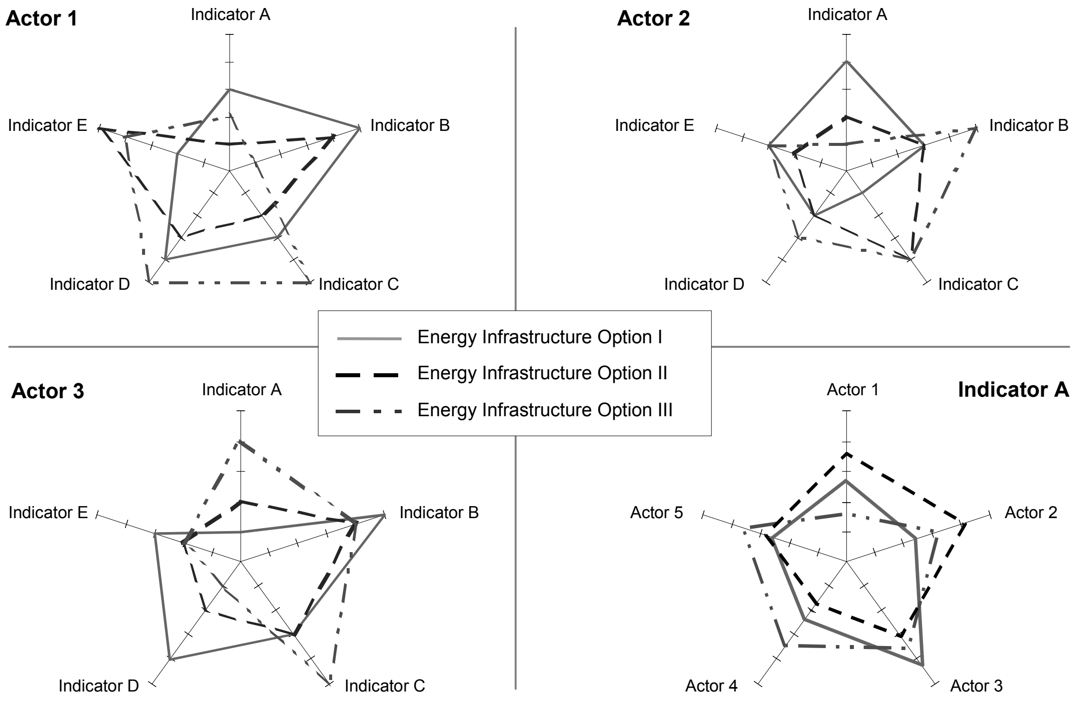

*Figure 5.4. Examples of (spider) web diagrams per actor (*Actor 1-3*) to structure the scores of infrastructure options on indicators. Also, web diagrams can be constructed that show the scores on options assigned by all actors on one particular indicator (*Indicator A, *at the bottom right). The web diagrams are largely based on the spider model described by Nijkamp et. al. (1997).*

Each actor has a web diagram, and the axes of the web diagram represent the indicators used in the impact assessment. The scores of the infrastructure options on each indicator are then projected on the axis concerned, where each axis can have a different scale (in terms of class types or in the range of min./max. values). To improve the transparency of the web diagrams, the scales can be chosen in such a way that scores at the outer boundary of the web represent the 'better' or 'more preferred' scores per actor. This could imply that the direction of the scales (i.e., the place of the minimum values is either at the center or at the outer boundary) differs per actor. Nonetheless, for reasons of consistency the minimum and maximum value of a particular indicator should be the same for all actors and all options.

In addition, web diagrams can be constructed per indicator (the last web diagram in Figure 5.4), where actors form the axes and the scores they assign to the options are plotted for that particular indicator. Other variations of web diagrams can be constructed as well, such as a web diagram per infrastructure option, taking the indicators as axis and plotting the score-curves per actor. Or web diagrams that plot the scores on the sub-indicators of a general indicator.

As already posed in the Section 5.2.6, the way indicators are framed influences the appraisal of the scores on these indicators (Tversky and Kahneman, 1988). The scale that is chosen for an indicator can also influence the appraisal; decreasing the range between the minimum and maximum values on an axis can blow up minor differences in scores. These framing and scaling issues deserve further attention, but time-constraints prevent us from addressing them in more detail within this research framework.

So the comparison and appraisal step is largely an internal process; actors do not have to make explicit the criteria they use for appraisal. Only the outcomes of the internal appraisal process are made explicit, but this is done during the evaluation step, which is the topic of the next section.

5.2.9. Step VIII: Evaluate the Outcomes

After the appraisal step, the actors have at least a general idea of the options they prefer and/or the options they reject. In the evaluation step, the actors interact to discuss the impacts of the energy infrastructure options, make explicit their attitudes concerning the options, learn about the considerations of other actors, negotiate with each other, and possibly express preferred infrastructure option(s). Often, actors will prefer different infrastructure options, and they will try to convince the other actors that their option is the ‘best’ one. The options that face strong objections of many actors should be discarded as unattainable in order to allow for a more detailed study of (variations of) the less controversial ones. During the evaluation step, the actors may also revalue their own preferences, express a need for further information, or state the adjustments in options or indicators they would like to be seen made. This implies a repetition of earlier steps, and initiates the next iteration(s) of the method.

5.2.10. Initiate Next Iterations and Select Final Energy Infrastructure

If the need for more information and the adjustments in indicators and/or infrastructure options are made explicit, the next iteration can start. Also, new actors may have been identified during the evaluation step, so that their interests and preferences have to be determined as well. Note that actors that are added at a later stage might find the process already developing into a certain direction (using a certain set of options), which might restrict the influence that these new actors have in the process. Besides new actors, the iterations often involve new indicators, or new ways of measuring existing ones. In addition, infrastructure options may need to be adjusted, or entirely new ones constructed. Consequently, the impacts have to be assessed again, and the options have to be compared and appraised once more, which will also lead to a repetition of the evaluation step.

Usually, the iterations will progress from a general assessment of infrastructure options towards a detailed assessment of only a few (variations of) options. After the necessary iterations, the process ends with the selection of an energy infrastructure that has a broad support base among the actors. Or, if the energy planners are not the decision makers, a select number of infrastructure options is chosen. The final selection is ‘appropriate’ rather than ‘optimal’ to reflect that context-related issues are addressed, and compromises and trade-offs have been made to reach a mutually supported outcome.

Of course, the new method can only provide proper support within the boundaries of its applicability. These boundaries or limitations of the new method are discussed in the next section.

5.3. Limitations of the New Method

The new decision support method described in this chapter helps actors steer the development of local energy infrastructure into a desirable direction. However, for a proper application of the method, actors need to take into account the limitations of the method. General limitations were already discussed in § 1.6.3. Additional limitations include:

! The method is developed for regions in developing countries that experience a rapid growth in economic activity, and consequently require new energy infrastructure. This does not have to imply that the method is unsuited in other situations. For instance, regions in industrialized countries might profit from the method as well, just as regions that want to attract more economic activity by improving their local energy infrastructure[5]. However, these regions where not the focus of our research, so further research is needed before using the method in situations like these.

! The method does not *predict* the future, nor does it decide for the energy planners which action is good or best. It helps the energy planners to explore different directions in local energy infrastructure development and the (possible) consequences associated with those directions. The actors ultimately have to decide which energy infrastructure options are appropriate.

! The method supports actors in selecting appropriate energy infrastructure at the local level. However, this does not imply that the outcomes of the method are appropriate at the national level as well. Therefore, it is important that actors take into account the regulatory and policy framework of the national government, to better embed the chosen energy infrastructures in society.

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[5] Note that there is no guarantee that investments in energy infrastructure will automatically result in economic development, as discussed in Chapter 1.

! The method does not adequately address interactions between the different sectors of the local economy, nor does it adequately address interactions between the local and the national level. The focus of the method is restricted to the energy sector at the local level.

! The outcomes of the method are case specific: what is appropriate in one region may not be appropriate in other regions, even if the latter show similar characteristics as the former. Also, applying the method in the same region, but at a different time generally results in different outcomes. The co-evolution of the local energy infrastructure and regional development usually implies that the outcomes of the method differ per case. However, the method itself is generally applicable under the conditions stated.

! As a result of the incorporation of context-related aspects, and due to the existence of conflicting interests and trade-offs, the new method generally does not lead to financially or technically *optimal* energy infrastructure (i.e., most efficient from a technical or financial point of view). However, in a given context, the method will help select *appropriate* energy infrastructure that has a broad support base among the relevant actors in the region.

! The cultural or social infrastructure in the region must allow for the participation of all relevant actors and the inclusion of all relevant aspects in the energy planning process. This may limit the use of the method to specific regions (e.g., democracies), but time-constraints prevent us from investigating this issue in more detail, even though it deserves further attention.

! Finally, as a result of the use of actors' interests and preferences, any application of the method, and thus its outcome, will be biased. This is not a drawback, though, because –as Meppem and Gill (1998, p. 127) rightly argue– not one measure or appraisal method will ever be completely objective, as the collection of 'objective' data (if possible) always contains a subjective element; unavoidably, choices have to be made on which data to include and which to ignore.

So when applying the method, these limitations should be kept in mind. Another important constraint at this point is the fact that the new method has not been tested yet, so nothing can be said about its applicability or added value. To apply the method in practice, we will have to operationalize it, and this issue is the topic of the next section.

5.4. Operationalization of the New Method

5.4.1. Tool Testing and the Importance of Case Studies

The new decision support method presented in this paper is based on literature reviews, a field study, as well as interviews with experts in the field. However, for the method to be practical it is essential that case studies are used to gain experience in its application; to further examine the limitations of the method; and –if necessary– to adjust the method.

However, fully applying the method implies the use of time-consuming case-studies; most planning processes can take up to 5 years or more. This amount of time is not available within the framework of the research project, which makes real testing of the method impossible. Nonetheless, what we can do is make *plausible* that the method will actually work in practice, by testing the assumptions used in the method, and by giving an example of the implementation principle of in particular the *models* of the method.

Another issue is to prove that the method works better than existing ones. One of the underlying aims of the new method is to improve the quality of decision making without requiring the actors to be rational all the time. But when has the quality of decision making improved? If the actors are satisfied with the outcome? The method, however, does not focus on the outcome, it focuses on the *process*. And a satisfactory outcome does not necessarily imply that the process went satisfactory as well. Furthermore, the method is a combination of prescriptive and descriptive approaches, and does not make use of theoretical axioms such as rational behavior. So if practice deviates from the method, is practice 'wrong', or should the method be adjusted? These questions cannot easily be answered and touch upon ethical issues as well. Maybe the only way to distinguish whether the quality of decision making has improved is to determine whether the decisions made can be supported with explicit arguments, and prove to be well-weighed. But even this is not an easy task, as pointed out by Einhorn and Hogarth (1988, p. 137-139).

A possible way to validate the new method is to ask those that have worked with it whether they experienced it to provide better support than existing methods, assuming they do have enough experience with other methods to make such a statement. But this requires the use of (many) case studies. Although this cannot be done within the scope of this research, it is essential that the validation of the method is investigated in more detail in the future.

So due to time-constraints, only the assumptions used in the new method are tested within this research framework. In the next chapter (Chapter 6) we will discuss the results of a field study in Costa Rica, set up to test the assumptions. Future research can then focus on applying the new method in case studies in order to determine the added value of the new method. First, however, we will turn to the role that a mediator can play in applying the new method.

5.4.2. Necessity of a Mediator

In practice, it might be constructive and helpful to make use of an independent mediator (e.g., a consultancy, governmental institutions, or non-governmental organization) to execute the process steps. The mediator can work out the method steps, do research on energy resources and technologies, help identify relevant actors and facilitate the interaction and communication between them, fulfill information needs, help make explicit the interests and preferences of actors and convert them into indicators, point out trade-offs and conflicting interests, and help look for solutions and compromises (Jelsma (1995, p. 156); Weber et. al. (1999, p. 39). However, practice shows that finding an independent mediator can prove to be a problem, as these mediators must be paid, and the actor that pays these costs tends to be favored at least slightly.

5.5. Conclusions

In this chapter, we have presented a new decision support method that can help steer the development of local energy infrastructures in developing countries into desirable directions. We distinguish between the *method* and the *models*. The method is a conceptual framework and provides a transparent structure for the entire energy planning process, while the models are calculation tools that form part of the method and that speed up the completion of process steps. The method aims to improve the quality of decision making by supporting the actors in selecting appropriate energy infrastructure using the *triple-i* (i^3) approach: the method is informative, interactive, and iterative. Keywords of the new method are context-related aspects, energy services, actor participation, indicators based on the actors' interests and preferences, interaction and learning, and appropriate energy infrastructure.

The new method starts with determining energy demand. As we have seen in Section 5.2.2, energy demand is actually the desire for certain energy services. These energy services must be known to determine which energy forms can be supplied to the end-users. Next, the relevant actors have to be identified, as well as their interests and preferences, in order to include all relevant aspects. Simultaneously, the range of available energy resources and energy technologies that can produce the proper amount and forms of energy has to be mapped. And subsequently, energy infrastructure options must be constructed out of this range. Then, the interests and preferences of actors are used to construct indicators, which –in turn– are used to assess the impacts of energy infrastructure options. The measures used to determine the scores on the indicators (i.e., the impacts) are either of a qualitative, ordinal, quasi-quantitative, or quantitative class of measures. Once the impacts are assessed, the infrastructure options can be compared and appraised, and subsequently evaluated. The evaluation step usually initiates a next iteration of steps, as the preferences of actors can change or indicators and infrastructure options are adjusted due to the interaction and learning. Therefore, the new method has a dynamic structure that allows for jumps back and forth the process, without having to complete steps first. So the final outcome will be the result of a series of iterations, and will be *appropriate* rather than 'optimal' or 'best'. The term 'appropriate' then reflects the compromises and trade-offs that need to be made to find a broadly supported outcome.

Note that the new method described in this paper is a *decision support* tool, and not meant to decide for the energy planners which actions or options are good or appropriate. This will ultimately be the decision *and* responsibility of the actors involved in the energy planning process. In addition, the method should not be seen as a rigid structure from which no deviations are allowed. Because even though the method is set up to be flexible, practice proves to be complex. So the method should be seen as a handhold or heuristic; as a collection of ideas to benefit actors engaged in local energy planning in developing countries. Deviations and adjustments are therefore allowed if they are thought to better fit the circumstances.

For a proper application of the method in practice, the actors must be aware and take into account the method's limitations stated in Section 5.3 (and Section 1.6.3). Nonetheless, the method has not yet been tested in practice, so little is known about its actual applicability. Therefore, case studies are essential to validate the method, but time-constraints prevent us from doing any real method testing within the framework of this research. We can only test the assumptions on which the method is based, and make plausible that it will work in practice, and this will be done in the next chapters.

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6 Field Study: Local Energy Planning in Huetar Norte, Costa Rica

6.1. Purpose of the Field Study

In the previous chapter we explained that the new method presented in this thesis can *not* be fully tested due to time constraints (see § 5.4.1). However, we can test the assumptions used in the new method, and that is what we aim to do in Chapter 6. Remember that, despite the field study in Brabant, we still don't have any data on *local* energy planning in *developing countries*, even though the new method is specifically developed for these countries[1]. So another field study is necessary, this time in a developing country, to verify whether the assumptions of the new method hold under the circumstances of those countries. Of course, using only one case study will not prove that the assumptions hold in every situation, but it will give a first indication of how realistic the assumptions are.

This chapter discusses the results of a field study in Costa Rica, which we conducted to verify whether the planning of local energy infrastructure in developing countries concurs with the new method, and in particular with the assumptions used in it.

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[1] As already stated in § 1.5.3, we do not reject the idea that the method can also be used in industrialized countries, but this was not the focus of our research and thus not investigated further.

The assumptions that we want to verify include:

- Due to differences in regional economic development within a country, there is a need for regional energy planning.
- More actors should be included in energy planning than just the energy companies and investors in order to include all relevant aspects.
- Other than technical and financial aspects play a key role in the local energy planning decision process.
- Different actors have different interests and preferences, and thus different information needs.
- Providing information and a structure to process it improves the quality of decision-making because decisions are better weighed.
- Actors learn during the planning process, which influences the decisions made.

The field study consisted of three visits: the first was a one-month visit in 1999 for general orientation and to attend a workshop, after which the Huetar Norte region was chosen as the region of focus. A second visit in May-July 2001 was used to describe the local energy planning process and identify relevant actors and issues. A last visit (in November-December 2001) was used to get feedback of the actors on the operationalization of the method. For the field study, we examined among others policy documents, annual reports, newspapers, and Internet sites to gather information. Also, we interviewed experts and stakeholders in the field of energy planning in Costa Rica, and visited several sites in the northern parts of Costa Rica to get better insight in the actual situation (see also the references and the list of interviews in Appendix E).

There were several reasons for choosing Costa Rica for the field study. First of all, Costa Rica has a stable political and economic climate, which helps in gathering reliable data. Also, many data that have been collected in the past are relatively easy to access. In potential, this can considerately reduce the time needed to complete the field study. Furthermore, in its national energy plans Costa Rica has shown an interest in diversifying its energy supply, and it wants to use renewable energy resources to do so (DSE, 2000). Also, Costa Rica has stressed the importance of sustainable development and the conservation of its natural environment, which is illustrated –among others– by the reciprocal Sustainable Development Agreement[2] it has signed with the Netherlands (Ecooperation, 1999). Another important reason for choosing Costa Rica was the fact that we already had contacts in the field of energy planning, which helped in conducting the field study. The region Huetar Norte was chosen because it has shown an increase in economic development in recent years, in particular in the agricultural sector and in tourism. As a consequence, the energy demand in the region increased more than the national average, and new energy infrastructure is needed.

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[2] In 1994, the Netherlands concluded Sustainable Development Agreements with Costa Rica, Bhutan, and Benin as a way to enhance the implementation of the Rio Declaration signed two years earlier at the UN Conference on Environment and Development. The Agreements are bilateral and based on reciprocity, equality, and participation (Ecooperation, 1999, p. 7).

In the remainder of this chapter we will first give a description of the national and regional context in which local energy planning takes place (§ 6.2), followed by an overview of the main actors involved in (or affected by) energy planning, as well as their interests and preferences (§ 6.3). We will then address the key issues in local energy planning in Huetar Norte (§ 6.4), and in the last section (§ 6.5), we will evaluate the assumptions of the new method using the data obtained from the field study. These data are also used in the next chapter (Chapter 7), where we will give an example of how the new method can be applied in practice.

Note that some of the data obtained during the field study in Costa Rica were rather old, and that most of the documents were in Spanish. Also, the data of different sources did not always prove to be consistent. For instance, CEPAL (2001b), INEC (2001), WB (2001), EdelaN (2001), and IMF (2002) all mention different numbers for the population in Costa Rica in 2000, ranging from 3.7 to 4.0 million people.

6.2. Description of the Context

6.2.1. General Information on Costa Rica and Huetar Norte

Costa Rica is about the same size as the Netherlands, but only inhabits about 3.9 million people (EdelaN); 4 times less than the Netherlands. The transition towards democracy in Costa Rica already began at the end of the 19th century, and the country has a stable democracy since 1949 (Solís, 1997; EdelaN, 2001a). None of the political parties has a substantial majority in the Parliament and consequently, most major political decisions require extensive discussions and negotiations that often exceed the four-year periods of governance (Vargas, 2001, p. 88).

The country is divided into seven provinces, which consist of a total of 81 cantons that are in turn divided into numerous districts. However, considering characteristics such as geography and climate, six homogeneous regions can be distinguished, among which the Huetar Norte region (EdelaN, 1998). The Huetar Norte region is situated in the north of Costa Rica, at the Nicaraguan border, encompassing the northern parts of the provinces Alajuela and Heredia[3] (see Figure 6.1). Table 6.1 gives an overview of the general characteristics of Costa Rica and Huetar Norte. The region covers a total surface of 9803 km^2 and is characterized by its large tropical lowlands (‘llanuras’) and its tropical climate: a total annual (all-year round) precipitation of 2-4 (!) meters, an average temperature of 25°C, and a relative humidity of 80%-90% (MAG, 1999).

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[3] The Huetar Norte region includes the cantons of Los Chiles, San Carlos, Guatuso, Upala de Alajuela (all of which belong to the province of Alajuela), and the canton of Sarapiquí de Heredia (of the province of Heredia). It also includes the following *districts* of the province of Alajuela: Peñas Blancas de San Ramón, Río Cuarto de Grecia, and Sarapiquí de Alajuela.

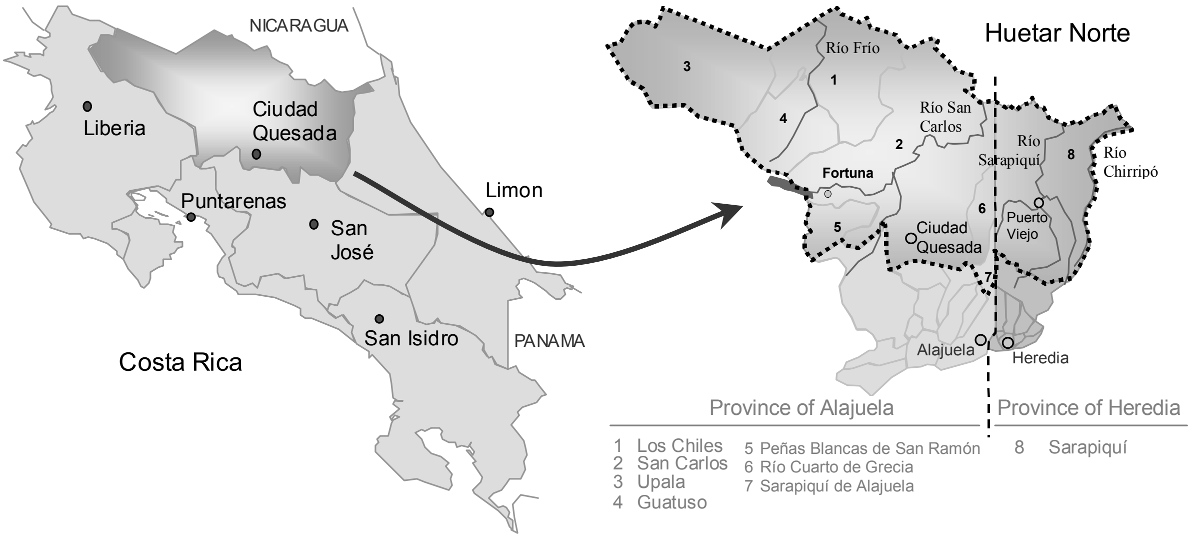

Figure 6.1. The Huetar Norte region situated in the north of Costa Rica, encompassing the northern parts of the provinces of Alajuela and Heredia.

Table 6.1. General information on Costa Rica and Huetar Norte.

Costa Rica	2000	Huetar Norte
51,100	Total surface area (km^2)	9,803
3.94	Total inhabitants (million)	0.26
77.1	Inhabitants per km^2	26.5
15,884	GDP in million current US$	n.a.
1.7%	Growth in real GDP	n.a.
4,028	GDP per capita (US$)	n.a.
5.2%	Unemployment rate	5.1%
94.5%	Electrification rate	93%
1,701	Installed electrical capacity (MW)	367
2,730	Electricity demand per household (kWh/yr)	2,302
5.8%	Growth in electricity demand 1995-2000	7.3% [a]

[a] Based on the area in Huetar Norte serviced by Coopelesca.
n.a. = not available. *Source: EdelaN (2001b), INEC (2001), CEPAL(2001a), CEPAL (2001b) , Reyes (2001), MAG (2000), Alfaro (2001), ICE, Alvarado (2001).*

The mountain chains at the southern border of the region locate the origin of important rivers such as Río Frío, San Carlos, Cureña, Zapote, Sarapiquí, Chirripó, and Pocosol, that flow towards the Nicaraguan border at the north of the region. Generally, the lowlands near the Nicaraguan border flood extensively during the wet season (June-November). Originally, the region was covered with mixed tropical forest, but agricultural land, pastures, and secondary forest have now replaced much of the original vegetation (EdelaN, 1998).

With about 260 thousand inhabitants in 2000 (INEC, 2001), Huetar Norte has a rural character: its average population density of 26.5 habitants per km^2 is the lowest in Costa Rica.

More than 80% of the population in Huetar Norte lives in rural areas (compared to a national average of about 41%) and many live without proper access to basic housing or facilities such as tap water and sewerage (INEC, 2001; EdelaN, 2001b). Only the area immediately surrounding the city Ciudad Quesada (also referred to as 'San Carlos') has an urban character, with a population density of 240 persons/km^2. Roads are generally rough and public transport is poor, with the exception of the main cities such as San Carlos and Puerto Viejo, and towns such as Fortuna that are located near tourist attractions (Arenal volcano).

6.2.2. Economic Development

Even though public debts are high (45% of GDP by end-1999), Costa Rica has a stable economy, with an average real economic growth of about 5% a year between 1960-2000 (IMF (2002); EdelaN (2001b). Traditionally, the dependency on export of agro-products such as coffee and banana is high, but with the current low world prices the export has declined in recent years. On the other hand, increasing revenues from tourism and the export of micro-electronics (Intel) has diminished the dependency on agro-products somewhat during the last decades (ICT, 1999).

Economic data on the region Huetar Norte are not abundant, but a valuable contribution came from the forth *Estado de la Nación* (EdelaN, 1998), with a special topic on Huetar Norte, albeit that the data are slightly outdated. The same applies to Bravo's *Diagnósticos Regionales* of 1997 that includes the Huetar Norte region. More recent regional data were available from the Ministry of Agriculture and Breeding (MAG) and the Costa Rican Tourism Institute (ICT), although the latter were not specific on the region.

The Huetar Norte region heavily depends on agriculture, but just as to the rest of Costa Rica, tourism is becoming of increasing importance in the region. According to EdelaN (1998), the increase in economic activity in the region is mainly restricted to three sub-regions: San Carlos-Alajuela, Sarapiquí, and Upala-Guatuso-Los Chiles. All three sub-regions show an increase in agro-industrial activities (including forestry), although the agro-products differ per sub-region.

Bravo (1997, p. 1) states that there are many small and medium enterprises (SMEs) in the region, while MAG (2001, p. 149) mentions that many of these SMEs are organized in chambers, associations, cooperations and such. The majority of the SMEs is active in cattle breeding or agriculture, and the latter mainly cultivate traditional crops such as beans, rice, and also corn primarily for national consumption. Most of the land in the region is owned by large international companies that export agro-products such as bananas, sugar cane, and coffee. However, with declining world prices for coffee and bananas, the land use for non-traditional export products (such as yucca, palm heart, pineapple, and oranges) has shown a rapid increase in recent years (MAG, 2001). The wood industry is also very active in the region, not only by extracting wood from the forests, but also with reforestation projects (Bravo, 1997; EdelaN, 1998).

Besides a growth in agricultural activity, the three sub-regions also show a substantial increase in the commercial sector, in particular related to tourism (e.g., hotels, restaurants, internet cafés, outdoor activity centers, etc.) (EdelaN, 1998). The increasing number of tourists visiting the areas has caused an increase in private and community investments in the commercial sector, but the state support for improvements on roads and sewerage, or development of tourist facilities remains low (Gámez, 2001).

The Huetar Norte region offers excellent opportunities for eco-tourism, adventurous tourism, and scientific tourism[4]. Eco-tourists can enjoy the scenic beauty in the region, including the Arenal volcano near Fortuna, the Arenal lake, national wildlife reserve Caño Negro, national park Braulio Carrillo, and national park Tortuguero. Adventurous types can use one of the many rivers in the region for white water rafting, canoeing, fishing, or swimming. Another tourist attraction in the Huetar Norte region are the hot springs of Tabacón, and the region is also popular for bird watching, boat tours for wildlife watching, as well as for hiking and horseback riding (OEA, 1997; Bravo, 1997; EdelaN, 1998; MAG, 2001). An example of scientific tourism is the vast numbers of students, scientists, and others interested that visit the La Selva biological station near Puerto Viejo de Sarapiquí each year. This station is world famous for its research on tropical rain forest. Recently, also the agro-industry has discovered the tourists, offering excursions to banana and coffee plantations.

6.2.3. Environmental Problems

A mayor environmental problem in Huetar Norte and the rest of Costa Rica is *deforestation*. No recent data were available, but Calderón and Umaña (1997, p. 34) estimate that in the two decades between 1970 and 1990, Costa Rica has lost about half of its dense forest area. The same picture is drawn for the Huetar Norte region by Bravo (1997, p. 2), who estimates that during the decade 1983-1993 almost half of the forest area in the region has disappeared, leaving only 136,115 ha in 1993. Of the remaining forests, only 25% was primary forest; about half was intervened forest; 15% was secondary forest; and 11% was reforested. The areas most affected are Los Chiles, Upala, Sarapiquí, San Carlos, and Guatuso (Bravo, 1997).

According to Calderón and Umaña (1997, p. 35), the growing demand for land, as a result of population growth, agricultural expansion or other economic activity, is the main cause for deforestation, although the demand for timber also contributed to an accelerated loss of forest.

Deforestation causes a series of environmental impacts that reinforce each other, such as soil erosion, soil fertility depletion, weakening of watersheds, changes in ecosystems, and loss of biodiversity. (Bravo, 1997; Calderón and Umaña, 1997, p. 35; EdelaN, 1998)

Another environmental problem, mentioned by Bravo (1997, p. 3), is the contamination of rivers with municipal waste and the agro-residues from the SMEs and industries. The current

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[4] There are many definitions on eco-tourism and other types of tourism. We will not attempt to give an unambiguous definition here, but in Chapter 7, we will use different types of tourists and define them accordingly.

facilities for waste collection and recycling are not adequate, while there is a lack of water treatment of rivers that have been contaminated. In addition, many farmers use pesticides, which not only pollute the environment, but are also a thread to human health and aquatic life. Most banana plantations also use plastics, which pollute the environment and threaten the lives of animals that eat the plastic or get tangled up in it. However, the banana companies have recently shown considerable progress in this regard, not in the least because of environmental laws that came into effect, although the latter are still not adequately enforced (OEA, 1993; EdelaN, 1996; Zamora and Obando, 2001; Bendell, 2001).

6.2.4. Existing Energy Infrastructure

The existing energy infrastructure in Costa Rica that is used to supply energy forms to end-users (excluding energy for transport purposes) is based on the generation, transmission and distribution of *electricity*, and is relatively well developed compared to other developing countries: more than 95% of the households is connected to the national electricity grid (EdelaN, 2001). Box 6-1 gives a short history of the Costa Rican energy infrastructure development.

Water is an abundant resource in Costa Rica, and the existing energy infrastructure heavily depends on it: according to CEPAL (2001b, p. 28), about 72% of the 1700 MW of total installed capacity is based on hydropower, and more than 80% of current annual electricity supply is generated with hydro systems, see Table 6.2. Other systems include geothermal systems, wind turbines, and fossil fuel based thermal systems. The fossil fuels used for the thermal systems have to be imported from abroad, as there are no proven national reserves (Cruz, 1997, p. 155). In addition, some isolated areas that are not connected to the grid are equipped with PV solar systems, such as Isla Caballo, Dos Bocas de Aguirre, Colas de Gallo, La Esperanza, and Gandoca (Vargas and Otoya (2000); La Nación (23 Nov. 1997).

Table 6.2. Installed capacity and annual production of electricity per type of system in Costa Rica in 2000.

System	Total Installed Capacity (MW)		Annual Production (GWh/yr)	
Hydro	1225,5	72,8%	5684,1	82,5%
Geothermal	145,0	8,5%	937,5	13,6%
Thermal [a]	286,2	16,8%	81,4	1,2%
Wind	42,5	2,5%	182,7	2,7%
Biomass	-	-	-	-
Total	1699,1		6885,7	
Public	1479,7	87%	5761,2	83%
Private	219,4	13%	1124,5	16%

Figures may not add due to rounding. Source: CEPAL (2001b).

[a] Thermal systems are based on fossil fuels, mainly on diesel and gas.

Box 6-1. The development of the Costa Rican energy infrastructure.

The Development of the Costa Rican Electricity Sector

The development of the Costa Rican electricity sector can roughly be divided into three phases (Vargas, 2001a, p.78):

I.	1884 – 1949	Electrification of the main cities in Central Valley
II.	1949 – 1990	National Strategies to electrify the entire country
III.	1990 >	Liberalization and international integration of the electricity sector

Electrification in Costa Rica began in 1884 with a private 50 kW generating unit to electrify downtown San José (Fernández, 1985; Vargas, 2001a). Soon, other private producers emerged in Central Valley and a few years later, these private companies emerged into the National Power and Lighting Company (CNFL). Meanwhile, the government established the National Electricity Service (SNE) to regulate the tariffs and quality of services, but only the densely populated areas in the Central Valley (such as San José, Heredia, and Alajuela) were connected to an electricity grid, and the performance of the infrastructure was generally poor, with black outs and technical problems occurring frequently.

The second phase of development started in 1949 with the establishment of a state company responsible for the planning, production, transmission, and distribution of electricity: the Instituto Costarriccense de Electricidad (ICE). In the 1950s, all existing production companies became part of ICE, although CNFL could maintain a special status. Total installed capacity had now increased to 36.6 MW, but still less than 41% of the population was connected to the grid. The first priority of ICE was to increase the electrification rate so that the more remote areas also gained access to electricity. Other companies besides ICE and CNFL were founded to distribute electricity to remote areas, such as Empresa de Servicios Publicos de Heredia (ESPH), Junta Electrificadora de Servicios Electricos de Cartago (JASEC) and four rural co-operatives in Guanacaste (Coopeguanacaste), Los Santos (Coopesantos), San Carlos (Coopelesca), and Alfaro Ruiz (Coopealfaro). These companies were complementary to –rather than competing with– ICE. At the end of the 1980s, the national electricity grid served more than 90% of the households, and was also connected to the other Central American countries through a high-voltage transmission line for export and import of electricity. However, the high rate of electrification was largely financed with (foreign) loans, and in the 1980s Costa Rica faced a tremendous public debt, which initiated the third phase of the infrastructure development (IADB (1999); IMF (2001); Vargas, 2001a).

The third phase started in the late 1980s and the beginning of the 1990s, partly as a result of the reform programs that were needed to decrease the high debt of the Costa Rican economy in general and the electricity sector in particular (IADB (1999); Anderson). In 1990, Law 7200 was one of the first laws resulting from the reform process to affect the electricity sector. This law permits –under strict conditions– private production of electricity as a way to attract private investments for the expansion of the energy infrastructure. In 1995, Law 7508 modified Law 7200 to allow for a greater percentage of private production, and ease some of the conditions (see § 6.2.5). In 1996, SNE was transformed into a new regulating authority for public services (ARESEP) under Law 7593. This new authority determines (among others) the electricity tariffs and the standards for technologies and quality of service. It also issues concessions for all public service entities. ICE underwent substantial organizational changes in 1998, dividing its activities into different strategic business units (Vargas, 2001a). Currently, Costa Rica is preparing for the creation of an inter-American market for electricity: the SIEPAC project (IADB, 1999; Vargas, 2001a).

Table 6.2 also shows that the thermal systems only account for 1,2% of annual production, even though they make up for 16,8% of total installed capacity. This is due to the fact that these systems are mainly used during peak demand (Alvarado, 2001).

At present, the energy sector is dominated by the government-owned energy company Instituto Costarricense de Electricidad (ICE) that until recently had a monopoly on electricity production. However, in order to attract the necessary energy infrastructure investments, independent power producers (IPPs) are now allowed to generate electricity under laws 7200 and 7508, albeit under strict conditions (see § 6.2.5). In 2000, private installed capacity accounted for 13% of total installed capacity (CEPAL, 2001b). According to Alvarado (2001), the IPP projects are meant to substitute the current fossil fuel based systems (owned by ICE), which operate mainly during peak demands.

The transmission of electricity will remain a monopoly of ICE, but the distribution and retail of electricity is traditionally divided among several energy companies, who each have a monopoloy on distribution in their service area (IADB, 1999). Besides ICE and CNFL these companies include: Empresa de Servicios Públicos de Heredia (ESPH), Junta Electrificadora de Servicios Eléctricos de Cartago (JASEC) and the four rural co-operatives of Guanacaste (Coopeguanacaste), Los Santos (Coopesantos), San Carlos (Coopelesca), and Alfaro Ruiz (Coopealfaro). Figure 6.2 shows the areas currently covered by a distribution grid of one of the energy companies. Note that the service areas of most rural energy companies is often larger than shown in Figure 6.2, as not yet all (isolated) parts of the country have been electrified. The transmission and distribution losses amount to 11% of total grid-connected production. Costa Rica is currently connected to other Central-American countries through a high-voltage power line, which enables export or import of electricity. The SIEPAC project, currently being implemented, aims at creating an Inter-American market for electricity using this connection (Vargas, 2001a).

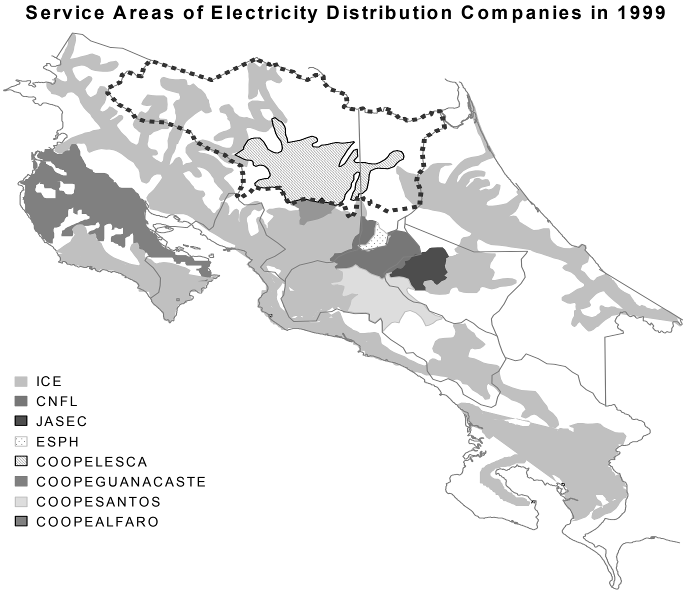

Figure 6.2. Map of the areas currently serviced by the distribution companies in Costa Rica. The dotted line shows the contour of the Huetar Norte region. Source: CENPE (1999).

Figure 6.3 gives an overview of the energy companies and governmental organizations in the electricity sector in Costa Rica. Note that the electricity production companies only include those companies that produce for the national grid. The roles of the organizations involved in energy planning are discussed in § 6.2.5.

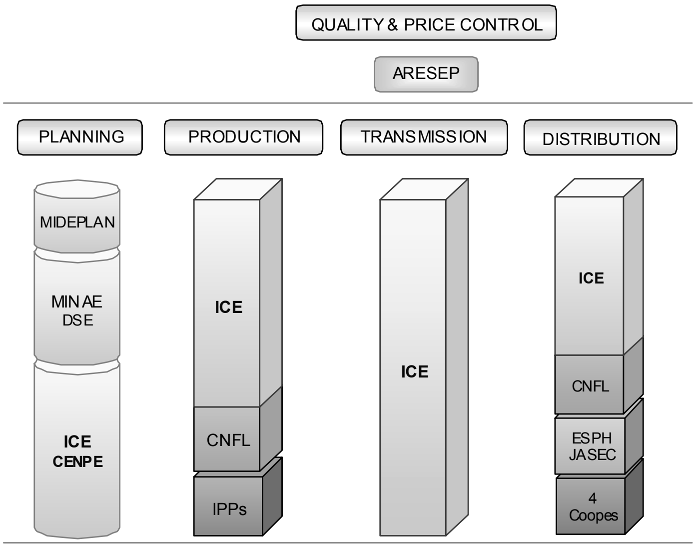

Figure 6.3. Overview of the energy companies and governmental organizations in the electricity sector in Costa Rica.

In the Huetar Norte region, water is the main energy resource, which is abundantly available in especially the wet season (June-November). Also, there is some potential for geothermal energy, with the existence of volcanoes at the south-eastern border of the region. With forests, cattle, and agricultural activities in the area, biomass resources seem abundant, but may not be available for generation purposes, due to environmental regulation or the fact that the biomass is already used for other purposes. Solar energy is also relatively abundant, while the potential for wind energy is low, and there are no significant known reserves of uranium, coal, gas, or oil in the area.

Most of the Huetar Norte region is serviced by the energy company Cooperativa de Electrificación Rural de San Carlos R.L. (Coopelesca). According to Reyes (2001), Coopelesca covers an area of 4965 km^2 in the cantons of San Carlos de Alajuela and Sarapiquí de Heredia, but the distribution grid does not yet service the entire area at this moment, as the remote areas with very low population densities are not yet electrified. This is also reflected in the electrification rate of about 93% in the Coopelesca area, compared to a national average of 94,5% (Reyes, 2001; CEPAL, 2001b). The majority of the electricity that Coopelesca supplies to the end-users is bought from ICE, although since the end of 1999 Coopelesca also produces a small part of demand itself, using a 8 MW hydropower plant near San Carlos. The transmission line (230kV) passing through San Isidro, San Carlos, and further on in the east-south-east direction belongs to ICE, which also supplies electricity to a small part of the northwest area of Huetar Norte.

Concerning energy demand, we only could obtain consistent data for the Coopelesca area, which includes two of the three sub-regions within Huetar Norte that show increased economic activity: San-Carlos-Alajuela and Sarapiquí (see § 6.2.2). So for practical reasons, we will focus on the area serviced by Coopelesca for the remainder of our analysis. This way, we can obtain consistent regional data on energy demand and supply, and we have at least one actor that has decision-making authority in the region.

According to Alfaro (2001), electricity demand in the Coopelesca area grew with is 7,3% per year during the period 1995-2000. In comparison, national electricity demand grew with an average of 5.8% per year in that same period (CEPAL, 2001b). Most clients are residential, but the industrial clients, although few in number, account for almost one-third of consumption (see Figure 6.4).

The energy consumption per client is significantly lower in the Coopelesca area than the national average for all types of consumers. For instance, the residential consumers in the Coopelesca area use 2,302 kWh/yr of electricity, while national average amounts to 2,730 kWh/yr (see also Table 6.3). The electricity prices of Coopelesca also differ from those of ICE: residential consumers of Coopelesca pay less. However, as Table 6.3 shows, the average electricity prices for both commercial and industrial clients in the Coopelesca area are higher than those of ICE. Note that the average prices of commercial and industrial clients also include the costs for demanded power (kW). Both Coopelesca and ICE use a cross-subsidy from commercial to residential clients (IADB, 1999; CEPAL, 2001b), while the residential clients from Coopelesca are also subsidized by the industrial clients.

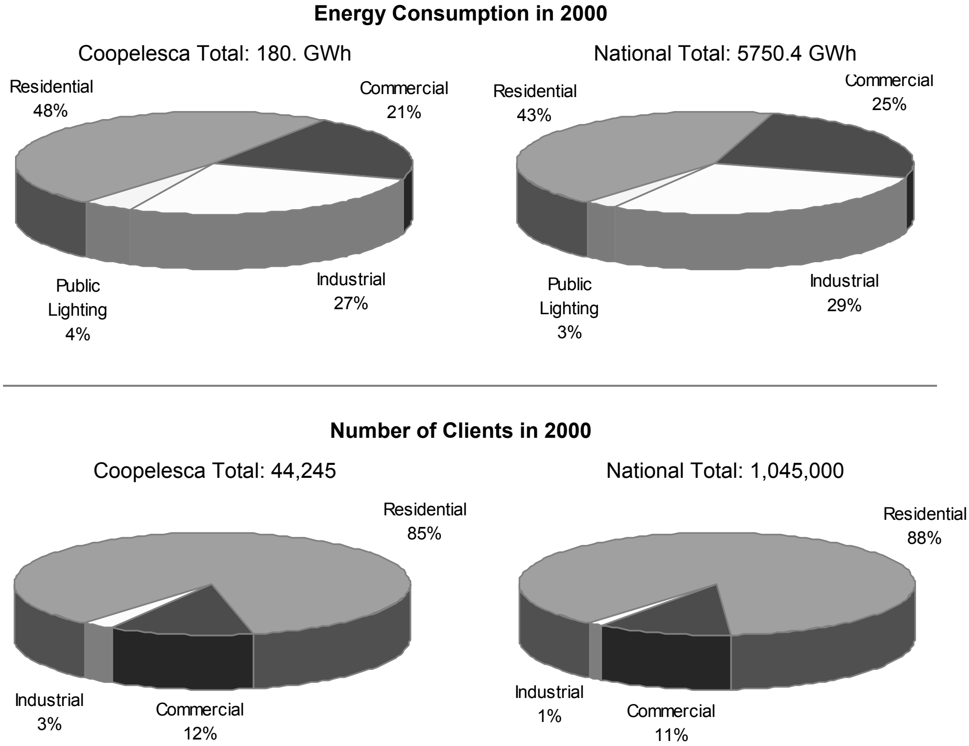

Figure 6.4. Shares in energy consumption and number of clients per consumer type in 2000 for Coopelesca and Costa Rica. Source: CEPAL (2001b), Alfaro (2001), ARESEP (2001).

Table 6.3. Electricity consumption for Coopelesca compared to the national average, and electricity prices of Coopelesca compared to ICE in 2000, per type of consumer.

	Electricity Consumption per Client (kWh/yr)		Electricity Prices (colones/kWh)	
Consumer Type	*Coopelesca*	*National Average*	*Coopelesca*	*ICE*
Residential	2,299	2,733	14.73	18.46
Commercial	7,198	12,171	31.20	26.26
Industrial	40,049	146,202	25.85	20.67
Total Average	4,076	5,503	20.91	20.67

Exchange rate in 2000: 310 ¢/US$. Source: Alfaro (2001), CEPAL (2001b), ARESEP (2001).

6.2.5. Current Energy Planning

Currently, energy planning occurs at a national level, involving ICE, the Ministry of the Environment and Energy (MINAE), the Ministry of Planning (MIDEPLAN), and the regulatory authority for public services ARESEP (see also Figure 6.3). The IADB (1999) states that ICE is responsible for sector planning, implying the design and implementation of electricity generation and transmission expansion plans so that demand is met at all times. These plans are made by CENPE, the planning department of ICE, which regularly publishes its results in Expansion Plans of Electricity Generation (CENPE, 2000). According to IADB (1999), ICE is required to give preference to the use of sustainable renewable energy, and to consider environmental protection, energy efficiency, and energy conservation criteria. Recent droughts and a subsequent lack of water have made ICE aware of the need to diversify the Costa Rican supply mix, as the sector currently highly depends on water for electricity generation (Anderson). The Department of Energy (DSE) of MINAE is in charge of defining policies and long-term strategies for the entire energy sector. The results are presented, among others, in the National Energy Plans (DSE, 2000). MIDEPLAN operates on an even higher aggregation level, coordinating economic expansion among the various sectors. ARESEP is the regulatory authority that sets tariffs, issues new concessions for public service entities, takes measures to improve the transparency of the regulatory process, establishes customer rights and obligations, and arbitrates in conflicts.

Little is done concerning planning on the local level. However, some distribution companies, such as Coopeguanacaste and Coopelesca, aim to reduce the amount of (expensive) electricity bought from ICE during peak demand, by planning and installing decentral electricity systems (Reyes, 2001). Also, ICE does some local planning (mainly concerning PV solar systems) to provide isolated areas with electricity for basic needs.

In 1990 Law 7200 set off the liberalization of the electricity sector in Costa Rica, which was subsequently expanded in 1995 under Law 7508. Liberalization was necessary to attract new investments in the energy infrastructure, as the high public debts prevented the government (i.e., ICE) from investing in new capacity (IADB, 1999). Vargas (2001a) mentions that additional attempts to privatize the national electricity company ICE met with strong opposition of society and political parties, which was also evident from the articles and opinions that appeared in the national newspaper La Nación as from March 2000 about the "Combo ICE".

The new laws on liberalization allow independent private producers (IPPs) to own and operate electricity production systems. However, private production is subject to strict conditions. Law 7200 (1990) allows independent private producers to generate electricity, but they can only use renewable energy resources to do so, and are compelled to sell the electricity to ICE. Also, the capacity per system may not exceed 20MW, while the total private capacity may not be more than 15% of total installed capacity. Furthermore, local capital participation must be at least 65%, and each private project plan has to be accompanied by an environmental impact assessment study and has to be approved by ICE. Law 7508 (1995) modifies Law 7200 by increasing the percentage of private capacity to 30% of total installed capacity, while the unit size of private systems is raised to 50MW. In addition, the required local capital participation is reduced to 35%. However, under law 7508 the concessions for new projects are subject to a bidding procedure, resulting in so-called BOT contracts for the ultimately selected bidders: the latter can *build* and *operate* a generation unit for a specified period of time (usually 20 years), after which the unit is *transferred* to ICE.

So IPPs are not directly linked to local demand; they use decentral energy systems to produce electricity that is sold to ICE, which consequently supplies it to the national grid. However, the planning of these decentral energy projects can be regarded as local energy planning. The *autonomous* private production (i.e., by systems not connected to the national grid, such as a photovoltaic systems) is not affected by laws 7200/ 7508, but these projects do have to comply with the existing environmental and conservation laws. Currently, local energy planning in Costa Rica is only applied at a limited scale, but with the liberalization of the energy sector this is expected to change in the near future.

6.3. Main Actors, Interests, and Preferences in Local Energy Planning

To be able to identify the relevant actors involved in local energy planning, and in order to give an adequate description of their interests and preferences, the field study will narrow its focus on the local energy planning process in one of the rapidly developing areas in Huetar Norte: Sarapiquí. The Sarapiquí area is part of the Coopelesca area and is one of the sub-regions with increased economic activity discussed in 6.2.2. The situation in Sarapiquí is exemplary for many other areas in Costa Rica.

So the remainder of the field study will analyze the planning and selection of new energy infrastructure in Sarapiquí. Sarapiquí is located in the west of the Coopelesca area, and includes the town Puerto Viejo and the area southwest of it. Sarapiquí –like many other areas in Costa Rica– highly depends on agriculture, but recently has experienced a boom in tourism.

The main tourist attractions in the area are its natural beauty and biodiversity, and the rivers. The increase in tourists visiting the area has caused a need for new energy infrastructure to supply electricity to the newly-built tourist facilities such as hotels, restaurants, and Internet cafes (Gámez (2001); ICT (1995; 2000). Coopelesca currently distributes electricity to the consumers in the area, but ICE and other energy companies have planned several energy projects in or near the area.

For the identification of the relevant actors that can influence the planning process we used in-depth interviews with experts and local stakeholders, read policy documents, reports, project proposals, and newspapers, and searched the Internet (see the References at the end of this chapter and Appendix E). The following actors appeared relevant in the Sarapiquí area:

- National Government
- Municipalities
- Energy Companies
- Local Entrepreneurs
- Local Habitants
- Farmers
- Interest Groups
- Support Organizations

Each of these actors, as well as their interests and preferences will be discussed in more detail in the following subsections.

6.3.1. National Government

The national government of Costa Rica determines the regulatory and policy framework within which the other actors in local energy planning must operate. An adequate national framework is required to get local plans and actions that benefit society as a whole. Currently, the Costa Rican government still plays a dominant role in energy planning, despite the liberalization process of recent years. In fact, recent attempts to privatize the state-owned energy company ICE have met with strong opposition in society as well as from political parties (La Nación, 25 June, 2000; Vargas, 2001a).

The main aim of the national government is to achieve and maintain a continuous, secure, economically efficient, self-sufficient, sustainable energy supply that is in harmony with nature (DSE, 2000). The instruments that the Costa Rican government uses in setting the framework to achieve its aim include policy plans, laws and regulations, standards, subsidies and taxes, and supply of information. An important policy document is the National Energy Plan, which reflects the medium-term strategies in national energy planning and is published regularly (DSE, 2000). Another important issue that affects energy planning is the government's environmental policy, attempting to conserve the natural beauty of the country and protect the many different ecosystems and rare species. The natural beauty and wildlife currently present in Costa Rica also attracts many tourists each year. Therefore, the government actively promotes efficient and rational use of energy and the use of renewable energy to keep the negative impacts on the environment as low as possible.

Laws and regulations that affect energy planning include Law 7200 and Law 7508, regulating the liberalization of the electricity sector (as discussed in § 6.2.5), and Law 7593 enacted in 1996, which created the regulatory authority ARESEP. This regulatory authority, among others, sets standards for the quality of services and determines the tariffs for these services. ARESEP also determines the fees that are included in the electricity tariffs to electrify remote areas and subsidize low-income consumers. Another important law is Law 7848 (1996), which encompasses the international treaty on the creation of a Central-American electricity market (i.e., the SIEPAC project). According to Alvarado (2001), some believe that the SIEPAC project –when implemented– will threaten the future competitiveness of the 'clean' Costa Rican energy sector, as powerful large foreign energy companies that mainly use fossil fuel based energy systems push aside the national companies that mainly use renewable energy sources. The government also supplies information, among other on its web site, in documents and articles, as well as through advertisements. Table 6.4 lists some examples of the instruments used by the Costa Rican national government.

Table 6.4.Some examples of instruments used by the Costa Rican government to provide a regulatory and policy framework for the energy sector.

Instruments	***Examples***
Policy Plans	Plan Nacional de Energía 2000-2015. Medium-term strategies for the energy sector.
Laws & Regulations	Law 7200 and Law 7508 (Liberalization of electricity production) Law 7593 (Creation of ARESEP, regulatory authority for public services) Law 7848 (International treaty on the creation of a Central-American electricity market)
Standards	ARESEP quality control and tariff setting
Subsidies	Cross-subsidies to support low-income consumers.
Information Supply	Through Internet, articles, reports, and advertisements

The role of the local government, the municipality, is quite different from that of the national government, and will be discussed in the next section.

6.3.2. Municipalities

Generally, the municipalities appeared to play a minor role in local energy planning in Costa Rica. However, in the case of Sarapiquí, the Municipality of Sarapiquí did affect the energy planning process: at the end of 2000, it helped in organizing a referendum on the use of the Sarapiquí river (Gámez, 2001; La Nación, 25 Sept. 2000). This referendum was the first local referendum to be held in Costa Rican history and therefore supervised by the

Supreme Court of Elections (Gámez, 2001). Initiator of the referendum was the local environmental interest group ABAS (Asociación para el Bienestar Ambiental de Sarapiquí) that tried to declare the Sarapiquí river as a 'historical natural monument' to protect it against the adverse effects of the many hydropower projects planned in the river or one of its tributaries (La Nación, 25 Sept. 2000). The result of the referendum showed a 90% score in favor of the declaration. However, only 12% of those entitled to vote actually showed up to do so. This provoked the energy company ESPH –who had planned a hydro project in the Sarapiquí river– to question the legitimacy of the referendum (La Nación, 28 Oct. 2000). But the referendum had no minimum threshold with respect to the number of votes, and the municipality saw no reason to discard the results. The Legislative Assembly has yet to officially declare the Sarapiquí river as a historical natural monument. According to SeMueve (2000), the instrument of a referendum now forces energy companies to discuss their plans with communities and municipalities affected by the energy projects.

6.3.3. Energy Companies

There are three traditional energy companies that play a role in energy planning in the Sarapiquí area: Coopelesca, ICE, and ESPH. In addition, several IPPs have hydropower projects in operation or planned in the area.

Coopelesca

The rural co-operative Coopelesca R.L. is the main distributor of electricity in the Huetar Norte region, with a service area that includes the canton of San Carlos in the Province of Alajuela and the area along the Sarapiquí riverbanks in the Province of Heredia (see Figure 6.2). Most of the distributed electricity is purchased from ICE (Alfaro, 2001), but since the end of 1999 Coopelesca has its own hydropower production unit. According to Reyes (2001), this unit is mainly used to reduce the amount of electricity bought from ICE during peak demand, as the price of electricity in these hours is high. Reyes (2001) also states the following important issues for Coopelesca when considering the distribution of electricity: supply of electricity to clients has to be reliable, equipment must have a long lifetime (>20 yrs), the current distribution infrastructure has to be further improved, and the infrastructure has to be expanded to people not yet connected to the grid. With respect to electricity production, projects of Coopelesca have to be profitable and low-risk (i.e., 'proven' technologies). According to Reyes, this rules out photovoltaic systems because they supply "too little electricity at too high a cost". In addition, Reyes states that it also important that energy systems are easy to control, implying that they deliver electricity when needed. Therefore, Reyes does not consider wind turbines as viable systems, as wind energy is inherently unreliable in its supply. Hydropower systems, on the other hand, comply with all the set criteria.

ICE

The Instituto Costarricense de Electricidad (ICE) is the state-owned energy company that, despite the liberalization processes, still has great influence on planning and implementation of energy projects. ICE is the only energy company that is allowed to install energy projects larger than 50MW and has the exclusive right to use fossil fuels for national electricity generation (Alvarado, 2001; Jiménez, 2001; Vargas, 2001b). Furthermore, ICE has a monopoly in transmission, while it is also active in the distribution of electricity. Since its foundation in 1949, ICE has gained a lot of experience and know-how in especially hydropower projects. Although ICE's direct energy planning activities are mainly done at a national level, ICE's influence on local energy planning is considerable, as each new project proposed by any of the other energy companies has to be submitted for approval by ICE. The main aim of ICE is to secure a long-term reliable energy supply for the Costa Rican society as a whole and improve the international competitiveness of the national energy sector (DSE, 2000; ICE, 2001).

ESPH

ESPH (Empresa de Servicios Públicos de Heredia) is a public utility that is active in the supply of drinking water, maintenance of the sewerage system, and the distribution of electricity in the province of Heredia, although not directly in the Huetar Norte region (see Figure 6.2). ESPH had planned a lucrative hydropower project in the district of La Virgen in the Sarapiquí area, as part of the private production initiatives under laws 7200 and 7508. However, strong local opposition at the site, among others reflected in the outcome of a referendum, severely delayed this project and ESPH later decided to abandon the project all together (La Nación (Oct. 28, 2000); Gámez (2001), see also § 6.3.2). ESPH has also planned a project of 16 wind turbines situated near the village of Vara Blanca, at the southern border of the Huetar Norte region, totalling a capacity of 9.6 MW (PCF, 2001).

Independent Power Producers

Under the laws 7200 and 7508, independent power producers (IPPs) are now allowed to produce electricity. But the IPPs are only allowed to use renewable energy sources for production, and the installed capacity per project may not exceed 50MW. Also, an environmental impact study is required for each project, while total private production may not exceed 30% of total installed capacity (see also § 6.2.5).

Alvarado (2001), director of the organization for independent power producers ACOPE, states that each project proposed by an independent power producer (or co-operative or public utility) has to be submitted for approval by ICE, which verifies the project's compatibility with the existing infrastructure. Once the projects have been approved and constructed, private producers sell their electricity to ICE, under long-term contracts that last up to 20 years. ICE has the obligation to buy the electricity from IPPs, also at times when demand is low, so that any excess electricity has to be exported abroad. According to Alvarado (2001), the IPPs are mainly interested in profitability and low risk, and prefer clear and stable regulations concerning private production.

So the energy companies have different interests and preferences in planning new energy projects. Coopelesca will use a new system to produce electricity during the peak hours of demand, to avoid buying the expensive electricity from ICE at those times. Coopelesca's choice for the capacity of a system will therefore for an important part depend on the growth in electricity demand of its clients. ICE, on the other hand, will use new generation systems to improve the national electricity infrastructure and enhance the competitiveness of the national energy sector, led by national plans and strategies. Finally, the independent private producers (IPPs) and the public utility ESPH will likely choose a system that maximizes their profit when selling the generated electricity to ICE.

All energy companies appear to favor hydropower projects because information and expertise on this technology is readily available and the estimates on costs and benefits are fairly accurate as a result of past experiences. Hydropower projects, however, appear to raise opposition from several local groups in Sarapiquí, among which the local entrepreneurs, the habitants, farmers, and interest groups.

6.3.4. Local Entrepreneurs

The Sarapiquí area has shown a boost in tourism in recent years, and the number of local entrepreneurs in tourism activities and services has increased accordingly (Gámez (2001); ICT (1995; 2000). In our field study, we only looked at the entrepreneurs related to tourism. Note that the increase in tourists not only generates extra year-round income and opportunities –among others for women– to generate extra income, it also stimulates improvements to roads and bridges and such, to increase the accessibility to the area, thereby creating a reinforcing effect that increases the number of tourists further.

The field study in Sarapiquí shows that the group of local entrepreneurs in tourism can be divided into two actors: One consisting of the entrepreneurs offering activities or services that require electricity, and those with activities that depend on the nearby rivers, as the interests of these two groups differ, especially with respect to hydropower projects.

Local Entrepreneurs Depending on Electricity

The entrepreneurs that offer electricity-dependent activities and services (such as hotels, restaurants, and Internet cafes) require reliable supply of electricity to serve the needs of their clients (Gámez, 2001). Since the Sarapiquí area is part of the service area of Coopelesca, the latter is the main actor responsible for reliable electricity supply. According to Gámez (2001), most entrepreneurs acknowledge that the current energy infrastructure is inadequate to meet growing demand, and they understand that new infrastructure is required. So they will not easily oppose to new energy plans. However, both Gámez (2001) and Martínez (2001) state that local entrepreneurs will oppose to any plans that affect the natural beauty of the area, as this will also affect the number of tourists visiting the area, and thus their source of income.

Local Entrepreneurs Depending on River Water

There are also entrepreneurs that use the rivers in the area as a source of income, mostly offering activities or services that do not require electricity. These activities include fishing, white water rafting, canoeing, boat trips for wildlife watching, and such. The local entrepreneurs with water based activities fear that new hydropower projects may affect the water flow or amount of fish in the rivers, and thus affect the income of the entrepreneurs that use them (La Nacion, 7 Sep. 1998; Gámez, 2001; Martínez, 2001). In addition, these entrepreneurs also fear that energy projects will negatively affect the natural beauty, and thus the area's attractiveness for the tourists.

6.3.5. Local Habitants

Another type of actor that can be affected by local energy planning, especially when hydropower projects are concerned, is the group of local habitants. Relatively many households in the rural area do not have proper access to tap water or sewerage and use the rivers for their water needs such as washing, bathing, and cooking (Gámez, 2001; EdelaN, 2001). Many also use the river for leisure activities. The many hydropower projects planned in the area can affect the water flow of the rivers, or make them inaccessible due to safety reasons (e.g., sudden changes in flow). Also, the local habitants fear that energy projects will harm the environment, and some oppose to the idea that projects may not generate electricity for regional use, but for use in other parts of Costa Rica or even abroad.

Other issues indirectly related to local energy planning arise from the effects of tourism. Tourism increases the number of jobs in the area and generally increasing wages, making people less dependent on agriculture (Brandon, 1996). But tourism can also negatively affect the local habitants. For instance, some of the people interviewed during the field study said that (they feared that) the many tourists visiting the area might affect local traditions and values. And improvements to the energy infrastructure to better serve tourists will likely increase electricity prices for local habitants, while tourism generally causes the prices of food to increase as well. Better infrastructure will only attract more tourists, causing a reinforcing effect.

The referendum held in Sarapiquí at the end of 2000 proves that local habitants, even though currently excluded from the planning process, can nonetheless influence this process (see § 6.3.2). This referendum made clear that many local habitants oppose to new hydropower projects in the area, and that energy companies have to take into account the interests of these actors to avoid strong opposition to their energy plans.

6.3.6. Farmers

Besides the entrepreneurs and local habitants, the farmers also depend on the rivers in the area. Huetar Norte as well as Sarapiquí heavily depend on agriculture and agro-related industry. Water is needed to irrigate the lands, and farmers fear that the hydropower projects will not leave enough water in the rivers, causing their income to drop. As an article in La Nación (Sep. 7, 1998) shows, this fear has already led to uproar among farmers in San Ramón, where an IPP had planned a 5 MW hydropower project in the Esperanza river. If ignored, the concerns of the farmers and the consequent riots can cause a delay in the planned projects of energy companies. The influence that farmers have on local energy planning can even increase when they organize themselves in interest groups, as the local habitants did.

6.3.7. Interest Groups

Interest groups can play an important role in energy planning due to their capacity to mobilize people and make their preferences heard. For example, the fact that the referendum in Sarapiquí was held was mainly a result of local habitants organizing themselves in interest groups such as ABAS (see § 6.3.2). And the result of the referendum shows that these interest groups can considerably influence the energy planning process. As mentioned, an important interest group in Sarapiquí is ABAS (Asociación para el Bienestar Ambiental de Sarapiquí), which initiated the referendum in an attempt to let the Sarapiquí river be declared a “historical natural monument” with the intention to protect the river against the many hydropower projects planned in the area. According to Martínez (2001), ABAS fears these projects will irreversibly affect the high level of biodiversity in the area, while the benefits of hydropower projects are marginal for the area. Another interest group is CATUSA, the chamber of tourism for the Sarapiquí area, which looks after the interests of the local entrepreneurs that focus on tourism (Gámez, 2001). Furthermore, the IPPs have organized themselves in ACOPE, the association of independent power producers. This association provides information on private electricity production and lobbies for the interests of IPPs, such as the need for clear and stable regulation. ACOPE’s focus is mainly on the national government policies and actions (Alvarado, 2001), although the recent local opposition to the (mainly private) hydropower projects, may cause ACOPE to broaden its focus in the future.

6.3.8. Support Organizations

Support organizations help the actors in the energy planning process. They only affect the planning process by providing information and support in order to improve the quality of decision-making. They do not –like the other actors– attempt to steer the planning process into a particular direction. In the Sarapiquí area, no organizations were active at the time of the field study, but the non-governmental organization BUN (Biomass Users Network) is known to have worked in the Huetar Norte region on local energy projects (not just related to biomass), providing information and now-how on decentral energy systems (Siteur, 2001).

6.3.9. Overview of Actors, Interests, and Preferences

Table 6.5 gives an overview of the main actors, their interests, and preferences that affect local energy planning in the Huetar Norte region, as discussed in the previous sections.

Table 6.5. Interests and preferences of relevant actors in energy planning in Sarapiquí, Costa Rica.

Actors		**Interests and Preferences**
National Government		• Energy supply security • Energy savings and rational use of energy • Electrification of isolated areas • International competitiveness of the Costa Rican energy sector • Conservation of the environment
Municipality of Sarapiquí		• Support in organizing a referendum
Energy Companies	Coopelesca:	• Reliability of supply • Profitability (low costs, high revenues) • Compatibility with existing energy infrastructure • Low risk • Long lifetime of production systems • Easy control of production systems • Improvement of the existing electricity infrastructure • Further expansion of the electricity infrastructure
	ICE:	• Reliability of supply • International competitiveness of the Costa Rican energy sector
	ESPH/ IPPS:	• Profitability • Low risk
Local Entrepreneurs in Tourism	Electricity –dependent:	• Reliable electricity supply • Conservation of the natural beauty
	Water –dependent:	• Water flow in the rivers • Conservation of the natural beauty
Local Habitants		• Jobs and wages • Conservation of the environment • Conservation of traditions and values • Low prices for electricity and food
Farmers		• Continuous and sufficient water supply for irrigation
Interest groups	ABAS:	• Conservation of the environment (i.e., rivers, forests, and wildlife)
	CATUSA:	• Reliable electricity supply • Conservation of the environment
	ACOPE:	• Clear and stable regulations
Support Organizations		• Support the planning process • Provide information

In the next section (§ 6.4) we will use the interests and preferences of the actors to discuss the key issues in local energy planning in Sarapiquí.

6.4. Key Issues in Local Energy Planning

Given the interests and preferences of the actors in Sarapiquí, many of the issues in local energy planning appear to evolve around hydropower projects. Many of the planned projects concern hydropower plants, not in the least because water is an abundant resource, there is a lot of experience in using the technology (it is considered a conventional option), and the equipment and related services are widely and readily available. Until now, the energy companies have shown little interest in the impacts of these projects on the local people[5] (i.e., local entrepreneurs, habitants, farmers, and interest groups), and the latter are currently not included in the planning process. Most of the local actors perceive hydro-projects to have many negative impacts, while offering only few benefits. For instance, local entrepreneurs offering water-based activities for tourists fear that hydropower plants will reduce the water flow of the rivers, making them less attractive for tourists, and thus reducing the income of the entrepreneurs. Some local habitants depend on the rivers for bathing and washing, activities that can be dangerous with a hydropower plant further upstream. Also, local farmers are afraid that there won't be enough water left in the river to irrigate their land, while local fisherman worry about the effects of hydro-plant on the amount of fish in the rivers. And many fear the effects of energy projects on wildlife and natural beauty in the area. In addition, some local actors oppose to the idea that electricity is not generated for regional use, but instead for export to neighboring regions or even foreign countries, so that the area only experiences the costs and not the benefits.

Even though the local actors are currently ignored in the energy planning process, they try to influence this process with the (little) information they have available. The referendum in Sarapiquí (§ 6.3.2) as well as the commotion in San Ramón (§ 6.3.6) are clear examples of how this influence can delay planned projects, or even cause energy companies to abandon a project all together. Note that the opposition is mainly directed towards the (small) private projects, and not towards ICE. Martínez (2001) believes that one of the reasons for this is that ICE is too powerful to oppose to; it is considered a waste of time. Jiménez (2001), on the other hand, states that ICE is 'of the people' and not so much profit-minded as the private producers, as shown by the reactions on the attempts to privatize ICE.

The entrepreneurs that depend on electricity for their activities and services demand a reliable electricity supply. They acknowledge that this might require new energy projects, but not at the expense of the natural beauty of the area. Also, some entrepreneurs argue that the need for new energy infrastructure can be kept to a minimum if the area would focus on eco-

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[5] Recently, some improvements can be noticed, apparently as a result of strong local opposition to the hydropower projects (Alvarado, 2001).

tourism, as the eco-tourists are thought to have only basic needs and will require little energy. The little extra energy needed could then be supplied by ‘clean’ solar systems. However, the energy companies are not eager to use the ‘risky’ solar systems, as these systems are perceived to be too costly and incompatible with existing energy infrastructure. They opt for the ‘proven’ hydropower plants. Nonetheless, the opposition from groups in society against the private hydropower projects may cause a change in focus. In addition, recent dry years have made national planners aware of the need for diversifying the energy resource mix.

The main goals of the national government are to meet future (national) energy demand *and* strengthen the international competitiveness of the national energy sector, among others by actively promoting small-scale renewable energy projects. Hydropower projects in particular appear interesting because of their proven cost-effectiveness. Note that biomass as a source for energy generation –although seemingly abundant– is not specifically promoted. Another concern of the national government is the implementation of a Central-American electricity market, which might cause an increase in the import of (cheaper) fossil fuel based electricity from abroad, thereby replacing the national production of ‘clean’ electricity.

As a result of the differences in interests, the actors have different preferences for future energy infrastructures. Energy companies opt for hydropower, but many local actors have expressed a preference for less ‘harmful’ technologies such as solar systems. During the interviews for the field study, most parties acknowledged knowing little about the range of relevant infrastructure options available to them, not to mention the consequences associated with these options. However, most actors seem eager to learn more about the options that can avert the negative impacts of hydropower systems. Especially the smaller energy companies realize that –with current opposition to hydro-projects and the consequent delays in plans– it might be necessary to widen the scope of energy technologies taken into consideration.

At the time of the field study, few or no studies existed on the range of energy infrastructure options, and this lack of knowledge, along with the distrust that existed, caused actors to behave rigidly, leaving little room for attempting to solve conflicts. Nonetheless, the actors interviewed during the field study appeared interested in learning more about each other’s interests and considerations, acknowledging that they depend on one another for obtaining a reliable and appropriate energy infrastructure.

Figure 6.5 shows an overview of the actors and issues involved in local energy planning in Huetar Norte.

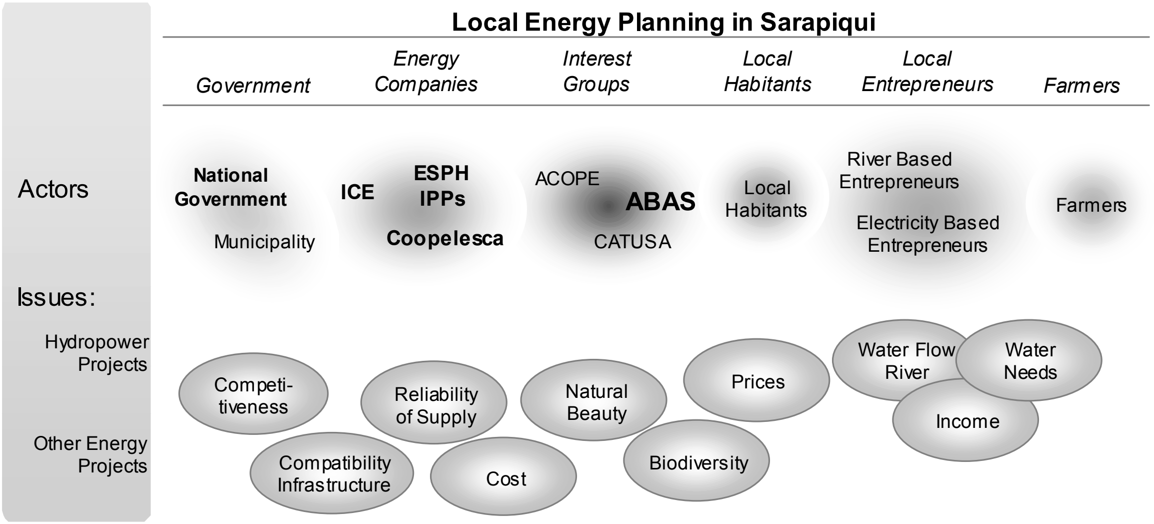

Figure 6.5. Actors and key issues in local energy planning in Sarapiquí.

6.5. Evaluating the Assumptions of the New Method

The new method presented in Chapter 5 aims to support the local energy planning process (i.e., the selection of new energy infrastructure), especially in those regions of developing countries that experience strong economic growth and –as a consequence– an increase in energy demand. The method requires the participation of all relevant actors and uses the actors' needs, interests, and preferences to construct indicators for the impact assessment. The method allows the actors to learn about the (potential) consequences of their own preferences *and* of those of others, and lets them gain insight in conflicting interests as well as in the considerations underlying the preferences of the other actors. Furthermore, the flexible iterative structure of the method allows for easy adaptations in indicators and/or options, supporting and improving the learning process that takes place. Therefore, the new method is believed to overcome the main constraints of existing methods.

The complexity of energy planning in practice –influenced by sometimes unpredictable human behavior– obstructs a conventional manner of scientific verification to prove that the new method is better than existing ones. Another complicating factor in testing the new method is the relatively long periods associated with the average planning process (up to 5 years or more). Furthermore, since the focus of the new method is on supporting the *process* rather than on reaching a specific outcome, the outcomes do not necessarily reflect how well a process went, let alone how much the method contributed to a successful process. For instance, much will also depend on factors such as commitment of actors and communication skills. So an objective testing of the method seems a difficult task, indeed. As discussed in Section 5.4.1, a true verification of the new method lies outside the scope of this research project. However, we were able to test the assumptions underlying the method (see § 6.1), using a field study of Huetar Norte as described in this chapter.

One of the assumptions in the new method is that due to differences in regional economic development there is a need for regional planning. The field study of the Huetar Norte region shows that this is clearly the case, in particular in the sub-regions San Carlos-Alajuela and the Sarapiquí. As a result of increased tourism and a growth in agro-activity, these sub-regions show an above average growth in energy demand (see § 6.2.2). The second assumption (that more actors should be included in energy planning than just the energy companies and investors), and the third assumption (that other than technical and financial aspects play a key role in the local energy planning decision process) are both supported by the fact that several local energy projects were delayed or even abandoned as a result of ignoring relevant actors and their interests (see § 6.3.5, § 6.3.6, and § 6.4).

The results of the field study also supports the fourth assumption by showing that most actors lack knowledge on the range of options (and their consequences), while different actors have different interests and preferences, and thus different information needs. Consequently, these differences often result in different preferred energy infrastructure options. The last two assumptions (i.e., that providing information and structure improves the quality of decision-making; and that actors learn during the planning process, which influences their decisions) were not tested during the field study. This would have required active participation of our side in the current energy planning process (e.g., by providing information and structure). However, it was not our intention to influence the current process, as the field study was descriptive of nature, and the available amount of time would not have allowed for proper support to the actors. As a consequence, no data could be obtained to test the last two assumptions. But the actors appeared to be interested in learning more about other options and each other’s interests and considerations, acknowledging that they depend on one another for the final outcome. They also showed interest in the new method for energy planning and were eager to know more about any results whenever ready. This seems to favor the use of the new method. We will address the last two assumptions in a more theoretical manner in the next chapters, based on data from the Costa Rica field study. Nonetheless, the field study did give us a first indication that at least the first four assumptions are realistic with respect to local energy planning in developing countries.

Finally, when conducting the field study, we experienced a weak point of the new method with respect to choosing the size of the region and the subsequent identification of relevant actors. The field study began with a focus on the Huetar Norte region, but to obtain data on energy demand and to have an actor with decision-making authority, we narrowed the region down to the Coopelesca area. So the availability of (reliable) data may influence the choice of region. And only after we reduced the region further to the Sarapiquí area we could identify several actors –along with their interests and preferences– and describe the actual energy planning process at the local level. So defining the right size of the region to identify all the relevant actors proves difficult at first instance. In the next chapter, we will give an example of how the new method can be made operational, using the data obtained from the field study in Huetar Norte.

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Acronyms

ABAS	Asociación para el Bienestar Ambiental de Sarapiquí
ACOPE	Asociación Costarricense de Productores de Energía
ARESEP	Autoridad Reguladora de Servicios Públicos
BUN	Biomass User Network
CCP	Centro Centroamericano de Población (Universidad de Costa Rica)
CINPE	Centro Internacional de Política Económica Para El Desarrollo Sostenible
CNFL	Compañía Nacional de Fuerza y Luz
DSE	Dirección Sectoral de Energía
EdelaN	Estado de la Nación
ESPH	Empresa de Servicios Públicos de Heredia
IADB	Inter-American Development Bank
ICE	Instituto Costarricense de Electricidad
ICT	Instituto Costarricense de Turismo
IMF	International Monetary Fund
INEC	Instituto Nacional de Estadística y Censos
JASEC	Junta Electrificadora de Servicios Electricos de Cartago
MAG	Ministerio de Agricultura y Ganadería
MIDEPLAN	Ministerio de Planificación
MINAE	Ministerio del Medio Ambiente y Energía
OAS	Organization of American States
OEA (OAS)	Organización de Estados Americanos
PNUD	Programa de las Naciones Unidas para el Desarrollo
SIEPAC	Sistema de Interconexión Eléctrica de los Países de América Central
SNE	Servicio Nacional de Electricidad
UCR	Universidad de Costa Rica
UNA	Universidad Nacional de Costa Rica

7

Applying the Method: Construction of an Operational Tool

7.1. Purpose of the Tool

This chapter presents an example of how the new method for local energy planning can be applied in practice. As explained in Chapter 5 (§ 5.4.1), a real application of the new method in practice is unattainable within the scope of this research because the actual planning process takes several years. However, to make plausible that the method actually works, we use a hypothetical –but realistic– example to explain how the steps of the method can be made operational. This operationalization process results in a practical tool that gives easy access to information on energy infrastructure options and their consequences, gives actors insight in interests and preferences of other actors, and makes options easily comparable. This way, it facilitates the completion of the method steps, and thus supports the actors in selecting appropriate local energy infrastructure in developing countries. In this chapter, we will discuss what procedures are followed to operationalize each step of the method, and describe how the tool is constructed following the method steps. In Chapter 8 we will give a demonstration of the tool. Note that the tool is still a prototype and that it has not been optimized from a programming point of view. A detailed description of the procedures, formats, and formulas used in the tool can be found in Appendix F. The tool is developed for this example specifically, but many of the procedures are general of nature and can be used when designing other case-specific models. The tool is constructed using Excel, a spreadsheet type software program. We acknowledge that there may be other software packages equally or better fit for the purpose, but the main advantage of Excel is its widespread availability in most (developing) countries.

The tool is constructed along the steps of the method, using the data of the Costa Rica field study as input. The example concerns the selection of local energy infrastructure in the service area of Coopelesca[1] for the period 2000-2020. This region was chosen because there is a direct link between the energy demand in the area and the energy supplied by Coopelesca. Also, Coopelesca has reliable data on current energy demand, which is an important starting point for applying the new method, as current energy demand sets the boundary conditions for future energy demand, and thus the scale of the future energy infrastructure. Nonetheless, the field study did not provide all the data that were needed to operationalize the method, and assumptions had to be made where reliable data are lacking.

In Section 7.2 we will describe how we assess future energy demand, resulting in the construction of a Business-As-Usual demand scenario (see Section 7.3). In Section 7.4, we (re)state the main actors in energy planning in the Coopelesca area, as well as their preferences, interests, and the key issues. The following section (§ 7.5), discusses how we can map the available energy resources, technologies, and supply options. The next step is then to translate the interests of the actors into indicators, and spot possible conflicts between actors in advance (§ 7.7). Once we know how much energy has to be supplied to the region, what supply options are available to do so, and what indicators will be used in the impact assessment, we can construct the energy infrastructure options (§ 7.8). In Section § 7.9 we discuss the procedures to assess the scores on the indicators, in particular the choice of measures and units. The next step is to create a format for the appraisal of the options (§ 7.10), which is followed (in § 7.11) by the evaluation step and consequently the next iterations of the method until a final selection is made. Finally, in Section § 7.12, we will discuss the conclusions that can be drawn from the construction of the tool.

7.2. Assessing Future Energy Demand

The scale of the future energy infrastructure in a region is primarily determined by *how much* energy has to be supplied to the region. In turn, how much energy has to be supplied (and in which forms) depends on the energy demanded by the end-users. And current energy consumption serves as a starting point for determining how much future energy demand will be.

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[1] The Coopelesca area includes the canton of San Carlos de Alajuela and the districts of Sarapiquí de Alajuela, Río Cuarto de Grecia, Peñas Blancas de San Ramon, La Virgen de Heredia, and Puerto Viejo de Heredia.

7.2.1. Current Energy Services and Consumption

The field study in Costa Rica revealed that the energy services[2] of the end-users in the Coopelesca area include the operation of electrical appliances, lighting, cooking, heating of tap water, and sometimes space cooling in hotels and other (commercial) buildings. Space heating is not common in the area (it has a tropical climate). As a result of the relatively high electrification rate, electricity is used for almost all of the energy services: most warm meals are cooked on electric stoves, and most consumers use in-house electrical heaters for heating tap water.

Table 7.1 lists the number of clients and current energy consumption per type of consumer in the Coopelesca area in 2000[3]. Table 7.1 shows that Coopelesca distributes electricity to a total of 44.245 clients in the cantons of Sarapiquí and San Carlos. The majority of the consumers is residential (86%), but the few industrial consumers account for a large part (27%) of total electricity demand. Current demand amounts to a total of 180 GWh/yr. These data will serve as a starting point for further analysis of future energy demand, the topic of the next section.

Table 7.1. Electricity consumption, number of clients, and consumption per client of Coopelesca in 2000, per type of consumer. Source: Alfaro (2001).

2000 Consumer Type	Electricity Consumption (MWh/yr)	Avg. Annual Growth Rate 1995-2000	Number of Clients	Avg. Annual Growth Rate 1995-2000	Consumption per Client (kWh/yr)	Avg. Annual Growth Rate 1995-2000
Residential	87,047	6.3%	37,864	6.1%	2,299	0.2%
Commercial	37,159	7.7%	5,162	6.1%	7,198	1.5%
Industrial	48,792	8.5%	1,218	0.9%	40,049	7.6%
Public Lighting	7,326	10.3%				
Total Average	180,325	7.3%	44,245	5.9%	4,076	1.3%

Note: Values may not add due to rounding.

7.2.2. Scenarios on Future Energy Demand

The future amount and forms of energy that have to be delivered to the end-users in the Coopelesca area set the boundary conditions for the scale of the future energy infrastructure in the region. However, determining future energy demand proves difficult, especially for a period of 20 years, which is generally too long for a simple extrapolation of past trends (see § 2.6.1). As explained in § 1.2, energy demand depends on socio-economic developments in and outside the region (e.g., population growth, growth in income, tourism, agro-activity, etc.), but the exact relationships are unknown and future developments are inherently

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[2] Energy services are the purposes for which people demand energy, see § 5.2.2.

[3] Note that the data on regional energy demand of Coopelesca (Alfaro, 2001) do not entirely coincide with data of CEPAL (2000): the latter states slightly higher values for demand of all types of consumers. We chose to use the data of Coopelesca because these data are also used by Coopelesca for their energy plans.

uncertain. A factor that further complicates the analysis is the inconsistency between data of different sources (e.g, on population or regional energy demand). To overcome these problems, we make use of scenarios to explore –not predict– future developments. Note that the demand scenarios merely point out possible directions of development and are not intended to provide an exact and detailed analysis of the future. To enable an assessment of a wide variety of demand scenarios, we have to use a tool structure that is flexible towards the input variables affecting energy demand. Also, in line with standard project evaluation theory, we will construct a business-as-usual (BAU) scenario, which is the 'without' case and serves as a reference to construct and evaluate other scenarios, as some impacts of energy infrastructure options are easier expressed as a ratio of some reference (BAU) situation. We will discuss the construction of the business-as-usual scenario here to show how the method can be made operational. The BAU scenario describes a situation in which no specific attempts are made to steer the regional development into a specific direction. For our BAU example we assume that the number of tourists visiting the area will increase moderately, causing a moderate increase in tourists facilities such as hotels and restaurants. However, agro-activities will remain an important source of income in the area. The waste caused by tourists and agro-activities is not alarming, but requires proper disposal to avoid substantial environmental damage. Nonetheless, the area becomes more crowded and noisier, and some of the scenic beauty is affected. Energy demand will increase moderately for all types of consumers (i.e., residential, commercial, and industrial) along the lines of past trends.

In order to quantify the BAU demand scenario, and consequently construct other scenarios, we have to determine the variables that influence future energy demand. The remainder of this section will describe these variables. In the next section (§ 7.3), we will quantify the variables used for the BAU scenario, and Chapter 8 will address examples of other demand scenarios. Note that due to time-constraints and lack of (reliable) data, it is not always possible to base assumptions and values on scientific arguments; sometimes assumptions have to be based on educated guesses or common sense, using the knowledge we gained from the Costa Rica field study.

Remember that the Coopelesca area includes two of the three sub-regions that have shown increased economic activity in recent years: the San Carlos-Alajuela area and the Sarapiquí area. In both sub-regions tourism and agro-(industrial) activities are the main drivers for economic development, so we will use these sectors to extract relevant variables.

First the tourism sector. Tourism will mainly affect future energy demand of the *commercial* consumers, as many local entrepreneurs will require (extra) energy to satisfy the needs of tourists. For the purpose of the example, we make a distinction here between the 'luxury' tourists and the 'eco-tourists'. There are no unambiguous definitions on 'luxury' or 'eco'-tourists to be found in the literature, so we use definitions that stress the differences between the two types of tourists as much as possible even though we realize that the distinction will not be as clear-cut in practice. We assume that the luxury tourists have relatively high expenditures and appreciate a comfortable stay in luxury hotels, having many facilities at their disposal. On average, the luxury tourists stay in one area for a long period of time, occasionally making daytrips to other areas. The eco-tourists, on the other hand, stay in (small) eco-hotels that have only basic facilities, they spend money on a low-budget basis (which is considerably less than the luxury tourists), and travel from place to place rather than staying at one place for a longer period of time. The eco-tourists generally appreciate places undiscovered by most tourists, and respect the environment as well as the local customs, to which the eco-tourist willingly tries to adapt (to a certain extent). Note that a tourist can behave as an eco-tourist in one region (e.g., Huetar Norte with its abundant nature and wildlife), while switching to luxury tourism when moving to another region (e.g., the coastal areas with tropical beaches). These descriptions of luxury and eco-tourists play an important role when constructing different energy demand scenarios, but also have consequences for the impacts of energy infrastructure options (see Chapter 8).

We assume a positive relationship between the number of tourists and the commercial energy demand of hotels (which for the sake of simplicity also include restaurants), and a luxury tourist is assumed to use more energy than an eco-tourist. In addition, we distinguish between the energy consumption of (luxury or eco-) *couples* and *singles*, assuming a couple uses more energy than one single person, but less than the sum of two singles. Another important variable is the average number of nights that a tourist spends in the area.

Regarding the agro-sector, the changes in cultivated area and the intensification of agro-activities in the area will mainly affect future energy demand of the industrial consumers, either through an increase in the number of clients or through a change in the energy demand per client. The future energy demand of residential consumers is affected by migration (changing the number of clients) or changes in household income (as a result of developments in tourism and the agro-sector). Higher households income is assumed to increase the number of electrical appliances per household, and thus the electricity demand per residential client.

Another issue concerning energy demand is the form in which the energy is supplied to the end-users. Current energy supply to end-users consists of electricity only, but the desired energy services can –in principle– be fulfilled by different forms of energy. Since the construction of the tool is only to demonstrate how the method can be made operational, we will –for the sake of simplicity– only distinguish between two energy services: heating tap water and operating electrical appliances (including electrical stoves for cooking). To limit the scope of analysis further, we only make this distinction for the residential consumers and the hotels (including restaurants). So the households and hotels can demand electricity and heat, while the other clients demand electricity only.

When constructing demand scenarios, most of the changes in variables for the period 2000-2020 will be controlled by changing the growth rates (e.g., of number of clients, or of demand per client). Furthermore, to be able to track the changes in development of the different scenarios, we will divide the 20-year planning period into four periods of 5 years each, taking the year 2000 as a mutual starting point of all demand scenarios. In the next section we will explain the construction of the BAU demand scenario.

7.3. Construction of the Business-As-Usual Demand Scenario

In the previous section we have seen that we need to know how many clients there are, and how much the average demand per client is in order to determine future energy demand. For the year 2000, data are obtained from Coopelesca (Alfaro, 2001). Table 7.1 already presented data on the number of residential, commercial, and industrial clients; the average energy consumption per client; and the growth rates over the period 1995-2000. For the sake of simplicity, we will ignore the energy needed for public lighting, as the amount is relatively small (< 5% of total demand) and the consumption is not allocated to one particular client. The future energy demand for each type of client will be discussed in separate subsections below. Note that in our example, the commercial clients also include the hotels, implying that we need to distinguish between three types of sub-clients: eco-hotels, luxury hotels, and other commercial clients. Also, for the residential clients and for the luxury and eco-hotels, we want to distinguish between heat demand and electricity demand.

7.3.1. Residential Energy Demand

Residential energy demand consists of demand for heating tap water and demand for electricity. We will start with determining what part of electricity demand in 2000 was designated to heat tap water. Based on discussions with experts, we estimate that 80% of the households have hot tap water, and each person per household uses hot water for an average of 10 minutes per day (Van Helden, 2001). The average number of persons per household in the Coopelesca area in 2000 is 4.3 (INEC, 2001). Furthermore, we assume that the water is heated using an in-house electrical heating element with a capacity of 3,000 W. This implies that each household (i.e., residential client) uses 628 kWh/yr for heating tap water, 27% of the total electricity demand in 2000. The growth rates for future heat demand and future electricity demand in the BAU demand scenario are educated guesses, taking into account the fact that the *growth* in the number of residential clients will likely decrease due to the already high rate of electrification, while the demand per residential client will increase moderately due to economic development. The growth rates are listed in Table 7.2. Note that the BAU demand scenario has the same growth rates for residential heat demand per client as for residential electricity demand per client.

Table 7.2. Variables, values, and growth rates for residential energy demand in the Business-as-Usual scenario.

Residential Energy Demand	**2000**		**2005**	**2010**	**2015**	**2020**
Variables	*Unit*	*Values*	*Annual Growth Rates*			
Number of clients	-	37,864	5.7%	4.7%	3.5%	2.9%
Electricity demand per client	kWh/yr	1,672	1.0%	2.0%	2.0%	2.0%
Heat demand per client	kWh/yr	628	1.0%	2.0%	2.0%	2.0%

7.3.2. Commercial Energy Demand

The future energy demand of commercial clients is more complex to determine, as this group of clients can be subdivided into eco-hotels, luxury hotels and other commercial clients. The literature on energy demand of hotels in developing countries is scarce, but the consumption levels are generally expressed in energy units per tourist per night. So if we want to determine total commercial energy demand, we first have to determine the energy consumption per tourist per night, the number of tourists visiting the area, and the number of nights they stay there. In addition, we need to know the number of rooms, the number of hotels, and the average occupancy rate of hotels in the area in order to determine the future energy demand per hotel. Keep in mind that we want to make a distinction between eco-hotels and luxury hotels, and between heat demand and electricity demand. For the sake of simplicity, we assume that all luxury tourists stay in luxury hotels and all eco-tourists stay in eco-hotels. We will first determine values for the year 2000 and the average annual growth rates over the period 1995-2000 to have a basis for choosing the future values.

The data on the number of tourists, the number of nights they spend, the number of rooms and hotels, and the average occupancy rate for the year 2000, as well as annual growth rates for the period 1995-2000 are all derived from the ICT, the Costa Rican tourism institute (ICT, 1995a; 2000a). However, the ICT does not provide data for the Coopelesca area as such. For instance, the numbers of tourists are available for the 'zona turística llanuras del norte' (the tourist area of the northern planes) and the 'conjunto turístico Sarapiquí' (the tourist area around Sarapiquí). In 2000, there were a total of 816,056 (international) tourists[4] in Costa Rica, of which about 32% visited at least one of the two tourist areas mentioned above, staying for an average of 2.9 nights. And although the tourist areas are not clearly defined, they are likely to cover more than the entire Coopelesca area. We assume that the larger part of the 32% will visit the Coopelesca area, taking an estimate of 28% for the total number of (international) tourists in Costa Rica that visit the Coopelesca area. Furthermore, the ICT does not –like we do– distinguish between luxury tourists and eco-tourists. However, since the major attraction of the Coopelesca area is its natural beauty, we estimate that 60% of the visiting tourists are eco-tourists. As explained earlier (§ 7.2.2), we assume that the eco-tourists on average spend less time in one area than the luxury tourists. Therefore, we will assume that eco-tourists spend an average of 2.5 nights in the Coopelesca area, and –given the overall average of 2.9 nights of stay– this implies that the luxury tourists stay 3.5 nights. Table 7.3 gives an overview of the values we obtained for the number of tourists and the nights they spent in the Coopelesca area.

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[4] For the sake of simplicity, we will disregard *national* tourists and visitors that are in Costa Rica for business purposes. The international non-tourist visitors have a distinctly different behavioral pattern, while according to ICT (2000) their number is relatively small. The number of national tourists is about the same as the number of international tourists, but no data could be obtained on their behavioral pattern, and therefore they are excluded from the analysis.

Table 7.3. Number of tourists and growth rates in 2000. Source: ICT (1995a, 2000a).

Number of Tourists	**2000**	*Avg. An. Growth Rate 1995-2000*
Total tourists visiting Costa Rica	816,056	6.8%
Fraction visiting Coopelesca area	28%	-
Total tourists visiting Coopelesca area	228,496	11.0%
Avg. nights of stay	2.9	4.7%
Fraction eco-tourists	60%	-
Eco-tourists visiting Coopelesca area	137,097	11.0%
Luxury tourists visiting Coopelesca area	91,398	11.0%
Avg. nights of stay eco-tourists	2.5	4.7%
Avg. nights of stay luxury tourists	3.5	4.7%

The number of rooms and hotels in the Coopelesca area are also derived from data of ICT (1995a, 2000a). ICT states that in 2000 there were a total of 24 hotels and 737 rooms available in the canton of San Carlos and the tourist area of Sarapiquí, which together (more or less) cover the Coopelesca area. However, ICT only lists the hotels and rooms that are certified with a 'Declaratoria Turística'[5], which we will label as luxury hotels. But there are also many hotels without such a certificate. ICT states that about 80% of all hotels in Costa Rica do not have a declaratoria, so we will take this percentage to calculate the number of eco-hotels in the Coopelesca area, which amounts then to 97. Furthermore, the ICT provides data on the average number of rooms per hotel. For eco-hotels (i.e., hotels *without* a declaratoria) this average is 10.5 rooms per hotel, resulting in a total number of eco-rooms of 1019. The average number of rooms per luxury hotel can then be calculated by dividing the number of rooms (737) by the number of hotels (24), which results in an average of 30.7 rooms per luxury hotel. We also have to determine the occupancy rate of hotels in order to link the energy demand of tourists to the energy demand of hotels. The occupancy rate is the ratio of occupied rooms and the total number of available rooms taken over a certain period (e.g., a year). To determine the occupancy rate we use the number of visitors, the number of nights they stay, and the number of rooms per hotel. Remember that we assumed that all luxury tourists stay in luxury hotels and all eco-tourists stay in eco-hotels. We also have to make an assumption on the fraction of total visitors that travel as couples, as this will decrease the need for rooms. We will assume that 80% of the luxury tourists and 70% of the eco-tourists[6] travel as couples, while the remaining fraction travels as single. Details on the calculation can be found in Appendix F. Here we only state the results for 2000: eco-hotels have an average occupancy rate of 59.9% and luxury hotels an occupancy rate of 71.4%. These values are in line with values mentioned by ICT for hotels in Central Valley (ICT, 2000a). An overview of data on hotels in the Coopelesca area is presented in Table 7.4. Growth rates are derived by comparing the values of 2000 with those of 1995.

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[5] A 'Declaratoria Turística' indicates that a hotel complies with certain (voluntary) requirements set by the government.

[6] The eco-tourist is believed to also include the 'backpacker' type of tourist, who is believed to travel alone more often than the luxury tourist.

Table 7.4. Values and assumptions on hotels in the Coopelesca area in 2000. Source: ICT (1995a, 2000a).

Eco- and Luxury Hotels in the Coopelesca area	**2000**	*Avg. An. Growth Rate 1995-2000*
Total number of luxury hotels	24	4.8%
Eco-hotels as fraction of total number of hotels	80%	-
Total number of eco-hotels	97	4.7%
Total number of hotels	121	4.6%
Total number of luxury rooms	737	8.2%
Rooms per luxury hotel	30.7	3.3%
Rooms per eco-hotel	10.5	-0.4%
Total number of eco-rooms	1019	4.3%
Total number of rooms	1756	5.9%
Fraction of total luxury tourists traveling as couples	80%	-
Fraction of total eco-tourists traveling as couples	70%	-
Occupancy rate luxury hotels	71.4%	1.3%
Occupancy rate eco-hotels	59.9%	20.5%

Note: The luxury hotels are set equal to the hotels with Declaratoria Turística, the eco-hotels are set equal to hotels *without* such a declaratoria.

We now only have to determine the energy demand per tourist per night to calculate the energy demand per hotel. As mentioned earlier, information in the literature on the energy consumption of tourists is scarce, and we did not manage to obtain data related to the Coopelesca area or Costa Rica. However, we did manage to find some data elsewhere. For instance, Gössling (2000) mentions an estimate of 6 kg of crude oil consumption per tourist per day for (what we would define as 'luxury') hotels with self-supporting power generation units in Zanzibar, Tanzania. This estimate excludes the energy for cooking, and corresponds to a consumption of about 270 MJ of primary energy per tourist per day, or about 81 MJ of end-use energy[7]. Becken et. al. (2001) mention an (end-use) energy consumption per visitor per night of 155 MJ for hotels and 39 MJ for backpackers (the latter are likely similar in energy use to our definition of eco-tourists). However, these consumption values also include the energy used for space heating, and only hold for New Zealand, whose climate and economic conditions differ from those of Costa Rica, and in particular the Coopelesca area. Another source of information was a Dutch consultancy firm that had detailed data on energy consumption by hotels in Europe, showing an average consumption level of 100 MJ per tourist per night, of which about 75 MJ was accounted for by heating both space and tap water (Uit De Bosch, 2001). Again, the climate and economic conditions of Europe differ considerably from those of Costa Rica.

The consumption levels mentioned above seem rather high for hotels in Coopelesca, taking into account the differences in climate (space heating), and level of economic development. Also, the average consumption per commercial client in 2000 was only 7,198 kWh/yr (see Table 7.1). A consumption level of 100 MJ per tourist per night would eventually imply that

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[7] Primary energy is the energy contained in the energy resource used. The end-use energy is the energy that has already been converted into the proper form of energy and can directly be used by the end-user/ consumer. We assumed an efficiency of 30% for converting the primary energy into the end-use energy using a small-scale diesel generator.

the average consumption per (luxury) hotel is 229,900 kWh/yr, which seems rather out of proportion given the average consumption level of commercial clients (for calculation details see Appendix F). Therefore, we will assume that energy consumption of luxury tourists in 2000 is 50 MJ per day (13.9 kWh/day) per tourist. As defined in Section 7.2.2, luxury tourists use more energy than eco-tourists, so we will assume that an eco-tourist on average consumes 25 MJ per day (6.9 kWh/day).

However, a tourist couple will consume more energy than one single tourist, but less than two singles of the same type of tourist (i.e., eco- or luxury), as couples usually share particular energy services (e.g., they watch TV together). So we have to divide energy consumption according to energy services for which the energy is used. We distinguish the following energy services for meeting the needs of tourists: cooking, heating tap water, and operating electrical appliances. We assume that couples use twice as much energy as singles for both cooking and heating tap water, but assume that they use the same amount as singles for operating electrical appliances. Furthermore, eco-tourists have a lot less facilities at their disposal than the luxury tourist. For instance, eco-tourists will generally not have TVs in their rooms, nor will they have laundry facilities. So the energy consumed by eco-tourist for operating electrical appliances is substantially lower than that for luxury tourists. Also, we assume that all luxury hotels have hot tap water, but only 50% of the eco-hotels do so, implying that eco-tourists on average use less energy for heating tap water than luxury tourist.

More concrete, we assume that each tourist uses 3.75 MJ per day (i.e., about 1.0 kWh/day) for heating tap water[8] *if* available. Also, each tourist accounts for an estimated 0.45 kWh/day for cooking on an electric stove[9]. Given the overall consumption of 13.9 kWh/day per luxury single, the consumption of energy for operating electrical appliances is then 12.44 kWh/day for both luxury singles and luxury couples. Similar, given the overall consumption of 6.9 kWh/day for eco-singles, the consumption of energy for operating electrical appliances is then 6.0 kWh/day for both eco-singles and eco-couples. Total energy consumption is then 13.9 kWh/day for each luxury single, and 15.3 kWh/day for each luxury couple, while each eco-tourist will use 6.9 kWh/day, and each eco-couple 7.9 kWh/yr.

Table 7.5. Values and assumptions used to determine daily energy demand of tourists in 2000.

Daily Energy Demand of Tourists in 2000		**Luxury Tourists**		**Eco-Tourists**	
	Unit	*Per Single*	*Per Couple*	*Per Single*	*Per Couple*
Energy for heating tap water [a]	kWh/day	1.00	2.00	0.50	1.00
Energy for cooking	kWh/day	0.45	0.89	0.45	0.98
Energy for operating electrical appliances	kWh/day	12.44	12.44	6.00	6.00
Total energy use per tourist	kWh/day	13.9	15.3	6.9	7.9
	MJ/day	50	55.2	25	28.4
[a] Assuming 100% of the luxury hotels, and 50% of the eco-hotels have hot tap water.					

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[8] We assume that each tourists uses 45 liters of warm water per day, and that the water has to be heated from 20 °C to 40 °C, while it takes 4.17 kJ to increase the temperature of one liter with one degree.

[9] Based on an estimated 700 kWh/yr for (electrical) cooking per *household*, with 4.3 members per household.

With the data on tourists and hotels presented earlier in Table 7.3 and Table 7.4, we can now calculate the energy consumption per hotel. Details on the calculation are listed in Appendix F, the results are shown in Table 7.6. Note that we only distinguish between heat demand and electricity demand, as cooking is assumed to be done on an electrical stove. No data were available to determine growth rates during the period 1995-2000.

Table 7.6. Values and assumptions used to determine energy demand of hotels in 2000. See also Appendix F.

Energy Demand of Hotels in 2000	Unit	**Luxury Hotels**	**Eco-Hotels**
Electricity demand per hotel	kWh/yr	105,55	15,355
Heat demand per hotel	kWh/yr	13,329	1,767
Total energy demand per hotel	kWh/yr	118,783	17,122

The energy consumption of other commercial clients can now easily be calculated by multiplying the energy consumption per hotel with the total number of hotels, and consequently subtracting this amount from the total energy consumption of all commercial clients of Coopelesca as stated in Table 7.1. Note that for the other commercial clients, we do not make a distinction between electricity and heat demand. The results are shown in Table 7.7. Since growth rates for the energy demand of hotels for 1995-2000 are lacking, we are also unable to determine past growth rates for energy demand of the other commercial clients.

Table 7.7. Determining number and energy demand of other commercial clients in 2000.

Commrecial Energy Consumption 2000	Number of Clients	Total Consumption (MWh/yr)	Consumption/ Client (kWh/yr)
Total Commercial Clients	5,162	37,159	7,198
Luxury Hotels	24	2,851	118,783
Eco-Hotels	97	1,661	17,122
Total Hotels	121	4,512	37,286
Total Other Commercial Clients	5,041	32,647	6,476

We now have the details on commercial energy consumption for the year 2000, but we still have to determine the *future* demand of this type of client. For the sake of simplicity, we assume that the percentage couples, the number of rooms per hotel, and the average occupancy rate are constant over the entire period between 2000-2020, so that the growth in number of tourists is the same as the growth in the number of rooms and the number of hotels. The future energy demand of hotels now only depends on the chosen growth rates for the number of tourists, the number of days they stay, and the energy consumption per tourist, as well as on the chosen percentage of hotels with hot tap water.

We assume that the percentage of luxury hotels that have hot tap water remains 100% during the entire 20-year period, while the percentage of eco-hotels with hot tap water –as a result of economic development– will gradually increase from 50% in 2000 to 70% in 2020. Furthermore, the growth in energy consumption per tourist is modest and mainly a result of an increase in the use of electrical appliances, as the energy for hot water and cooking is thought to be constant. Note that the demand for operating electrical appliances per couple is the same as the demand per single, and actually represents the demand per occupied room. The growth rates for electricity consumption per luxury room are taken higher than those for eco-rooms, as the latter have fewer facilities. Since there were no data available on past trends in electricity consumption of tourists, the growth rates for future demand are educated guesses, chosen in the same order of magnitude as the growth rates of electricity demand per residential client (see Table 7.2). We do have data on past growth rates for the number of tourists and the number of nights spent per tourist in the Coopelesca area, albeit that these apply to tourists in general (see Table 7.3). These rates will serve as guidelines for the choice of future growth rates, although we will assume that the growth rates decline gradually, resulting in an absolute number of eco- and luxury tourists that has about doubled after 20 years. Furthermore, we will assume that the number of nights spent in the area does not increase in the business-as-usual scenario. The future growth rates associated with the other commercial clients are educated guesses, as relevant data are lacking. Table 7.8 presents an overview of the variables and constants that determine future commercial energy demand, as well as the chosen values and growth rates.

Table 7.8. Variables, values, and growth rates for commercial energy demand in the Business-as-Usual scenario.

Commercial Energy Demand	**2000**		**2005**	**2010**	**2015**	**2020**
Variables	*Unit*	*Value*	*Annual Growth Rates*			
Number of luxury tourists	-	91,398	6.0%	4.0%	3.0%	2.0%
Number of eco-tourists	-	137,097	6.0%	4.0%	3.0%	2.0%
Number of nights of luxury stay	-	3.5	0.0%	0.0%	0.0%	0.0%
Number of nights of eco-stay	-	2.5	0.0%	0.0%	0.0%	0.0%
Demand for appliances per luxury room	kWh/day	12.4	1.0%	1.5%	2.0%	2.5%
Demand for appliances per eco-room	kWh/day	6.0	0.5%	0.5%	1.0%	1.0%
Fraction of luxury hotels with hot tap water	-	100%	100%	100%	100%	100%
Fraction of eco- hotels with hot tap water	-	50%	55%	60%	65%	70%
Number of other clients	-	5,041	3.5%	3.0%	2.0%	1.5%
Electricity demand per other client	-	7,151	3.0%	3.0%	2.5%	2.0%
Constants	*Value*	*Unit*	**2005**	**2010**	**2015**	**2020**
Fraction of luxury couples	-	80%	80%	80%	80%	80%
Fraction of eco-couples	-	70%	70%	70%	70%	70%
Rooms per luxury hotel	-	30.7	30.7	30.7	30.7	30.7
Rooms per eco-hotel	-	10.5	10.5	10.5	10.5	10.5
Occupancy rate luxury hotels	-	71.4%	71.4%	71.4%	71.4%	71.4%
Occupancy rate eco-hotels	-	59.9%	59.9%	59.9%	59.9%	59.9%
Demand for cooking per luxury tourist	kWh/day	0.45	0.45	0.45	0.45	0.45
Demand for cooking per eco-tourist	kWh/day	0.45	0.45	0.45	0.45	0.45
Demand for hot tap water per luxury tourist	kWh/day	1.00	1.00	1.00	1.00	1.00
Demand for hot tap water per eco-tourist	kWh/day	0.50	0.50	0.50	0.50	0.50

With these values and growth rates, the future energy demand of luxury hotels, eco-hotels, and other commercial clients can be calculated, including the future heat demand for hotels. Note that the constants in Table 7.8 will hold for every scenario that we develop, so for the sake of clarity, the constants can best be put in a separate database that contains general variables and constants (see Chapter 8). With the BAU scenario ready for both the residential and commercial energy demand, we now have to determine future energy demand for the industrial clients, which we will do in the next section.

7.3.3. Industrial Energy Demand

We assume that industrial energy demand in the Coopelesca area will largely be influenced by (changes in) the activities of farmers and the agro-industry. We assume that electricity is the only energy form delivered to the industrial clients. The variables that affect electricity demand of the industrial clients include the number of clients and the electricity demand per client. The chosen growth rates shown in Table 7.9 are based on the growth rates between 1991-2000 (Alfaro, 2001), assuming a downward trend in growth.

Table 7.9. Variables, values, and growth rates for industrial energy demand in the Business-as-Usual scenario.

Industrial Energy Demand	**2000**		**2005**	**2010**	**2015**	**2020**
Variables	*Value*	*Unit*	*Annual Growth Rates*			
Number of Industrial Clients	1,218	-	0.5%	0.5%	0.5%	0.5%
Electricity demand per client	40,060	kWh/yr	5.5%	4.5%	4.0%	3.5%

We now have all the variables, initial values and growth rates that are needed to construct the BAU energy demand scenario. The next section will restate all the variables, values, and constants that are mentioned above.

7.3.4. Overview of the Business-As-Usual Demand Scenario

The constants and general variables that apply to *every* demand scenario for the entire period between 2000-2020 are listed in Table 7.10. The variables, values, and growth rates specific for the BAU demand scenario are presented in Table 7.11.

Table 7.10. Constants and general variables that hold for 2000-2020 for all demand scenarios.

		2000	**2005**	**2010**	**2015**	**2020**
Constants & General Variables	*Unit*	*Values*				
Fraction of luxury couples	-	80%	80%	80%	80%	80%
Fraction of eco-couples	-	70%	70%	70%	70%	70%
Rooms per luxury hotel	-	30.7	30.7	30.7	30.7	30.7
Rooms per eco-hotel	-	10.5	10.5	10.5	10.5	10.5
Occupancy rate luxury hotels	-	71.4%	71.4%	71.4%	71.4%	71.4%
Occupancy rate eco-hotels	-	59.9%	59.9%	59.9%	59.9%	59.9%
Fraction of luxury hotels with hot tap water	-	100%	100%	100%	100%	100%
Fraction of eco- hotels with hot tap water	-	50%	**55%**	**60%**	**65%**	**70%**
Demand for cooking per luxury tourist	kWh/day	0.45	0.45	0.45	0.45	0.45
Demand for cooking per eco-tourist	kWh/day	0.45	0.45	0.45	0.45	0.45
Demand for hot tap water per luxury tourist	kWh/day	1.00	1.00	1.00	1.00	1.00
Demand for hot tap water per eco-tourist	kWh/day	0.50	0.50	0.50	0.50	0.50

Table 7.11. Overview of the variables, initial values, and growth rates in the Business-as-Usual demand scenario.

	2000		**2005**	**2010**	**2015**	**2020**
Variables	*Values*	*Unit*	*Annual Growth Rates*			
Residential Energy Demand						
Number of clients	37,864	-	5.7%	4.7%	3.5%	2.9%
Electricity demand per client	1,672	kWh/yr	1.0%	2.0%	2.0%	2.0%
Heat demand per client	628	kWh/yr	1.0%	2.0%	2.0%	2.0%
Commercial Energy Demand						
Number of luxury tourists	91,398	-	6.0%	4.0%	3.0%	2.0%
Number of eco-tourists	137,097	-	6.0%	4.0%	3.0%	2.0%
Number of nights of luxury stay	3.5	-	0.0%	0.0%	0.0%	0.0%
Number of nights of eco-stay	2.5	-	0.0%	0.0%	0.0%	0.0%
Demand for appliances per luxury room	12.4	kWh/day	1.0%	1.5%	2.0%	2.5%
Demand for appliances per eco-room	6.0	kWh/day	0.5%	0.5%	1.0%	1.0%
Number of other clients	5,041	-	3.5%	3.0%	2.0%	1.5%
Electricity demand per other client	7,151	kWh/yr	3.0%	3.0%	2.5%	2.0%
Industrial Energy Demand						
Number of Industrial Clients	1,218	-	0.5%	0.5%	0.5%	0.5%
Electricity demand per client	40,060	kWh/yr	5.5%	4.5%	4.0%	3.5%

Table 7.12 gives an overview of the values for the energy demand of different clients resulting from the BAU demand scenario.

Table 7.12. Overview of energy demand of different clients for the BAU demand scenario.

Overview Energy Demand	**Unit**	**2000**	**2005**	**2010**	**2015**	**2020**
Total Energy Demand	**GWh/yr**	**173.0**	**237.3**	**319.7**	**409.5**	**508.8**
Residential	GWh/yr	87.0	120.7	167.7	219.9	280.1
Commercial	GWh/yr	37.2	51.2	68.4	85.5	101.8
Industrial	GWh/yr	48.8	65.4	83.5	104.2	126.9
Total Electricity Demand	**GWh/yr**	**149.2**	**203.7**	**273.0**	**348.5**	**431.1**
Residential	GWh/yr	63.3	87.7	121.9	159.8	203.6
Commercial	GWh/yr	37.2	50.5	67.6	84.4	100.6
Of which luxury hotels	GWh/yr	2.5	3.55	4.6	5.9	7.3
Of which eco-hotels	GWh/yr	1.5	2.04	2.5	3.1	3.6
Of which other commercial clients	GWh/yr	33.1	45.0	60.4	75.5	89.8
Industrial	GWh/yr	48.8	65.4	83.5	104.2	126.9
Total Heat Demand	**GJ/yr**	**87,344**	**121,117**	**167,932**	**219,880**	**279,608**
Residential	GJ/yr	85,576	118,668	164,841	216,157	275,326
Commercial – Luxury Hotels	GJ/yr	1,152	1,541	1,875	2,174	2,400
Commercial – Eco-Hotels	GJ/yr	617	908	1,215	1,550	1,882

Again, the details on how we obtained these values and which assumptions we made can be found in Appendix F. The values for 2000 are the same for each demand scenario, but (some of) the growth rates of other demand scenarios will differ from the BAU demand scenario.

7.4. Identifying Main Actors, Interests, Preferences, Key Issues

In Section 6.3 we already discussed the relevant actors in local energy planning in the Sarapiquí area (which is part of the Coopelesca area). The actors for the Coopelesca area will largely be the same as for the Sarapiquí area, so we can use the overview of actors, interests and preferences as listed earlier in Table 6.5. However, in order to make the first iteration cycle not too complicated, we have grouped the actors into (apparently homogeneous) actor types (e.g., energy companies, entrepreneurs, habitants), and assume that the interest groups (e.g., ACOPE, ABAS, CATUSA) are part of the actor types whose interests they represent (energy companies, local habitants, and entrepreneurs, respectively), as shown in Table 7.13.

Table 7.13. Interests and preferences of relevant actors in energy planning in the Coopelesca area.

Actors	**Interests and Preferences**
National Government	• Energy supply security • Energy savings and rational use of energy • Electrification of isolated areas • International competitiveness of the Costa Rican energy sector • Conservation of the environment
Energy Companies	• Reliability of supply • Profitability (low costs, high revenues) • Compatibility with existing energy infrastructure • Low risk • Long lifetime of production systems • Easy control of production systems • Improvement of the existing electricity infrastructure • Further expansion of the electricity infrastructure • International competitiveness of the Costa Rican energy sector
Local Entrepreneurs in Tourism	• Reliable electricity supply • Conservation of the natural beauty • Water flow in the rivers
Local Habitants	• Jobs and wages • Conservation of the environment • Conservation of traditions and values • Low prices for electricity and food
Farmers	• Continuous and sufficient water supply for irrigation
Support Organizations	• Support actors • Provide information

Later, during next iterations, these actor types can then –if necessary– be split up into more specific actors. Note that we have excluded the municipalities as relevant actors because we believe that their role will be marginal in future energy planning if all other relevant actors are included in the process. Although the role of support groups in energy planning is currently marginal, we have included this actor because independent support groups such as NGOs or consultants can play an important role as mediators in the planning process.

Based on the interests and preferences listed in Table 7.13, we distinguish several key issues that are important to take into account when setting indicators. We assume that the key issues in local energy planning in the Coopelesca area will also largely coincide with the key issues of the Sarapiquí area (mentioned in § 6.4). Restating these key issues briefly: many local habitants, local entrepreneurs providing river-based activities, and farmers in the area oppose to new hydro-power projects because they fear that these projects will affect the water flow in rivers, and thus endanger their water needs or income. Local habitants and local entrepreneurs, often organized in interests groups such as ABAS or CATUSA, also fear that energy projects may negatively affect the natural beauty and biodiversity in the area (which could also affect the number of tourists visiting the area, and thus the revenues of entrepreneurs). There are also local habitants who fear that prices of food and energy will increase with increasing numbers of (luxury) tourists, and that local traditions and values will be affected. They argue that an improved energy infrastructure will only attract more luxury tourists, and that the area should pursue a strategy based on eco-tourism. The national government, however, fears that the opposition to new energy projects will harm the international competitiveness of the national energy sector on the inter-American energy market now being implemented. There are also local entrepreneurs that require electricity for their tourism facilities and services, and they demand a sufficient and reliable supply of energy, implying the need for extra energy infrastructure. Coopelesca wants to implement new energy systems to reduce the energy they have to buy from ICE, especially during peak periods of demand. The risk, high costs, and control difficulties that Coopelesca associates with energy technologies such as wind turbines or solar systems result in a preference for hydro-power systems, as this technology is proven and easy to add to the existing energy infrastructure. Not linked to local energy demand are the energy project plans of IPPs and ICE, who produce for national energy demand. Figure 7.1 is based on the figure that was presented earlier in § 6.4 for Sarapiquí, and states the key issues in local energy planning for the actor types in the Coopelesca area.

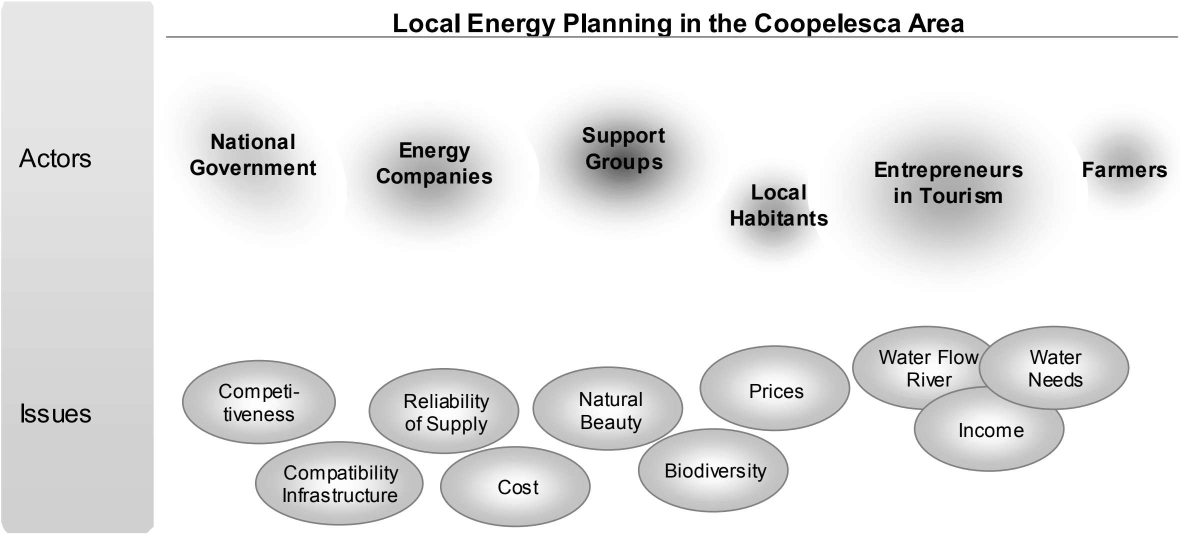

Figure 7.1. Actors and key issues in local energy planning in the Coopelesca area.

The interests and preferences of actors are translated into indicators in Section 7.7, but first we will discuss how to map the available energy resources and technologies, as their availability might also affect the choice of indicators.

7.5. Assessing Future Energy Supply

As soon as future energy demand of the end-users is determined in terms of amounts and forms of energy, we can start answering the question of *how* the energy is supplied to the end-users i.e., which energy supply scenarios can be constructed. But the answer to this question will largely depend on the energy resources and technologies available in the area. The current energy infrastructure –including already planned projects– usually forms the starting point of any analysis on supply options, so that is where we will start as well.

7.5.1. Current Energy Infrastructure

The current energy infrastructure in the Coopelesca area is based on the supply of electricity only. Table 7.14 gives an overview of the current and planned energy projects in the area. Coopelesca imports most of the electricity that it distributes from outside the region (i.e., from ICE), but Coopelesca does own one power plant: Chocosuela I, a hydropower plant of 8 MW located in the vicinity of the city San Carlos, and in operation since the end of 1999. The Chocosuela plant produced 31,864 MWh in 2000 (Alfaro, 2000).

Table 7.14. Current and planned energy projects (all hydro-power) in the Coopelesca area. Source: CENPE (2000), Alvarado (2001).

Energy Projects in Coopelesca Area		Unit	In operation	**Sarapiquí Basin**	**San Carlos Basin**	**Pizote Basin**	**Total**
Projects In Operation							
ICE	Toro I & II	(MW_e)	n.a.	-	90	-	90
ICE	Arenal	(MW_e)	n.a.	-	157	-	157
Coopelesca	Chocosuela I	(MW_e)	1999	-	8	-	8
Private	Total	(MW_e)	>1990	55	56.5	-	112
Total		**(MW_e)**		**55**	**312**	**0**	**367**
Projects Planned							
ICE	Peñas Blancas	(MW_e)	2002	-	35.5	-	35.5
Coopelesca	Chocosuela II & III	(MW_e)	2003	-	18	-	18
ICE	Cariblanco	(MW_e)	2006	75	-	-	75
Private	Total	(MW_e)	n.a.	15	38.5	37	91
Total		**(MW_e)**		**90**	**92**	**37**	**219**
n.a. = not available							

Coopelesca has already planned an expansion of Chocosuela, which adds two more units and increases the total capacity of the system to 26 MW. The extra units will be operational in 2003, producing an estimated 113,880 MWh per year (PCF, 2001)[10]. Current distribution

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[10] Assuming an average load factor of 0.50. For details see Appendix F.

losses amount to an average of 8% (Alfaro, 2000). Note that the already planned hydro-power projects of ICE and IPPs will not affect the amount of electricity that Coopelesca has to import, but does affect the resource potential for future projects in the region. The resource potentials of the different energy sources are the topic of the next section.

7.5.2. Energy Resource Potentials

To assess the potential of the different energy resources, we will include the entire Huetar Norte region in the analysis. The main reason for doing so is practical: it proved difficult to find reliable data on the resource potentials, and the data that we obtained mostly apply to the entire Huetar Norte region. Nonetheless, there is another argument to focus on the entire Huetar Norte region. The liberalization of the national electricity production –in principle– allows Coopelesca to initiate energy projects outside of its region, and it seems likely that if Coopelesca would do so, it will choose project locations that are close to its own service area, as Coopelesca is familiar with the local circumstances there. Below, we will discuss the resource potentials of fossil fuels, wind energy, solar energy, biomass energy, geothermal energy, and of course, hydro-energy in the Huetar Norte region.

- *Fossil Fuel Reserves & Uranium*

Huetar Norte has no proven oil, gas or uranium reserves, but coal reserves are known to exist in the western part of Huetar Norte, from Upala to San Carlos (DSE, 1994, 36-38). However, these reserves are currently not commercially exploited. Also, ICE is the only institution that is allowed to use fossil fuels for electricity production, so these resources are less relevant for our example.

- *Wind Energy Potential*

Another resource that is less relevant in Huetar Norte is wind energy. As Figure 7.2 shows, wind speeds in the region are low (on average less than 3 m/s), and therefore the energy potential is low as well.

- *Solar Energy*

According to Vargas (2001), solar energy will mainly be used in autonomous systems, serving isolated communities that are difficult to connect to the national electricity grid. However, Figure 7.2 shows that the annual solar irradiation in Huetar Norte (1485-1700 kWh/m^2) is relatively high compared to the rest of the world (with an annual average irradiation of about 1,000 kWh/m^2). This implies that even solar energy for grid-connected buildings could be an option. The potential for solar energy depends –besides the solar irradiation– on the available space for solar systems. In our example, we assume that only the roofs of households and hotels will provide space for solar energy.

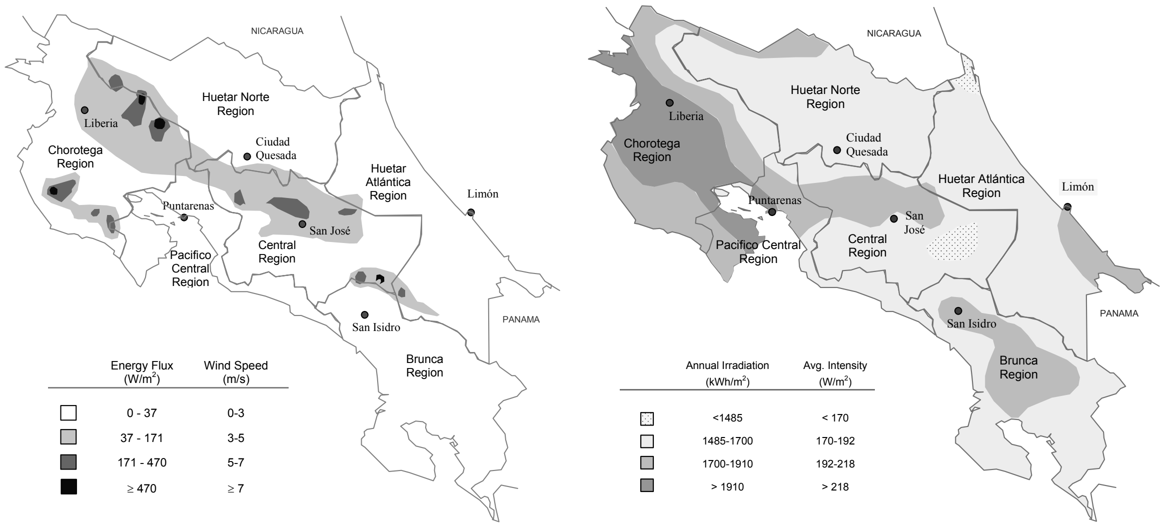

Figure 7.2. Average wind speeds (left) and annual solar irradiation (right) in Costa Rica. Source: DSE (1994).

- *Biomass Energy*

The rural households in Huetar Norte often still use wood and other types of biomass for cooking (Vargas and Otoya, 2001), but biomass as a source for energy generation –although seemingly abundant– is not specifically promoted, which may be explained by the deforestation problems in the past decades. Nonetheless, the residues of the many agro-(industrial) activities in the Huetar Norte provide a vast potential for energy production. For the sake of simplicity, this demonstration will only look at the energy potential from residues of banana, sugar cane, oranges, pineapple, and wood. All these biomass types are cultivated on a large scale in the Huetar Norte region, and many of the products are consequently processed by the agro- or wood industry in the region (Azofeifa (2001); Saenz (2001)). The resource potential of biomass residues depends on the *annual supply* of agro-residues and wood (in tons of biomass per year), as well as on the *energy content* of the residues (in GJ per ton). We assume an average energy content of 18 GJ/ton$_{dry}$ for dry matter, and 8 GJ/ton$_{wet}$ for wet matter[11]. The details on assumptions and calculations on the amount of residues produced each year can be found in Appendix F. Based on our analysis, we estimate the current potential of dry biomass to be 5,538 TJ/yr, while the potential of wet biomass is 12,022 TJ/yr. Note that the biomass potential changes proportionally with the annual production of agro-products.

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[11] Biomass potential can be based on dry matter or on wet matter. Dry biomass results from extracting water out of the wet biomass. The energy content per unit of dry matter is higher than that per unit of wet matter. Dry biomass can be used for combustion. Wet biomass is generally unsuited for combustion, as too much energy is lost through the evaporation of water in the biomass. Wet biomass (water content 50%-80%) can be used for biomass digestion in order to produce biogas, which can consequently be used for heating purposes or in gas turbines to generate electricity. See also Van Beeck (1998, 11).

- *Geothermal Energy*

ICE (2000, p. 12) states in its expansion plan for 2001-2018 that the total (economic) potential for geothermal energy in Costa Rica amounts to 1000 MW, slightly higher than the value of 865 MW mentioned by DSE (1994, 36). In fact, a 110 MW geothermal plant is currently already in operation near the Miravalles volcano, just outside the Huetar Norte region (CEPAL (2001); ICE (2000)). According to DSE (1994), there are three areas of high potential: Rincón de la Vieja, Miravalles, and Tenorio, all three located in the vicinity of volcanoes along the southwestern border of the Huetar Norte region. Tenorio has an estimated potential of 100-120 MW, while Rincon de la Vieja has a potential of 140 MW (IGA, 1995). In addition, DSE mentions two areas with medium to high potential (Platanar-Porvenir and Arenal-Pocosol, both located in the Huetar Norte region), two areas with medium potential (the Orosi and Cacao volcanos just outside the western border of the Huetar Norte region), and some areas outside Huetar Norte with lower potentials. So all high- or medium-potential areas are located in the Huetar Norte region. Therefore, we roughly estimate the geothermal potential in Huetar Norte to be 700 MW. Note that many of the areas with high or medium potentials are located in national parks, so existing or future environmental regulation may partly limit the exploitation of the potential.

- *Hydro-Energy Potential*

Besides the high amount of rainfall in Huetar Norte, there are numerous surface waters that are fed by the river basins of San Carlos, Sarapiquí, Infiernito, Pocosol, Río Frío, Zapote, Pizote, and Chirripó. The abundance of water has already set off private investments in hydro-electric systems in the area, now totaling a capacity of 112 MW (see Table 7.14). The exact potential for hydro-energy in Huetar Norte is not known, although there are data available that give an indication. In the *Plan Nacional de Energía 1995-2015*, DSE cites a study done by ICE on hydropower potentials for systems larger than 20 MW. Three river basins are mentioned for the Huetar Norte region: Sarapiquí (332 MW), San Carlos (283 MW), and Chirripó (377 MW). Note that these potentials can further increase if small-scale hydro-systems are also included. For the other river basins in Huetar Norte no literature exists on potentials, but we assume (conservatively) that in each of these river basins small-scale hydropower systems can be installed that amount to a total of 20 MW per basin. Note that Table 7.14 shows that a hydro-project of 37 MW is already planned in the Pizote river, so we will take this value as the potential for this river. Consequently, the total hydro-energy potential in Huetar Norte is estimated to be at least 1029 MW, and could amount to 1300 MW if small-scale projects are included. As with geothermal energy, the use of hydro-energy may be limited by current or future environmental regulations, as many of the potential areas are located in national parks.

An overview of the energy resource potentials is presented in Table 7.15. Now that we have mapped the potential energy resources, we can take a look at the supply options, which are discussed in the next section.

Table 7.15. Energy resource potentials in the Huetar Norte region.

Energy Source		**Potential**
Fossil Fuels	MW	not accessible
Wind Energy	MW	≈ 0
Solar Energy	$kWh/m^2/yr$	1485 - 1700
Biomass Energy (wet)	TJ_{wet}/yr	12,022
Biomass Energy (dry)	TJ_{dry}/yr	5,538
Geothermal Energy	MW	700
Hydro-Energy	MW	1029 – 1300

Source: DSE (1994), CENPE (2000), Azofeifa (2001), Saenz (2001). See Appendix F for details on values and assumptions for the biomass potential.

7.5.3. Characteristics of Relevant Energy Supply Technologies

When assessing the future energy supply options, we do not only have to map the energy resource potentials, we also need to map the relevant energy technologies that can convert the resources into the proper forms of energy. Of course, the relevancy of the technologies is first of all determined by the availability of resources, but the technologies also have to be able to convert the resources into the demanded forms of energy. So in our example, wind turbines are *not* relevant (not enough resource potential), neither are the technologies that require fossil fuels as input. In contrast, hydropower units, biomass combustion units, geothermal units, and PV solar systems are all relevant for supplying electricity, while biomass digestion units, biomass combustion units, and thermal solar systems are all relevant for supplying heat. Remember that heat supply is only relevant for residential clients and hotels (see § 7.2).

Important in the construction of supply scenarios is that they match with the demand scenarios at all times i.e., that they supply the proper amounts and forms of energy demanded by the clients. Therefore, we have to map all the characteristics that determine how much a certain energy technology requires of a certain resource to produce a certain amount and form of energy. For instance, in the case of a biomass combustion unit, we need to know the energy content of the biomass resource used, the annual supply of biomass, the conversion efficiency of the unit, its capacity factor, and the distribution losses of the grid to be able to determine whether there is enough resource to fulfill regional energy demand, and how much of the resource is needed exactly. Note that we only look at the *technical* characteristics here, to be able to answer the question whether it is technically feasible to use a certain energy technology in the future energy infrastructure. Other characteristics (social, environmental, etc.) are assessed during the impact assessment (see § 7.9). So the actors can select energy technologies for supply scenarios without knowing the consequences of their decision beforehand. We will first briefly discuss the characteristics of the technologies that generate electricity. Details on the characteristics of different technologies can be found in Appendix B. Most of the electricity technologies are characterized by the following parameters: the resource potential (already determined in § 7.5.2); the average capacity of the systems; the capacity factor (which is the fraction of time that a system operates at its nominal capacity[12]); and –if applicable– the losses occurring during the regional distribution of the generated electricity.

- *Electricity Technologies: Hydropower Systems*

In our example, hydropower systems include local-scale systems with an average capacity of 1 MW, which supply energy for small towns near river borders, and systems with an average capacity of 30 MW that are applied on the regional level (i.e., supplying energy for the entire Coopelesca area). The resource potential for regional systems is taken to be the lower value listed in Table 7.15 (i.e., 1029 MW applying for systems > 20 MW), while the potential for local systems is assumed to be the difference between the upper and lower value (271 MW). By definition, local systems have an average capacity of 1 MW, while regional systems have an average capacity of 30 MW. Furthermore, we assume that all regional systems use a water reservoir to guarantee a continuous supply of water, resulting in a capacity factor of 50%. This value is based on capacity factors stated by CEPAL (2001, p.28) of units with similar sizes currently operating in Costa Rica. The capacity factor for local systems will likely be lower, as these systems do not make use of water reservoirs and may be unable to operate at nominal capacity during dry periods, when there is a lack of water. The capacity factor for local systems is therefore set at 40%. Both capacity factors are assumed to be constant for the entire 20-year period. According to data from Coopelesca (Alfaro, 2001), the distribution losses of the Coopelesca grid are 8%, but this applies only to the regional systems, as the local systems are situated directly at the place of consumption, so that the losses will be marginal.

- *Electricity Technologies: Biomass Combustion Units*

For biomass combustion, we assume a resource potential of 5,538 GJ_{dry}/yr (see § 7.5.2) in 2000, but this potential may change in future years due to changes in agro-production. Note that many of the biomass residues (except wood) need to be dried first before they can be combusted, as their water content is too high for direct combustion. The biomass residues are converted into electricity with an average efficiency of 25%, and since small-scale combustion technology is rather well developed, we assume this efficiency remains constant over the 20-year period. Furthermore, we assume that the average capacity of the combustion units is 30 MW, and the average capacity factor 50% (remaining constant over the entire 20-year period). Again, distribution losses are 8% when distributing the generated electricity throughout the region.

- *Electricity Technologies: Geothermal Systems*

We estimate the potential for geothermal energy in Huetar Norte to be 700 MW, but the resource is only available at the western and southwestern border of the region. Therefore, we assume an average capacity per system of 50 MW. The geothermal systems generally

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[12] For instance, a 1 MW power plant with a capacity factor of 80% produces on average: 1 x 0.80 x 8760 = 7,008 MWh/yr, where 8760 is the amount of hours in one year.

have a high capacity factor. For instance, the Miravalles plant currently in operation in Costa Rica has a capacity factor of 81% (CEPAL, 2001, p.28). Therefore, we will assume a capacity factor of 80% for geothermal systems, and this factor is not expected to change throughout the 20-year period. As the geothermal systems are regional systems, the distribution losses are 8%.

- *Electricity Technologies: PV Solar Systems*

The solar irradiation in the Huetar Norte region ranges from 1485-1700 kWh/m^2/yr, but for the sake of simplicity we will assume an average irradiation of 1500 kWh/m^2/yr. We assume that the PV solar systems are used as micro-systems, to be mounted on the roofs of households and hotels in the Coopelesca area only. So apart from the solar irradiation, the solar energy potential also depends on the total available roof surface in the Coopelesca area. Based on personal experience in the area, we will assume an average roof surface of 10 m^2 per building for both households and eco-hotels, and an average roof surface of 50 m^2 per luxury hotel. So we also have to know the number of households and hotels in the area, and make a distinction between already grid-connected houses that will use grid-connected PV systems, and isolated houses that would have to use stand-alone PV systems (the efficiencies of grid-connected systems differ from those of stand-alone systems). We will assume that all hotels are grid-connected. The capacity of PV systems is expressed as the *marginal capacity* in peak watt[13] per square meter (W$_p$/m^2), which increases over the years due to improvements in the PV cell efficiency. In 2000, the marginal capacity is taken to be 100 W$_p$/m^2, increasing to 125 W$_p$/m^2 by the year 2020. The annual electricity production can easily be calculated by using the *specific efficiency* of the system expressed in kWh/kW$_p$/yr. This specific efficiency is assumed to be 1500 kWh/kW$_p$/yr, and taken constant over the years, as the output of the system increases proportionally with an increase in marginal capacity. For details on the assumptions and calculations see Appendix F. Because the PV systems are micro-systems i.e., located directly at the place of consumption, the distribution losses are assumed to be zero. There can, however, be losses associated with the orientation of the PV systems, as the PV systems produce less electricity when they do not directly face the sun. We assume average orientation losses of 5%.

- *Electricity Technologies: Import from the National Grid*

One of the options to supply electricity to the end-users is to import electricity from the national grid into the region, which is currently done in large amounts: according to Alfaro (2001), 84% of regional demand was supplied by electricity from the national grid in 2000. We assume that an unlimited amount of electricity can be imported from the national grid. To know the required amount of import, we only have to know the distribution losses, which were earlier set at 8%.

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[13] A peak watt is the power produced by a PV solar cell under standard test conditions of 1000 W/m^2 irradiation (AM1.5 spectrum), and a temperature of 25°C.

An overview of the characteristics of the relevant electricity technologies is given in Table 7.16. A more detailed description of energy technologies and the assumptions used in this section can be found in Appendix B and Appendix F respectively.

Table 7.16. Overview of the characteristics of electricity technologies. See also Appendix B and Appendix F.

Electricity Technology	Scale	Input Variables	Unit	2000	2005	2010	2015	2020
Hydropower	Local	Resource Potential	MW$_e$	271	271	271	271	271
		Average Capacity	MW$_e$	1	1	1	1	1
		Capacity Factor	%	40%	40%	40%	40%	40%
		Distribution Losses	%	8%	8%	8%	8%	8%
	Regional	Resource Potential	MW$_e$	1029	1029	1029	1029	1029
		Average Capacity	MW$_e$	30	30	30	30	30
		Capacity Factor	%	50%	50%	50%	50%	50%
		Distribution Losses	%	8%	8%	8%	8%	8%
Biomass Combustion	Regional	Resource Potential [a]	TJ/yr	5,538	5,821	6,118	6,430	6,758
		Generation Efficiency	%	25%	25%	25%	25%	25%
		Average Capacity	MW$_e$	30	30	30	30	30
		Capacity Factor	%	50%	50%	50%	50%	50%
		Distribution Losses	%	8%	8%	8%	8%	8%
Geothermal	Regional	Resource Potential	MW$_e$	700	700	700	700	700
		Average Capacity	MW$_e$	50	50	50	50	50
		Capacity Factor	%	90%	90%	90%	90%	90%
		Distribution Losses	%	8%	8%	8%	8%	8%
PV Solar	Micro	Solar Irradiance	kWh/m^2/yr	1,500	1,500	1,500	1,500	1,500
		Surface/House	m^2	10	10	11	13	15
		Surface/Luxury Hotel	m^2	50	50	52	55	60
		Surface/Eco-Hotel	m^2	10	10	11	13	15
		Marginal Capacity	W$_p$ /m^2	100	104	110	117	125
		Specific Efficiency	kWh/kW$_p$/yr	1,500	1,500	1,500	1,500	1,500
		Battery Eff. (Stand-Alone)	%	60%	60%	60%	60%	60%
		Orientation Losses	%	5%	5%	5%	5%	5%
National Grid	National	Distribution Losses	%	8%	8%	8%	8%	8%

[a] Based on an average annual growth in cultivated area of 1% for all products, and a constant yield per hectare for all products.

We will now discuss the characteristics of the technologies that produce heat. Most of the heat technologies are characterized by the following parameters: the resource potential (already determined in § 7.5.2); the conversion efficiency; and –if applicable– the losses occurring during the regional distribution of the generated electricity.

- *Heat Technologies: Biomass Digestion Units*

Biomass digestion results in biogas (methane) and compost. The biogas can consequently be used to generate heat, while the compost can be used to fertilize the land. Biomass digestion is especially suited for relatively wet biomass (water content up to 80%), so in our analysis we will only include the residues from the harvesting and processing of bananas, sugar cane, oranges, and pineapple. In 2000, the potential energy supply for digestion of the residues from only these agro-products is 11,831 TJ/yr (see Appendix F), but this potential changes with changing agro-production. We assume that the efficiency of digesting residues into biogas is 30%, based on a literature study by Van Beeck (1998). The biogas can be stored in gas tanks for transport and backup. This implies that –although the digestion units supply gas to the entire region– the distribution occurs with minimal losses. Remember that only households and hotels have a specified heat demand. The end-users consequently burn the biogas in boilers in order to heat their tap water, where we assume that the efficiency of the boiler systems is the same as that of heating tap water with electricity.

- *Heat Technologies: Biomass Combustion Units*

Combustion of biomass to generate heat is only suited for dry biomass, in this case wood residues, since the other biomass residues are too wet and can better be digested to generate heat. The estimated energy supply of wood residues in 2000 was 214 TJ/yr (see Appendix F). Note that the future supply of wood residues will depend on the future wood production. The wood is converted into heat in regional plants with an average efficiency of 80%, and the heat is consequently distributed to the end-users in the region with an average loss in heat of 10%. Note that the biomass combustion units can best be placed in areas where the demand for heat is relatively high.

- *Heat Technologies: Thermal Solar Systems*

The thermal solar systems produce heat on a micro-level, i.e., directly at the place of consumption. As already mentioned, the average solar irradiance in the region is taken to be 1500 $kWh/m^2/yr$ or 5.4 $GJ/m^2/yr$. The available roof surface is the same as for PV solar systems, although both type of systems cannot, of course, use the same space at the same time (i.e, we ignore hybrid PV/thermal systems). We assume that the marginal efficiency of the collectors for households and eco-hotels is 2.5 GJ_{th} of heat produced per square meter each yr, while the luxury hotels are assumed to use more efficient systems with a marginal efficiency of 3.0 $GJ_{th}/m^2/yr$. Furthermore, we assume that grid-connected houses and hotels use (electric) auxiliary heating equipment to reduce the size of the thermal systems, supplying 30% of heat demand in 2000 (for all type of clients), but decreasing to only 15% of heat demand in 2020. The values stated here are based on estimates of Van Helden (2001).

An overview of the characteristics of the relevant heat technologies can be found in Table 7.17. Again, a detailed description of the heat technologies and the assumptions used can be found in Appendix B and Appendix F respectively. With the characteristics of the energy technologies known, we can begin to construct alternative supply scenarios, the topic of the next section.

Table 7.17. Overview of the characteristics of heat technologies. For details see Appendix B and Appendix F.

Heat Technology	Scale	Input Variables	Unit	2000	2005	2010	2015	2020
Biomass Digestion [a]	Regional	Resource Potential [a, c]	TJ/yr	11,831	12,435	13,069	13,736	14,436
		Digestion Efficiency	%	30%	30%	30%	30%	30%
		Distribution Losses	%	0%	0%	0%	0%	0%
Biomass Combustion [b]	Regional	Resource Potential [b, c]	TJ_y/yr	214	225	237	249	261
		Conversion Efficiency	%	80%	80%	80%	80%	80%
		Distribution Losses	%	10%	10%	10%	10%	10%
Thermal Solar	Micro	Solar Irradiance	GJ/m^2/yr	5.4	5.4	5.4	5.4	5.4
		Surface/ House	m^2	10	10	11	13	15
		Surface/ Luxury Hotel	m^2	50	50	52	55	60
		Surface/ Eco-Hotel	m^2	10	10	11	13	15
		Marginal Efficiency (small) [d]	GJ/m^2	2.5	2.6	2.8	2.9	3.0
		Marginal Efficiency (large) [d]	GJ/m^2	3.0	3.1	3.3	3.4	3.5
		Auxiliary Heating	%	30%	30%	25%	20%	15%

[a] Biomass digestion involves conversion of agro-residues (excluding wood) into biogas.

[b] Biomass combustion involves conversion of wood into heat.

[c] Based on an average annual growth in cultivated area of 1% for all products, and a constant yield per hectare for all products.

[d] Small systems are used for households and eco-hotels and have lower marginal efficiencies than the large system, which are used for luxury hotels.

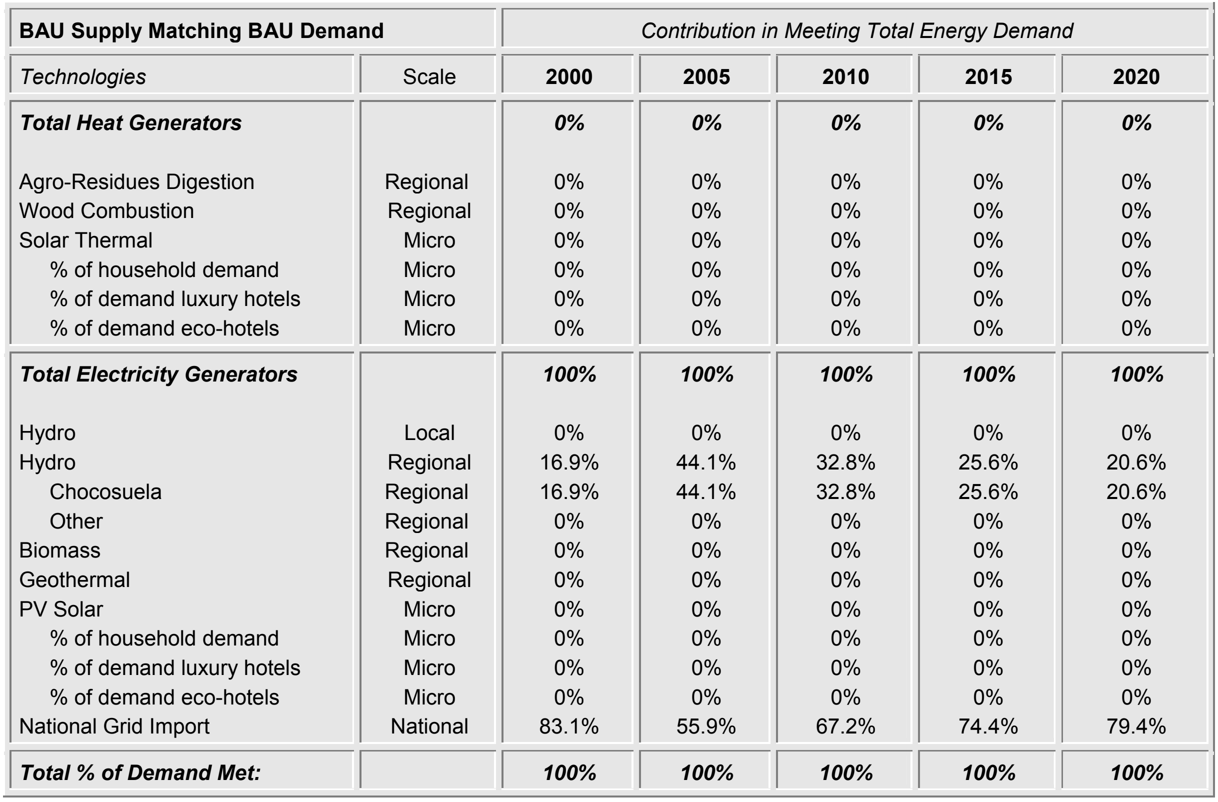
7.6. Construction of Supply Scenarios: The Business-As-Usual Scenario

Using the relevant resources and technologies discussed in the previous sections, we can construct a variety of supply scenarios, with the contribution of a technology and resource varying between the scenarios. To limit the number of supply scenarios that have to be analyzed, we will use 'extreme' scenarios that indicate a wide range of supply options, such as obtaining self-sufficiency at the micro level, or making maximum use of the local resource potentials. However, we have to create a format that ensures that all constructed supply scenarios meet the demanded energy at all times. Therefore, we will use a format in which the actors can choose how much each of the technologies contributes in meeting demand. So each technology will supply a certain percentage of demand (including the option of 0%). In cases where *regional* generation is not sufficient to fulfill demand, the remainder of demand will be imported from the national electricity grid. So each set of percentages that can fulfill energy demand can be regarded as a supply scenario. In Section 7.8, where we discuss how to construct energy infrastructure options, we will explain how to get supply percentages that add up to 100% of the energy demanded. Concrete examples of extreme supply scenarios are discussed in Chapter 8, where we will demonstrate the tool. Here, we will explain how the Business-as-Usual (BAU) supply scenario is set up.

The BAU supply scenario reflects a situation in which no radical changes occur in the local energy infrastructure, which develops along the lines of past trends. For our example this implies that all end-users in the Coopelesca area use electricity to fulfill their energy services, and that almost all the electricity is imported from outside the region (i.e., bought from ICE). Only Coopelesca's own hydropower plant Chocosuela –including the planned expansion with two more units in 2003– will contribute in the supply of electricity. The format of supply scenarios is illustrated in Table 7.18, using the values for the BAU scenario that match with the BAU demand scenario. Since no heat technologies are used in the BAU supply scenario (heat demand is met by using electricity), the contribution of the heat technologies is zero.

Note that after 2005 –when the extra units Chocosuela II and III are in operation– the annual production of the Chocosuela plant is fixed, while energy demand increases, which causes the changes in percentages of imported electricity stated in Table 7.18. Also note that for PV and thermal solar systems, the actors can indicate the contribution of these technologies with respect to the demand *per type of client*, as these technologies are used on a micro-scale.

Table 7.18. The format for constructing supply scenarios, using the BAU supply scenario that matches the BAU demand scenario as an example. For details see Appendix F.



BAU Supply Matching BAU Demand		*Contribution in Meeting Total Energy Demand*				
Technologies	Scale	**2000**	**2005**	**2010**	**2015**	**2020**
Total Heat Generators		***0%***	***0%***	***0%***	***0%***	***0%***
Agro-Residues Digestion	Regional	0%	0%	0%	0%	0%
Wood Combustion	Regional	0%	0%	0%	0%	0%
Solar Thermal	Micro	0%	0%	0%	0%	0%
% of household demand	Micro	0%	0%	0%	0%	0%
% of demand luxury hotels	Micro	0%	0%	0%	0%	0%
% of demand eco-hotels	Micro	0%	0%	0%	0%	0%
Total Electricity Generators		***100%***	***100%***	***100%***	***100%***	***100%***
Hydro	Local	0%	0%	0%	0%	0%
Hydro	Regional	16.9%	44.1%	32.8%	25.6%	20.6%
Chocosuela	Regional	16.9%	44.1%	32.8%	25.6%	20.6%
Other	Regional	0%	0%	0%	0%	0%
Biomass	Regional	0%	0%	0%	0%	0%
Geothermal	Regional	0%	0%	0%	0%	0%
PV Solar	Micro	0%	0%	0%	0%	0%
% of household demand	Micro	0%	0%	0%	0%	0%
% of demand luxury hotels	Micro	0%	0%	0%	0%	0%
% of demand eco-hotels	Micro	0%	0%	0%	0%	0%
National Grid Import	National	83.1%	55.9%	67.2%	74.4%	79.4%
Total % of Demand Met:		***100%***	***100%***	***100%***	***100%***	***100%***

So far, this chapter has addressed the setup of demand scenarios (§ 7.3), the relevant actors as well as their interests, preferences and key issues (§ 7.4), and a format to easily construct supply scenarios (§ 7.6). The construction of energy infrastructure options is now simply a matter of choosing demand scenarios and finding matching supply scenarios. The next step is then to assess the consequences or impacts of the options. If we want to assess and compare the impacts of each energy infrastructure option equally, the same indicators will have to be used for all the options –at least during one and the same iteration. So before we discuss the construction of infrastructure options (in § 7.8), we will first discuss how we can set indicators for the assessment and comparison of impacts, and present a format to quickly spot possible conflicting preferences in advance.

7.7. Setting Indicators

7.7.1. From Interests to Indicators

One of the key features of our method is that it incorporates the interests of relevant actors to enable an impact assessment that truly reflects the issues perceived important by these actors. The relevant actors and their interests have already been identified in § 7.4 (see Table 7.13). Here, we will translate these interests into indicators for the assessment and comparison of the (consequences of) options. All the energy infrastructure options that are constructed need to be assessed with the same set of indicators –at least during one iteration– in order to get a fair and equal comparison. Note that during following iterations, the set of indicators may change as a result of learning or new information. As explained in § 5.2.6, the number of indicators has to be limited to keep the comparison clear. So, initially, general indicators are used, which can later be divided into several sub-indicators during following iterations if they prove to be important, while less important indicators can be left as they are.

Based on the interests and preferences listed in Table 7.13 and the key issues described in Section 7.4, we conclude that any damage to the environment caused by energy projects is of special concern to the entrepreneurs, local habitants and environmental interests groups, and in general terms also to the national government. In particular, these actors want more information on the effects of hydropower projects on the water quality and quantity, and on wildlife quantity and quality as well. Farmers are mainly interested in whether hydro-projects affect the amount of water in the rivers they use for irrigation. So environmental damage will be one of the indicators for the impact assessment.

Another issue, of importance mainly to the government and the energy company ICE, is the competitiveness of the national electricity sector. A bad competitiveness of the national sector will likely increase electricity imports, and thus reduce the revenues from electricity exports, and might also increase the dependency on foreign energy companies. In addition, these foreign energy companies mainly use fossil fuels that cause (among others) CO_2 emissions and thus pollute the environment (Alvarado, 2001). However, the competitiveness also affects the position of independent private producers: with a liberalized Central-American energy market, a decrease in the competitiveness of the national energy sector can make the import of foreign electricity more lucrative than generating it nationally. In that case, there will be less room for independent private producers to build and operate (renewable) energy systems.

For the energy companies that distribute energy to their clients, the reliability of the supply is also important, especially when considering intermittent energy resources such as solar energy. In our example, Coopelesca is the only energy distribution company in the area (although ICE does also distribute electricity elsewhere in the Huetar Norte region). Furthermore, another issue important to all the energy companies is the risk and uncertainty associated with energy resources and technologies. The so-called 'proven technologies' that have been commercially available for quite some time and with which the energy companies have had experience are usually associated with less risk and uncertainty, whereas new technologies that only recently became available are associated with much higher risk and uncertainty.

How the region will develop economically is –not surprisingly– important to the entrepreneurs, farmers, and local habitants in the region, but also to the national government, as regional development affects national development as well. Regional economic development is made up out of a variety of variables, which are often difficult to measure quantitatively on the local level. And all actors will –of course– be interested in the effects that the options have on their financial situation, and might want to know how the costs and benefits are distributed among the actors in the region. The latter issue is typically important to the national government, who looks after the overall benefits for society as a whole.

So for our example of energy planning in the Coopelesca area, we will begin with a set of 8 general indicators, reflecting (in random order) the interests and information needs of the actors involved: Environmental Damage; Competitiveness of the National Energy Sector; Reliability of Energy Supply; Regional Economic Development; Risk and Uncertainty; Monetary Costs; Monetary Benefits; and Distribution of Costs and Benefits. As explained above, next iterations may change this set of indicators. Each of these general indicators can usually be sub-divided into several, more specific, indicators in a later stage. Therefore, it might be helpful to have a database available of possible general indicators and possible associated sub-indicators, from which actors can select the indicators they are interested in or want to know more about. A first attempt of making such a database can be found in Appendix D. Once the indicators are set, we can spot possible conflicting interests between actors. A framework for spotting conflicts is presented in the next section.

7.7.2. Spotting Possible Conflicts Between Actors

After setting the indicators for the impact assessment, the actors express their preferred scores on each of the indicators to spot possible conflicts in advance. Figure 7.3 illustrates how this can be done for the environmental damage indicator.

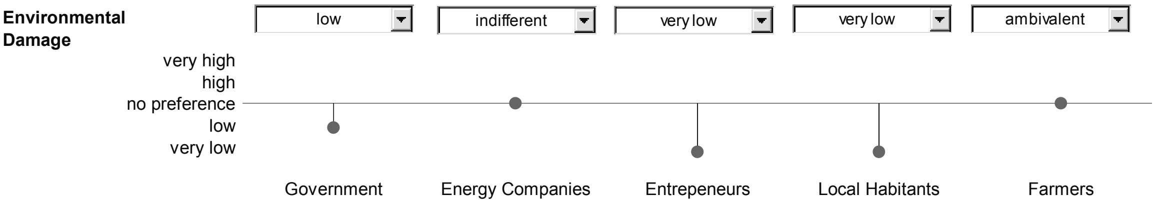


Figure 7.3. Format for spotting conflicting interests between actors by letting them express their preferred scores. Conflicting preferences are immediately evident from opposite amplitudes.

Each actor can choose a score per indicator, ranging from 'very high' to 'very low'. The chosen score is shown as an upward or downward bar. Bars above the horizontal axis indicate a preference for higher scores, bars below the axis a preference for lower scores. Higher bars indicate a preference for higher scores. Dots on the axis indicate that the actor –currently– has no preference regarding that indicator, either because the actor is indifferent, has no opinion, or is ambivalent. An actor is indifferent if the actor does have an opinion, but is not particularly interested in this indicator and thus does not have a preferred score. An actor is ambivalent if the actor does have an opinion and is interested in the indicator, but does not have a preference for either a low or a high score (usually because sub-indicators of the indicator show conflicting scores e.g., air quality is high but water quality is low). Possible conflicts between actors are immediately evident from opposite bars. However, conflicts may also arise between actors with an explicit preference and actors with no preference, especially if the latter result from indifference.

Note that preferences may change over time, as a result of interaction and learning. Also note that actors do not have to rank the indicators in order of importance i.e., assign priorities. For most actors, ranking is a difficult task, as their priorities tend to fluctuate: when new information becomes available or when actors interact, they learn about impacts, options, and each others' considerations, which might affect their preferences and priorities. Most of the priorities, however, will become apparent during the evaluation step, when actors express their preferences for energy infrastructure options.

We will now finally turn to the construction of the energy infrastructure options, an essential step in the energy planning process, as one of the options will eventually become part of the energy infrastructure of the future.

7.8. Mapping Infrastructure Options: Matching Demand and Supply

With the indicators set for a first iteration, and a setup for making demand and supply scenarios, we can now begin to construct the infrastructure options. Basically, the infrastructure options are constructed by combining the demand scenarios with the supply scenarios. However, the format used to construct the energy infrastructure options must ensure that the supply scenarios match with the demand scenarios i.e., that energy demand is met at all times, whichever options are chosen. This section discusses such a format.

Starting point of the matching procedure are the energy demand scenarios. The amount and forms of energy demanded in a scenario by each of the consumer types determine how much of each energy form has to be generated. In our example, we distinguish two energy forms: electricity and heat. To determine which technologies supply the required energy forms we use the supply scenarios, which contain the percentages that each technology contributes in meeting demand. Note that regional systems have to generate more energy than strictly demanded by the clients to compensate for distribution losses. So the contribution in meeting energy demand is not the same as the percentage that a technology accounts for in total production. The losses occurring during the conversion of a resource into the proper form of energy also require that more of a resource is used than strictly demanded. To determine how much of a resource has to be used exactly, we use the characteristics of the technologies listed in Table 7.16 and Table 7.17.

We also have to verify whether the need for a resource does not exceed the maximum potential of that resource. Determining how much of a resource is used is important because this determines many of the impacts of options, as we will see in Section 7.9. As already mentioned in § 7.6, we assume that if energy supply with local technologies does not add up to 100% of energy demand, the remainder is supplied by importing electricity from the national grid. However, there is also the option that local technologies generate more than local demand. In that case, the surplus of energy is *exported* i.e., supplied to the national grid to be sold to ICE [14]. However, this can only be done with electricity, so heat is generated for local demand only.

For the sake of clarity, we will give an example that illustrates –for the year 2005– how energy demand in the BAU demand scenario is met, using an imaginary supply scenario that makes use of *all* the technologies (the BAU supply scenario is less useful here, as it is mainly based on the import of electricity). The example starts with an overview of the amounts and forms of energy demanded by the different clients in the BAU demand scenario (see Table 7.19).

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[14] We acknowledge that the current regulations in Costa Rica prevent a situation in which electricity is sold to ICE only when local production exceeds local demand, but we ignore this in our example for the sake of simplicity.

Table 7.19. Overview of energy demand of different clients in 2005 for the BAU demand scenario.

Overview Energy Demand – BAU Scenario	*Unit*	**2005**
Total Energy Demand	**GWh/yr**	**237.3**
Residential	GWh/yr	120.7
Commercial	GWh/yr	51.2
Industrial	GWh/yr	65.4
Total Electricity Demand	**GWh/yr**	**203.7**
Residential	GWh/yr	87.7
Commercial	GWh/yr	50.5
Of which luxury hotels	GWh/yr	3.55
Of which eco-hotels	GWh/yr	2.04
Of which other commercial clients	GWh/yr	45.0
Industrial	GWh/yr	65.4
Total Heat Demand	**GJ/yr**	**121,117**
Residential	GJ/yr	118,668
Commercial – Luxury Hotels	GJ/yr	1,541
Commercial – Eco-Hotels	GJ/yr	908

With the amount and forms of energy demand calculated, we have to choose which technologies we want to use for meeting demand, using the same format as in Table 7.18. The imaginary supply scenario is constructed by filling in the percentage that each technology contributes in meeting demand. However, some cells in Table 7.18 (i.e. percentages) are calculated automatically, including:

- *Solar Thermal – Total*
  The total contribution of solar thermal systems is determined through the percentages that the thermal systems on the roofs of the households, luxury hotels and eco-hotels contribute in meeting the heat demand of the respective clients. The produced amounts of heat resulting from these percentages are then summed and divided by total energy demand (including electricity) to get the contribution of all thermal systems.

- *Total Heat Generators*
  The total percentage of demand met by all heat generators is calculated by summing the percentages of regional heat technologies (including local and micro-systems). Note that the total contribution should not exceed the percentage that heat demand accounts for in total energy demand, as we already mentioned that heat cannot be exported (or stored, for that matter).

- *Hydro – Total Regional*
  The percentage that the regional hydropower systems contribute in meeting demand is the sum of the contribution of the already existing power plant Chocosuela and the contribution of other regional systems. The latter is an input variable, so can be changed by the actors.

- *Hydro – Chocosuela*
  As the capacity of the Chocosuela plant is fixed (after the expansion with two more units in 2003), the contribution of the Chocosuela plant cannot be changed by the actors, although the percentage will (automatically) change when electricity demand changes.

- *PV Solar – Total*
  Similar to the calculation of the total contribution of thermal solar systems, the total contribution of PV solar systems is determined through the percentages that the PV systems on the roofs of the households, luxury hotels and eco-hotels contribute to the electricity demand of the respective clients. The produced amounts of electricity resulting from these percentages are then summed and divided by the total demand for energy (including heat) to get the percentage that PV systems contribute in meeting total energy demand.

- *Import of electricity*
  Only the part of demand that is not met by regional supply is met with import, so the percentage of import depends on the contribution of the regional technologies. Note that all electricity that exceeds the amount demanded is exported out of the region, resulting in a negative percentage for the import of electricity.

- *Total Electricity Generators*
  The total percentage of demand met by all electricity generators is calculated by summing the percentages of regional electricity technologies (including local and micro-systems), and adding the percentage of imported electricity if the latter is positive.

- *Total Percentage of Demand Met*
  The total percentage of demand that is met is the sum of the percentage of all electricity generators and the percentage of all heat generators. Note that if the total percentage is more than 100%, this indicates that electricity is exported (which would also imply a negative value for the electricity imported from the grid) and/or heat generation exceeds the demand for heat.

The percentages of the remaining cells are chosen by the actors. For the construction of the imaginary supply scenario, we initially want to choose an (arbitrary) value of 10% for each cell. However, not all technologies may have enough resources available to contribute this percentage[15]. And even though the resource potential may be sufficient in theory, the actual

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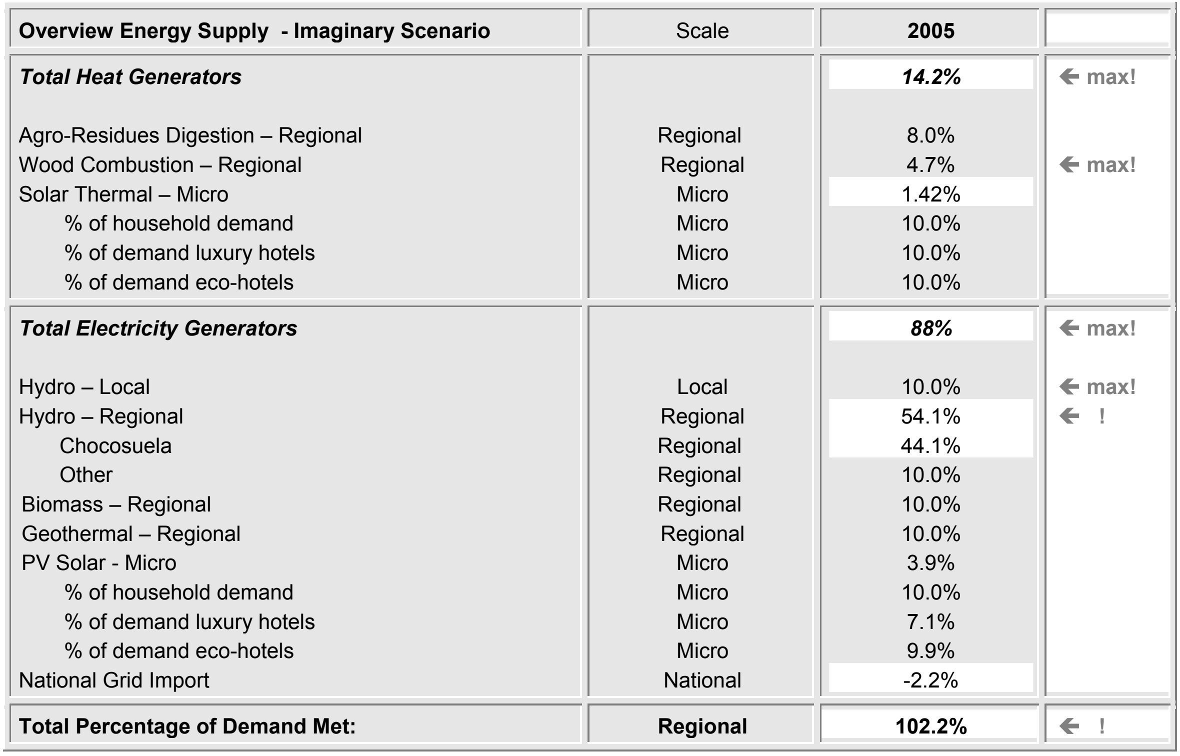
[15] Note that –if applicable– any losses during the generation and distribution of the demanded forms of energy also need to be taken into account, see Appendix F.

potential may not always be available e.g., due to regulations or inaccessibility of the area, as mentioned earlier when discussing resource potentials (§ 7.5.2). Therefore, we assume that only a certain percentage of the resource potential is available for energy generation. The percentages used in this example are listed in the third column of Table 7.21[16]. Given the amounts of energy demanded and the initially chosen values (10% for all cells) for the contribution in meeting demand, we now need to verify whether the required amount of energy can actually be generated, so whether the required amount of resources is actually available, and notify the constructer of the supply scenario when a chosen percentage exceeds the maximum. For details on the calculations, we refer to Appendix F, the results of these calculations are presented in Table 7.20 and Table 7.21.

As Table 7.20 shows, the check on available capacity indicates that there is not enough wood available to generate the required heat: the maximum contribution in meeting energy demand is 4.7%. In addition, the maximum available capacity for PV systems on the roofs of luxury and eco-hotels only allows a contribution in meeting electricity demand of 7.1% and 9.9% respectively.

Table 7.20. Contribution in meeting demand of the energy technologies in the imaginary supply scenario. The transparent cells are calculated automatically.



Overview Energy Supply - Imaginary Scenario	Scale	**2005**	
Total Heat Generators		***14.2%***	← **max!**
Agro-Residues Digestion – Regional	Regional	8.0%	
Wood Combustion – Regional	Regional	4.7%	← **max!**
Solar Thermal – Micro	Micro	1.42%	
% of household demand	Micro	10.0%	
% of demand luxury hotels	Micro	10.0%	
% of demand eco-hotels	Micro	10.0%	
Total Electricity Generators		***88%***	← **max!**
Hydro – Local	Local	10.0%	← **max!**
Hydro – Regional	Regional	54.1%	← **!**
Chocosuela	Regional	44.1%	
Other	Regional	10.0%	
Biomass – Regional	Regional	10.0%	
Geothermal – Regional	Regional	10.0%	
PV Solar - Micro	Micro	3.9%	
% of household demand	Micro	10.0%	
% of demand luxury hotels	Micro	7.1%	
% of demand eco-hotels	Micro	9.9%	
National Grid Import	National	-2.2%	
Total Percentage of Demand Met:	**Regional**	**102.2%**	← **!**

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[16] Also note that the biomass that is used for generating heat cannot at the same time be used for generating electricity. The same holds for the total roof surface used for PV systems and thermal solar systems. We assume that first the percentages for meeting heat demand are chosen, then the percentages for meeting electricity demand.

Table 7.21. Required and maximum generation for the year 2005, using the BAU demand scenario and an imaginary supply scenario. For details on calculations, see Appendix F.

Required & Maximum Generation	Required Generation	Available Potential	Available Capacity	Maximum Generation	Max. Contribution
Total Heat Generators	***125,621 GJ/yr***	**-**	**-**	***1,495,602 GJ/yr***	**-**
Agro-Residues Digestion - Regional	68,469	20%	310.9 kton_{wet}/yr	746,074 GJ/yr	87%
Wood Combustion – Regional	45,040	20%	2.5 kton_{dry}/yr	**45,040 GJ/yr**	**4.7%**
Solar Thermal – Micro	12,112	70%	502,480 m^2	704,488 GJ/yr	82%
% of household demand	11,867	70%	499,576 m^2	699,406 GJ/yr	589%
% of demand luxury hotels	154	70%	1,606 m^2	2,810 GJ/yr	182%
% of demand eco-hotels	91	70%	1,298 m^2	2,272 GJ/yr	250%
Total Electricity Generators	***226.3 GWh/yr***	**-**	***471 MW$_e$***	***10,841 GWh/yr***	**-**
Hydro – Local	25.8	20%	54 MW$_e$	190 GWh/yr	74%
Hydro – Regional	139.7	20%	206 MW$_e$	901 GWh/yr	349%
Biomass – Regional	25.8	20%	18 MW$_e$	80 GWh/yr	31%
Geothermal – Regional	25.8	20%	140 MW$_e$	981 GWh/yr	380%
PV Solar – Micro	9.2	100%	52 MW$_e$	78 GWh/yr	33%
% of household demand	8.8	100%	52 MW$_e$	78 GWh/yr	89%
% of demand luxury hotels	0.25	100%	0.17 MW$_e$	**0.25 GWh/yr**	**7.1%**
% of demand eco-hotels	0.20	100%	0.14 MW$_e$	**0.20 GWh/yr**	**9.9%**
National Grid Import – National	**- 5.7**	unlimited	unlimited	unlimited	unlimited

Table 7.20 also shows that the heat generators supply the maximum percentage, implying that the heat technologies supply 100% of heat demand. If the total percentage of the heat generators would have been lower than the maximum value, the remainder of heat demand is met through electricity, while a percentage higher than the maximum value would imply a waste of generated heat. Furthermore, the negative percentage for the import of electricity from the national grid indicates that the regional technologies supply more electricity than demanded, so that the surplus is exported to the national grid. This also results in a value exceeding 100% for the total percentage of demand that is met.

Table 7.21 shows that the total amount of exported electricity is 5.7 GWh/yr. Note that the required amount that has to be generated by the energy systems is more than the energy demanded in Table 7.19 as a result of distribution losses or –in the case of PV systems– orientation losses. Again, the details on calculating the appropriate values for matching energy demand and supply can be found in Appendix F.

With this format we can construct energy infrastructure options that ensure demand is met at all times. This brings us to the assessment of the impacts of these options.

7.9. Assessing the Impacts of Energy Infrastructure Options

Assessing the impacts of the energy infrastructure options implies that we determine the scores on the indicators that were set in Section 7.7. But before we can determine scores, we first have to choose measures and units, as discussed in § 7.9.1. During the first iteration of the method steps, the demand scenarios and supply scenarios are extreme, while the indicators will usually be general. So the (possible) impacts are first described in a mostly qualitative manner, while measures will initially be of an ordinal type (§ 7.9.2). Next iterations will likely contain more specific scenarios and more detail, so that quantitative measures can be used (see § 7.9.3). When all measures are chosen, we can determine the actual scores on the indicators (§ 7.9.4).

7.9.1. Choosing Measures & Units

Before we can assess the scores on indicators, we have to determine how we measure the scores. Remember that in § 5.2.7 we distinguished 4 types of measures to determine scores on indicators:

- Nominal/ Qualitative
- Ordinal
- Quasi-Quantitative
- Quantitative/ Numerical

The nominal measures cannot distinguish between better or worse scores, so are less useful for the comparison of impacts. Most likely, the measures will initially be quasi-quantitative or ordinal. Next iterations will likely contain more specific scenarios and more detail, so a full impact assessment can be done, including numerical measures where possible. It may be helpful to create a separate database of possible measures for commonly-used indicators from which the actors can pick the ones they prefer. Appendix D lists some of the possible measures (and formulas) that can be used to assess scores on certain indicators, but is far from complete. Many other indicators and measures can be used; Appendix D lists only those used in our example.

The choice of units is usually not controversial once the measures are agreed upon, as the units will provide the same information, only in a different form. The choice of units is often a matter of local custom: when expressing the amount of energy, some prefer the use of calories as a unit, while others prefer the use of joules, kilowatt-hours, or tons of oil equivalent (t.o.e.). With respect to ordinal scores, the actors also have to agree upon the minimum and maximum scores that can be assigned (e.g., 1-5 or 1-10, etc.). For a clear comparison and to avoid confusion it is important to ensure that each actor uses the same range.

7.9.2. First Iteration: General Indicators and Qualitative Description of Impacts

In Section 7.7.1 we already set the following indicators for the impact assessment: Environmental Damage; Competitiveness of the National Energy Sector; Reliability of Energy Supply; Regional Economic Development; Risk and Uncertainty; Monetary Costs; Monetary Benefits; and Distribution of Costs and Benefits. Below we will give a brief description of the impacts that these indicators represent. In the next section (§ 7.9.3) we will discuss what measures we will use to determine the scores of options.

- *Environmental Damage*

  The environmental damage caused by an infrastructure option includes adverse changes in the quality of air, water and soil, but also the quantity of water in rivers, and the condition of existing wildlife in the area. An often-used indicator for air quality are CO_2 emissions. CO_2 emissions are a byproduct of (among others) energy generation with fossil fuels and cause a global warming of the atmosphere[17]. The higher the CO_2 emissions, the stronger the global warming effect, but there is a time lag between cause and effect.

  The quantity of water (important to farmers, local habitants, and entrepreneurs depending on water-related activities) may be affected by hydropower plants, especially those without a water reservoir.

  The quality of water and soil will be affected by solid waste from tourism and agro-residues (we will ignore municipal waste, assuming it to be the same for all scenarios). If the waste is not recycled and disposed of properly, it ends up in the surface waters and on the ground, causing possible harm to the environment, wildlife, and eventually human health.

  Another form of environmental damage is deforestation, caused by activities in the agro-sector such as land clearing or wood exploitation (deforestation caused by the construction of large hotels and roads for the tourism sector is disregarded for now). Deforestation can cause loss in soil quality and affect wildlife quantity and quality. Wildlife can also be affected by the residues from the agro-(industrial) activities. So the more agro-activities, the more deforestation, and the more current wildlife is harmed.

  The tourism sector can also affect the wildlife quantity and quality: tourists, especially luxury tourists with low awareness of their effect on the environment, disturb the wildlife with their presence and the noise they make. Note that damage to the environment and the wildlife will make the area less attractive for tourism, especially eco-tourism.

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[17] Many governments have signed the Kyoto Protocol, agreeing to reduce future CO_2 emissions in order to mitigate global warming. For more information on global warming, see IPCC (1996). Furthermore, other emissions such as methane (CH_4) also cause global warming, but for the sake of simplicity these are not included in this demonstration.

- *Competitiveness of the National Energy Sector*

The competitiveness of the national energy sector will mainly be a concern of the national government and of the energy companies. If the competitiveness of the national energy sector decreases compared to the surrounding countries, importing electricity from those other countries becomes more lucrative than generating it nationally. In that case, there will be less room for independent private producers to build and operate (renewable) energy systems. In addition, the electricity of other countries is often generated using fossil fuels that cause (among others) CO_2 emissions. Moreover, importing more energy can negatively affect the energy supply security. And if the competitiveness of the national energy sector decreases, less energy will be exported to other countries, causing the revenues from electricity export to decline.

The competitiveness of the national energy sector will likely depend on the costs of the chosen energy infrastructure relative to the costs of energy infrastructure in other countries. But the competitiveness can also depend on, for instance, the reliability of supply.

- *Reliability of Energy Supply*

The supply of energy based on intermittent energy resources such as wind and solar radiation is inherently uncertain. Moreover, the energy from these sources comes in *flows* that can usually not be controlled or stored, unlike resources such as oil or wood. The latter two resources are *energy carriers*, which can easily be kept in storage for later use. Even water can be considered an energy carrier, because it can be stored in a reservoir for later use. On the other hand, water in Costa Rica is also considered an intermittent source given the fact that Costa Rica has a dry season, although this effect is much smaller than for sources such as wind and sunlight. In general (and disregarding political factors such as wars or national strikes), energy flows with intermittent supply are less reliable than energy carriers that can be stored to guarantee a continuous supply. However, measures can be taken to increase the reliability of intermittent sources; at times when supply exceeds demand the energy flows can be converted into energy carriers that can be stored (e.g., chemical energy in batteries). Note that the national grid can also serve as a storage facility if the percentage of intermittent sources is not too high. And a disadvantage of energy carriers such as fossil fuels is that their resources are limited: sooner or later they will be depleted. Figure 7.4 classifies energy sources in intermittent or continuous supply, and in energy carriers or energy flows. Note that geothermal energy is considered an energy flow, but has a continuous supply.

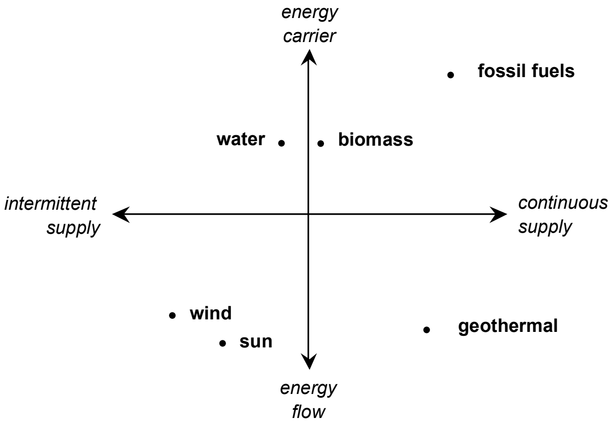

Figure 7.4. Energy flows and energy carriers with intermittent or continuous supply.

Another factor affecting the reliability of energy supply is the peak demand as a ratio of the maximum production. Although in our analysis we use the average annual energy demand, the actual demand will vary during a day, week, month or year. For instance, at night when most people are asleep, energy demand will be less than during lunch hours, when demand reaches a peak. The total energy production must always exceed the maximum power demand at peak times to avoid black outs. If the installed capacity is not sufficient to handle peak demands, this decreases the reliability of the energy supply.

- *Regional Economic Development*

Factors that contribute to regional economic development are tourism, energy production and distribution, and the agro-sector. On the other hand, a factor that can negatively affect regional development is waste production and improper disposal of waste. Due to a general lack of data on regional development it is usually difficult to quantify the exact effects that an energy infrastructure option has on regional economic development.

- *Risk & Uncertainty*

The so-called ‘proven technologies’ that have been commercially available for quite some time and with which a lot of experience has been gained are likely associated with less risk and uncertainty, whereas the risk and uncertainty associated with new technologies that only recently have become available are much higher.

- *Monetary Costs*

The monetary costs we take into account only include the costs of the energy infrastructure and the costs of recycling and disposal of waste from tourists. Both these monetary costs can be measured numerically.

- *Monetary Benefits*

  Like the monetary costs, the monetary benefits can be measured numerically. The total monetary benefits include energy revenues, revenues from tourism, and the revenues from agro-(industrial) activities.

- *Distribution of Costs & Benefits*

  Some impacts affect only certain groups in society or certain economic sectors. And some groups may benefit from one scenario, while facing costs in another. Therefore, it is important to know how the costs and benefits of a scenario are distributed among the actors.

This concludes the description of the indicators. In the next section we will discuss what measures we use for the indicators described above.

7.9.3. Next Iteration: More Detail and Quantitative Data

In this section we will briefly describe the measures used to determine the scores on (sub-) indicators used in our example. Details on the formulas used can be found in Appendix D.

- *Environmental Damage*

  The sub-indicators of environmental damage include CO_2 emissions caused by the import of electricity from the national grid, as national electricity production is partly done by fossil fuels. No CO_2 emissions are associated with the regional renewable resources and technologies. The waste generated by tourists is measured by the amount of waste produced per tourist per day, the number of tourists, and the days of stay. Note that we assume that luxury tourists produce more waste than eco-tourists. Furthermore, we assume that 0.4% of the waste generated by tourists ends up in the surface waters. The noise and disturbance of tourists is measured using a ‘disturbance factor’, which is indexed at 1 for 2000 and depends on the number of tourists. The disturbance factor of luxury tourists is higher than that for eco-tourists.

  For the agro-residues that are not used for other purposes (such as energy generation), we assume that 0.1% ends up in the surface waters. A measure for the water quantity is difficult to give, but the hydropower capacity will give some indication. The expansion of cultivated area for agro-activities is taken to be a measure for deforestation.

- *Competitiveness of the National Energy Sector*

  How the competitiveness of the national energy sector is affected by the choice for a particular local energy infrastructure is difficult to measure, as it involves, among others, the cost of the regional energy infrastructure and the reliability of supply. Therefore, we will let the actors assign an ordinal score to this indicator.

- *Reliability of Energy Supply*

For the reliability of the energy supply we could use measures such as the number of intermittent sources and the load factor, although actors might have a subjective opinion on this indicator as well, so that a quasi-quantitative measure seems appropriate.

- *Regional Economic Development*

In our analysis, we will define regional economic development as the monetary revenues and costs occurring: in the tourism sector (tourism revenues); in the energy sector (energy infrastructure costs en energy revenues, profit); in the agro-sector (agro revenues); and for the government (cost of waste disposal). These revenues and costs are the same as the ones mentioned under the indicators ‘Monetary Costs’ and ‘Monetary Benefits’.

- *Risk & Uncertainty*

Perceptions on risk and uncertainty are highly subjective, so we will use ordinal scores that reflect the actors’ opinions.

- *Monetary Costs*

The monetary costs we take into account only include the costs of the energy infrastructure and the costs of recycling and disposal of waste from tourists. The monetary costs of the energy infrastructure include investment cost of new generation systems, operation and maintenance costs of these systems, fuel costs, and the costs of distributing the energy.

Investment costs are measured using the cost per kW capacity and the total required capacity. The operation and maintenance costs are expressed in percentages of total investment costs, while fuel costs are assumed to be zero for all renewable regional resources[18]. To compare the costs of the different systems all costs are converted into annual cost, using constant prices and an interest rate of 12%, which is a common rate in Costa Rican energy project proposals. In order to calculate least-cost options in scenarios, we have to determine the (long run) marginal cost of using an energy system. The marginal costs are calculated by dividing the total annual cost of a system by the total amount of electricity or heat it produces each year, which results in the (long run) marginal cost of respectively electricity (in US$/kWh) and heat (in US$/GJ). The overall marginal cost of the entire energy infrastructure option is then the weighed average of the marginal costs of all the electricity and heat systems.

The costs of recycling and waste disposal are determined by the annual costs of disposing a unit of waste and the total amount of waste produced per year (both controlled by annual growth rates). Note that in our analysis, we only consider the disposal of waste produced by tourists. Waste disposal in the agro sector is assumed to be the responsibility of the farmers and the agro-industry. Other (municipal) waste is assumed to be the same for all scenarios and is not included in the analysis. Improper disposal of waste and residues has a

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[18] This applies to biomass residues as well, even though it is likely that there are costs associated with collecting and transporting the biomass to the power plants. For the sake of simplicity we ignore these costs here.

damaging effect on the environment. Note that for our example a lack of data prevents us from determining changes in the costs of living in the area, but the actors (e.g., local habitants) can assign an ordinal score to this sub-indicator to express their opinion.

- *Monetary Benefits*

The total monetary benefits include energy revenues, revenues from tourism, and the revenues from agro-(industrial) activities. The energy revenues consist of the payments of the residential, commercial, and industrial clients, *and* from electricity export (if applicable). Remember that residential clients and hotels can consume –and thus pay for– heat besides electricity. The electricity revenues from a particular type of client are determined by the price per unit of electricity (US$/kWh) for that type of client, the (average) annual amount of electricity consumed per type of client, and the total number of clients of that type. The same holds for the revenues of heat. Revenues from electricity export are determined by multiplying the price per unit of exported electricity and the amount of electricity exported.

Tourism revenues are calculated using the number of tourists that visit an area (distinguishing between luxury and eco-tourists), the number of days they stay in the area, and their daily expenditures.

Agro-revenues consist of the price per unit of agro product multiplied by the amount produced of that product and consequently summing these values. In our analysis, we only include the production of bananas, sugar cane, oranges, pineapples, and wood because these products have an international market and are also processed by the agro-industry in the area.

An additional sub-indicator of monetary benefits is the annual profit of the energy distribution company, which determines the continuity of business and the scope for new investments. The higher the profit in a scenario, the more lucrative this scenario is for the energy company. The profit percentage is determined by dividing the total energy revenues by the total costs of the energy infrastructure and subtracting 1.

- *Distribution of Costs & Benefits*

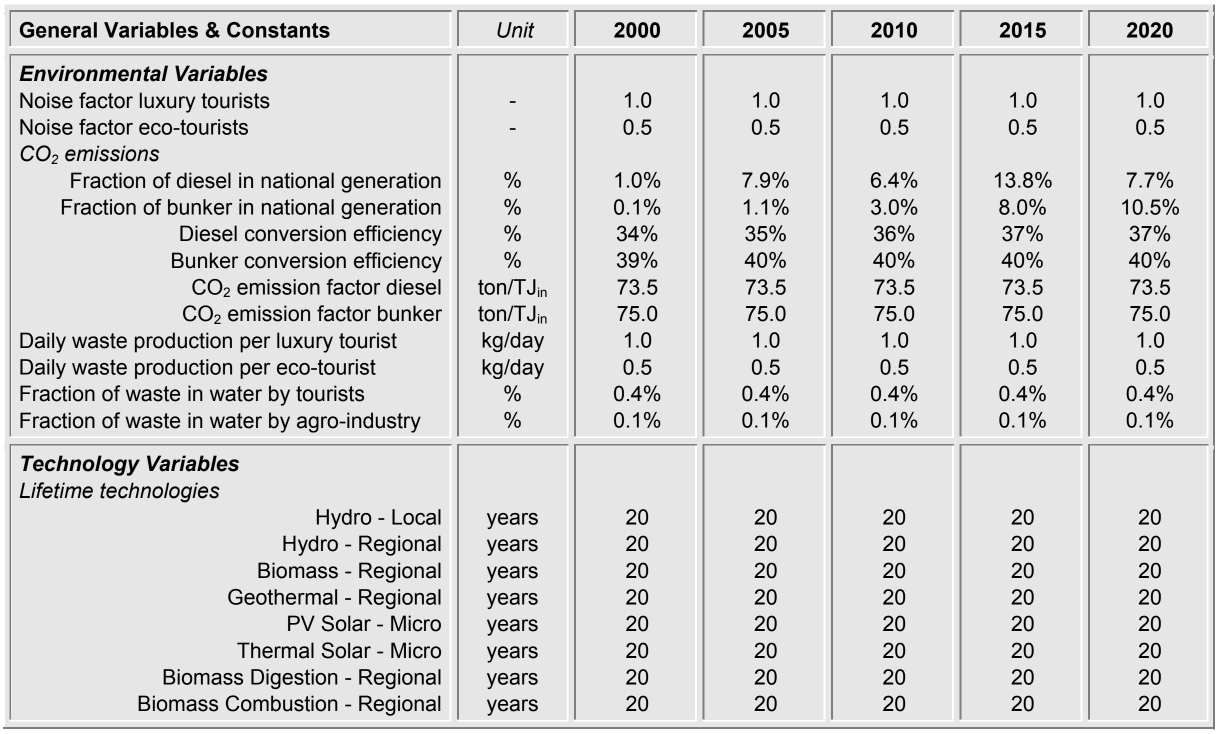
To determine the distribution of costs and benefits, we will only consider the monetary costs and benefits already determined for the indicator ‘Regional Economic Development’ and we attribute these to the actors in the following way: The government (i.e., tax payers) pay the costs of waste disposal, the energy revenues and the costs of the energy infrastructure are allocated to the energy companies, tourism revenues go to the local entrepreneurs, and the farmers receive the agro revenues. Furthermore, local habitants, entrepreneurs, and farmers have to pay their energy bills. For each scenario, the monetary costs and benefits attributed to an actor are compared with the same costs and benefits for the business-as-usual scenario in the year 2020.

The input data that are needed to calculate the scores on the sub-indicators are listed in Table 7.22 and Table 7.23. For details we refer to Appendix D.

Table 7.22. General variables and constants that apply to all scenarios for 2000-2020.

General Variables & Constants	*Unit*	**2000**	**2005**	**2010**	**2015**	**2020**
		Value	*Growth Rates*			
Demand for appliances per luxury room	kWh/day	12.4	1.0%	1.5%	2.0%	2.5%
Demand for appliances per eco-room	kWh/day	6.0	0.5%	0.5%	1.0%	1.0%
Cost Variables						
Exchange rate	¢/US$	310	10%	10%	10%	10%
Rate of interest	%	12%	12%	12%	12%	12%
Daily expenditure per luxury tourist	US$/day	140	1.0%	1.0%	1.0%	1.0%
Daily expenditure per eco- tourist	US$/day	50	0.5%	0.5%	0.5%	0.5%
Price of agro-products						
Banana	US$/kg	0.30	0%	0%	0%	0%
Sugar Cane	US$/kg	0.01	0%	0%	0%	0%
Oranges	US$/kg	0.05	0%	0%	0%	0%
Pineapple	US$/kg	0.36	0%	0%	0%	0%
Wood	US$/kg	0.04	0%	0%	0%	0%
Cost of waste disposal	US$/ton/yr	250	0%	0%	0%	0%
Investment costs energy technologies						
Hydro - Local	$\text{US\$/kW}_e$	1,000	-0.5%	-0.5%	-0.5%	-0.5%
Hydro - Regional	$\text{US\$/kW}_e$	1,000	-0.5%	-0.5%	-0.5%	-0.5%
Biomass - Regional	$\text{US\$/kW}_e$	1,300	-1.0%	-1.0%	-1.0%	-1.0%
Geothermal - Regional	$\text{US\$/kW}_p$	2,500	-1.0%	-1.0%	-1.0%	-1.0%
PV Solar - Micro	$\text{US\$/kW}_p$	7,500	-8.0%	-8.0%	-8.0%	-8.0%
Thermal Solar - Micro	$\text{US\$/m}^2$	300	-3.0%	-3.0%	-3.0%	-3.0%
Agro-Residues Digestion - Regional	$\text{US\$/kW}_{th}$	1,500	-1.0%	-1.0%	-1.0%	-1.0%
Wood Combustion – Regional	$\text{US\$/kW}_{th}$	1,000	-1.0%	-1.0%	-1.0%	-1.0%
O&M costs energy technologies						
Hydro - Local	% of total I	2.5%	2.5%	2.5%	2.5%	2.5%
Hydro - Regional	% of total I	2.5%	2.5%	2.5%	2.5%	2.5%
Biomass - Regional	% of total I	5.0%	5.0%	5.0%	5.0%	5.0%
Geothermal - Regional	% of total I	3.0%	3.0%	3.0%	3.0%	3.0%
PV Solar - Micro	% of total I	2.0%	2.0%	2.0%	2.0%	2.0%
Thermal Solar - Micro	% of total I	2.0%	2.0%	2.0%	2.0%	2.0%
Agro-Residues Digestion - Regional	% of total I	5.0%	5.0%	5.0%	5.0%	5.0%
Wood Combustion – Regional	% of total I	5.0%	5.0%	5.0%	5.0%	5.0%
Fuel costs						
All Biomass Combustion- Regional	$\text{US\$/ton}_{dry}$	0.0	0.0%	0.0%	0.0%	0.0%
Agro-Residues Digestion– Regional	$\text{US\$/ton}_{wet}$	0.0	0.0%	0.0%	0.0%	0.0%
Wood Combustion – Regional	$\text{US\$/ton}_{dry}$	0.0	0.0%	0.0%	0.0%	0.0%
Price of Electricity						
Residential	US$/kWh	14.73	12%	14%	15%	15%
Commercial	US$/kWh	31.20	14%	15%	15%	15%
Industrial	US$/kWh	25.85	13%	14%	15%	15%

Table 7.23. General variables and constants that hold for 2000-2020 for all scenarios.



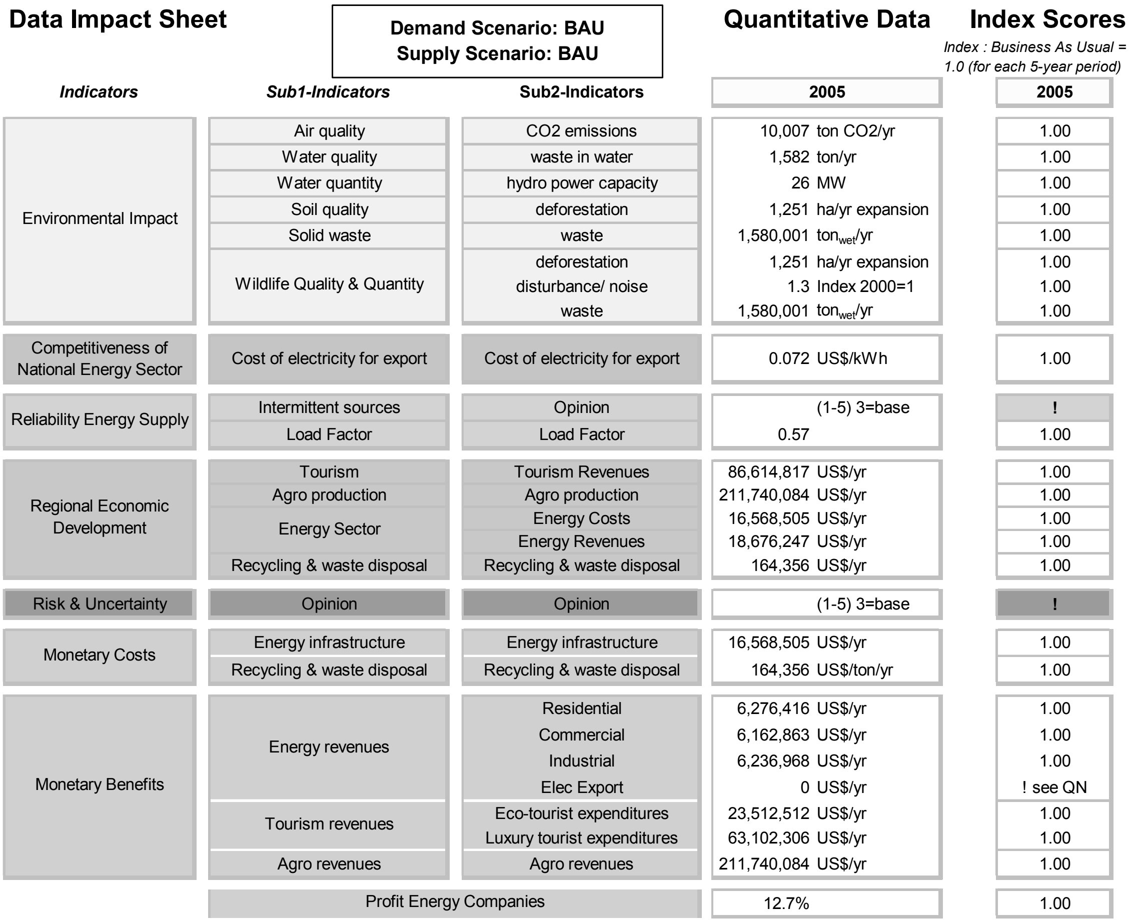
General Variables & Constants	*Unit*	2000	2005	2010	2015	2020
Environmental Variables						
Noise factor luxury tourists	-	1.0	1.0	1.0	1.0	1.0
Noise factor eco-tourists	-	0.5	0.5	0.5	0.5	0.5
CO_2 emissions						
Fraction of diesel in national generation	%	1.0%	7.9%	6.4%	13.8%	7.7%
Fraction of bunker in national generation	%	0.1%	1.1%	3.0%	8.0%	10.5%
Diesel conversion efficiency	%	34%	35%	36%	37%	37%
Bunker conversion efficiency	%	39%	40%	40%	40%	40%
CO_2 emission factor diesel	ton/TJ_{in}	73.5	73.5	73.5	73.5	73.5
CO_2 emission factor bunker	ton/TJ_{in}	75.0	75.0	75.0	75.0	75.0
Daily waste production per luxury tourist	kg/day	1.0	1.0	1.0	1.0	1.0
Daily waste production per eco-tourist	kg/day	0.5	0.5	0.5	0.5	0.5
Fraction of waste in water by tourists	%	0.4%	0.4%	0.4%	0.4%	0.4%
Fraction of waste in water by agro-industry	%	0.1%	0.1%	0.1%	0.1%	0.1%
Technology Variables						
Lifetime technologies						
Hydro - Local	years	20	20	20	20	20
Hydro - Regional	years	20	20	20	20	20
Biomass - Regional	years	20	20	20	20	20
Geothermal - Regional	years	20	20	20	20	20
PV Solar - Micro	years	20	20	20	20	20
Thermal Solar - Micro	years	20	20	20	20	20
Biomass Digestion - Regional	years	20	20	20	20	20
Biomass Combustion - Regional	years	20	20	20	20	20

As soon as it is clear which measures are used to determine the scores on the indicators, the actual impact assessment can begin, which is the topic of the next section.

7.9.4. Determining Scores on the Indicators

After we have chosen the measures for all the indicators, we can assess the impacts of the energy infrastructure options by determining the scores on the indicators. As stated earlier, the first iteration will involve mainly general indicators and ordinal measures, and most of the scores will initially be assigned by the actors. As the planning process advances, more data become available for the impact assessment, and some ordinal measures can be replaced by quasi-quantitative or even quantitative measures. So we have to create a format that allows for a ‘quick and dirty’ impact assessment, as well as a detailed assessment with quantitative data when more information becomes available.

In our example, the format used for the impact assessment is based on a sheet containing impact data, and on ‘indicator scorecards’. At the start of the impact assessment, the impact data sheet will normally only list the general indicators, including a qualitative description of the (possible) impacts that each indicator encompasses. During next iterations, the general indicators are divided into sub-indicators, which are also listed on the impact data sheet. Also, measures are chosen and data are obtained to determine the scores on the (sub-)indicators. Each iteration will add more detail to the impact assessment, and all new data are presented in the impact data sheet, which expands like the branches of a tree. Figure 7.5 shows an example of a detailed impact data sheet for the period 2001-2005. Note that the impact data for the year 2000 are the same for all scenarios, because they all depart from the same situation.



Data Impact Sheet

Demand Scenario: BAU
Supply Scenario: BAU

Quantitative Data | **Index Scores**

Index : Business As Usual = 1.0 (for each 5-year period)

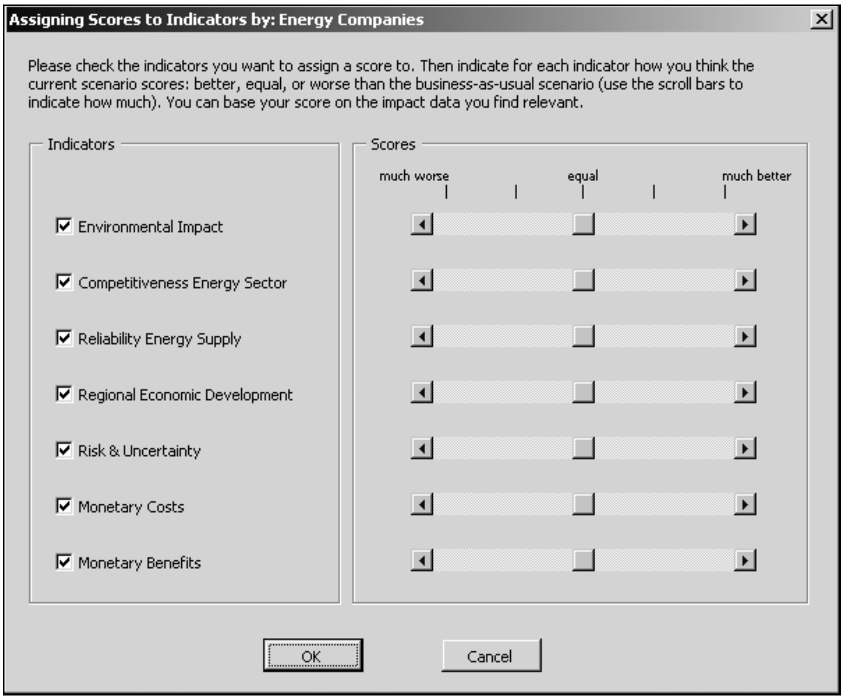
Indicators	*Sub1-Indicators*	Sub2-Indicators	2005		2005
Environmental Impact	Air quality	CO2 emissions	10,007	ton CO2/yr	1.00
	Water quality	waste in water	1,582	ton/yr	1.00
	Water quantity	hydro power capacity	26	MW	1.00
	Soil quality	deforestation	1,251	ha/yr expansion	1.00
	Solid waste	waste	1,580,001	ton_{wet}/yr	1.00
	Wildlife Quality & Quantity	deforestation	1,251	ha/yr expansion	1.00
		disturbance/ noise	1.3	Index 2000=1	1.00
		waste	1,580,001	ton_{wet}/yr	1.00
Competitiveness of National Energy Sector	Cost of electricity for export	Cost of electricity for export	0.072	US$/kWh	1.00
Reliability Energy Supply	Intermittent sources	Opinion		(1-5) 3=base	!
	Load Factor	Load Factor	0.57		1.00
Regional Economic Development	Tourism	Tourism Revenues	86,614,817	US$/yr	1.00
	Agro production	Agro production	211,740,084	US$/yr	1.00
	Energy Sector	Energy Costs	16,568,505	US$/yr	1.00
		Energy Revenues	18,676,247	US$/yr	1.00
	Recycling & waste disposal	Recycling & waste disposal	164,356	US$/yr	1.00
Risk & Uncertainty	Opinion	Opinion		(1-5) 3=base	!
Monetary Costs	Energy infrastructure	Energy infrastructure	16,568,505	US$/yr	1.00
	Recycling & waste disposal	Recycling & waste disposal	164,356	US$/ton/yr	1.00
Monetary Benefits	Energy revenues	Residential	6,276,416	US$/yr	1.00
		Commercial	6,162,863	US$/yr	1.00
		Industrial	6,236,968	US$/yr	1.00
		Elec Export	0	US$/yr	! see QN
	Tourism revenues	Eco-tourist expenditures	23,512,512	US$/yr	1.00
		Luxury tourist expenditures	63,102,306	US$/yr	1.00
	Agro revenues	Agro revenues	211,740,084	US$/yr	1.00
	Profit Energy Companies		12.7%		1.00

Figure 7.5. Example of an Data Impacts sheet of the BAU option for the period 2001-2005.

When most of the (sub-)indicators are quantified, it may be helpful to also use '*index scores*' besides the quantitative scores, as shown in the last column of Figure 7.5. An index score is calculated by dividing the impact score of an alternative option by the impact score of the BAU option. So the index scores give an indication of how well an option scores compared to the BAU option, and the index scores of the BAU option itself are always 1.0 for each 5-year period.

Note that sub-indicators that are measured with opinions of actors (e.g., 'Competitiveness of the Energy Sector', 'Risk and Uncertainty') do not have an index score, and neither has the export of electricity (under 'Monetary Benefits') because it is zero for the BAU option. Also note that the indicator 'Distribution of Costs and Benefits' is not explicitly included in the overview. The distribution among the actors is derived from the comparison of the costs and benefits that accrue to the different actors.

The quantitative data and the index scores on an Data Impacts sheet do not automatically lead to an overall score on a general indicator, as the indicators are rarely measured in only one objective way, let alone uniquely defined (i.e., without the use of sub-indicators). Nonetheless, for a transparent comparison of options, we need the overall scores. Therefore, the overall scores on the general indicators are determined with the help of scorecards. For each energy infrastructure option included in the impact assessment, the actors each have to fill in a scorecard. On the scorecards, the actors have to indicate whether they think the infrastructure option concerned scores better or worse than the BAU option on a particular indicator, basing their score on the data given in the impact data sheet which they perceive to be relevant data. If an actor is not interested in a particular indicator, or if the actor has no opinion, the indicator concerned can be unchecked and no score has to be assigned. The scorecards can be used each time new or additional data are added to the impact data sheet, so at least once every iteration. An example of a scorecard is given in Figure 7.6.



Assigning Scores to Indicators by: Energy Companies

Please check the indicators you want to assign a score to. Then indicate for each indicator how you think the current scenario scores: better, equal, or worse than the business-as-usual scenario (use the scroll bars to indicate how much). You can base your score on the impact data you find relevant.

Indicators

☑ Environmental Impact
☑ Competitiveness Energy Sector
☑ Reliability Energy Supply
☑ Regional Economic Development
☑ Risk & Uncertainty
☑ Monetary Costs
☑ Monetary Benefits

Figure 7.6. Example of a scorecard, in this case for the energy companies.

Note that the scores on a uniquely defined and uniquely measured indicator are inserted automatically on the scorecard (e.g., as an index score using the BAU score as a reference). Such a score cannot be changed by the actors, and is the same on the scorecards of all actors for that option. When the scores on the indicators have been determined, the next step in the method, appraisal of the impacts, can begin.

7.10. Web Diagrams for Appraisal and Comparison of Impacts

The scores on the indicators have to be presented in a clear manner for the actors to get an overview of all the impacts, and to compare the different options. Remember that the appraisal and comparison of the options are done implicitly; actors do not have to make explicit the criteria or considerations they use for appraisal. Nonetheless, some of the underlying criteria and considerations will become apparent during the evaluation step, where outcomes of the internal appraisal process are made explicit and discussed among the actors (see § 7.11).

A clear structure for presenting an overview of the scores is provided by web diagrams, as illustrated in Figure 7.7 and already discussed in Section 5.2.8. Each actor has a web diagram, and the axes of the web diagram represent the indicators used in the impact assessment. The scores of the infrastructure options on each indicator are projected on the axis concerned, where each axis can have a different scale (in terms of measure type, or in the range of min./max. value). However, for reasons of consistency, the minimum and maximum value of a particular indicator are the same for all actors and all options. To improve the transparency of the web diagrams, the scales are chosen in such a way that scores at the outer boundary of the web represent the ‘better’ or ‘more preferred’ scores per actor. In addition, the last web diagram in Figure 7.7 represents the distribution of costs and benefits among the actors. This web diagram deviates substantially from the other web diagrams: it has the actors as axis, and the ‘scores’ are the net (monetary) benefits that accrue to each actor for the different options. The scores are automatically inserted in the web diagram and cannot be changed by actors.

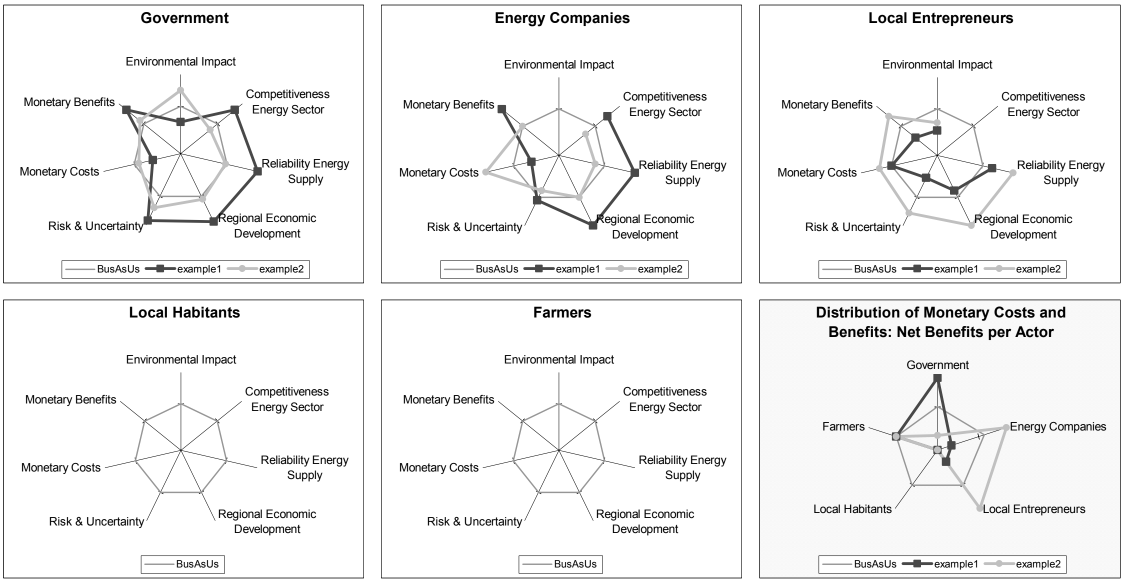


Figure 7.7. Example of the overview of impacts using web diagrams. The web diagrams per actor already show the scores of the BAU option on the indicators, while the scores of other options (i.e., ‘example 1’ and ‘example 2’) are included for the government, energy companies, and entrepreneurs. The last web diagram shows the distribution of costs and benefits among the actors.

Note that other variations of web diagrams can be constructed as well, such as a web diagram per infrastructure option, taking the indicators as axis and plotting the score-curves per actor. Or web diagrams that plot the scores on the sub-indicators of a general indicator. As already mentioned in Section 5.2.5, the way indicators are framed influences the appraisal of the scores on these indicators. The scale that is chosen for an indicator can also influence the appraisal; decreasing the range between the minimum and maximum values on an axis can blow up minor differences in scores. The appraisal and comparison are done in one of the last steps of a method iteration. The next section will address the remainder of the method steps, which require a lot of interaction among actors and in which the tool plays only a minor role.

7.11. Evaluation of the Scores, Next Iteration(s), and Final Selection

After the appraisal step, the energy infrastructure options are evaluated among the actors in the evaluation step, using the web diagrams of all the actors as a handhold. The outcome of the evaluation step usually induces the next iteration of the method steps, and this will continue until the support base for a particular energy infrastructure is large enough to select it as the final energy infrastructure to be implemented. This process was already presented earlier in Chapter 5 and is illustrated again in Figure 7.8,.

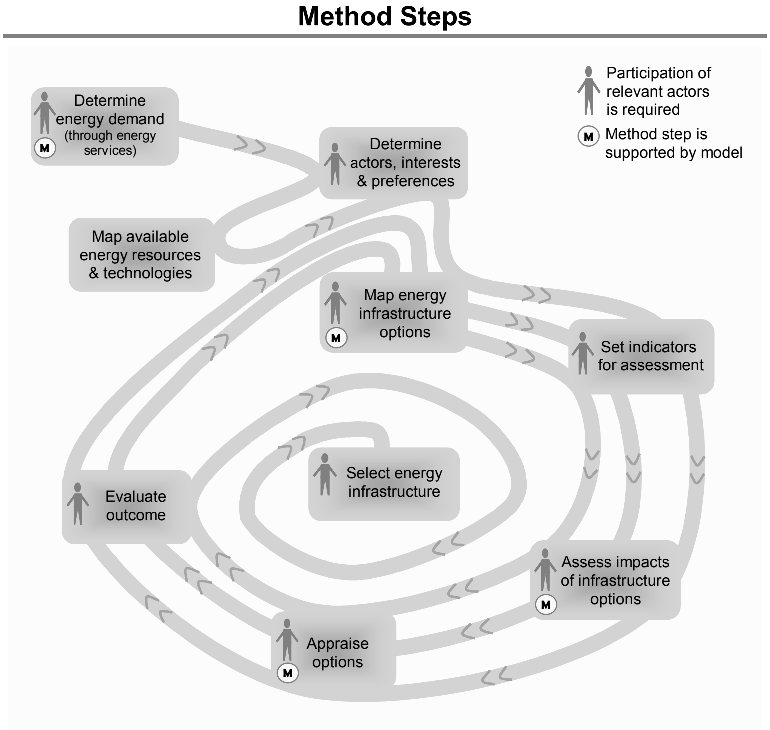


Figure 7.8. The evaluation step usually induces a new iteration cycle until a mutually supported appropriate energy infrastructure is selected.

These last steps of the method involve a lot of interaction among the actors, and the role of the tool is minor. This does not imply, however, that no support can be given to the actors. For example, the interactions can be given more structure and may develop more constructively if an independent mediator operates as a ‘gateway’ for the opinions and information needs of actors, especially when distrust exists among them. The intermediary would also be the most designated actor to make the tool consistent with local circumstances, and look after a proper use and operation of the tool. More specifically, the mediator can interview experts for information and interview actors to extract their interests and preferences. The mediator can also fill the database with local data, construct demand scenarios, map the available energy resources and technologies, construct supply scenarios, set the indicators, construct energy infrastructure options, and find measures to determine the scores on the indicators. Doing all this, of course, while constantly conferring with the actors.

7.12. Epilogue

In this chapter we have given an example of the construction of an operational tool as a way to make the new method operational. The example concerns a hypothetical but realistic energy planning process in the Coopelesca area for the period 2000-2020, making use of the data obtained from the field study in Costa Rica and other sources. The tool is meant to facilitate the steps of the method, and Figure 7.9 shows which steps of the method are supported by the tool. The tool is a prototype, so its construction has not been optimized from a programming viewpoint. Also, a real application of the method in practice will require a sensitivity analysis on the variables used in the tool, but since our tool is merely constructed to give a hypothetical demonstration, the sensitivity analysis is excluded.

In practice, the tool will be constructed during the first iteration of the method steps. This first iteration will likely only include the first five or six steps of the method, until the impact assessment. This first iteration will also be used to construct the Business-As-Usual (BAU) reference scenarios, and consequently other predefined scenarios that can be easily derived from the format of the BAU scenarios. To get better insight in how the actors will use the tool when assessing different energy infrastructure options, Chapter 8 will give a demonstration of the tool.

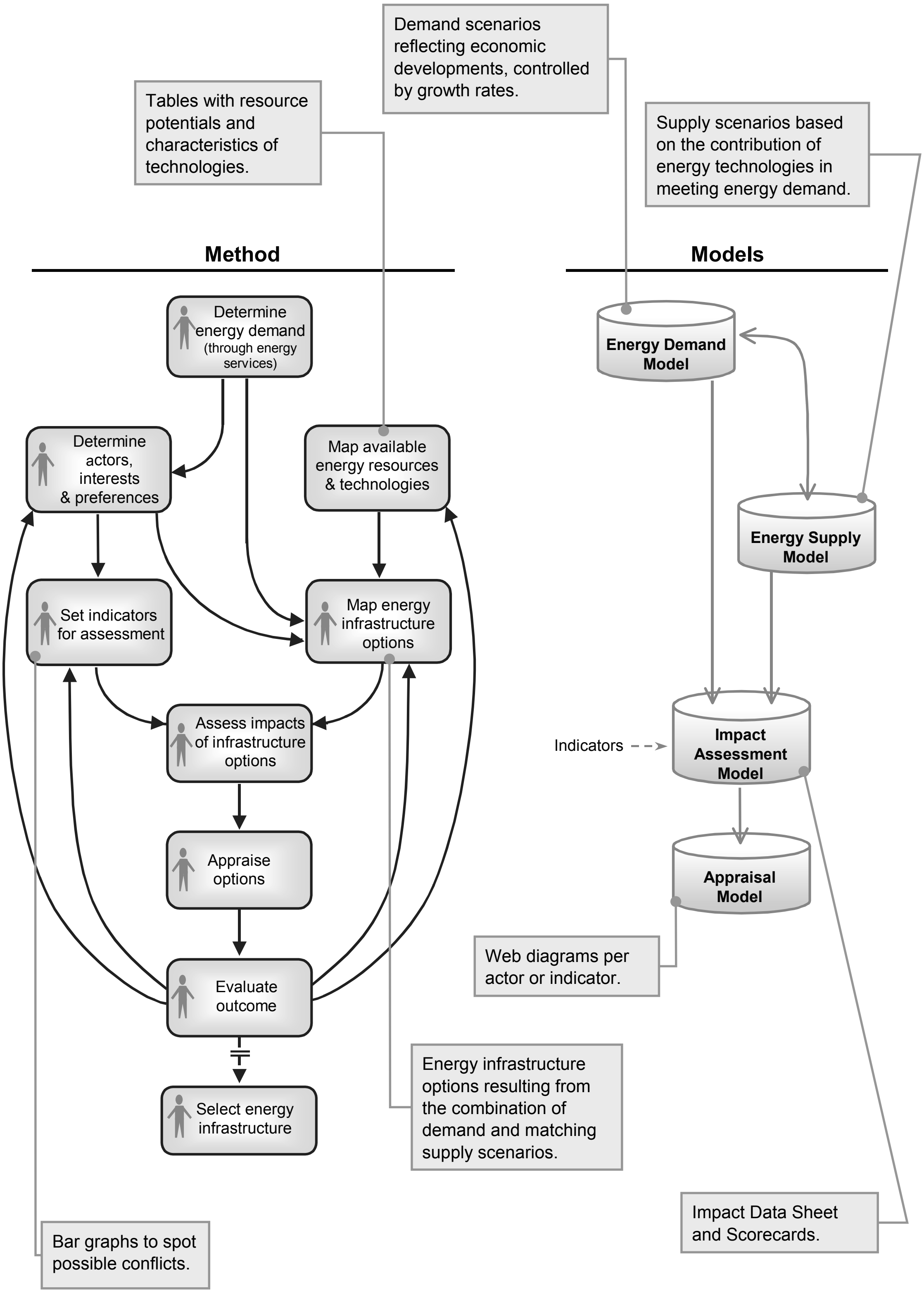


Figure 7.9.Overview of the support offered by the tool when following the steps of the new method.

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8

Applying the Method: Tool Demonstration

8.1. Introduction

This chapter will give a demonstration of the tool that we constructed in Chapter 7. It describes how the tool is presented to the actors and gives an example of how the tool can be used for the construction, assessment and comparison of different energy infrastructure options. However, as explained in Chapter 7, this demonstration does not reflect an actual case, as energy planning can take up to five years or more and this time was not available. Consequently, the field study in Costa Rica did not provide all the data that are needed for this demonstration, in particular concerning the (changing) preferences and opinions of actors. Furthermore, the tool that we constructed in Chapter 7 is a *prototype* and needs to be optimized from a programming viewpoint and at least has to include a sensitivity analysis. Finally, the tool makes use of scenario analysis using ‘extreme’ scenarios. These scenarios imply a discontinuity in current trends and are therefore necessarily based on educated guesses. The ‘extreme’ scenarios describe approximate directions of development and should not be interpreted as exact predictions of the future. The ‘extreme’ scenarios are chosen in such a way that they clearly show the differences in consequences associated with the developments. The directions of development only apply to the region concerned; developments outside the region are assumed to be the same for all scenarios. All these factors make that this demonstration has a hypothetical character, and does not necessarily reflect the actual developments or the actual opinions of the actors. Nonetheless, the educated guesses on which this demonstration is based are derived from the data of the Costa Rica field study and interviews with actors and experts, and are believed to be realistic enough to show how the tool can be used in practice. Further research will then have to determine the degree of usefulness of the tool.

8.2. Tool Description

In Chapter 7 we discussed the procedures to construct several tool parts. The constructed tool parts are put into two Excel spreadsheet files: the Database file and the TOOL file, as shown in Figure 8.1.

The Database file contains general variables and constants that apply to all the infrastructure options constructed. This file is used at the start of the planning process to adjust values to local circumstances, but can also be changed after each iteration cycle to add (generally applicable) variables and constants that are needed to calculate scores on newly added indicators. The Database file is linked with the TOOL file so that any changes in the Database file will automatically be updated in the TOOL file.

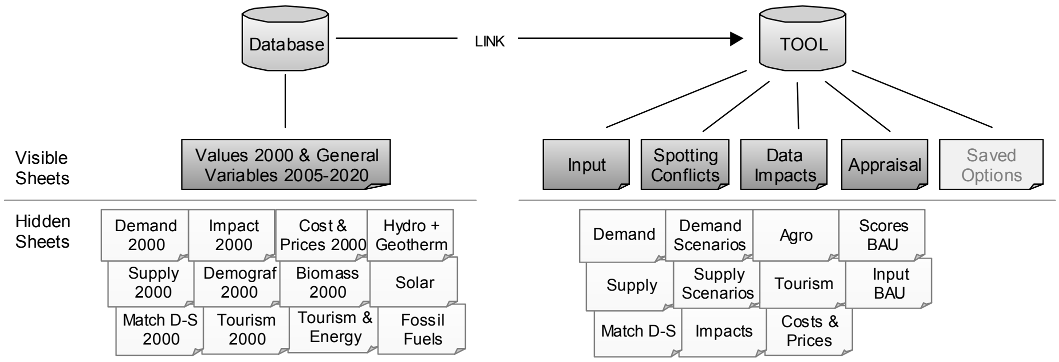


Figure 8.1. Outline of the Database and TOOL spreadsheet files, with visible and hidden sheets.

The TOOL file consists of several (work)sheets: the *Input* sheet is used to construct energy infrastructure options i.e., combinations of demand scenarios and supply scenarios; the *Spotting Conflicts* sheet can be used to let actors express their preferred scores on the indicators in order to spot possible conflicting interests between actors; and the *Data Impacts* sheet lists the ordinal and numerical scores on (sub-)indicators. Both the Input sheet and the Data Impacts sheet can be used to save a particular infrastructure option, creating a new sheet in the TOOL file with a name assigned by the actors and containing both the input values and the data on impacts. The sheets of the saved infrastructure options –in turn– allow the actors to assign overall scores to indicators for a particular option, using scorecards. The results of the impact assessment are presented in the *Appraisal* sheet, which contains an overview of the web diagrams of the different actors.

Note that both the Database file and the TOOL file have many hidden sheets (not visible to the users) that are merely used to calculate values and cannot be changed by the actors. A mediator is the most designated actor to design and operate the tool, and explain the other actors how to use it. In the following sections, we will discuss all the visible sheets of the Database file and the TOOL file in more detail, starting with the general variables and constants in the database.

8.3. Database: General Variables and Constants

Some of the variables and constants used in constructing energy infrastructure options have a general character: they apply to all the constructed options. For instance, all options start from the same situation in 2000, so all option have the same values for the year 2000. But there are also general variables for the period 2005-2020. These general variables usually reflect developments on which local actions have no (significant) influence. For instance, the conversion efficiencies of energy technologies are usually not influenced by local developments, nor will the (international) prices of technologies. In Chapter 7, we already presented general variables and constants for the *demand* scenarios in Table 7.10. In addition, the resource potentials and technology characteristics listed in Table 7.15, Table 7.16, and Table 7.17 hold for all *supply* scenarios. Note that in § 7.8 we also set a cap on the available resource potential (parts of the resource potentials cannot be exploited e.g., due to regulations), but we only did so for 2005. Table 8.1 lists the percentages of the total resource potentials assumed available in all the 5-year periods.

Table 8.1. Percentages of total resource potentials available in 200-2020.

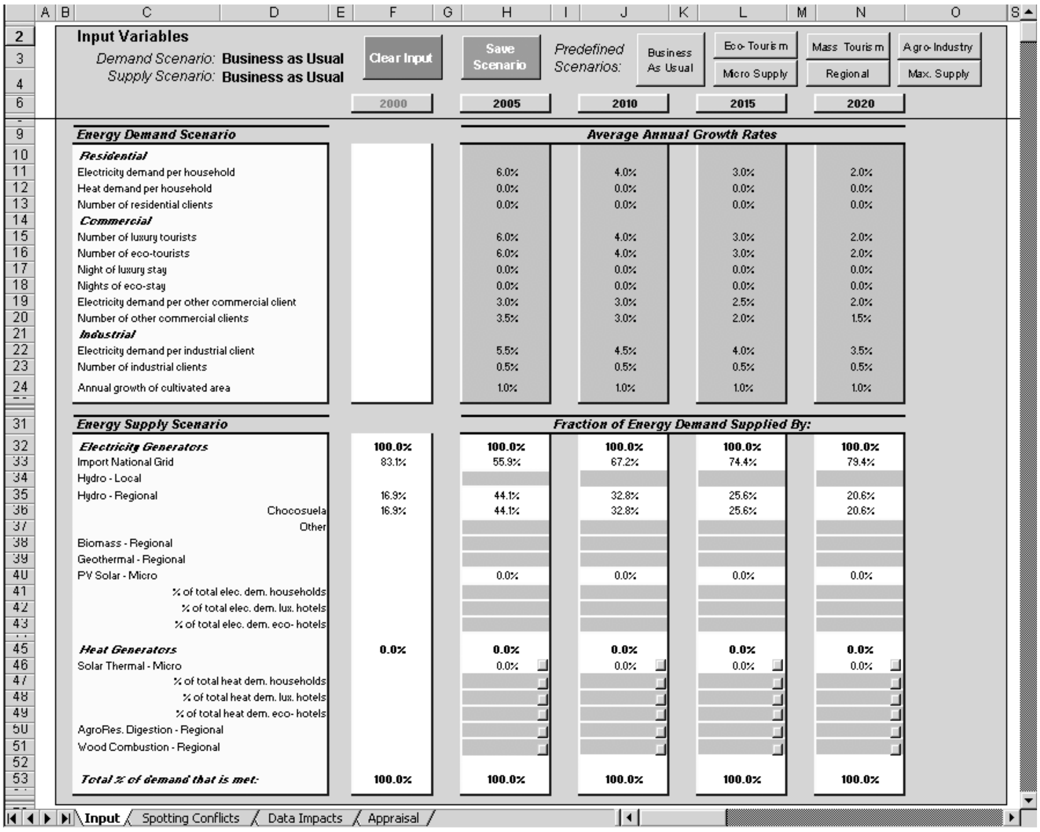
		Available Percentages				
Energy Resources for:	Scale	**2000**	**2005**	**2010**	**2015**	**2020**
Hydro	Local	20%	20%	30%	40%	50%
Hydro	Regional	20%	20%	30%	40%	50%
Biomass	Regional	20%	20%	30%	40%	50%
Geothermal	Regional	20%	20%	30%	40%	50%
PV Solar	Micro	100%	100%	100%	100%	100%
% of household demand	Micro	100%	100%	100%	100%	100%
% of demand luxury hotels	Micro	100%	100%	100%	100%	100%
% of demand eco-hotels	Micro	100%	100%	100%	100%	100%
Agro-Residues Digestion	Regional	20%	20%	30%	40%	50%
Wood Combustion	Regional	20%	20%	30%	40%	50%
Solar Thermal	Micro	70%	70%	75%	80%	85%
% of household demand	Micro	70%	70%	75%	80%	85%
% of demand luxury hotels	Micro	70%	70%	75%	80%	85%
% of demand eco-hotels	Micro	70%	70%	75%	80%	85%

All the data in the above mentioned tables can be put in the Database file. In addition, the database contains the general variables and constants used to calculate the scores on the (sub-) indicators, as listed in Table 7.24 and Table 7.25. All other variables are input variables and thus part of the TOOL file, which will be discussed in the next section.

8.4. Tool Input: Energy Demand Scenarios

The first sheet that the users get to see in the TOOL file is the Input sheet as shown in Figure 8.2. The actors can use this sheet to construct energy infrastructure options by inserting values for the energy demand and supply scenarios. The values in the white cells in Figure 8.2 are automatically calculated and cannot be changed.

The Input sheet also contains several buttons. The 'Clear Input' button can be used to clear all input values that can be changed by the users, resulting in zero growth rates for the demand scenario and only contributions in supply of Chocosuela and the national grid. The 'Save Scenario' button will save the current input values (i.e., the energy infrastructure option) *and* the corresponding impact data on a new sheet.



Input Variables

Demand Scenario: **Business as Usual**
Supply Scenario: **Business as Usual**

Energy Demand Scenario	2000	2005	2010	2015	2020
		Average Annual Growth Rates			
Residential					
Electricity demand per household		6.0%	4.0%	3.0%	2.0%
Heat demand per household		0.0%	0.0%	0.0%	0.0%
Number of residential clients		0.0%	0.0%	0.0%	0.0%
Commercial					
Number of luxury tourists		6.0%	4.0%	3.0%	2.0%
Number of eco-tourists		6.0%	4.0%	3.0%	2.0%
Night of luxury stay		0.0%	0.0%	0.0%	0.0%
Nights of eco-stay		0.0%	0.0%	0.0%	0.0%
Electricity demand per other commercial client		3.0%	3.0%	2.5%	2.0%
Number of other commercial clients		3.5%	3.0%	2.0%	1.5%
Industrial					
Electricity demand per industrial client		5.5%	4.5%	4.0%	3.5%
Number of industrial clients		0.5%	0.5%	0.5%	0.5%
Annual growth of cultivated area		1.0%	1.0%	1.0%	1.0%

Energy Supply Scenario		***Fraction of Energy Demand Supplied By:***			
Electricity Generators	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**
Import National Grid	83.1%	55.9%	67.2%	74.4%	79.4%
Hydro - Local					
Hydro - Regional	16.9%	44.1%	32.8%	25.6%	20.6%
Chocosuela	16.9%	44.1%	32.8%	25.6%	20.6%
Other					
Biomass - Regional					
Geothermal - Regional					
PV Solar - Micro		0.0%	0.0%	0.0%	0.0%
% of total elec. dem. households					
% of total elec. dem. lux. hotels					
% of total elec. dem. eco- hotels					
Heat Generators	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**
Solar Thermal - Micro		0.0%	0.0%	0.0%	0.0%
% of total heat dem. households					
% of total heat dem. lux. hotels					
% of total heat dem. eco- hotels					
AgroRes. Digestion - Regional					
Wood Combustion - Regional					
Total % of demand that is met:	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Figure 8.2. The Input sheet for constructing energy demand and supply scenarios.

In addition, the Input sheet contains buttons which –when clicked– automatically generate *predefined* demand and supply scenarios[1]. These predefined scenarios are constructed after quantified data were available, especially regarding costs, and are used here to facilitate the demonstration.

The Business-As-Usual button will insert the Business-As-Usual (BAU) energy infrastructure option, containing the BAU demand and supply scenarios that were already discussed in Chapter 7 (see Table 7.11 and Table 7.19). This BAU options represents a continuation of current trends. Note that the values listed in Figure 8.2 belong to the BAU energy infrastructure option. The other predefined scenarios reflect 'extreme' situations either concerning future socio-economic development and thus energy demand, or concerning the way energy is generated and supplied to the end-users. The 'extreme' scenarios thus represent a discontinuity in current trends. The 'extreme' scenarios are chosen in such a way that they clearly show the differences in consequences. The following sub-sections will focus on the three predefined 'extreme' *demand* scenarios: Eco-Tourism, Mass-Tourism, and Agro-Industry. Section 8.5 will discuss the predefined *supply* scenarios.

8.4.1. Eco-Tourism Demand Scenario

The Eco-Tourism demand scenario assumes a development focused on promoting eco-tourism in the Coopelesca area, so tourism activities are geared to the demands and needs of eco-tourists. The eco-tourists are defined as requiring only basic facilities, spending money on a low-budget basis, and traveling from place to place rather than staying at one place for a long period of time. The eco-tourists generally appreciate places undiscovered by most tourists, and respect the environment as well as the local customs, to which the eco-tourist willingly tries to adapt (to a certain extent).

In the Eco-Tourism demand scenario, the number of eco-tourists rises substantially, resulting in an absolute value in 2020 that is about 2.5 times more than the number of eco-tourists in the BAU scenario for that same year. However, this does not disrupt the live of the local inhabitants as much as would an increase in the number of luxury tourists. The eco-tourists also stay longer in the area compared to the BAU scenario, using (small) hotels with only basic facilities (e.g., not all hotels or rooms have hot showers, none have TVs). The lack of luxury facilities cause the luxury tourists to stay away, causing the number of luxury tourists in 2020 to drop to about half of that in the BAU scenario. Some facilities such as Internet cafes become available in the major towns, increasing the number of commercial clients (other than hotels) slightly compared to the BAU scenario.

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[1] Each button, when clicked, will first show a dialog box that explains what the following action will be. Clicking the 'Cancel' button in the dialog box will abort the action and return to the main program, clicking 'OK' will execute the action.

In addition, laws are established and enforced to ensure the conservation of the environment, and awareness and education programs inform both the local people and the visitors about how to remain the pressure on the environment low. However, the increasing number of eco-tourists could imply that –even though the pressure on the environment per eco-tourist is relatively low– some sites may require a daily quota of visitors to prevent exceeding their resilience capacity. The revenues from eco-tourism are likely not sufficient to depend upon for the entire local community[2], and other sources of income i.e., agro-industrial activities, remain necessary. However, expansion of the agricultural activities would negatively affect the natural scenery –and thus the attractiveness of the sites to eco-tourists. So growth in the agro-industry is only allowed through intensification of production (i.e., more electricity demand per industrial client), holding the number of industrial clients and the cultivated area constant. This also implies that absolute values for the number of industrial clients and the size of the cultivated area drop slightly compared to the BAU scenario, in which there is room for expansion. Other growth rates are assumed to be the same as in the BAU scenario. Table 8.2 gives an overview of the growth rates used in the Eco-Tourism demand scenario. Values in bold indicate the differences with the BAU scenario.

Table 8.2. Values and growth rates for the Eco-Tourism demand scenario.

Eco-Tourism Demand Scenario	**2000**		**2005**	**2010**	**2015**	**2020**
Variables	*Values*	*Unit*	*Annual Growth Rates*			
Residential Energy Demand						
Number of clients	37,864	-	5.7%	4.7%	3.5%	2.9%
Electricity demand per client	1,672	kWh/yr	1.0%	2.0%	2.0%	2.0%
Heat demand per client	628	kWh/yr	1.0%	2.0%	2.0%	2.0%
Commercial Energy Demand						
Number of luxury tourists	91,398	-	**3.0%**	**1.0%**	**-1.0%**	**-3.0%**
Number of eco-tourists	137,097	-	**7.0%**	**9.0%**	**9.5%**	**9.0%**
Number of nights of luxury stay	3.5	-	0.0%	0.0%	0.0%	0.0%
Number of nights of eco-stay	2.5	-	**1.0%**	**2.0%**	**3.0%**	**2.0%**
Number of other clients	5,041	-	**4.5%**	**4.0%**	**3.0%**	**2.5%**
Electricity demand per other client	7,151	kWh/yr	3.0%	3.0%	2.5%	2.0%
Industrial Energy Demand						
Number of industrial clients	1,218	-	**0.0%**	**0.0%**	**0.0%**	**0.0%**
Electricity demand per client	40,060	kWh/yr	**6.0%**	**5.0%**	**4.5%**	**4.0%**
Growth in cultivated area			**0.0%**	**0.0%**	**0.0%**	**0.0%**

8.4.2. Mass-Tourism Demand Scenario

The Mass-Tourism demand scenario implies a development focused on promoting mass-tourism in the region, and facilities are geared to the demands and needs of luxury tourists. The luxury tourists have high expenditures (see Table 7.24) and appreciate a comfortable

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[2] For more information on local development through eco-tourism, see Stem (2001).

stay, having much more facilities at their disposal than the eco-tourists. On average, the luxury tourists stay in one area for a long period of time, occasionally making daytrips to other areas.

In the Mass-Tourism scenario, the number of luxury tourists rises substantially, amounting to an absolute value in 2020 that is about 2.5 times more than the number of luxury-tourists in the BAU scenario. The nights they stay also increases. This affects the lives of the local people, as places become crowded and noisy and local entrepreneurs adapt their goods and services towards the needs and demands of the luxury tourists. Also, both the increasing number of luxury tourists and the increased economic activity raise the pressure on the environment. Eco-tourists start avoiding the crowded places in search for more authentic, undisturbed sites, reducing the number of eco-tourist in 2020 to only 30% of that in the BAU scenario for that same year. Furthermore, there is little space for expansion of agricultural activity. For many it becomes more lucrative to work in the tourism sector, so that agricultural activities are abandoned to create room for tourism activities. The number of industrial clients and the cultivated area in 2020 is therefore only 70% of those values in the BAU scenario. Tourism thus becomes the main source of income by far, and attracts people from other regions seeking (better) jobs, thereby increasing the number of residential clients. On average, these residential clients will have more income, as expenditures of luxury tourists provide more revenues than the agro-activities. As a result, households have more electrical appliances, causing in turn an increase in the electricity demand per residential client. The number of tourism entrepreneurs (i.e., commercial clients other than hotels) also increases compared to both the BAU scenario and the Eco-Tourism scenario. The facilities that the entrepreneurs offer are also more luxury, causing an increase in the electricity demand per other commercial client as well. Other growth rates are assumed to be the same as in the BAU scenario. Table 8.3 gives an overview of the growth rates used in the Mass-Tourism demand scenario.

Table 8.3. Values and growth rates for the Mass-Tourism demand scenario.

Mass-Tourism Demand Scenario	**2000**		**2005**	**2010**	**2015**	**2020**
Variables	*Values*	*Unit*	*Annual Growth Rates*			
Residential Energy Demand						
Number of clients	37,864	-	**6.0%**	**5.5%**	**4.0%**	**3.5%**
Electricity demand per client	1,672	kWh/yr	**1.5%**	**2.5%**	**3.0%**	**2.5%**
Heat demand per client	628	kWh/yr	1.0%	2.0%	2.0%	2.0%
Commercial Energy Demand						
Number of luxury tourists	91,398	-	**9.0%**	**14.0%**	**20.0%**	**18.0%**
Number of eco-tourists	137,097	-	**3.0%**	**1.0%**	**-1.0%**	**-3.0%**
Number of nights of luxury stay	3.5	-	**1.0%**	**3.0%**	**4.0%**	**3.0%**
Number of nights of eco-stay	2.5	-	**-1.0%**	**-3.0%**	**-4.0%**	**-5.0%**
Number of other clients	5,041	-	**5.0%**	**4.5%**	**4.0%**	**3.0%**
Electricity demand per other client	7,151	kWh/yr	**4.0%**	**4.0%**	**3.0%**	**3.0%**
Industrial Energy Demand						
Number of industrial clients			**0.0%**	**-1.0%**	**-2.0%**	**-2.0%**
Electricity demand per client	1,218	-	5.5%	4.5%	4.0%	3.5%
Growth in cultivated area	40,060	kWh/yr	**0.5%**	**-0.5%**	**-1.5%**	**-1.5%**

Note that if no measures are taken (e.g., waste disposal plans, environmental laws, etc.), the pressure on the environment increases to a degree that sites become unattractive, which may eventually lead to a decrease in the number of luxury tourists on the longer term.

8.4.3. Agro-Industry Demand Scenario

The Agro-Industry demand scenario implies a development focused on expansion of agricultural activities and the associated agro-industry related to bananas, sugar cane, oranges, pineapple, and wood. As a consequence, in 2020 the number of industrial clients and the cultivated area both have increased to a value that is about 1.5 times the values in the BAU scenario. Land clearings and expansion of the infrastructure negatively affect the natural scenery, causing both luxury and eco-tourism to become marginal sectors in the region, with tourists mostly passing through to more attractive areas. As a consequence, the number of commercial clients (other than hotels) also decreases. However, the expansion of agro-activities creates jobs in the agro-sector, causing migration of people from other regions to the Coopelesca area and consequently an increase in the number of residential clients. Nonetheless, the income of households is not significantly improved compared to the BAU scenario, so the electricity demand per household is the same as in the BAU scenario. Other growth rates are assumed to be the same as in the BAU scenario. Table 8.4 gives an overview of the growth rates used in the Agro-Industry demand scenario.

Table 8.4. Values and growth rates for the Agro-Industry demand scenario.

Agro-Industry Demand Scenario	**2000**		**2005**	**2010**	**2015**	**2020**
Variables	*Values*	*Unit*	*Annual Growth Rates*			
Residential Energy Demand						
Number of clients	37,864	-	**6.0%**	**5.5%**	**4.0%**	**3.5%**
Electricity demand per client	1,672	kWh/yr	1.0%	2.0%	2.0%	2.0%
Heat demand per client	628	kWh/yr	1.0%	2.0%	2.0%	2.0%
Commercial Energy Demand						
Number of luxury tourists	91,398	-	**3.0%**	**-1.0%**	**-3.0%**	**-6.0%**
Number of eco-tourists	137,097	-	**3.0%**	**-1.0%**	**-3.0%**	**-6.0%**
Number of nights of luxury stay	3.5	-	**-1.0%**	**-3.0%**	**-4.0%**	**-5.0%**
Number of nights of eco-stay	2.5	-	**-1.0%**	**-3.0%**	**-4.0%**	**-5.0%**
Number of other clients	5,041	-	**2.0%**	**1.5%**	**1.0%**	**0.5%**
Electricity demand per other client	7,151	kWh/yr	3.0%	3.0%	2.5%	2.0%
Industrial Energy Demand						
Number of industrial clients			**1.0%**	**2.0%**	**4.0%**	**3.0%**
Electricity demand per client	1,218	-	5.5%	4.5%	4.0%	3.5%
Growth in cultivated area	40,060	kWh/yr	**1.5%**	**2.5%**	**4.5%**	**3.5%**

This concludes the description of the predefined demand scenarios. Note that the users of the tool can also insert other demand scenarios manually, or use a predefined scenario as a basis, which is then (partly) altered manually[3]. We will now turn to the predefined supply scenarios.

8.5. Tool Input: Energy Supply Scenarios

Apart from the Business-As-Usual button, there are three other buttons on the Input sheet that automatically generate predefined supply scenarios: the ‘Micro Supply’ button, the ‘Regional Supply’ button, and the ‘Max. Supply’ button. These buttons correspond to a supply scenario for self-sufficiency at the micro level, a supply scenario for self-sufficiency at the regional level, and a supply scenario that uses the maximum available regional resources. All three predefined supply scenarios are discussed below. The exact percentages that technologies contribute in a supply scenario depend on the chosen demand scenario, so are not given here, but examples are given in Section 8.6, when discussing examples of possible energy infrastructure options. Note that the users of the tool can also insert supply scenarios manually, but only after the demand scenario has been constructed, as the supply scenarios must match demand at all times.

8.5.1. Micro Supply Scenario: Self-Sufficiency at the Micro-Level

The Micro supply scenario is based on attaining self-sufficiency at the micro level: every building uses a micro-system to generate –as much as possible– the energy that is demanded by that same building (and the equipment in it). Generally, this is only feasible if the demand per building is relatively low, which is the case if only basic needs are met or if energy-efficient in-house equipment is used. Most buildings are currently already connected to an existing energy infrastructure. For those buildings we will require that only the *growth* in energy demand has to be met by micro-systems, while the status quo of the existing infrastructure is preserved. So there is no substitution of energy infrastructure that already existed (or was already planned) in 2000. If the required supply exceeds the resource potential associated with the micro-systems, the remaining demand is met by importing electricity from the national grid, which thus serves as a back-up facility. The energy technologies in the Micro Supply scenario include PV (photovoltaic) solar panels to generate electricity, and thermal solar collectors to supply the energy used for heating tap water. For the sake of simplicity, we will exclude –for now– the buildings that are not yet grid connected from the analysis.

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[3] Note that some predefined supply scenarios need to be recalculated after demand values have been changed, see § 8.5.

8.5.2. Regional Supply Scenario: Self-Sufficiency at the Regional Level

The Regional Supply scenario is based on self-sufficiency at the regional level: it uses the available regional energy sources to meet energy demand, in order of least cost. So this option does not only meet the growth in energy demand by regional energy production, it also substitutes all electricity imported from the national grid. For details on the calculation see Appendix F. This supply scenario is –in potential– able to meet a considerable increase in energy demand, as the regional energy resources are substantial.

8.5.3. Maximum Supply Scenario: Maximum Use of Energy Potential

The Maximum Supply scenario aims for the maximum use of all regional energy resources. The available regional energy sources are used to meet regional demand of both heat and electricity. However, the available resources in Huetar Norte easily exceed the amount needed to meet regional demand. If the costs of supplying electricity to the national grid are lower than the price received for the exported electricity (the so-called pay-back price per kWh), the regional technologies will use as much resources as possible to generate electricity for export, in order of cost effectiveness (note that in our example heat cannot be exported). For details on the calculations see Appendix F. This supply scenario is suited for meeting high increases in energy demand.

This concludes the description of the predefined supply scenarios, and the discussion of the Input sheet. We will now discuss the construction of energy infrastructure options, which are basically combinations of demand and supply scenarios.

8.6. Tool Input: Energy Infrastructures Options

Including the BAU scenarios, there are sixteen possible energy infrastructure options following from the combinations of the predefined supply and demand scenarios, but not all of them are equally realistic. Many more options are possible if scenarios are constructed manually. To allow for a clear and detailed discussion, we will restrict the analysis to only four of them:

- The Business-As-Usual option
- Option I: Eco-Tourism & Self-Sufficiency Supply on the Micro-Level
- Option II: Mass Tourism & Self-Sufficiency Supply on the Regional Level
- Option III: Agro-Industry & Maximum Use of Energy Potential

We already presented the BAU supply scenario that matches with the BAU demand scenario in Table 7.19. The contributions of energy technologies that result from the other combinations are listed in Table 8.5 (Option I), Table 8.6 (Option II), and Table 8.7 (Option III) respectively. Table 8.5 shows that for Option I (Eco-Tourism & Micro Supply), the PV systems cannot supply all of the extra electricity demand in the periods 2005, 2015, and 2020 because the resource potential is not sufficient. This is visible from the 'max' indicators preceding the percentages. Table 8.6 shows that for Option II (Mass-Tourism & Regional Supply), the least-cost heat technology is wood combustion, but the resource potential is not enough to meet total heat demand. The second-least-cost technology for heat supply appears to be regional hydropower, at least for the periods 2005, 2010,and 2015. Regional hydropower is also the least-cost technology for supplying electricity, and has enough resource potential to meet the remaining heat demand and the total demand for electricity during all periods. However, for the period 2020, the second-least-cost technology for supplying heat becomes agro-residues digestion, which together with wood combustion can meet total heat demand for this period.

Table 8.5. The Micro Supply scenario that matches the Eco-Tourism demand scenario of Option I.

Micro Supply matching **Eco-Tourism**		*Contribution in Meeting Total Energy Demand*				
Technologies	*Scale*	**2000**	**2005**	**2010**	**2015**	**2020**
Total Heat Generators		***0%***	***3.9%***	***6.9%***	***8.7%***	***10.1%***
Agro-Residues Digestion	Regional					
Wood Combustion	Regional					
Solar Thermal	Micro		3.9%	6.9%	8.7%	10.1%
% of household demand	Micro		27.9%	48.1%	60.4%	68.9%
% of demand luxury hotels	Micro		13.7%	17.9%	13.7%	25.6%
% of demand eco-hotels	Micro		38.3%	49.2%	60.2%	67.2%
Total Electricity Generators		***100%***	***96.1%***	***93.1%***	***91.3%***	***89.9%***
Hydro	Local					
Hydro	Regional	16.9%	43.8%	32.2%	24.7%	19.6%
Chocosuela	Regional	16.9%	43.8%	32.2%	24.7%	19.6%
Other	Regional					
Biomass	Regional					
Geothermal	Regional					
PV Solar	Micro		10.4%	18.2%	23.2%	26.9%
% of household demand	Micro		27.9%	48.1%	60.4%	68.9%
% of demand luxury hotels	Micro		**max**. 7.1%	6.3%	**max**. 7.4%	**max**. 7.7%
% of demand eco-hotels	Micro		**max**. 9.9%	8.8%	**max**.13.6%	**max**.16.0%
National Grid Import	National	83.1%	41.9%	42.6%	43.0%	43.0%
Total % of Demand Met:	**Regional**	***100%***	***100%***	***100%***	***100%***	***100%***

Table 8.6. The Regional Supply scenario matching the Mass-Tourism demand scenario of Option II.

Regional Supply matching Mass-Tourism		*Contribution in Meeting Total Energy Demand*				
Technologies	*Scale*	**2000**	**2005**	**2010**	**2015**	**2020**
Total Heat Generators		***0%***	***4.6%***	***5.0%***	***5.0%***	***max. 13.5%***
Agro-Residues Digestion	Regional					8.9%
Wood Combustion	Regional		**max**. 4.6%	5.0%	**max**. 5.0%	**max**. 4.7%
Solar Thermal	Micro					
% of household demand	Micro					
% of demand luxury hotels	Micro					
% of demand eco-hotels	Micro					
Total Electricity Generators		***100%***	***95.4%***	***95.0%***	***95.0%***	***86.5%***
Hydro	Local					
Hydro	Regional	16.9%	95.4%	95.0%	95.0%	86.5%
Chocosuela	Regional	16.9%	42.5%	29.7%	21.2%	14.9%
Other	Regional		52.9%	65.9%	73.8%	71.6%
Biomass	Regional					
Geothermal	Regional					
PV Solar	Micro					
% of household demand	Micro					
% of demand luxury hotels	Micro					
% of demand eco-hotels	Micro					
National Grid Import	National	83.1%	0%	0%	0%	0%
Total % of Demand Met:	Regional	***100%***	***100%***	***100%***	***100%***	***100%***

Table 8.7. The Max. Supply scenario that matches the Agro-Industry demand scenario of Option III.

Max. Supply matching Agro-Industry		*Contribution in Meeting Total Energy Demand*				
Technologies	*Scale*	**2000**	**2005**	**2010**	**2015**	**2020**
Total Heat Generators		***0%***	***4.8%***	***5.4%***	***5.4%***	***15.6%***
Agro-Residues Digestion	Regional					10.2%
Wood Combustion	Regional		**max**. 4.8%	**max**. 5.4%	**max**. 5.4%	**max**. 5.4%
Solar Thermal	Micro					
% of household demand	Micro					
% of demand lux. hotels	Micro					
% of demand eco-hotels	Micro					
Total Electricity Generators		***100%***	***! 427.8%***	***! 906.4%***	***! 861.7%***	***! 817.7%***
Hydro	Local		**max**. 74.5%	**max**. 79.8%	**max**. 75.7%	**max**. 71.7%
Hydro	Regional	16.9%	**max**. 53.4%	**max**.378.7%	**max**. 59.3%	**max**.340.2%
Chocosuela	Regional	16.9%	44.6%	31.9%	22.7%	17.2%
Other	Regional		308.7%	**max**.346.8%	**max**.336.6%	**max**.323.0%
Biomass	Regional			**max**. 35.7%	**max**. 35.6%	**max**. 35.4%
Geothermal	Regional			**max**.412.2%	391.1%	370.3%
PV Solar	Micro					
% of household demand	Micro					
% of demand lux. hotels	Micro					
% of demand eco-hotels	Micro					
National Grid Import	National	83.1%	-332.6%	-881.8%	-767.1%	-733.3%
Total % of Demand Met:	Regional	***100%***	***! 432.6%***	***! 911.8%***	***! 867.1%***	***! 833.3%***

Table 8.7 shows that Option III (Agro-Industry & Maximum Supply) implies the export of electricity from the Coopelesca area to the national grid. Technologies for which the costs of generating and transporting regional electricity to the national grid are lower than the payback price will use their resource potential to the maximum amount available. This is the case for local-hydro, regional-hydro, biomass, and geothermal (although the latter only as from 2010). Note that the amount of exported electricity (listed as the negative value for 'national grid import' in Table 8.7) will almost certainly affect national electricity production, both in amount produced and in price, but this effect lies outside the scope of our analysis.

With the infrastructure options constructed, we can begin to assess the impacts of these options. However, first we will use the Spotting Conflicts sheet to determine whether indicators can cause conflicting interests between actors.

8.7. Spotting Conflicts Between Actors

The Spotting Conflicts sheet lets actors express their preferred scores on indicators so that possible conflicts between actors can be spotted in advance. Since we do not know the preferred scores of the real actors exactly (the indicators could not be set during the Costa Rica field study, so no feedback was obtained from the actors concerning their preferred scores), we will assume likely preferences of the actors be to be able to continue the demonstration. Figure 8.3 shows the 'Spotting Conflicts' sheet after the actors have expressed their (assumed) preferred scores on all the indicators.

There are no obvious conflicting interests, as there are no opposite bars for any of the indicators. However, actors that have not expressed a preference (because they either have no opinion, are indifferent, or are ambivalent with respect to a particular indicator, see § 7.7.2) can also get in conflict with actors that have very pronounced preferences. For instance, the habitants and entrepreneurs prefer a very low score on environmental damage, whereas the farmers are ambivalent: they realize that a polluted environment could impair their production, but they also want to be able to expand their activities even if this implies further deforestation and loss of primary nature. The energy companies appear to be indifferent; they are not particularly interested in the scores on this indicator. So both the energy companies and the farmers could opt for an energy infrastructure option that causes substantial environmental damage, while such an option is certainly rejected by the local habitants and entrepreneurs. Another potential conflict could be found in the preferred scores on the competitiveness of the energy sector. Only the government and the energy companies have a distinct preference for a high competitiveness, the other actors have no opinion or are indifferent. Regional economic development is also an indicator that could lead to possible conflicts, as the government and the entrepreneurs prefer (very) high economic development, while local habitants are ambivalent. The latter argue that not all forms of rapid economic development will benefit regional society.

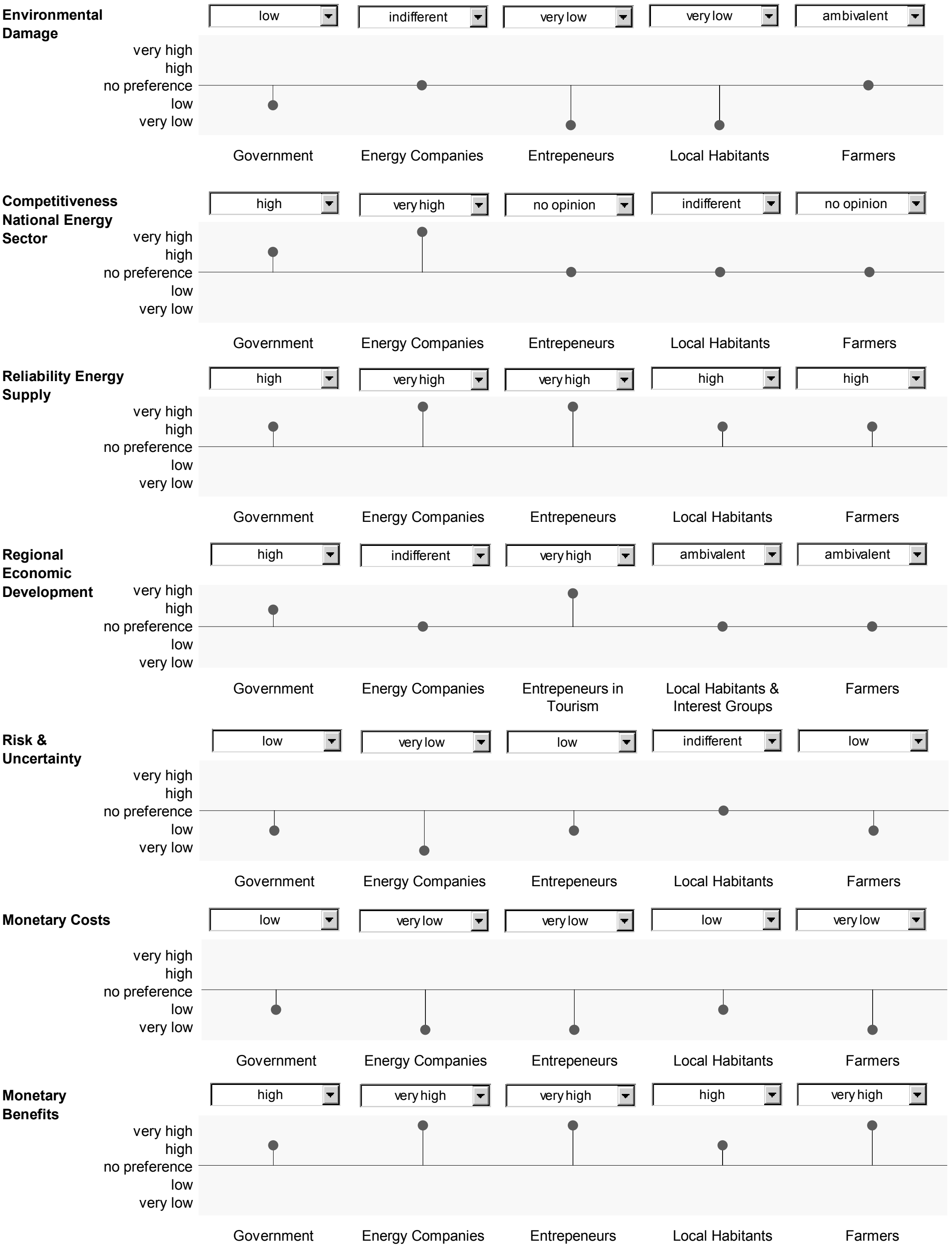


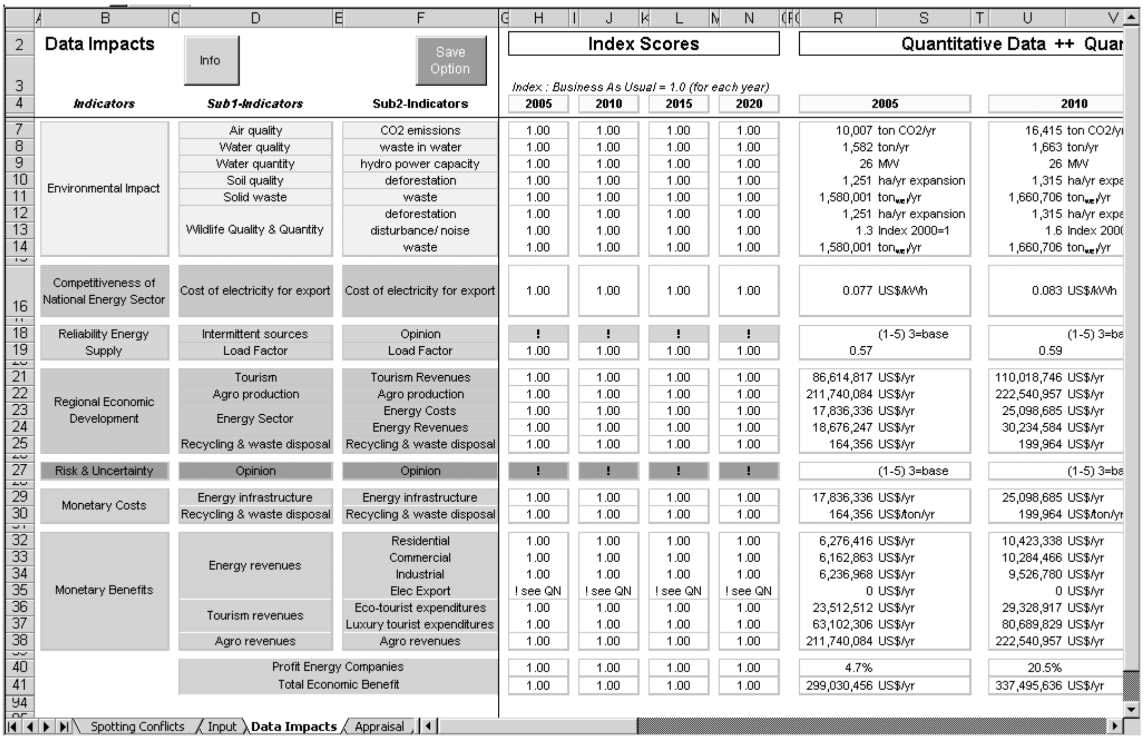
Figure 8.3. The 'Spotting Conflicts' sheet showing the actors' preferred scores on the indicators. Conflicting preferences are immediately evident from opposite amplitudes.

They fear that traditions and values may be affected, especially with herds of 'inconsiderate' tourists, or that the environment will be severely damaged as a result of development. Farmers are also ambivalent, as they prefer economic development, but only if this implies that there is room for expansion of agro-activities. Note that preferred scores on the costs and benefits indicators all point out in the same direction, but can nonetheless imply conflicts, as the costs and benefits are usually not equally divided among the actors; high benefits for one actor may imply high costs for another. This is also expressed by the ‘Distribution of Costs and Benefits’ indicator, which is not included in the ‘Spotting Conflicts’ sheet as it does not have higher or lower scores. Also note that preferences may change when actors gain new information. This new information is usually related to the impacts of options, and thus presented on the ‘Data Impacts’ sheet, our next topic.

8.8. Viewing Impact Data

8.8.1. Data Impacts Sheet

The ‘Data Impacts’ sheet contains the quantitative data corresponding to the chosen energy infrastructure option in the ‘Input’ sheet. The sheet also contains the ‘index scores’ relating the absolute scores of the chosen option to those of the Business-As-Usual option, to give better insight in the relative impacts. Figure 8.4 illustrates what the ‘Data Impacts’ sheet looks like. The ‘Info’ button on the ‘Data Impacts’ sheet gives more information on what type of data the sheet contains, how to interpret the data, and what is expected of the user.



Data Impacts

Index : Business As Usual = 1.0 (for each year)

			Index Scores				Quantitative Data ++ Quar	
Indicators	***Sub1-Indicators***	**Sub2-Indicators**	**2005**	**2010**	**2015**	**2020**	**2005**	**2010**
Environmental Impact	Air quality	CO2 emissions	1.00	1.00	1.00	1.00	10,007 ton CO2/yr	16,415 ton CO2/y
	Water quality	waste in water	1.00	1.00	1.00	1.00	1,582 ton/yr	1,663 ton/yr
	Water quantity	hydro power capacity	1.00	1.00	1.00	1.00	26 MW	26 MW
	Soil quality	deforestation	1.00	1.00	1.00	1.00	1,251 ha/yr expansion	1,315 ha/yr expa
	Solid waste	waste	1.00	1.00	1.00	1.00	1,580,001 ton_{we}/yr	1,660,706 ton_{we}/yr
	Wildlife Quality & Quantity	deforestation	1.00	1.00	1.00	1.00	1,251 ha/yr expansion	1,315 ha/yr expa
		disturbance/ noise	1.00	1.00	1.00	1.00	1.3 Index 2000=1	1.6 Index 200
		waste	1.00	1.00	1.00	1.00	1,580,001 ton_{we}/yr	1,660,706 ton_{we}/yr
Competitiveness of National Energy Sector	Cost of electricity for export	Cost of electricity for export	1.00	1.00	1.00	1.00	0.077 US$/kWh	0.083 US$/kWh
Reliability Energy Supply	Intermittent sources	Opinion	!	!	!	!	(1-5) 3=base	(1-5) 3=ba
	Load Factor	Load Factor	1.00	1.00	1.00	1.00	0.57	0.59
Regional Economic Development	Tourism	Tourism Revenues	1.00	1.00	1.00	1.00	86,614,817 US$/yr	110,018,746 US$/yr
	Agro production	Agro production	1.00	1.00	1.00	1.00	211,740,084 US$/yr	222,540,957 US$/yr
	Energy Sector	Energy Costs	1.00	1.00	1.00	1.00	17,836,336 US$/yr	25,098,685 US$/yr
		Energy Revenues	1.00	1.00	1.00	1.00	18,676,247 US$/yr	30,234,584 US$/yr
	Recycling & waste disposal	Recycling & waste disposal	1.00	1.00	1.00	1.00	164,356 US$/yr	199,964 US$/yr
Risk & Uncertainty	Opinion	Opinion	!	!	!	!	(1-5) 3=base	(1-5) 3=ba
Monetary Costs	Energy infrastructure	Energy infrastructure	1.00	1.00	1.00	1.00	17,836,336 US$/yr	25,098,685 US$/yr
	Recycling & waste disposal	Recycling & waste disposal	1.00	1.00	1.00	1.00	164,356 US$/ton/yr	199,964 US$/ton/y
Monetary Benefits	Energy revenues	Residential	1.00	1.00	1.00	1.00	6,276,416 US$/yr	10,423,338 US$/yr
		Commercial	1.00	1.00	1.00	1.00	6,162,863 US$/yr	10,284,466 US$/yr
		Industrial	1.00	1.00	1.00	1.00	6,236,968 US$/yr	9,526,780 US$/yr
		Elec Export	! see QN	! see QN	! see QN	! see QN	0 US$/yr	0 US$/yr
	Tourism revenues	Eco-tourist expenditures	1.00	1.00	1.00	1.00	23,512,512 US$/yr	29,328,917 US$/yr
		Luxury tourist expenditures	1.00	1.00	1.00	1.00	63,102,306 US$/yr	80,689,829 US$/yr
	Agro revenues	Agro revenues	1.00	1.00	1.00	1.00	211,740,084 US$/yr	222,540,957 US$/yr
	Profit Energy Companies		1.00	1.00	1.00	1.00	4.7%	20.5%
	Total Economic Benefit		1.00	1.00	1.00	1.00	299,030,456 US$/yr	337,495,636 US$/yr

Figure 8.4. Example of the Data Impacts sheet (with qualitative data and index scores corresponding to the BAU energy infrastructure option).

To further assess an option, it has to be saved, and to save a chosen option the user can click on the 'Save Scenario' button (present in both the 'Data Impacts' sheet and the 'Input' sheet). This will create a new sheet named by the actor, containing both the input values and the data on the impacts.

8.8.2. Saved Option Sheets

A saved option will look very similar to the general Data Impacts sheet, except for the deviating buttons in the upper left corner: the 'Info' button, the 'Assign Scores' button, the 'View Input Values' button, and the 'Delete Option' button (see also Appendix G). Each saved option sheet starts with an information box explaining the purpose of the sheet and what is expected of the user. Clicking the 'Info' button on the sheet will also show this information. The 'View Input Values' button shows the input values underlying the impact data shown on the sheet, and the 'Assign Scores' button is used to determine the overall scores on the indicators (see § 8.9). Note that the users can also delete a saved option (and all the scores assigned to the indicators for this option) by clicking the 'Delete Option' button.

The options that we want to save for further assessment are the BAU option as a reference case and the three extreme energy infrastructure options presented in Section 8.6: Option I - Eco-Tourism & Micro Supply; Option II - Mass-Tourism & Regional Supply; and Option III - Agro-Industry & Maximum Supply. The Saved Option sheets are named 'Data BAU'; 'Data EcoT&Micro' representing Option I; 'Data MassT&Regional' representing Option II; and 'Data Agro&Max' representing Option III. The impact data corresponding to these options (and the BAU option) are listed in Appendix G. Here, we only present the general conclusions that can be drawn from the impact data, and this is the subject of the next section.

8.8.3. Assessing the Scores on Indicators

In this section we discuss how the three extreme energy infrastructure options score (relative to the BAU scenario) on the indicators, and what conclusions can be drawn from that. Details on the impact data corresponding to these options (and the BAU option) are listed in Appendix G.

➢ *Environmental Impacts*

The Data sheets on the impacts of the options reveal that all three options cause less CO_2 emissions than the BAU option. Option I (EcoT&Micro) has about half of the emissions of the BAU option, while Option II (MassT&Regional) has no emissions at all. Option III (Agro&Max) causes the lowest amount of CO_2 emissions: it has negative amounts of CO_2 emissions due to the fact that this Option involves export of electricity that is generated with renewable resources. This implies that CO_2 emissions are *avoided*; the electricity exported does not have to be generated by a fossil fuel system elsewhere.

The amount of waste that ends up in the environment and in surface waters is lowest with Option II, as agro-activities have diminished and thus biomass residues (that make up for the majority of the waste) are relatively few. Next in line is Option I, followed by Option III, and the BAU option. So all extreme options have lower amounts of waste ending up in the environment than the BAU option. Note that Option III does produce more biomass residues than any other option, but these residues are (partly) used for energy production, while the number of tourists has dropped and thus the waste produced by them. Also note that in 2005, Option III implies slightly more waste than the BAU option, but this is reversed in the next periods.

An indication for the quantity of water is the installed capacity of hydropower systems. Option I has the same installed capacity as the BAU option, while both Option II and Option III have more installed capacity, although Option III has the most capacity by far.

Deforestation is measured by the expansion of cultivated area for agro-activities, and is lowest (i.e., negative) for Option II, as most agro-activities have been substituted by tourism activities and more land becomes available again for forests. Option I also has less deforestation than the BAU option: even though it still depends partly on agro-activities, the efforts to conserve the environment restrict a further expansion of the cultivated area. Option III, on the other hand, causes a substantial increase in deforestation compared to the BAU option, as a result of the focus on agro-activities and the severe decrease in tourism activities.

Finally, noise and disturbance is lowest in Option III, due to the absence of a large number of tourists. Option I and Option II both imply more noise and disturbance than the BAU option, with Option II causing the most disturbance by far. Note that in 2005, both Option I and Option II cause slightly less disturbance and noise than the BAU option, but this changes in the subsequent periods.

- *Competitiveness on the International Energy Market*

The competitiveness of the national electricity (production) sector is ‘measured’ by letting actors assign scores that express their opinion on how the infrastructures score on this indicator.

- *Reliability of Energy Supply*

The reliability of the energy supply is also ‘measured’ by the opinions of actors, although they can take into consideration aspects such as the extent to which intermittent energy resources are used (see § 8.6). Option I (EcoT&Micro) uses the existing energy infrastructure plus solar systems for the additional energy demand after 2000. The sun is an intermittent *flow* of energy and relatively unreliable, but any demand that is not met by the solar systems is automatically imported from the national grid[4]. Option II

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[4] However, if –because of a lack of sun– the solar systems supply less than what they are estimated to do, and extra electricity has to be imported, this implies extra unforeseen costs.

(MassT&Regional) depends largely on hydropower systems and a little on wood combustion units, technologies that use *energy carriers* that can be stored (see § 7.9.2). However, dry periods may cause a lack of water, while the availability of wood depends on the production of the agro-sector. So the supply of these energy carriers is not guaranteed, although sufficient backup such as water reservoirs and wood storage can overcome a temporary decrease in resource supply. Option III (Agro&Max) uses hydropower plants, biomass units, and geothermal units. So besides the use of (large amounts of) water and biomass, this option also uses the earth's heat, which is a continuous energy flow and thus relatively reliable. Note that the reliability of supply can also be affected by the diversity of resources used: a more diverse mix of resources spreads the risk of not meeting demand. From this perspective, Option III would provide more reliability, followed by Option I, while Option II makes use of only hydropower units. Note that in any case, a lack of regional resources can always be overcome by importing electricity, although the national electricity production heavily depends on hydropower.

- *Regional Economic Development*

Overall economic development is measured by summing the (annual) revenues from tourism, agro-activities and energy, and subtracting the (annual) costs of energy and waste disposal. Doing so reveals that Option II scores highest, followed by Option III (Agro&Max) and Option I (EcoT&Micro). So all options have a higher economic development than the BAU option (the result is shown on the last line of the Data Impacts sheets in Appendix G). Note that for the period 2005, both Option I and Option III have a dip in economic development compared to the proceeding and following periods. Also note that Option I only has a higher economic development than the BAU option as from the period 2020; before that period economic development is lower.

- *Risk & Uncertainty*

The risk & uncertainty indicator is 'measured' by the opinions of actors. The risk and uncertainty associated with energy technologies is low for hydropower systems, as the technology is widely applied in Costa Rica, with a widespread network for services and spare parts, and a long history of experience. Geothermal units and solar systems are also currently applied in Costa Rica, but not widespread. In addition, biomass units are currently only incidentally used by individuals, so not much experience has been gained with these systems.

- *Monetary Costs*

The monetary costs include the costs of the energy infrastructure and the cost of disposing waste caused by tourism. The costs of the energy infrastructure are highest for Option III (Agro&Max), as it involves by far the highest energy production, and thus the most capacity installed. The BAU option has the lowest costs of energy infrastructure, but the costs of Option I (EcoT&Micro) are not much higher than the BAU option. Note that higher costs of the energy infrastructure may be offset by higher energy revenues. The cost of waste disposal is lowest for Option III, as there are only few tourists in this option. On the other hand, Option I and especially Option II (MassT&Regional) have higher costs than the BAU option due to the substantial increase in tourists associated with these options.

- *Monetary Benefits*

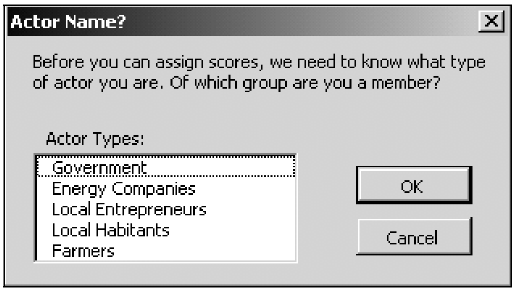
The monetary benefits include the revenues from energy, tourism, and agro-activities. The revenues from tourism are highest for Option II (MassT&Regional), followed by Option I (EcoT&Micro) and the BAU option. Option III (Agro&Max) has almost no tourism activities, and thus has much lower tourism revenues than the other options. The revenues from agro-activities are –not surprisingly– highest for Option III, while Option I and Option II have lower agro-revenues than the BAU option. The revenues from energy are highest for Option III (due to the export of electricity), and lowest for the BAU option, although the energy revenues in Option I are not much higher than the BAU option. Whether the energy revenues make up for the costs of the energy infrastructure is expressed by the profit of the energy companies, which is highest for Option II, followed by the BAU option. So Option I and Option III both have lower profits than the BAU option (Option I the lowest), although for both options the profits are still positive. Note the development in profits: in 2005, Option III is still more profitable than the BAU option, but this has changed in the period 2015. Similarly, Option II is less profitable than the BAU option in the beginning, but more profitable as of 2010. Option I starts off unprofitable, but recovers and is profitable as of 2015, although still not as profitable as the BAU option.

The last indicator ‘Distribution of Costs and Benefits’ is not directly visible on the Data Impacts sheets, but can be derived from it. The distribution of costs and benefits follows from attributing the costs and revenues of the different cost items to the different actors. Concerning the cost of waste disposal, the government has to pay the lowest cost for Option III (Agro&Max), while Option I (EcoT&Micro) and especially Option II (MassT&Regional) imply increased cost compared to the BAU option. For the energy companies, only Option II will imply more profit than the BAU option, while Option I and Option III both imply lower (but still positive) profit. The revenues for the entrepreneurs are highest for Option II, followed by Option I and the BAU option. Option III would imply a substantial reduction in tourism revenues. Finally, for the farmers only Option III has higher revenues of agro-activities than the BAU option, while Option I and Option II both have lower revenues than the BAU option. When considering the overall economic development of the region, all options show more growth than the BAU option, but Option II the most, followed by Option III.

Having examined the data on the Data Impacts sheets of the different energy infrastructure options, the actors are now ready to assign the overall scores to the indicators, which is the topic of the next section.

8.9. Assigning Scores to Indicators

After the actors have carefully examined the Data sheets with the impacts of the saved energy infrastructure options, they can assign overall scores on the general indicators by clicking on the ‘Assign Scores’ button. When this button is clicked, first a text box appears that explains what the button does and then –if continued– another window appears that asks the user to select an actor type (see Figure 8.5).



Before you can assign scores, we need to know what type of actor you are. Of which group are you a member?

Figure 8.5. After clicking the ‘Assign Scores’ button, actors first have to select the actor type they belong to.

After selecting an actor type, the actual ‘Assigning Scores’ window appears, showing all the indicators and a scrollbar next to each of them (see Figure 8.6). The identified actor is asked to express the overall scores for each indicator, based on the impact data that the actor regards as relevant. Expressing the scores is done by using the scroll bars, and the scores are relative to the Business-As-Usual option: moving the thumbnail to the left-hand side implies that –in the actor’s opinion– the current energy infrastructure option scores worse than the BAU option (the more it is moved to the left the worse it scores). Alternately, moving the thumbnail to the right-hand side implies that the current option scores better than the BAU option.

By default, all the checkboxes left of the indicators are checked. If the identified actor has no opinion or does not want to assign a score to a particular indicator, it can uncheck the checkbox, which makes the scrollbar disappear. The actor must select at least one indicator to be able to proceed. After assigning the scores, the user can click the OK button[5]. This will cause the program to switch to the ‘Appraisal’ sheet, where the newly assigned scores are listed in the web diagram of the appropriate actor type (see Figure 8.7). If an actor wants to change its scores for a particular option, it can just repeat the assign-scores procedure for that option. The newly assigned scores will overwrite the old ones for that option and that particular actor.

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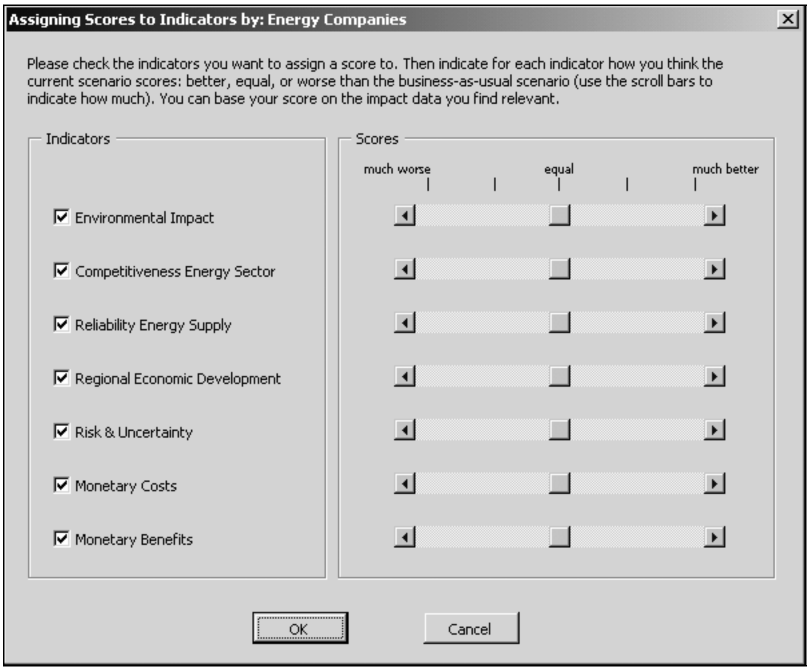
[5] Clicking Cancel will abort the assigning-scores procedure all together.



Assigning Scores to Indicators by: Energy Companies

Please check the indicators you want to assign a score to. Then indicate for each indicator how you think the current scenario scores: better, equal, or worse than the business-as-usual scenario (use the scroll bars to indicate how much). You can base your score on the impact data you find relevant.

Indicators

☑ Environmental Impact
☑ Competitiveness Energy Sector
☑ Reliability Energy Supply
☑ Regional Economic Development
☑ Risk & Uncertainty
☑ Monetary Costs
☑ Monetary Benefits

Figure 8.6. After the identified actor has selected an actor type, a new window appears where the actor can assign scores to the relevant indicators (in this example the identified actor is Energy Companies, as show in the title bar of the new window).

No actual data are available from the Costa Rica field study on the evaluation of the impact data by the actors. Consequently, we could not obtain actual scores on the general indicators, but to be able to fully demonstrate the tool, we will assume certain scores based on our interpretation of the interviews with the actors. The following sections address these overall scores.

8.9.1. Scores Assigned by the Government

We assume that the government believes there is less environmental damage with Option I (EcoT&Micro) than with the BAU option, as CO_2 emissions and waste have reduced, and deforestation is halted. Option II (MassT&Regional) has even less environmental damage than Option I, as CO_2 emissions are zero, waste is further reduced, and instead of deforestation there is now more room for reforesting. The government is somewhat ambivalent towards Option III (Agro&Max), as CO_2 emissions can be avoided with this option, but deforestation is relatively high. The government doesn't really know what score to assign, so decides to leave the score equal to the BAU option. The government believes that the competitiveness of the energy infrastructure is not really affected by either Option I or Option II, but in their view Option III would improve the competitiveness because of the export of cheaper electricity out of the region. The reliability of supply is believed to be slightly worse for Option I, due to the dependency on the sun as a resource. Option II is about as reliable as the BAU option. Option III uses a diversity in technologies, and the resources used are all relatively reliable with respect to supply, so this options scores better than any of the other options. The score for regional economic development is best for Option II, while Option III and Option I score slightly better than the BAU option. The government has currently no opinion with respect to risk and uncertainty. Option II, and less so Option I, score bad on the costs for recycling and waste disposal. Option III, on the other hand, scores better than the BAU option. The net benefits for the government are the same as for the economic development indicator.

8.9.2. Scores Assigned by the Energy Companies

The energy companies do not want to assign a score to the environmental damage indicator. The energy companies believe that Option III (Agro&Max) scores best on the competitiveness of the energy infrastructure, while Option II (MassT&Regional) is equal to the BAU option, and Option I (EcoT&Micro) scores worse. Furthermore, the energy companies believe that Option III also scores better on the reliability of supply, while Option II is about as reliable as the BAU option. Option I is less reliable because it partly relies on the sun as a resource. All options score better than the BAU option with respect to regional economic development, although Option II scores the best. According to the energy companies, risk and uncertainty in Option II is the same as in the BAU option, but Option III involves more risk (and thus scores worse), as it makes use of rather new technologies (biomass and geothermal systems). Option I scores the worst, as the energy companies believe solar energy systems involve a lot of risk and uncertainty. The costs of the energy infrastructure are highest for Option III, so it scores worst on this indicator, and although the revenues of Option III make up for the costs, the net benefits for the energy companies in Option III are the worst of all options. Option II, on the other hand, scores very well on the net benefits, and the costs are not that much worse than the BAU option. Finally, Option I scores worse than the BAU option on costs, but better than any of the other options. The net benefits, however, are lower than the BAU option (but better than Option III).

8.9.3. Scores Assigned by the Local Entrepreneurs

The local entrepreneurs believe that Option I (EcoT&Micro) scores best on environmental damage, because the quantity of water is not affected by extra hydropower plants, while waste is reduced and deforestation is halted. Option II (MassT&Regional) also scores better than the BAU option, but the entrepreneurs are a little concerned about the use of that many hydropower plants. Option III (Agro&Max) scores worse than the BAU scenario because of the deforestation and the use of many hydropower systems that might affect the quantity of water. The entrepreneurs do not wish to assign a score on the competitiveness of the energy infrastructure. Concerning the reliability of the energy supply, the entrepreneurs believe that

Option I and Option II score the same as the BAU option, but Option III might score better than the other options, because of the many resources used. Option II scores best on regional economic development, Option I also scores better than the BAU option, while Option III scores much worse than the BAU option because it implies a downfall in tourism. Therefore, Option III also scores much worse than the BAU option on risk and uncertainty, while Option I and Option II are believed to score about the same as the BAU option. The cost related to the energy infrastructure for the entrepreneurs will not differ much between options, but the benefits will. Option II scores best on monetary benefits, as the revenues from tourism are highest. Option I also scores better than the BAU option, while Option III scores much worse than the BAU option.

8.9.4. Scores Assigned by the Local Habitants

The local habitants believe that Option I (EcoT&Micro) scores best on environmental damage, because deforestation is halted, waste is reduced and there is not too much disturbance and noise from tourists. Since the disturbance and noise in Option II (MassT&Regional) are very high, this option scores slightly worse than the BAU scenario, while Option III (Agro&Max) scores much worse, with a lot of deforestation and only a little reduction of waste compared to the BAU option. The habitants do not have an opinion on the competitiveness indicator, nor on the risk and uncertainty indicator. Concerning the reliability of supply, the habitants believe that all options will be about as reliable as the BAU option. Regional economic development is highest in Option II, while Option I and Option III also score better than the BAU option. Furthermore, the habitants believe that the many tourists in Option II will cause an increase in the costs of living, so this option scores worse on costs, while the other options score the same. The monetary benefits for the habitants are not clear, but they believe that their income will probably rise in Option II as a result of the tourist expenditures, while it will be about the same in the other options.

8.9.5. Scores Assigned by the Farmers

The farmers do not wish to assign a score to the environmental damage indicator, nor do they have an opinion on the competitiveness indicator. Concerning the reliability of supply, the farmers believe that Option III (Agro&Max) scores best because of the many different resources used. The other options are believed to score the same as the BAU option. Furthermore, according to the farmers, Option III also scores best on regional economic development, as this option provides full space for expansion of agro-activities. Option II (MassT&Regional) on the other hand, scores worst because there is almost no room for agro-activities whatsoever, while Option I (EcoT&Micro) also scores worse than the BAU option (but not as bad as Option II), because there is no room for expansion. On the same line, the risk and uncertainty is lowest for Option III, which thus scores best on this indicator, Option I scores worse, and Option II scores much worse than the BAU option. The costs related to energy are about the same for all options, although Option I might score slightly worse due to increased energy demand per client as a result of intensification efforts. The benefits for the farmers are highest in Option III, which thus scores best, while Option I score worse and Option II much worse than the BAU option.

Note that the actors, when assigning scores, do not have to make their considerations explicit, so the actors do not necessarily get to know why the other actors assign particular scores. However, some of these considerations may be revealed during the evaluation step (discussed in § 8.11). The results of assigning the scores are presented in the 'Appraisal' sheet, which brings us to the next section.

8.10. Appraisal of Options Using Web Diagrams

The scores assigned by the actors are automatically plotted in the corresponding web diagrams of the 'Appraisal' sheet. Figure 8.7 shows the web diagram associated with the scores discussed in § 8.9. Note that if an actor did not assign a score to an indicator, the plot will be interrupted for that indicator. The more the scores of an option lie at the outer boundary of the web diagram, the better that option scores in comparison with the BAU option and the other options. Note that the last web diagram on the Appraisal sheet (as illustrated in Figure 8.7) deviates from the others: it has the actors on the axis and (automatically) plots the expected net (monetary) benefits that accrue to each actor. The option with the highest net benefit[6] automatically gets the maximum score (i.e., lies at the outer boundary), while the scores of the other options are plotted relative to the range between the maximum and minimum scores. So this last web diagram shows the changes in net benefits for each actor that are caused by the different infrastructure options: actors are – financially– best off with the options that lie at the outer boundary of the web diagram. Options that score worse than the BAU option (i.e. these options lie closer to the origin than the BAU option) imply that actors are worse off than in the business-as-usual case.

The 'Appraisal' sheet helps the actors in appraising and comparing the different energy infrastructure options. In addition, the 'Spotting Conflicts' sheet can be used to verify whether any of the options matches with the preferred scores of several or even all actors. So after carefully examining the Appraisal sheet and the Spotting Conflicts sheet, the actors can determine which option they prefer, or which option they would certainly reject.

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[6] We use the index scores for 2020 to determine the options with the maximum and minimum net benefits for an actor.

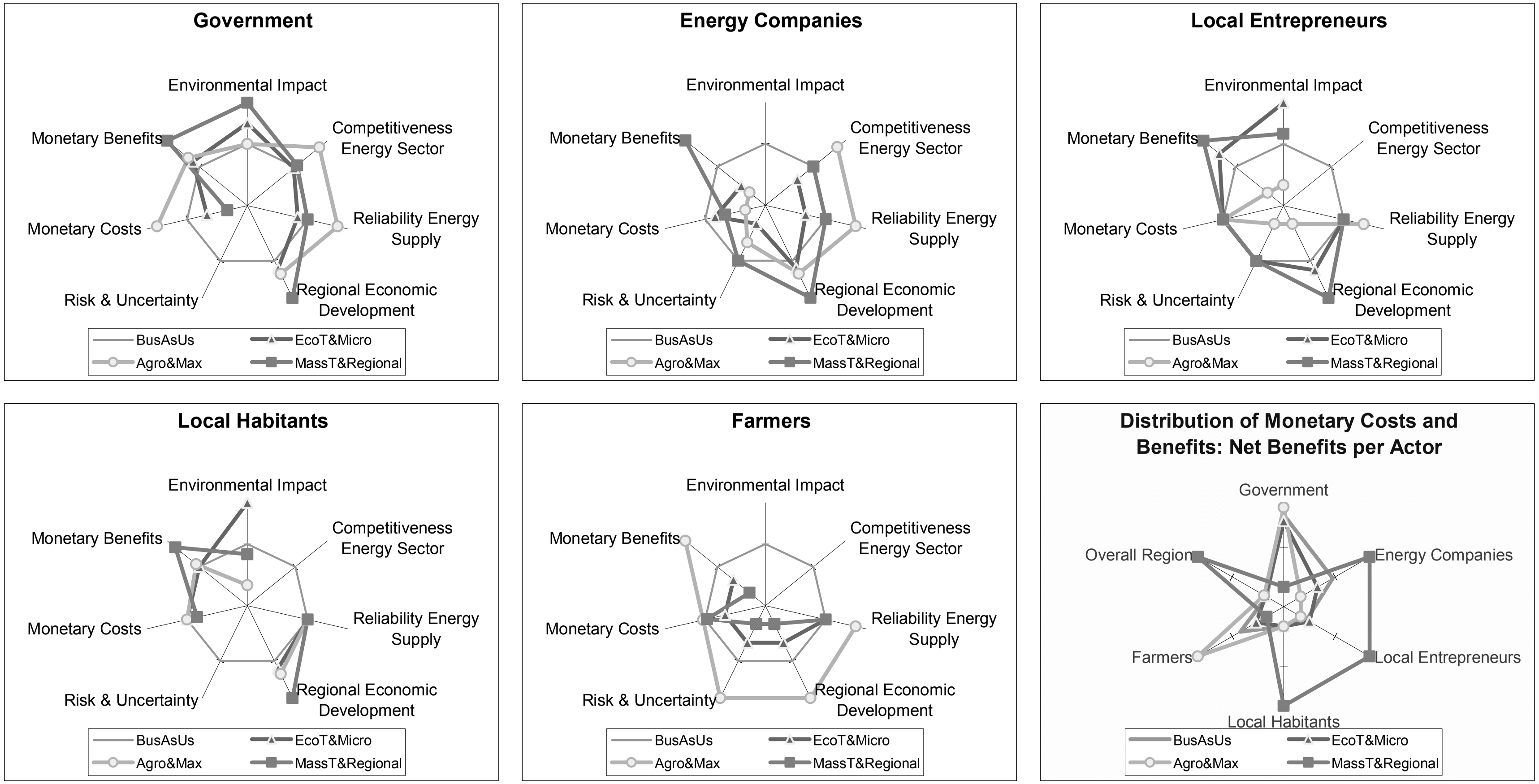

Figure 8.7. After an actor has assigned scores to the indicators of an energy infrastructure option, the results are shown in the 'Appraisal' sheet. The Business-As-Usual option is already listed –by default– as a reference option. The more the scores of an option lie to the outer boundary of the web diagram, the more desirable the option is for that actor.

Looking at Figure 8.7, the government believes all indicators are equally important, except for the ‘Risk & Uncertainty’ indicator to which the government has currently not assigned any scores. The government might have a slight preference for Option III, as it has no scores worse than the BAU option, while most scores are better than any of the other options. Option II is also attractive, but implies high cost of waste disposal, resulting in a low appraisal on monetary costs. The energy companies clearly reject Option I, as it scores bad on costs, (net) benefits, risk, reliability, and competitiveness; indicators which are all highly important to the energy companies. The energy companies currently do not have a distinct preference for either of the two other options. The local entrepreneurs clearly reject Option III, as it vlearly scores worse than any of the other scenarios on almost all indicators, except on the reliability indicator. But this indicator is not as important to them as, for instance, costs and benefits, risk, and regional economic development. Local habitants have a slight preference for Option I, as this option scores better on regional economic development than the BAU option *and* has the best score on environmental damage indicator. The farmers clearly opt for Option III, especially considering the excellent score on monetary benefits.

Note that the appraisal step is done implicitly; the actors do not have to make their considerations explicit. So the actors do not necessarily get to know the considerations underlying the preferences of the other actors. The actors do, however, have to express which option they prefer (or which option they will certainly reject), but this is done in the next step of the method.

8.11. Next Steps of the Method

The next step of the method is the evaluation of the energy infrastructure options, which will usually initiate the next iteration of the method steps until a final selection is made. During the evaluation step, the actors express which energy infrastructure option they prefer, or which ones they would certainly reject. Also, the actors can express a need for more information, and discuss with the other actors which changes they would like to be seen made to the measures, (sub-)indicators, and/or infrastructure options in order to find infrastructure options that better match with the preferences of the actors.

As discussed in Section 5.4.2, the role of an independent intermediary or mediator can become important in this step, especially when distrust exists among actors and/or conflicting interests. The use of the tool in the evaluation step is limited, although the web diagrams of the Appraisal sheet provide some insight in the considerations underlying the preferred options of the actors. The web diagrams can also be used as a handhold for actors to articulate what they find important and what additional information they need.

For instance, the local habitants could fear that besides agro-activities, mass tourism will also lead to deforestation, as the large hotels that have to be built also occupy space, while roads have to be constructed and made better to improve the access to the hotels. So they might like to have more information on this subject. They might also like to know more on the effects that mass tourism has on the cost of living (e.g., prices of food, energy prices, etc.). The energy companies, on the other hand, could be interested in changing Option III somewhat by lowering the amount of electricity exported, to see if this would improve their scores on costs and benefits. So new options can be constructed and indicators can be added or changed, initiating a new iteration of the method steps. During each new iteration the tool can be used from the beginning. This brings us to the end of the tool demonstration.

8.12. Evaluation of the Tool

The tool demonstrated in this chapter is meant to facilitate the steps of the new method; it helps the actors in quickly constructing energy demand and supply scenarios, and they can create energy infrastructure options by combing different demand and supply scenarios. The impacts of the infrastructure options are systematically assessed using impact data and scorecards, while the comparison and appraisal of the options is facilitated and made transparent by using web diagrams. Although the tool is still a prototype, most of the procedures used in the tool have a general character and can be applied to other cases as well. Nevertheless, adjustments will likely have to be made to adjust the tool to local circumstances. A mediator is the most designated actor to design and operate the tool. More specifically, the mediator can fill the database with local data, construct predefined demand and supply scenarios, explain the other actors how to use the tool, and make any necessary adjustments (e.g., after each iteration, if new indicators have to be added, and new measures included to calculate scores).

Note that the field study in Costa Rica did not provide sufficient data to fully demonstrate the tool in practice. The example given in this chapter therefore does not necessarily reflect the actual situation or the actual opinions or preferences of the real actors. Nevertheless, it is thought to be a realistic example given the interviews we conducted.

We would like to stress again that the energy infrastructure options and their consequences merely point out an approximate direction of development on the medium term, and should not be interpreted as an exact prediction of the future, because of the many educated guesses and assumptions that unavoidably have to be made.

An issue not yet addressed is that of the time and costs associated with applying the new method. Since the method has not yet been applied in practice, it is difficult to give exact figures, but it is certainly true that the interviews that have to be held and the interaction and mediation that have to take place will take time and are not free of charge. Also, the actors that traditionally perform the energy planning (e.g., energy companies and/or governments) may perceive the new method to be more troublesome at first, due to their loss of control over the decision process. However, practice in Brabant and Costa Rica has shown that at the moment, conflicts between current energy planners and excluded actors do exist, but only surface at the end of (or after) the energy planning process, when most decisions are taken and cannot easily be reversed. These conflicts can severely hamper the implementation and operation of the new energy infrastructure, inducing costs that are not immediately associated with (let alone attributed to) how energy planning is done. Dealing with conflicting interests from the beginning of the planning process avoids time-consuming and costly attempts to overcome opposition from excluded actors who can influence the decision process. And the time and costs of applying the new method are certainly expected to be less than restructuring (partly) built energy infrastructure that proves to be inappropriate.

So with Chapter 7 and Chapter 8 we have answered the forth and last sub-question of this thesis, on how the new method can be made operational, albeit that the example given here has a hypothetical character. This brings us to the final, concluding, chapter of this thesis.

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Stem, Caroline Jeanine (2001). *The Role Of Local Development In Protected Area Management: A Comparative Case Study Of Eco-Tourism In Costa Rica*. Dissertation, Cornell University.

9 Conclusions and Recommendations for Further Research

9.1. Conclusions

As discussed in Chapter 1, the aim of this thesis is to develop a new method to support all relevant actors involved in or affected by regional energy planning on the medium term (± 20 years), focusing on rapidly developing regions of developing countries. The method must provide information on the full range of options for the local energy infrastructure, and address all relevant aspects (i.e., impacts) associated with these options. In addition, the method must provide a structure to systematically appraise and compare the options and show the different viewpoints of the actors. In order to develop such a method, we introduced the following sub-questions:

I. What theories and tools already exist for supporting energy planning and what existing type of tool would best fit local energy planning in developing countries?
II. What are –in practice– the thresholds in the planning process concerning local energy infrastructure?
III. What other non-energy related theories provide useful information on steering the development of the local energy infrastructure in developing countries on the medium term?
IV. What is required to make the method operational?

These sub-questions are addressed in the following chapters of the thesis. Chapter 2 gives an overview of the way existing methods and models can be characterized, and consequently lists their drawbacks. Note that we distinguish between the *method* and *models*: the method provides the framework for the entire planning process, while the models are part of the method and used as calculation tools to facilitate the steps of the method. The characterization of existing methods and models gives us better insight in the type of method and model that would be suited to support local energy planning in developing countries. So based on the characterization, we develop a preliminary version of the method, which can be characterized as a mix of aspects from 'prescriptive'[1] and 'descriptive' methods, while also incorporating some aspects of political methods. The models used in the method will have a modular bottom-up approach to be able to easily adapt them to local circumstances and clearly differentiate between the various energy technologies. A key aspect of the method is that it uses the aspects that actors perceive as important as a basis to construct indicators for the impact assessment. Furthermore, the preliminary method has an 'energy-services-to-sources' approach, implying that the method starts with determining the *energy services* for which energy is demanded (e.g., cooking, heating tap water, operating electrical appliances), and the proper energy *forms* (electricity, gas, heat, etc.) with which the energy services can be fulfilled. Consequently, the energy resources and technologies have to be identified that can provide the proper amounts and forms of energy. This way, we can systematically analyze the full range of energy infrastructure options. Chapter 2 thus addresses the first sub-question of the thesis.

The literature studied in Chapter 2 did not, however, contain much information on how energy planning at the *local* level evolves in practice. It appears that local energy planning is not well documented in the literature. So to answer the second sub-question, we conducted a descriptive field study in the province of Brabant, the Netherlands, focusing on the energy planning process at new building sites. The main aim of this field study was to gain insight in what actually happens during the local energy planning process, and to determine whether the set-up of the preliminary method presented in Chapter 2 is indeed realistic. Brabant was chosen because information was easily accessible, up-to-date, and relatively reliable compared to a field study in a developing country, while communication problems were limited so that the required data could be gathered in a relatively short period of time. We realize that Brabant does not reflect the situation of a region in a *developing country*, but we believe that there are enough general elements in this energy planning process to use the results as a basis for the situation in developing countries. Nonetheless, a field study in a developing country will remain essential to test the validity of the method, but this will be addressed in Chapter 6. Chapter 3 presents the results of the Brabant field study, and although the study does not reveal any unexpected outcomes, it does provide us the necessary feedback on the assumptions made for the preliminary method. The main finding is that the set-up of the preliminary method is realistic, but that the new method should be adjusted so that it

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[1] Note that in this thesis the term 'prescriptive' is defined differently than in most literature, see § 2.5.

explicitly includes learning aspects and better allows for interaction between actors to be able to fully support the entire planning process.

Theories concerning these issues could not be found in the energy literature, so we studied additional non-energy related literature, of which the results are presented in Chapter 4. One of the useful non-energy related theories is the quasi-evolutionary theory, which provides a broad theoretical foundation for the new method. This theory is especially suited to help explain how the development of energy technologies generally evolves, how it can be influenced, and what the role of learning and interaction is. Note that other theories (e.g., stemming from a neo-classical framework, such as theories on bounded rationality, transaction costs, and learning curves) could be equally fit to explain developments in the energy infrastructure, or help in making investment decisions concerning this infrastructure. However, we prefer the use of the quasi-evolutionary theory because it is easy to comprehend and explicitly stresses the social factor.

Other additional theories that provide more concrete handholds to incorporate learning and interaction in the new method are found in the different types of Technology Assessment (TA) and in Participatory Technology Development (PTD). The different types of TA (including Strategic Niche Management) give information on how to include all relevant actors in the process, and on how to help them interact. They also provide a framework for incorporating learning in the planning process. However, they generally focus on long-term decisions at a national level in industrialized countries. The PTD approach, on he other hand, is more suited to use on the medium term, and its bottom-up character provides handholds for using small-scale technologies at the local level in developing countries.

Another useful concept for the new method is the concept of *appropriate technology*, and particularly the *context* school of appropriate technology. This school of thought rejects the use of *fixed predefined* indicators because the appropriateness of a technology can only be determined in the *context* in which it is applied. And each situation has a different context. In Chapter 2 we already discussed that the impact assessment of new method uses indicators that are based on the interests and preferences of the actors. The indicators are thus not fixed nor predefined; they are context dependent. The concept of appropriate technology thus provides a solid theoretical basis for the use of context-dependent indicators in the method.

The additional input from the non-energy related theories in Chapter 4 provides an answer to the third sub-question, and we use this input to further develop the preliminary method. How this is done is discussed in Chapter 5, where the new method is presented in full. In short, the new method can be characterized as the *triple-i* approach: it is *informative*, *interactive*, and *iterative*. First of all, the new method provides *information* in a structured way on the range of energy infrastructure options. It also requires *interaction* between actors (among others through participation in the planning process) to let them learn about each other's considerations. Interaction is also needed to construct the indicators that are used to assess, appraise, and compare the impacts of the energy infrastructure options. And finally, the *iterative* character allows the actors to learn to articulate their preferences and information needs, and allows them to change their preferences, or adjust the set of indicators and/or infrastructure options included in the analysis when new information becomes available. The method is transparent in assessing and comparing the different energy infrastructure options, and gives all relevant regional resources and small-scale (< 50 MW) energy technologies a fair and equal chance in the assessment. The new method thus allows the actors to make well-weighed decisions, and helps them to select appropriate energy resources and technologies in order to steer the development of the energy infrastructure into a desirable direction. However, the method does not present an ‘optimal’ or ‘best’ energy infrastructure to the actors: at the end of each iteration, the actors will have to decide which infrastructure options deserve further attention given their consequences, until the actors select a final option as appropriate.

The new method is not a normative type of method nor is it descriptive. A normative method demands that actors follow the (strict) rules of the method, implying that the users should adjust to the method if practice deviates from theory. A descriptive method would merely state how the current planning process evolves and how current actors behave, without attempting to change the behavior of actors. This implies that the new decision support method can require the actors to change their behavior in order to improve the quality of decision-making. However, we also acknowledge that the complexity of everyday life for each specific case is difficult to grasp in a general method. So in our view, it might be better sometimes to allow for adjustments in the method in order to provide real support in practice, than to force the actors to comply with strict rules, ultimately causing them to reject the method altogether, and thus providing no support at all. The method should thus be seen as a *handhold or heuristic* for energy planners on how to choose an appropriate energy infrastructure, rather than a normative set of rules and procedures that must be followed strictly.

Of course, the method also has to be tested, which is the topic of Chapter 6. In Chapter 6 we explained that the new method could not be fully tested within the research timeframe, as most energy planning process can easily take up to 5 years or more. However, we were able to verify whether the assumptions underlying the new method hold for local energy planning in developing countries. To do this, we conducted a second field study, this time in Huetar Norte, a region in Costa Rica that has recently shown strong economic growth in the agro-sector and in tourism. The results of the Huetar Norte field study show that economic development in the case of Costa Rica is indeed restricted to regions, while the exclusion of relevant actors from current energy planning has led to a hampering in energy planning. Also, many actors perceive aspects other than financial and technical ones as relevant, while they acknowledge a lack of information on the range of infrastructure options and their consequences. Two of the assumptions underlying the new method could not be tested within the research framework: we could not verify whether decision making is improved by providing information and a structure to process the information; and we could not assess how learning affects the planning process exactly. This will have to be tested in subsequent research.

The field study also revealed a rather weak point of focusing on the regional level: the choice of a region. The initial choice for Huetar Norte was adjusted to the Coopelesca area to have detailed and reliable data on current energy demand, while the region was further narrowed to the Sarapiquí area in order to identify the relevant actors. So the requirements for choosing a region deserve further attention in future research.

An example of how the new method can be made operational (sub-question IV) is given in Chapter 7 and Chapter 8, partially based on the data obtained in the Costa Rica field study. Chapter 7 deals with the construction of a practical tool, while Chapter 8 gives a demonstration of the tool. The tool (which is still a prototype) is a bottom-up, modular, spreadsheet type of model that uses energy demand and supply scenarios to construct energy infrastructure options. Business-As-Usual (BAU) scenarios for both energy demand and energy supply were constructed and consequently used as a reference case to easily construct and compare alternative scenarios. The BAU scenarios represent a continuation of current trends, whereas the other scenarios will initially reflect 'extreme' regional developments imply a discontinuity in current trends. The extreme scenarios are mostly based on educated guesses, using the BAU scenarios as a reference. The 'extreme' demand scenarios describe diverse or opposite socio-economic developments that determine future energy demand. So a choice for a particular demand scenario automatically implies the choice for a particular direction in socio-economic development. The 'extreme' supply scenarios reflect the full range of energy resources and technologies available. The extreme scenarios are thus used to clearly point out the differences in consequences between options. Combining a demand scenario with a matching supply scenario (i.e., regional demand is met at all times) creates an energy infrastructure option. Although the options will initially be 'extreme', the following iterations of the method steps will likely move towards variations of only one or two (less extreme) options in order to ultimately select a broadly supported appropriate energy infrastructure. The impacts of the infrastructure options are appraised and compared using Data Impacts sheets (Figure 7.5) and scorecards (Figure 7.6). The Data Impacts sheets contain the quantified scores and index scores on (sub-)sub-indicators. The actors can use the data that they regard relevant to determine their overall scores on general indicators, and they use the scorecards to assign their scores. So most impact scores are measured quasi-quantitatively.

The role of the tool at the end of each iteration of method steps (i.e., during the evaluation and ultimately the selection of an option) is modest. An independent mediator, on the other hand, can play an important role here by improving the communication between actors, mediate in conflicts, and try to remove any distrust that exists between actors. The mediator's main goal is to improve the quality of decision-making, without attempting to steer the planning process into a particular direction. The mediator is therefore also the most designated actor to look after a proper completion of the iterations of method steps, and support actors in applying the method, for instance by interviewing experts to obtain relevant information, and by interviewing the actors to extract their interests and preferences. Finally, the mediator is also the most designated actor to operationalize the method into a practical tool, and look after a proper use and operation of the tool.

The actors that previously performed the energy planning (e.g., energy companies and/or governments) may perceive the new method to be more troublesome at first, due to their loss of control over the decision process. However, practice in Brabant and Costa Rica has shown that at the moment, conflicts between traditional energy planners and currently excluded actors surface only at the end of (or after) the energy planning process, when most decisions are taken and cannot easily be reversed. These conflicts can severely hamper the implementation and operation of the new energy infrastructure, inducing costs that are not immediately associated with (let alone attributed to) the energy planning process, such as the costly and time-consuming attempts to overcome opposition, or the costs of restructuring (partly) built energy infrastructure that proves to be inappropriate. We believe that these costs can be avoided if conflicting interests are dealt with from the beginning of the planning process, implying that all relevant actors have to participate in the process. Of course there are also costs associated with applying the new method, and future research will have to show how high these costs are, but we are confident that it proofs to be worthwhile using the new method.

Since the new method has not been fully tested, case studies are needed for additional testing. However, based on the findings of the field study in Costa Rica, it seems likely that the new method improves decision-making regarding local energy planning in developing countries. Note that aspects such as communication skills, the motivation of actors, and power relations will likely also influence the quality of decision-making, but these aspects lie outside the scope of this research.

We would like to stress again that regional activities or plans have to fit within the regulatory and policy framework set by the national government (see § 6.3). Such a national framework ensures that regional policies benefit society as a whole, but developing countries in particular tend to have national frameworks that restrict new initiatives at the regional level, even if these would benefit the entire society.

From a scientific point of view, the research described in this thesis contributes to a better insight in the complex interactions and processes associated with the selection of local energy infrastructure for rapidly developing regions in developing countries. The integrated, multidisciplinary approach used to develop the new method clearly demonstrates that there are different ways to address an issue, and this research builds a bridge between theories of different disciplines. Also, the procedures used in the new method provide a handhold for dealing with aspects that are difficult to quantify. So the innovative aspect of the new method lies in its eclectic approach, creating a synthesis of existing theories rather than innovating a theory in one of the specific fields. And unlike existing methods and models, the new method supports the *entire* planning process. Nonetheless, existing models may prove useful during parts of the method e.g., when assessing future energy demand, or appraising economic effects of investments. The new method can thus be seen as *complementary* to existing methods and models. The example of a tool given in this thesis shows how the eclectic approach can be applied in practice. However, it is too early to generalize the results of this thesis; first, more case studies have to be conducted to properly test the method.

Another issue not addressed in detail is the fact that the method requires the participation of and a dialogue between actors, which might imply that the application of the method is restricted to societies that allow for participation and discussion, such as most democracies. Note that both regions used in the field studies (i.e., Brabant and Huetar Norte) are characterized by a culture or society that is democratic, open to discussion, and based on consensus building. Future research will have to determine the details concerning the regions to which the new method is applicable. In addition, our research focused on developing countries, but was mainly conducted by someone from a western culture. If we extend the quasi-evolutionary theory to our own research, you could argue that the new method should have been constructed in mutual cooperation with and with the participation of people from regions in developing countries. However, given the particular requirements associated with this research project, such a set-up was impossible. Nonetheless, we tried to include the opinions of those people through the interviews that we conducted. And all the aspects and issues not addressed in this thesis form the starting points for future research, the topic of the next section.

9.2. Recommendations for Further Research

Issues that deserve more attention in future research include first of all a proper testing of the method: case studies in which the new method is fully applied during the entire planning process have to show whether the method in general, and the information and structure it provides in particular, improve the quality of decision-making. More case studies are needed to show the effects of learning, and to study the influence of communication skills, motivation, and power relations on an effective application of the new method. Case studies are also needed to test whether the new method supports the energy planning decision process better than existing methods and models. In addition, the costs associated with applying the method have to be assessed in detail, and the choice of regions deserves more attention, as the field study showed some difficulties in selecting the right size of the region. The method may not be applicable to all regions even if they experience strong economic growth e.g., if the local culture is not open to discussion or does not allow for participation. Furthermore, future work could investigate whether the new method is also applicable to regions that do not experience rapid development, but want to stimulate such development by building an adequate energy infrastructure.

As already mentioned in the previous section, the tool presented in this thesis is still a prototype and requires at least a sensitivity analysis. Finally, the way the tool presents the results of the impact assessments also deserves more attention, in particular the choice of scales used in the web diagrams, and the framing or formulation of the indicators.

This concludes the last chapter of this thesis.

Appendix A: Energy Consumption per Capita vs. Gross Domestic Product per Capita

	Country	GDP/cap. (1995 US$)	GJ/cap.
	High-Income		
1	Luxembourg	55,979.401	503.6
2	Switzerland	46,997.466	188.0
3	Japan	42,103.071	160.8
4	Denmark	38,496.150	170.3
5	Norway	37,629.508	394.1
6	Austria	32,797.468	166.3
7	Germany	32,664.105	188.8
8	United States	32,153.799	353.1
9	Finland	31,935.058	239.2
10	Netherlands	31,403.051	249.2
11	Sweden	31,202.561	265.7
12	Iceland	30,931.319	316.0
13	Belgium	30,838.733	240.0
14	France	29,949.502	173.7
15	Singapore	28,215.330	287.5
16	Hong Kong	24,184.172	86.9
17	Australia	23,599.977	225.8
18	Canada	22,914.756	410.3
19	United Kingdom	21,759.424	175.3
20	Italy	20,943.557	133.3
21	Spain	17,796.472	112.6
22	New Zealand	17,760.504	220.0
23	Israel	17,558.477	101.7
24	Qatar	15,684.236	860.7
25	United Arab Emirates	15,359.847	796.7
26	Taiwan	15,034.199	107.5
27	Korea, South	13,063.522	104.5
28	Greece	13,060.623	110.2
29	Portugal	12,838.024	80.4
	Upper-Middle-Income		
30	Malta	10,215.863	75.2
31	Argentina	7,933.303	63.9
32	Saudi Arabia	6,850.939	218.8
33	Oman	6,568.725	125.9
34	Uruguay	6,446.488	36.0
35	Libya	5,948.942	129.8
36	Hungary	5,440.657	118.7
37	Chile	5,354.482	44.6
38	Malaysia	4,796.525	61.8
39	Brazil	4,696.716	44.6
40	Gabon	4,506.136	48.6
41	Poland	4,243.857	107.2
42	South Africa	3,904.055	99.4
43	Costa Rica	3,854.430	27.3
44	Mexico	3,783.525	63.1
45	Botswana	3,620.899	27.8
46	Venezuela	3,300.409	116.7
47	Panama	3,274.517	42.7
48	Burma	3,135.057	2.1
	Lower-Middle-Income		
49	Belize	3,064.500	28.1
50	Turkey	3,060.755	38.5
51	Thailand	2,747.853	25.7
52	Tunisia	2,490.600	25.0
53	Peru	2,368.062	18.3
54	Colombia	2,288.789	28.6
55	Jamaica	2,069.493	46.3
56	Dominican Republic	2,025.684	20.4
57	Iran	1,879.833	61.1
58	El Salvador	1,749.855	11.3
59	Paraguay	1,697.180	13.1
60	Algeria	1,640.149	55.6
61	Guatemala	1,553.965	9.0
62	Bulgaria	1,502.653	119.3
63	Romania	1,459.479	102.2
64	Ecuador	1,424.531	26.9
65	Morocco	1,349.223	13.9
66	Egypt	1,246.801	28.5
67	Philippines	1,141.254	12.1
68	Indonesia	995.007	13.6
69	Bolivia	955.402	14.3
70	Nigeria	909.518	9.2
71	China	818.373	25.5
72	Cote d'Ivoire(IvoryCoast)	753.690	5.7
73	Honduras	709.381	12.6
	Low-Income		
74	Lesotho	547.081	2.6
75	Pakistan	468.726	11.4
76	Benin	418.614	2.0
77	Haiti	325.161	2.0
78	Vietnam	319.023	4.3
79	Bangladesh	277.933	2.4
80	Rwanda	270.229	1.9
81	Madagascar	256.595	1.6
82	Burkina Faso	244.165	0.9
83	Tanzania	174.723	2.0
84	Malawi	162.351	2.3
85	Sierra Leone	161.432	4.1

Source: modification of the following data from US Energy Information Administration, *International Total Primary Energy and Related Information:* Per Capita Total Primary Energy Consumption, All Countries, 1980-2000; Gross Domestic Product at Market Exchange Rates, By Region with Most Countries, 1990-2000; Population, By Region with Most Countries and World Total, 1980-2000. Internet: www.eia.doe.gov/emeu/international/total.html (accessed July 2002).
Countries are classified according to income groups using the classification of the World Bank, Internet: www.worldbank.org/data/countryclass/countryclass.html (accessed July 2002).

Appendix B: Renewable Energy Technologies

This appendix briefly addresses the main (small-scale) renewable energy technologies that are commercially available in almost all developing countries. For a more detailed treatment of the technologies we refer to Johansson et. al. (1993) and the references at the back of this appendix. We will subsequently discuss Wind Energy Technology, Solar Energy Technology, Biomass Energy Technology, Geothermal Energy Technology, and Hydropower Technology.

B-1 Wind Energy Technology

The most commonly-applied wind energy technology is the horizontal axis wind turbine, as shown in Figure B.1. The power P that a wind turbine can generate is given by formula (Van Beeck, 1999):

$$P_{turb} = \tfrac{1}{2} \cdot C_p \cdot A \cdot \rho \cdot v^3 \qquad \textit{[Formula B-1]}$$

With P_{turb}= Power output of the wind turbine [W]
C_p = Coefficient of performance (rotor efficiency) [-]
A = Swept area of rotor blades [m^2]
ρ = Density of air (≈ 1.2 kg/m^3) [kg/m^3]
v = Wind speed at hub height [m/s]

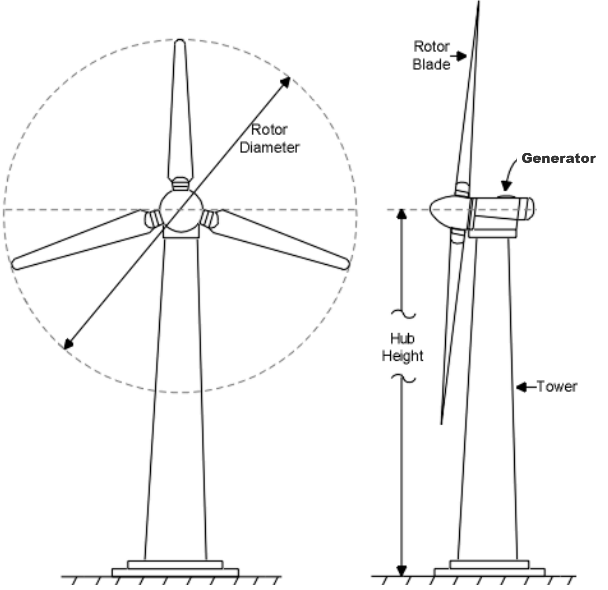

Figure B.1. A horizontal axis wind turbine. Source: Cavallo et.al.(1993).

The coefficient of performance is limited by a theoretical maximum of 16/27 (the Betz limit). Cavallo et.al. (1993) state that in practice, a modern large wind turbine can reach a C_p value of 0.5, but only at certain times; the average value for C_p will be lower due to the intermittent character of the wind.

Many variations of horizontal axis wind turbines exist, differing in hub height, rotor diameter, capacity, number of rotor blades, and so on. However, according to the World Bank (1991), increasing number of rotor blades generally implies decreasing efficiency: systems with two or three rotor blades represent the best trade-off between aerodynamic performance, balance, stability, and system cost.

Note that the third power in Formula B-1 implies that the power output of energy turbines is highly sensitive to the wind speed. Therefore, the average wind speed (measured at a certain height) is the main measure to quickly determine the wind energy potential in a region. In areas with relatively low wind speeds or in areas with rather high surface roughness (e.g., many trees or obstacles), the hub height can be increased to improve the performance of the wind turbine, as wind speeds increase with increasing height.

B-2 Solar Heat Technology: Thermal Collector Systems

Thermal collector systems can be very simple: a black barrel with water on a flat roof will do for many low-income households in developing countries. A more sophisticated commonly applied system is the flat plate collector (see Figure B.2). The collector has light absorbing material on the front side (facing the sun), and a spiral pipe attached to the back through which a fluid (e.g., water) runs. The collector absorbs sunlight and ambient heat, consequently heating the fluid in the spiral pipe. The hot fluid is usually directed to a heat exchanger/ storage tank to transfers its heat to tap water. Often, an auxiliary heater is used to reduce the dimensions of the system and cut the costs.

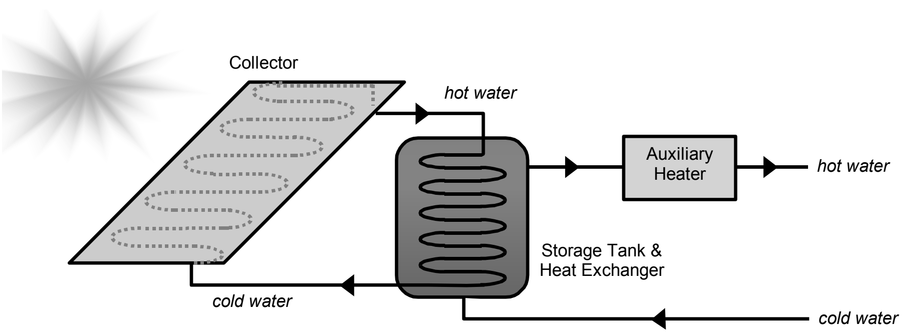

Figure B.2. A standard thermal collector system.

The main factors influencing direct power output include the solar intensity, the system efficiency, and the collector's surface. In formula :

$$P_{col} = i \cdot A \cdot \eta_{sys} \qquad \text{[Formula B-2]}$$

With P_{col} = Power output of the solar collector system [W]
i = Solar intensity [W/m^2]
A = Collector surface [m^2]
η_{sys} = Efficiency of the total system [-]

The system efficiency is affected by heat losses and the orientation of the collector (i.e., whether or not it is facing the sun). Furthermore, since the sun is an intermittent energy source, the actual performance of the collector system depends on seasonal influences and daily weather conditions, as well as on the amount of tap water used and the time at which it is used. To calculate the useful heat produced in a year, we have to determine the average power output $P_{col,avg}$ and multiply it with the number of sunhours in a year:

$$E_{col} = P_{col,avg} \cdot h \qquad \text{[Formula B-3]}$$

With E_{col} = Annual production of useful heat of the solar collector system [Wh/yr]
$P_{col,avg}$ = Average power output of the solar collector system [W]
h = Hours of sun in a year [hrs/yr]

B-3 Solar Electricity Technology: Photovoltaic Systems

A photovoltaic (PV) system consists of mutually connected cells that are mounted on a module and produce a direct current when (sun)light hits the cells' surface (see Figure B.3). Most cells are made of (polycrystalline) silicon. Other elements of a grid connected PV system include cables, a frame, and monitoring equipment.

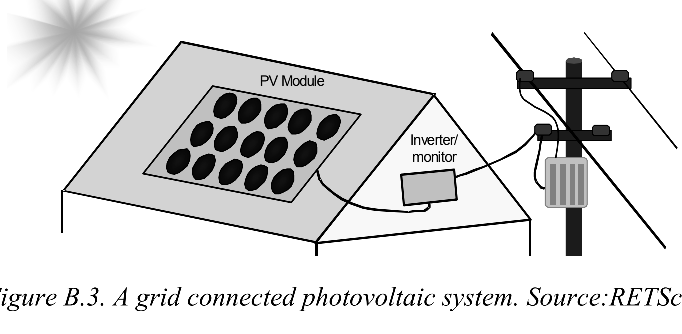

Figure B.3. A grid connected photovoltaic system. Source:RETScreen (1998).

A stand-alone (autonomous) PV system usually also requires a storage facility such as batteries. On the other hand, if the system is connected to an electricity grid it needs an inverter to change the direct current into alternating current. For grid-connected systems the grid serves as an infinite storage facility.

The main factors that influence the direct power output of the PV systems include the solar intensity, the system efficiency and surface of the PV modules included in the system. In formula:

$$P_{PV} = i \cdot A \cdot \eta_{sys} \qquad \text{[Formula B-4]}$$

With P_{PV} = Power output of the PV system [W]
i = Solar intensity [W/m^2]
A = Total surface of the PV modules included in the system [m^2]
η_{sys} = Efficiency of the total PV system [-]

The system efficiency is affected by the conversion efficiency of the PV cells, the orientation and tilt angle of the PV modules (whether or not they face the sun), and losses in cables and connections. Furthermore, since the sun is an intermittent energy source, the actual output depends on seasonal influences and daily weather conditions. Often, the performance of the PV system is also expressed in the *specific efficiency*, which reflects the amount of energy (kWh) produced per kW$_p$ installed capacity in a specified period (see also Appendix F, Formula F-9). If the specific efficiency is known, the annual energy production of a PV system can easily be calculated by multiplying the specific efficiency with the total capacity (in kW$_p$) of the PV system.

B-4 Biomass Energy Technology

The supply of biomass usually varies throughout the year due to seasonal influences (harvest periods, winter). Also, weather conditions may influence production and/or the quality of biomass. For instance, the energy content of wet biomass (in GJ/ton) is lower than that of dry biomass.

Basically, there are three main *methods* to convert biomass into energy: thermo-chemical conversion, biochemical conversion, and extraction (see Van Beeck, 1998). Only the first two methods are commercially applied in developing countries to produce energy, so we restrict our discussion to these two (extraction is mainly used for producing relatively expensive biodiesel). The choice for a certain process depends on the composition and availability of the biomass, the desired amount and type of energy forms (e.g., heat, electricity, fuel), conversion costs, environmental standards, and others.

B-4.1. Thermo-chemical Conversion Technologies

Thermo-chemical conversion is a method that uses high temperatures to convert the biomass into intermediate products such as gasses, liquid fuels and charcoal. The method can only be used for relatively dry biomass with a relatively high caloric value (e.g., wood). This implies that thermo-chemical conversion is only a relevant option if the moisture content of the biomass is low (<15%) or can easily be dried. Otherwise, too much energy is wasted on evaporating the water.

There are three types of thermo-chemical conversion processes: combustion, gasification, and pyrolysis (Van Beeck, 1998). Combustion is the most commonly used thermo-chemical process to convert biomass into energy, in particular in developing countries e.g., through open fires or wood stoves, or in more sophisticated boilers of steam turbine generation systems, which are mature and widely applied technologies for power generation. Gasification is a thermo-chemical process in which biomass is converted –under high temperatures– into a low caloric fuel. Currently, only few gasification plants are in operation, mostly in industrialized countries as pilot projects (Williams and Larson, 1993, 743). Pyrolysis is mostly used to produce charcoal, although some industrialized countries are now experimenting with the production of bio-oils.

B-4.2. Biochemical Conversion Technologies

Biochemical conversion technologies use micro organisms (bacteria, enzymes, yeast) to convert biomass into energy, and include fermentation, composting and anaerobic digestion technologies (Van Beeck, 1998). Fermentation is commonly known as a technology to produce transportation fuel (e.g., ethanol in Brazil), but anaerobic digestion is the most-used technology for generation of heat and electricity. Anaerobic digestion is a biochemical conversion process that uses bacteria to convert relatively wet biomass into a mixture of mainly methane and carbon dioxide (so-called biogas). Biogas can be used in gas engines, for cooking, space heating, or heating of tap water. Other products of digestion are water and compost, which can be used to fertilize land. The containers (digesters) in which the anaerobic digestion process takes place make use of a relatively simple technology that can be applied almost anywhere at any scale.

B-5 Geothermal Energy Technology

Geothermal energy technology makes use of the heat in the earth's crust e.g., in the vicinity of volcanoes or geysers. Geothermal energy can be used for direct heating purposes such as space and tap water heating or industrial process heat, or for electricity generation. Direct heating purposes require the applications to be located in the direct vicinity of the geothermal plant, to avoid too much heat loss (DiPippo, 1999). However, generated electricity can be easily transported over large distances without too much loss.

Geothermal power plants use wells that are drilled into underground reservoirs to tap hot steam or water, with which a steam turbine is set in motion that is connected to a generator. There are three types of geothermal power plants: direct steam (or dry steam) plants, flash steam plants, and binary plants.

The direct steam plants make use of wells with dry steam that is directly used in a steam turbine (DiPippo, 1999; EREN, 2002). Dry steam reservoirs are relatively rare, most geothermal wells are liquid-dominated. For the liquid-dominated wells with relatively high temperature (>200 °C), a flash steam plant can be used. The water from the well is sprayed into a tank that has a much lower pressure, causing the water to rapidly vaporize (i.e., 'flash') to steam. The steam then drives a turbine, which drives a generator. Sometimes, a second tank is used to flash any remaining liquid that has not vaporized in the first tank. The binary plant is used for wells with moderate temperatures. The water from the well is directed to a heat exchanger, where the heat is transferred to a second fluid that has a much lower boiling point than water. The water from the well causes the second fluid to flash to steam, which is then used to drive a turbine. The water from the well does not come in contact with the turbine, thus minimizing the adverse effects of erosion.

B-6 Hydropower Technology

Hydropower technology uses the potential energy or the kinetic energy of water to drive a turbine that is connected to a generator. There are two main types of turbines: impulse turbines and reaction turbines. The impulse turbines (such as the Pelton, Turgo, and crossflow turbine) are used when the 'head' (i.e., the vertical difference between the inlet tube and the turbine of the power plant) is relatively large. The power output of such a turbine is given by the following formula:

$$P_{H,i} = 9.8 \cdot Q \cdot \rho \cdot H \cdot \eta_{sys} \qquad \textit{[Formula B-5]}$$

With $P_{H,i}$ = Power output of the impulse turbine [W]
Q = Water flow [m^3/s]
ρ = Specific weight of water (=1,000 kg/m^3) [kg/m^3]
H = Head [m]
η_{sys} = Turbine efficiency [-]
9.8 = Gravitational constant [m/s^2]

So the power that can be produced at a hydroelectric site is a function of the available head and flow. According to Retscreen (1998) a conservative, "rule-of-thumb" relationship is that the power is equal to seven times the product of the flow (Q) and gross head (H) at the site (P = 7QH).

The reaction turbines (such as the Kaplan or Francis turbine) are used when the head is medium or low. The power output of such a turbine is given by the following formula:

$$P_{H,r} = C_p \cdot A \cdot \rho \cdot v^3$$ *[Formula B-6]*

With $P_{H,r}$ = Power output of the reaction turbine [W]
C_p = Coefficient of performance [-]
A = Swept area by turbine blades [m^2]
ρ = Specific weight of water (=1,000 kg/m^3) [kg/m^3]
v = Water velocity [m/s]

Note that run-of-river hydropower projects use the natural flow of the river (i.e., no reservoirs) and produce relatively little change in the river flow. For most run-of-river small-hydro sites where river flows vary considerably, turbines that operate efficiently over a wide flow range are usually preferred (e.g. Kaplan, Pelton, Turgo and crossflow designs).

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Appendix C: Characteristics of Energy Models

This appendix gives an overview of the main energy models existing today, including EFOM-ENV, ENERPLAN, ENPEP, LEAP, MARKAL, MARKAL-MACRO, MESAP, MESSAGE-III, MICRO-MELODIE, and RETscreen. The characterization is derived from Van Beeck (1999) and mainly based on the following literature sources: the World Bank (1999), United Nations (1985), and CEDRL (1998). The models are characterized according to the ten classification ways discussed in Chapter 2:

I. *Perspective on the Future*
Forecasting, exploring, backcasting

II. *SpecificPurpose*
Energy demand, energy supply, impacts, appraisal, integrated approach, modular build-up

III. *The Model Structure: Internal Assumptions & External Assumptions*
Degree of endogenization, description of non-energy sectors, description end-uses, description supply technologies.

IV. *The Analytical Approach*
Top-Down or Bottom-Up

V. *The Underlying Methodology*
Econometric, Macro-Economic, Economic Equilibrium, Optimization, Simulation, Spreadsheet/Toolbox, Backcasting, Multi-Criteria.

VI. *The Mathematical Approach*
Linear programming, mixed-integer programming, dynamic programming.

VII. *Geographical Coverage*
Global, Regional, National, Local, or Project

VIII. *Sectoral Coverage*
Energy sectors or overall economy.

IX. *The Time Horizon*
Short, Medium, Long Term

X. *Data Requirements*
Qualitative, quantitative, monetary, aggregated, disaggregated.

EFOM-ENV

Developers:	European Commission DDG-XII F/1, Belgium
Perspective:	Exploring
Specific Purpose:	Energy supply, subject to technical, environmental and political constraints. Detailed description of (renewable) technologies possible. Appraisal through cost-effectiveness analysis. The objective includes energy and environment policy analysis and planning in particular regarding emission reduction.
Assumptions:	Low degree of endogenization, no interaction between non-energy sectors, detailed decsription of energy supply and end-uses technologies. Endogenous analysis of generation expansion. Input needed: demand projections/ scenarios, supply costs, (environmental) constraints.
Top-Down vs. Bottom-Up:	Bottom-Up
Methodology:	Optimization
Mathematical Approach:	Linear Programming/ Dynamic Programming
Level:	National
Sectoral Coverage:	Energy producing and consuming sectors
The Time Horizon:	Medium to long term
Data Requirements:	Quantitative, monetary, disaggregated

ENERPLAN

Developers:	Tokyo Energy Analysis Group, Japan
Perspective:	Forecasting or exploring (depending on mode)
Specific Purpose:	Energy supply, energy demand, matching demand and supply
Assumptions:	Depends on mode
Top-Down vs. Bottom-Up:	Top-Down
Methodology:	Econometrics and simulation (depending on mode)
Mathematical Approach:	Not available
Level:	National
Sectoral Coverage:	Energy sector
The Time Horizon:	Short to medium
Data Requirements:	Quantitative

ENPEP

Developers:	International Atomic Energy Agency (IAEA), Autstria
Perspective:	Forecasting, exploring.
Specific Purpose:	Energy demand, supply, matching demand and supply, environmental impacts. Detailed analysis for electricity based on least cost optimization. Integrated approach. Allows for energy policy analysis, energy tariff development, investment analysis, generation expansion planning, environmental policy analysis.
Assumptions:	Demand: high degree endogenization, description of all sectors in economy. Supply: detailed description of end-uses and (renewable) technologies.
Top-Down vs. Bottom-Up:	Hybrid. Top-down for demand analysis and bottom-up for supply.
Methodology:	Macro-economic for demand, economic equilibrium for total energy system.
Mathematical Approach:	Not available
Level:	Local, National
Sectoral Coverage:	Entire economy
The Time Horizon:	Short (1-3 yrs), medium, long (max 50 yrs).
Data Requirements:	Quantitative, monetary, aggregated and disaggregated.

LEAP

Developers:	Stockholm Environmental Institute Boston, USA
Perspective:	Exploring, forecasting
Specific Purpose:	Demand, supply, environmental impacts. Integrated approach. the objective includes energy policy analysis, environmental policy analysis, biomass- and land-use assessment, preinvestment project analysis, integrated energy planning, full fuel cycle analysis. Applicable to industrialized as well as developing countries.
Assumptions:	Demand: rather high degree of endogenization and description of all sectors in economy Supply: simple description of end-uses and supply technologies, including some renewable.
Top-Down vs. Bottom-Up:	Demand: top-down, supply: bottom-up.
Methodology:	Demand: econometric or macro-economic. Supply: simulation
Mathematical Approach:	Not available.
Level:	Local, national, regional, global.
Sectoral Coverage:	All sectors.
The Time Horizon:	Medium, long term
Data Requirements:	Quantitative, monetary, aggregated/ disaggregated.

MARKAL

Developers:	International Energy Agency (IEA)/ ETSAP
Perspective:	Exploring
Specific Purpose:	Energy supply with constraints. The objective includes target-oriented integrated energy analysis and planning through a least cost approach.
Assumptions:	Low degree of endogenization, focuses only on the energy sector, detailed description of end-uses and (renewable) energy technologies possible.
Top-Down vs. Bottom-Up:	Bottum-up.
Methodology:	Toolbox/ Optimization
Mathematical Approach:	Linear programming, dynamic programming.
Level:	Local, national.
Sectoral Coverage:	Energy sector only
The Time Horizon:	Medium, long term.
Data Requirements:	Quantitative, monetary, disaggregated.

MARKAL-MACRO

Developers:	Brookhaven National Laboratory, USA.
Perspective:	Exploring
Specific Purpose:	Demand, supply, environmental impacts. Integrated approach for economy-energy-environmental analysis and planning. The objective is to maximize utility (discounted sum of consumption) from a neo-classical macro-economic perspective.
Assumptions:	Neo-classical growth model with nested substitution (CES) between capital/ labor aggregate and energy. Energy is represented as the weighted sum of useful energy demands in the MARKAL submodel. Detailed description of (renewable) technologies is possible.
Top-Down vs. Bottom-Up:	MACRO part is top-down, MARKAL part is bottom-up.
Methodology:	Macro-economic for MACRO and partial equilibrium through optimization for matching demand and supply in MARKAL.
Mathematical Approach:	Dynamic programming (non-linear).
Level:	Local, National
Sectoral Coverage:	All sectors.
The Time Horizon:	Medium, long term.
Data Requirements:	Qualitative, monetary, aggregated, disaggregated.

MESAP

Developers:	IER, University of Stuttgart, Germany.
Perspective:	Exploring, forecasting
Specific Purpose:	Modular package. Demand, supply, environmental through different modules: ENIS = database; PLANET/ MADE = demand which can be coupled to supply module; INCA = comparative economic assessment of single technologies; WASP = generation expansion based on least-cost analysis; MESSAGE = integrated energy systems analysis
Assumptions:	Depends on module.
Top-Down vs. Bottom-Up:	Top-down (demand) and bottom-up (supply).
Methodology:	Econometric (demand), simulation or linear programming (supply).
Mathematical Approach:	(among others) linear programming, dynamic programming
Level:	Local, national.
Sectoral Coverage:	All sectors through PLANET/ MADE.
The Time Horizon:	Medium, long term.
Data Requirements:	Quantitative, monetary, aggregated, disaggregated.

MESSAGE-III

Developers:	International Institute for Applied System Analysis (IIASA), Austria.
Perspective:	Exploring
Specific Purpose:	Energy demand and supply, environmental impacts. Modular package. the objective includes generation expansion planning, end-use analysis, environmental policy analysis, investment policy.
Assumptions:	Detailed description of energy end-uses and (renewable) energy technologies.
Top-Down vs. Bottom-Up:	Bottom-up.
Methodology:	Optimization.
Mathematical Approach:	Dynamic programming
Level:	Local, national.
Sectoral Coverage:	Energy sector.
The Time Horizon:	Short, medium, long term.
Data Requirements:	Quantitative, monetary, disaggregated.

MICRO-MELODIE

Developers:	CEA, France
Perspective:	Exploring
Specific Purpose:	Energy demand, supply, environment. Integrated approach. The objective includes an analysis of macro-economic energy and environment linkages.
Assumptions:	Multi-sectoral analysis with a description of conventional energy technologies only, in particular for the electricity sector.
Top-Down vs. Bottom-Up:	Top-down with a detailed description of the energy sector.
Methodology:	Macro-economic based on price equilibrium.
Mathematical Approach:	Not available
Level:	National.
Sectoral Coverage:	All sectors, with a detailed description of the energy sector.
The Time Horizon:	Medium, long term
Data Requirements:	Quantitative, monetary, aggregated, disaggregated.

RETscreen

Developers:	CEDRL/Natural Resources Canada
Perspective:	Exploring
Specific Purpose:	Energy supply. Specially designed for renewable energy technologies.
Assumptions:	Detailed description of supply technologies for generation expansion.
Top-Down vs. Bottom-Up:	Bottom-up
Methodology:	Spreadsheet/ Toolbox.
Mathematical Approach:	Not available.
Level:	Local, national.
Sectoral Coverage:	Energy Sector.
The Time Horizon:	Not avaliable
Data Requirements:	Quantitative, monetary, disaggregated.

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Appendix D: Indicators and Measures

This appendix contains indicators, measures, and formulas to assess the impacts of energy infrastructure options, but only those indicators are included that were used when applying the new method to the Coopelesca area, as described in Chapter 7 and Chapter 8. Many other indicators or measures (or units) are conceivable, so the list given here is far from complete. The set of indicators will likely differ per project, and can even differ within a project due to the iterations in the planning process. Actors have to mutually agree upon the indicators, measures, and assumptions used to calculate the scores for a proper application of the method. Figure D.1 shows the sub-indicators and sub-sub-indicators associated with each general indicator used in our example.

Indicators	***Sub1-Indicators***	**Sub2-Indicators**	**Scores: Index 2005-2020**	**Scores: Quantitative 2005-2020**
Environmental Damage	Air quality	CO_2 Emissions		
	Water Quality	Waste in Water		
	Water Quantity	Hydropower Capacity		
	Soil Quality	Deforestation		
	Solid Waste	Waste		
	Wildlife Quality & Quantity	Deforestation Disturbance/ Noise Waste		
Competitiveness Energy Sector	Cost of Electricity Export	Cost of Electricity Export		
Reliability Energy Supply	Opinion	Opinion		
	Load Factor	Load Factor		
Regional Economic Development	Tourism	Tourism Revenues		
	Agro production	Agro production		
	Energy Sector	Energy Revenues		
	Recycling & Waste Disposal	Recycling & Waste Disposal		
Risk & Uncertainty	Opinion	Opinion		
Monetary Costs	Energy Infrastructure	Energy Infrastructure		
	Recycling & Waste Disposal	Recycling & Waste Disposal		
Monetary Benefits	Energy Revenues	Residential Commercial Industrial Electricity Export		
	Tourism Revenues	Eco-Tourist Expenditures Luxury Tourist Expenditures		
	Agro Revenues	Agro Revenues		
	Profit Energy Companies			
	Total Economic Benefit			

Figure D.1. Possible general indicators and associated (sub-)sub-indicators to assess impacts of energy infrastructure options.

How the scores on the sub-indicators are determined will be discussed in separate sections below. However, the order in which the indicators are treated deviates somewhat from that of Figure D.1. The reason for this is that the indicators 'Regional Economic Development' and 'Competitiveness' make use of the same calculation procedures as the (sub-)indicators 'Monetary Costs' and 'Monetary Benefits'. So we will address the indicators in the following order:

- Environmental Damage
- Reliability Energy Supply
- Risk & Uncertainty
- Monetary Costs
- Monetary Benefits
- Regional Economic Development
- Competitiveness National Energy Sector

The 'Distribution of Costs & Benefits' indicator –although not directly apparent from Figure D.1– can be derived from the indicators for monetary costs and monetary benefits (see § D-8). In Section D-9, we will address the index scores that are used in the Data Impacts sheets of the TOOL. In the final section of this appendix (§ D-10), we present an overview of the values that we use for the general variables and constants listed in the subsections of this appendix.

D-1 Environmental Damage

The general indicator 'Environmental Damage' includes the following sub-indicators: Air Quality, Water Quality, Water Quantity, Soil Quality (Deforestation), Solid Waste, and Wildlife Quality and Quantity. The measures used to determine the scores on each of these sub-indicators are discussed in separate subsections below.

D-1.1. Air Quality

In our example, air quality is measured by CO_2 emissions. The CO_2 emissions are a byproduct of energy generation with fossil fuels, and cause a global warming of the atmosphere. In Costa Rica, only ICE uses fossil fuels (diesel and bunker fuel) for national electricity production, so importing electricity from the national grid into the Coopelesca area implies CO_2 emissions, while exporting electricity out of the area implies CO_2 emissions are avoided because the exported electricity substitutes fossil fuel based electricity generated elsewhere.

To calculate the CO_2 emissions caused by electricity import from the national grid, we first have to know what percentage of demand is met by import of electricity, and consequently the fraction of import that is based on fossil fuels. In addition, we have to account for the transmission and conversion losses, and finally, the amount of fossil fuels burned has to be multiplied by the CO_2 emissions factor to get the total amount of CO_2 emissions. So total CO_2 emissions are calculated with the following formula:

$$CO_2 = \frac{E}{\eta_{trans} \cdot \eta_{ff}} \cdot f \cdot \alpha \qquad \text{[Formula D-1]}$$

With CO_2 = Regional CO_2 emissions [ton CO_2 / year]
E = Amount of electricity imported from the national grid [GJ/yr]
η_{trans} = Efficiency of electricity transmission [-]
η_{ff} = Average conversion efficiency of fossil fuel systems [-]
f = Fraction of national electricity generation accounted for by fossil fuels [-]
α = Average CO_2 emission factor [ton CO_2 / GJ_{in}]

Import of electricity depends on the energy infrastructure option. In 2000, the fractions of diesel and bunker in national electricity production were 1.0% and 0.1% respectively, but ICE's expansion plan shows a substantial increase in the use of diesel and especially bunker in the future (CENPE, 2000). According to that same document, the average conversion efficiency for diesel is 34% and that for bunker fuel 39%, and since the conversion technologies are well developed, we estimate these efficiencies will only slightly improve in the future. According to ICE (2000), transmission losses are about 4%. The CO_2 emission factors for diesel and bunker are taken 73.5 ton/TJ_{in} and 75 ton/TJ_{in} respectively, based on data from ECAN (2000) and Aubé (2001). Table D.1 list the values of these variables used for each period. Note that other emissions such as CO, CH_4, NO_x, SO_2, particulates, or ozone also influence air quality, but are not included in our example for the sake of simplicity.

Table D.1. Values of general variables to determine air quality.

Values to Determine Air Quality	***Unit***	**2000**	**2005**	**2010**	**2015**	**2020**
CO_2 emissions						
Fraction of diesel in national generation	%	1.0%	7.9%	6.4%	13.8%	7.7%
Fraction of bunker in national generation	%	0.1%	1.1%	3.0%	8.0%	10.5%
Diesel conversion efficiency	%	34%	35%	36%	37%	37%
Bunker conversion efficiency	%	39%	40%	40%	40%	40%
CO_2 emission factor diesel	ton/TJ_{in}	73.5	73.5	73.5	73.5	73.5
CO_2 emission factor bunker	ton/TJ_{in}	75.0	75.0	75.0	75.0	75.0

D-1.2. Water Quality

Water quality is measured by the waste that ends up in the surface waters. In our analysis, we only take into account the waste generated by either the tourists or the agro-sector (the fraction of municipal waste in surface waters is assumed to be the same for all scenarios and left out of the analysis). Waste by tourists depends on the number of tourists visiting the area, the amount of days they spent in the area, and the waste they generate each day. A distinction is made between luxury tourists and eco-tourists, as the latter are assumed to generate less waste than the former. Furthermore, only a fraction of the waste generated by tourists will end up in the surface waters, and the same applies to the agro-residues. In formula:

$$W_{t,water} = \beta_{tourist} \cdot \left(N_{lux} \cdot D_{lux} \cdot w_{lux} + N_{eco} \cdot D_{eco} \cdot w_{eco} \right) + \beta_{agro} \cdot AR \qquad \text{[Formula D-2]}$$

With $W_{\text{t, water}}$ = Total amount of waste that ends up in surface water [kg/yr]
β_{tourist}, β_{agro} = Fractions of waste by tourists and agro-residues that end up in surface waters. [-]
N_{lux} , N_{eco} = Number of luxury tourists and number of eco-tourists respectively [-]
D_{lux} , D_{eco} = Duration of stay of luxury tourists and eco-tourists respectively [days/yr]
w_{lux}, w_{eco} = Marginal waste production per luxury tourist and eco-tourist [kg/day]
AR = Amount of agro-residues per year [kg/yr]

UNEP (2000) mentions waste production levels in Latin America of 1.0 kg/day per *inhabitant* with high income, and 0.5 kg/day per *inhabitant* with low income. Due to lack of other data, we assume that tourists generate the same amount of waste per day. So waste generation by luxury tourists is taken 1.0 kg/day and that for eco-tourists 0.5 kg/day for all periods. Furthermore, SIDES states that in 1997 a fraction of 0.4% of municipal waste ended up in surface waters, so we will take the same percentage for the waste generated by tourists, and assume this fraction is constant for all periods. No data were available on the fraction of agro-residues that ends up in surface waters, so we will estimate that a (constant) fraction of 0.1% ends up in the surface waters.

The number of luxury and eco-tourists and the time they spend in the area depend on the energy demand scenario chosen. The amount of agro-residues not only depends on the demand scenario chosen, but also on the supply scenario, as in some cases agro-residues are used for energy production. Appendix F contains more information on how the amount of agro-residues is calculated. Table D.2 lists the values of the general variables to determine water quality. Note that this indicator uses almost the same data as the sub-indicator 'Solid Waste' (§ D-1.5).

Table D.2. Values of general variables to determine water quality.

Values to Determine Water Quality	***Unit***	**2000**	**2005**	**2010**	**2015**	**2020**
Daily waste production per luxury tourist	kg/day	1.0	1.0	1.0	1.0	1.0
Daily waste production per eco-tourist	kg/day	0.5	0.5	0.5	0.5	0.5
Fraction of waste in water by tourists	%	0.4%	0.4%	0.4%	0.4%	0.4%
Fraction of waste in water by agro-industry	%	0.1%	0.1%	0.1%	0.1%	0.1%

D-1.3. Water Quantity

One indicator to determine the water quantity is the amount of installed hyrdo-capacity in the area. The total capacity of hydro plants installed in the region is the sum of the capacities of all the regional and local hydro plants in the region. However, the local hydro-plants with no reservoir will likely affect the (changes in) flow of the river more than the regional plants with reservoirs.

D-1.4. Soil Quality

In our example, the soil quality is interpreted as the amount of deforestation in the area, which is measured by the changes in total cultivated area by the agro sector. The cultivated area depends on the growth rates chosen in the energy demand scenarios. Note that other interpretations are possible.

D-1.5. Solid Waste

This sub-indicator uses almost the same data as the sub-indicator Water Quality (see § D-1.2); only the fractions of waste and agro-residues that end up in the surface waters are left out. In formula:

$$W_t = \left(N_{lux} \cdot D_{lux} \cdot w_{lux} + N_{eco} \cdot D_{eco} \cdot w_{eco}\right) + AR$$

[Formula D-3]

With W_t = Total production of waste [kg/yr]
N_{lux} , N_{eco} = Number of luxury tourists and number of eco-tourists respectively [-]
D_{lux} , D_{eco} = Duration of stay of luxury tourists and eco-tourists respectively [days/yr]
w_{lux} , w_{eco} = Marginal waste production per luxury tourist or eco-tourist respectively [kg/day]
AR = Amount of agro-residues per year [kg/yr]

As explained in § D-1.2, waste generation by luxury tourists is taken 1.0 kg/day and that for eco-tourists 0.5 kg/day for all periods, based on UNEP (2000). The number of luxury and eco-tourists and the time they spend in the area depend on the energy demand scenario chosen. The amount of agro-residues not only depends on the demand scenario chosen, but also on the supply scenario, as in some cases agro-residues are used for energy production. Appendix F contains more information on how the amount of agro-residues is calculated. The values of the general variables to determine the amount of solid waste were already listed in Table D.2.

D-1.6. Wildlife Quality & Quantity

The sub-indicator 'Wildlife Quality & Quantity' is divided into three sub-sub-indicators: Deforestation; Disturbance and Noise (by tourists); and Waste. All three are believed to have a major influence on the quality and quantity of wildlife in the area.

Deforestation

Deforestation is measured by the (changes in) total cultivated area by the agro sector: the more area is cultivated, the more forest area disappears (and the more wildlife is harmed). The cultivated area depends on the growth rates chosen in the energy demand scenario.

Disturbance / Noise

Due to a lack of data on the disturbance and noise caused by tourists, we introduce the *disturbance factor* as a measure for the effects of tourists on the quality and quantity of wildlife. The disturbance factor depends on the number of luxury and eco-tourists, the number of days these tourists stay in the area, and the marginal disturbance factor:

$$DF_t = N_{lux} \cdot D_{lux} \cdot df_{lux} + N_{eco} \cdot D_{eco} \cdot df_{eco}$$

[Formula D-4]

With DF_t = Total disturbance factor of tourists [-]
N_{lux} , N_{eco} = Number of luxury tourists and number of eco-tourists respectively [-]
D_{lux} , D_{eco} = Duration of stay of luxury tourists and eco-tourists respectively [days/yr]
df_{lux} , df_{eco} = Marginal disturbance factor per day per luxury tourists or eco-tourists respectively [-]

The luxury tourists are likely to cause more disturbance and noise than the eco-tourists, who are more considerate and aware of the harm they might cause. Therefore, we assign a marginal disturbance factor of 1.0 to luxury tourists and 0.5 to eco-tourists (see Table D.3).

Table D.3. Values of general variables to determine the disturbance factor.

Values to Determine Wildlife Quality & Quantity	*Unit*	2000	2005	2010	2015	2020
Noise factor luxury tourists	-	1.0	1.0	1.0	1.0	1.0
Noise factor eco-tourists	-	0.5	0.5	0.5	0.5	0.5

Waste

The waste sub-sub-indicator is measured the same way as the 'Solid Waste' indicator discussed in Section D-1.5.

D-2 Reliability Energy Supply

The reliability of the energy supply is measured by letting actors assign an ordinal score on this general indicator. The actors can take into consideration the extent to which intermittent resources are used, or the ratio of peak (power) demand and the total installed capacity, as given by the following formula for the load factor:

$$LF = \frac{P_{peak}}{IC} \qquad \text{[Formula D-5]}$$

With LF = Load Factor [-]
P_{peak} = Peak demand [MW]
IC = Total Installed Capacity [MW]

However, estimates of future peak demand are not easy to determine –or even estimate– on the medium term, and therefore it is common to assume a constant load factor and use average energy demands. Another measure could be the estimated time of failure each year due to blackouts or brownouts, if data are available.

D-3 Risk & Uncertainty

The actors' perception of the risk and uncertainty are highly subjective, so the actors assign ordinal scores to this indicator.

D-4 Monetary Costs

The 'Monetary Costs' indicator includes the cost of the energy infrastructure and the cost of waste recycling and disposal, which are discussed in separate subsections below.

D-4.1. Monetary Costs – Energy Infrastructure

Total costs of the energy infrastructure encompass the cost of the electricity infrastructure and the cost of the heat infrastructure, which –in turn– each consist of the product of the marginal cost and the amount of energy produced:

$$C_{infra} = c_{el} \cdot E_{p,elec} + c_h \cdot E_{p,heat} \qquad \text{[Formula D-6]}$$

With C_{infra} = Total annual cost of the energy infrastructure [US$/yr]
c_{el} = Marginal cost of electricity [US$/kWh]
c_{h} = Marginal cost of heat [US$/kWh]
$E_{\text{p,elec}}$ = Total required amount of electricity production [kWh/yr]
$E_{\text{p,heat}}$ = Total required amount of heat production [kWh/yr]

In our example, we use total annual costs to compare energy infrastructure options, because most documents and energy project proposals in Costa Rica used annual costs. However, other measures such as the net present value or the internal rate of return can also be used to determine the profitability of an investment, and are sometimes required in proposals e.g., for the World Bank or the Inter American Development Bank.

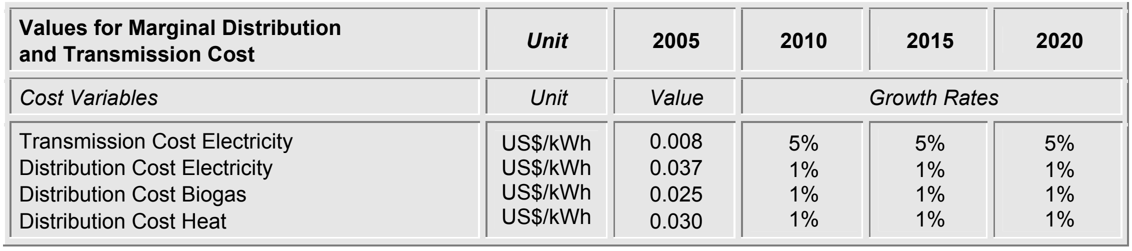
The required amount of energy production depends on the energy infrastructure option that is chosen. Appendix F contains details on how the required production is determined. Furthermore, the (long run) marginal costs c of electricity and heat can each be subdivided in the marginal cost of production c_{prod}, the marginal cost of distribution c_{distr}, and the marginal cost of transmission c_{trans}:

$$c = c_{prod} + c_{distr} + c_{trans} \qquad \text{[Formula D-7]}$$

Note that the marginal cost of energy is generally used to determine the least-cost options. Based on data from Coopelesca (Alfaro, 2001), we estimate the distribution cost of electricity for the period 2005 to be 0.037 US$/kWh (50% of the overall marginal cost), with a (constant) average annual growth rate of 1%. Note that not all energy technologies have distributions cost (e.g., the PV solar systems). The marginal cost of electricity transmission only applies to the electricity that is imported from the national grid. We assume that 11% of the total marginal cost is accounted for by the transmission, implying a value of 0.008 US$/kWh in 2005. The transmission cost is estimated to increase with an average annual rate of 5%.

Data on the marginal distribution cost of heat was lacking, but we estimate a value of 0.025 US$/kWh$_{\text{th}}$ for biogas and 0.030 US$/kWh$_{\text{th}}$ for heat, and for both a constant average annual growth rate of 1%. Heat cannot be imported in or exported out of the region, so there are no transmission cost. Table D.4 lists the values for the marginal distribution and transmission cost for each period.

Table D.4. Percentages to determine marginal distribution and transmission cost.



Values for Marginal Distribution and Transmission Cost	**Unit**	**2005**	**2010**	**2015**	**2020**
Cost Variables	*Unit*	*Value*	*Growth Rates*		
Transmission Cost Electricity	US$/kWh	0.008	5%	5%	5%
Distribution Cost Electricity	US$/kWh	0.037	1%	1%	1%
Distribution Cost Biogas	US$/kWh	0.025	1%	1%	1%
Distribution Cost Heat	US$/kWh	0.030	1%	1%	1%

With respect to the marginal cost of regional production, the calculation procedure is the same for electricity and heat:

$$c_{prod} = \sum_{i=1}^{n}\left[\phi_i \cdot \frac{\left(I_{an,i} + O\&M_i + F_i\right)}{E_{p,i}}\right]$$

[Formula D-8]

With $c_{prod,\,el}$ = Marginal production cost of a particular energy form [US$/kWh]
$i..n$ = Regional systems that produce the particular energy form [-]
ϕ_i = Fraction of total production of the energy form supplied by system i [-]
$I_{an,i}$ = Annuity of investment cost of system i [US$/yr]
$O\&M_i$ = Annual operations and maintenance costs of system i [US$/yr]
$F_{an,i}$ = Annual fuel cost of system i [US$/yr]
$E_{p,i}$ = Required amount of energy generated by system i [kWh/yr]

So for each energy form (i.e., electricity or heat) the c_{prod} needs to be calculated. The number *n* of regional systems that produce a particular energy form depends on the energy infrastructure chosen. The fraction of total production ϕ_i that a particular system contributes is calculated with the following formula:

$$\phi_i = \frac{E_{r,i}}{E_{p,tot}} \qquad \textit{where:} \qquad E_{p,i} = \frac{\lambda_i \cdot E_{d,tot}}{1 - \ell_{dist,i}} \qquad \textit{and:} \qquad \lambda_i = \frac{E_{d,i}}{E_{d,tot}}$$

[Formula D-9]

With i = Type of energy system
λ_ι = Fraction of energy demand that is met by system i [-]
ℓ_{dist} = Distribution losses [-]
$E_{p,tot}$ = Total required production of a particular energy form [GWh/yr]
$E_{d,tot}$ = Total energy demand (including all energy forms) [GWh/yr]
$E_{d,i}$ = Contribution in total energy demand accounted for by system i [GWh/yr]

According to data from Coopelesca (Alfaro, 2001), the losses of distributing electricity are 8%. Note that in Chapter 7 we stated that the distribution losses associated with micro-systems such as PV solar systems are zero, and that the distribution losses of biogas (produced by digestion systems) are taken zero as well. The distribution losses of heat from the combustion of wood is set at 10%, based on experience in the field study of Brabant. Due to the differences in distribution losses per type of system, the share ϕ_l of a particular system in total production is not the same as the share in meeting total demand given by λ_l. Also note that $E_{r,tot}$ refers to the total production of a particular energy form, while $E_{d,tot}$ refers to the overall demand for *all* energy forms. The values for $E_{p,i}$, $E_{p,tot}$, $E_{d,i}$, and $E_{d,tot}$ –and thus for ϕ_l and λ_l– depend on the chosen energy infrastructure option. Formula D-11 can now be rewritten as:

$$c_{prod} = \frac{1}{E_{p,tot}} \cdot \sum_{i=1}^{n} \left(I_{an,i} + O\,\&\,M_i + F_i \right)$$

[Formula D-10]

The investment cost of a system has to be converted to annual investment cost, and this is done with the following formula:

$$I_{an,i} = I_i \cdot \frac{(1+i)^T}{(1+i)^T - 1}$$

[Formula D-11]

With $I_{\mathrm{an,i}}$ = Annuity of investment cost of system i [US$/yr]
I = Total investment cost of system i [US$]
i = Interest rate [-]
T = Economic lifetime of the system [yrs]

The interest rate *i* is chosen to be 12%, as this percentage was also found in energy project proposals in Costa Rica, such as the one for Caño Grande III (1995). The economic lifetime of all systems is set at 20 years, a commonly used value for energy systems (Van Groenendaal, 1998). The values for the marginal investment costs of systems (in US$/kW) in 2000 are based on a literature review and interviews with experts (see Van Beeck (1998); Van Helden (2001)). The values for subsequent periods are determined using average annual growth rates, as illustrated by the following formula:

$$I_x = I_{x-1}(1+r)^T$$

[Formula D-12]

With I_x = Total investment cost at year x [US$]
I_{x-1} = Total investment cost at year x-1 [US$]
r = Average annual growth rate [-]
T = Time period between years x and x-1 [yrs]

The values for the marginal investment costs of systems in 2000 and the growth rates used for subsequent periods are listed in Table D.5. Note the negative growth rates for all energy systems: we assume that the marginal investment cost of all systems (especially those for solar systems) reduce as a result of technology development and standardization and economies of scale in producing the systems. The investment costs in the periods 2005-2020 only apply to newly installed capacity in the period concerned.

Table D.5. Values of general variables to determine annual investment cost for new capacity.

Values to Determine Annual Investment Cost	***Unit***	**2000**	**2005**	**2010**	**2015**	**2020**
Cost Variables	*Unit*	*Value*	*Growth Rates*			
Exchange rate	¢/US$	310	10%	10%	10%	10%
Rate of interest	%	12%	12%	12%	12%	12%
Investment costs energy technologies						
Hydro - Local	$\text{US\$/kW}_e$	1,000	-0.5%	-0.5%	-0.5%	-0.5%
Hydro - Regional	$\text{US\$/kW}_e$	1,000	-0.5%	-0.5%	-0.5%	-0.5%
Biomass - Regional	$\text{US\$/kW}_e$	1,300	-1.0%	-1.0%	-1.0%	-1.0%
Geothermal - Regional	$\text{US\$/kW}_p$	2,500	-1.0%	-1.0%	-1.0%	-1.0%
PV Solar - Micro	$\text{US\$/kW}_p$	7,500	-8.0%	-8.0%	-8.0%	-8.0%
Termal Solar - Micro	$\text{US\$/m}^2$	300	-3.0%	-3.0%	-3.0%	-3.0%
Agro-Residues Digestion - Regional	$\text{US\$/kW}_{th}$	1,500	-1.0%	-1.0%	-1.0%	-1.0%
Wood Combustion - Regional	$\text{US\$/kW}_{th}$	1,000	-1.0%	-1.0%	-1.0%	-1.0%

The (annual) operation and maintenance cost of a system are taken as a percentage of the total investment cost (*not* the annual investment cost) of that system, as listed in Table D.6.

Table D.6. Percentages to determine annual operation and maintenance cost.

Percentages to Determine O&M Cost	**Unit**	**2000**	**2005**	**2010**	**2015**	**2020**
Hydro - Local	% of total I	2.5%	2.5%	2.5%	2.5%	2.5%
Hydro - Regional	% of total I	2.5%	2.5%	2.5%	2.5%	2.5%
Biomass - Regional	% of total I	5.0%	5.0%	5.0%	5.0%	5.0%
Geothermal - Regional	% of total I	3.0%	3.0%	3.0%	3.0%	3.0%
PV Solar - Micro	% of total I	2.0%	2.0%	2.0%	2.0%	2.0%
Termal Solar - Micro	% of total I	2.0%	2.0%	2.0%	2.0%	2.0%
Agro-Residues Digestion - Regional	% of total I	5.0%	5.0%	5.0%	5.0%	5.0%
Wood Combustion - Regional	% of total I	5.0%	5.0%	5.0%	5.0%	5.0%

Note that for the sake of simplicity, we set the fuel cost of all (renewable) energy resources at zero (see § 7.9.3). Also note that if a system is installed in one period, but not used for energy production in the next period(s), the annual investment cost of that system still has to be payed.

D-4.2. Monetary Costs – Recycling & Waste Disposal

The cost of recycling and waste disposal only applies to waste generated by tourists. The total costs are given by the marginal cost of disposing one unit of waste, the marginal waste production per type of tourist, and the number of luxury and eco-tourists per year:

$$C_{RW} = \left(N_{lux} \cdot D_{lux} \cdot w_{lux} + N_{eco} \cdot D_{eco} \cdot w_{eco}\right) \qquad \textit{[Formula D-13]}$$

With C_{RW} = Total cost of recycling and waste disposal [US$/yr]
N_{lux} , N_{eco} = Number of luxury tourists and number of eco-tourists respectively [-]
D_{lux} , D_{eco} = Duration of stay of luxury tourists and eco-tourists respectively [days/yr]
w_{lux} , w_{eco} = Marginal waste production per luxury tourist and eco-tourist [kg/day]
c_{u} = Marginal cost of waste disposal [US$/kg]

The number of tourists and the number of days they stay depend on the chosen energy demand scenario. The marginal waste production per luxury or eco-tourist was already given in § D-1.5. The marginal cost of waste disposal are estimated to be 250 US$ per ton of waste, based on data from a study by Lardinois for Latin America (1996). Growth rates of marginal cost for the subsequent periods are taken zero, see Table D.7.

Table D.7. Values of general variables to determine the cost of waste disposal.

Values to Determine Cost of Waste Disposal	***Unit***	**2000**	**2005**	**2010**	**2015**	**2020**
Cost Variables	*Unit*	*Value*	*Growth Rates*			
Marginal cost of waste disposal	US$/ton/yr	250	0%	0%	0%	0%

D-5 Monetary Benefits

The monetary benefits include the energy revenues, the tourism revenues, and the agro-revenues. Also included is the sub-indicator ‘Profit Energy Company’.

D-5.1. Monetary Benefits – Energy Revenues

The total energy revenues are the sum of the revenues from the supply of heat and electricity to residential clients, commercial clients, and industrial clients, *and* from electricity export (if applicable). The electricity revenues from the three types of clients are determined by the price per unit of electricity (US$/kWh) for that particular type of client, the annual amount of electricity consumed per type of client, and the number of clients (of that particular type). The same holds for the revenues of heat. Revenues from electricity export are determined by the product of the price per unit of exported electricity and the amount of electricity exported. In formula:

$$R_E = \sum_{i=1}^{n} \sum_{j=1}^{m} \left(E_{d,ij} \cdot N_j \cdot p_{ij} \right) + E_{\exp} \cdot p_{\exp}$$

[Formula D-14]

With R_E = Total revenues from the energy sector [US$/yr]
$i...n$ = Energy forms (i.e., electricity and heat) [-]
$j...m$ = Types of clients (i.e., residential, commercial, industrial) [-]
$E_{d,ij}$ = Consumption of energy form i per type of client j [kWh/yr]
N_j = Total number of client type j [-]
p_{ij} = Price per unit of energy form i for client j [US$/kWh]
E_{exp} = Amount of electricity exported [kWh/yr]
p_{exp} = Price received for each unit of electricity exported [US$/kWh]

The number of clients, the consumption of energy forms per client, and the amount of energy exported depend on the energy demand and supply scenarios chosen. The price of electricity per client and the price per unit of exported electricity are derived from data of Coopelesca and ARESEP (Alfaro (2001); ARESEP (2001)), see Table D.8. ARESEP currently sets caps on the electricity prices of energy companies. Therefore, we assume the same electricity prices for all scenarios. The estimated growth rates listed in Table D.8 are based on the growth rates of electricity prices of Coopelesca in the period 1991-2000 (Alfaro, 2001). ARESEP also sets the price that electricity producers get for supplying electricity to the national grid, which is currently about 0.06 US$/kWh. The price of a unit of heat could not be determined as heat is currently not supplied to end-users, but we assume it to be the same as that of electricity.

Table D.8. Values of general variables to determine energy revenues.

Values to Determine Energy revenues	***Unit***	**2000**	**2005**	**2010**	**2015**	**2020**
	Unit	*Value*	*Growth Rates*			
Exchange rate	¢/US$	310	10%	10%	10%	10%
Price for Exported Electricity	US$/kWh	0.060	0%	0%	0%	0%
Price of Electricity						
Residential	US$/kWh	14.73	12%	14%	15%	15%
Commercial	US$/kWh	31.20	14%	15%	15%	15%
Industrial	US$/kWh	25.85	13%	14%	15%	15%
Price of Heat						
Residential	US$/kWh	14.73	12%	14%	15%	15%
Commercial	US$/kWh	31.20	14%	15%	15%	15%
Industrial	US$/kWh	25.85	13%	14%	15%	15%

D-5.2. Monetary Benefits – Tourism Revenues

The tourism revenues are determined by the number of tourists that visit an area (distinguishing between luxury and eco-tourists), the number of days they stay in the area, and the daily expenditures they make. In formula:

$$R_T = N_{lux} \cdot D_{lux} \cdot S_{lux} + N_{eco} \cdot D_{eco} \cdot S_{eco}$$ *[Formula D-15]*

With R_T = Total revenues from the tourism sector [US$/yr]
N_{lux} , N_{eco} = Number of luxury tourists and number of eco-tourists respectively [-]
D_{lux} , D_{eco} = Duration of stay of luxury tourists and eco-tourists [days/yr]
S_{lux} , S_{eco} = Daily expenditure of luxury tourists and eco-tourists [US$/day]

The number of tourists and the time they spend in the area depend on the energy demand scenario chosen. According to ICT (2000), the daily expenditure of tourists in 2000 is 86 US$/day. To distinguish between luxury and eco-tourists we estimate the daily expenditures of eco-tourists US$50/day, so that the expenditures of luxury tourists is US$140/day in 2000. Average annual growth rates to calculate the expenditures in subsequent periods are based on the growth rates between 1990-1995 and 1995-2000 (ICT, 1990b; 1995b; 2000b). Table D.9 lists the values of tourist expenditures.

Table D.9. Values of general variables to determine tourism revenues.

Values to Determine Tourism Revenues	***Unit***	**2000**	**2005**	**2010**	**2015**	**2020**
Daily Tourism Expenditures	*Unit*	*Value*	*Growth Rates*			
Daily expenditure per luxury tourist	US$/day	140	1.0%	1.0%	1.0%	1.0%
Daily expenditure per eco- tourist	US$/day	50	0.5%	0.5%	0.5%	0.5%

D-5.3. Monetary Benefits – Agro Revenues

The agro revenues consist of the price per unit of agro product multiplied by the amount produced of that product and consequently summing these values. In our analysis, we only include the production of bananas, sugar cane, oranges, pineapples, and wood because these products are traded on an international market and can also be processed on a large scale by the agro-industry.

$$R_A = \sum_{i=1}^{n} Y_i \cdot p_i \cdot 1000$$

[Formula D-16]

With R_A = Total revenues from the agro sector [US$/yr]
$1 \ldots n$ = Agro products (banana, sugar cane, oranges, pineapple, wood)
Y_i = Annual yield of product i [ton/yr]
p_i = Price per unit of product i on the international market [US$/kg]

The annual yield of agro-products depends on the energy demand scenario chosen. Appendix F contains more details on how this yield is determined. The price per unit of agro-product could not be determined accurately within the given time, but estimates are listed in Table D.10, based on SEPSA (2001).

Table D.10. Values of general variables to determine agro-revenues.

Values to Determine Agro-Revenues	***Unit***	**2000**	**2005**	**2010**	**2015**	**2020**
Price of agro-products	*Unit*	*Value*	*Growth Rates*			
Banana	US$/kg	0.30	0%	0%	0%	0%
Sugar Cane	US$/kg	0.01	0%	0%	0%	0%
Oranges	US$/kg	0.05	0%	0%	0%	0%
Pineapple	US$/kg	0.36	0%	0%	0%	0%
Wood	US$/kg	0.04	0%	0%	0%	0%

D-5.4. Profit Energy Company

The annual profit of the energy company determines the continuity of business and the room for new investments. The higher the profit in a scenario, the more lucrative this scenario is for the energy company. The profit is determined by dividing the total energy revenues by the total costs of the energy infrastructure and subtracting 1:

$$Pr_{EC} = \frac{R_{En}}{C_{En}} - 1 \qquad \textit{[Formula D-17]}$$

With Pr_{EC} = Annual profit (in %) during a 5-year period for the energy company [-]
R_{En} = Total energy revenues for the energy company [US$/yr]
C_{En} = Total energy costs for the energy company [US$/yr]

D-6 Regional Economic Development

The regional economic development is measured by determining the net benefits (which may be negative) for the tourism sector, the energy sector, the agro-sector, and the government. In formula:

$$REB = R_E - C_{infra} + R_T + R_A - C_{RW} \qquad \textit{[Formula D-18]}$$

With REB = Net regional economic benefit [US$/yr]
C_{infra} = Total cost of the energy infrastructure [US$/yr]
C_{RW} = Total cost of recycling and waste disposal [US$/yr]
R_E = Total energy revenues [US$/yr]
R_A = Total agro-revenues [US$/yr]
R_T = Total tourism revenues [US$/yr]

The calculation of the monetary costs and benefits has already been discussed in § D-4 and § D-5 respectively.

D-7 Competitiveness National Energy Sector

The competitiveness of the national electricity production sector is measured by letting actors assign an ordinal score. However, the actors can base their score on several considerations, such as (their opinion on) how the cost of national electricity production is affected by the regional infrastructure or how the regional energy infrastructure affects the (national) reliability of supply. The latter is difficult to quantify, but the costs of the national energy infrastructure can certainly be influenced if electricity is exported (or might be influenced when regional electricity production substitutes import of electricity from the national grid). So the (long-run) marginal costs of the regional electricity infrastructure can give an indication for the (changes in) competitiveness of the national electricity production sector: if regional marginal costs are lower, the competitiveness is improved. How to calculate the marginal costs of the regional electricity infrastructure was already discussed in § D-4.1.

D-8 Distribution of Costs & Benefits

To determine the distribution of costs and benefits, we will only consider the monetary costs and benefits already determined for the indicator ‘Regional Economic Development’ and we attribute these to the actors in the following way: The government (i.e., the tax payer) pays the costs of waste disposal; the energy revenues and the costs of the energy infrastructure are allocated to the energy companies; tourism revenues go to the local entrepreneurs; and the farmers receive the agro revenues. Furthermore, local habitants, entrepreneurs, and farmers have to pay their energy bills. For each scenario, the monetary costs and benefits attributed to an actor can be compared with the same costs and benefits for the Business-As-Usual scenario in the year 2020 to determine relative changes. Note that the attribution of costs and benefits is influenced by the structure of the economic analysis and very much project specific.

D-9 Index Scores: Business as Usual as a Reference

It is often useful to compare the quantitative scores on the impacts with the scores of the business-as–usual scenario to get a feeling for the size of the difference. Therefore, we also calculate –per period– the *index scores* by dividing a quantitative score of a scenario on a particular sub-(sub-)indicator with the scores of the Business-As-Usual scenario on that same indicator:

$$IS_{ij} = \frac{X_{ij}}{X_{BAU,i}} \qquad \textit{[Formula D-19]}$$

With IS_{ij} = Index score of energy infrastructure option i on indicator j [-]
X_{ij} = Quantitative score of option i on indicator j [variable]
$X_{BAU,i}$ = Quantitative score of the BAU option on indicator j [variable]

For instance, if an option has an index score of 3.0 for CO_2 emissions, this implies that the amount of CO_2 emissions associated with this option are three times higher than those of the BAU option, while an index score of 0.5 implies CO_2 emissions are half of those of the BAU option. Note that the index scores of CO_2 emissions can be *negative*. Negative scores for for CO_2 emissions occur when renewable electricity is exported out of the region. In such cases, the CO_2 emissions *in* the region are not only zero, but emissions are also avoided *outside* the region.

Negative index scores can also occur for the profit of energy companies, implying that the profit has turned into a loss. There are no index scores for energy revenues from electricity export due to the fact that no electricity is exported in the business-as-usual option. Also, there are no quantitative data –and thus no index scores– for ‘Reliability of Energy Supply’ and for ‘Risk & Uncertainty’ because the scores on these indicators are directly determined by the opinions of the actors. All index scores of the Business-As-Usual option do –of course– have a value of 1.0. So the actors can use both the index scores and the quantitative scores to base the assignment of their overall scores on.

D-10 Overview of Values to Determine Sub-Indicators

Table D.11 and Table D.12 give an overview of all the values and growth rates discussed in this appendix, which are needed to determine the scores on the sub-(sub-)indicators.

Table D.11. General variables and constants concerning costs that hold for 2000-2020 for all scenarios.

General Variables & Constants	***Unit***	**2000**	**2005**	**2010**	**2015**	**2020**
Cost Variables	*Unit*	*Value*	*Growth Rates*			
Exchange rate	¢/US$	310	10%	10%	10%	10%
Rate of interest	%	12%	12%	12%	12%	12%
Daily expenditure per luxury tourist	US$/day	140	1.0%	1.0%	1.0%	1.0%
Daily expenditure per eco- tourist	US$/day	50	0.5%	0.5%	0.5%	0.5%
Price of agro-products						
Banana	US$/kg	0.30	0%	0%	0%	0%
Sugar Cane	US$/kg	0.01	0%	0%	0%	0%
Oranges	US$/kg	0.05	0%	0%	0%	0%
Pineapple	US$/kg	0.36	0%	0%	0%	0%
Wood	US$/kg	0.04	0%	0%	0%	0%
Cost of waste disposal	US$/ton/yr	250	0%	0%	0%	0%
Transmission Cost Electricity	US$/kWh	-	0.008	5%	5%	5%
Distribution Cost Electricity	US$/kWh	-	0.037	1%	1%	1%
Distribution Cost Biogas	US$/kWh	-	0.025	1%	1%	1%
Distribution Cost Heat	US$/kWh	-	0.030	1%	1%	1%
Investment costs energy technologies						
Hydro - Local	$\text{US\$/kW}_e$	1,000	-0.5%	-0.5%	-0.5%	-0.5%
Hydro - Regional	$\text{US\$/kW}_e$	1,000	-0.5%	-0.5%	-0.5%	-0.5%
Biomass - Regional	$\text{US\$/kW}_e$	1,300	-1.0%	-1.0%	-1.0%	-1.0%
Geothermal - Regional	$\text{US\$/kW}_p$	2,500	-1.0%	-1.0%	-1.0%	-1.0%
PV Solar - Micro	$\text{US\$/kW}_p$	7,500	-8.0%	-8.0%	-8.0%	-8.0%
Termal Solar - Micro	$\text{US\$/m}^2$	300	-3.0%	-3.0%	-3.0%	-3.0%
Agro-Residues Digestion - Regional	$\text{US\$/kW}_{th}$	1,500	-1.0%	-1.0%	-1.0%	-1.0%
Wood Combustion - Regional	$\text{US\$/kW}_{th}$	1,000	-1.0%	-1.0%	-1.0%	-1.0%
O&M costs energy technologies						
Hydro - Local	% of total I	2.5%	2.5%	2.5%	2.5%	2.5%
Hydro - Regional	% of total I	2.5%	2.5%	2.5%	2.5%	2.5%
Biomass - Regional	% of total I	5.0%	5.0%	5.0%	5.0%	5.0%
Geothermal - Regional	% of total I	3.0%	3.0%	3.0%	3.0%	3.0%
PV Solar - Micro	% of total I	2.0%	2.0%	2.0%	2.0%	2.0%
Termal Solar - Micro	% of total I	2.0%	2.0%	2.0%	2.0%	2.0%
Agro-Residues Digestion - Regional	% of total I	5.0%	5.0%	5.0%	5.0%	5.0%
Wood Combustion - Regional	% of total I	5.0%	5.0%	5.0%	5.0%	5.0%
Price of Electricity						
Residential	US$/kWh	14.73	12%	14%	15%	15%
Commercial	US$/kWh	31.20	14%	15%	15%	15%
Industrial	US$/kWh	25.85	13%	14%	15%	15%
Price of Heat						
Residential	US$/kWh	14.73	12%	14%	15%	15%
Commercial	US$/kWh	31.20	14%	15%	15%	15%
Industrial	US$/kWh	25.85	13%	14%	15%	15%

Table D.12. General variables and constants that hold for 2000-2020 for all scenarios.

General Variables & Constants	***Unit***	**2000**	**2005**	**2010**	**2015**	**2020**
Noise factor luxury tourists	-	1.0	1.0	1.0	1.0	1.0
Noise factor eco-tourists	-	0.5	0.5	0.5	0.5	0.5
CO_2 emissions						
Fraction of diesel in national generation	%	1.0%	7.9%	6.4%	13.8%	7.7%
Fraction of bunker in national generation	%	0.1%	1.1%	3.0%	8.0%	10.5%
Diesel conversion efficiency	%	34%	35%	36%	37%	37%
Bunker conversion efficiency	%	39%	40%	40%	40%	40%
CO_2 emission factor diesel	ton/TJ_{in}	73.5	73.5	73.5	73.5	73.5
CO_2 emission factor bunker	ton/TJ_{in}	75.0	75.0	75.0	75.0	75.0
Daily waste production per luxury tourist	kg/day	1.0	1.0	1.0	1.0	1.0
Daily waste production per eco-tourist	kg/day	0.5	0.5	0.5	0.5	0.5
Fraction of waste in water by tourists	%	0.4%	0.4%	0.4%	0.4%	0.4%
Fraction of waste in water by agro-industry	%	0.1%	0.1%	0.1%	0.1%	0.1%
Economic Lifetime Technologies	years	20	20	20	20	20
Transmission Losses – Electricity	%	4%	4%	4%	4%	4%
Distribution Losses - Electricity	%	8%	8%	8%	8%	8%
Distribution Losses – Biogas	%	0%	0%	0%	0%	0%
Distribution Losses - Heat	%	10%	10%	10%	10%	10%

References

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Appendix E: Interviews with Actors & Experts

I. Questions Posed in the Interviews for the Field Study in Brabant, the Netherlands

The interviews held for the Brabant field study aimed to get better insight in how the local energy planning process evolves in practice. The interviews were held in Dutch, and on request the respondent got a copy of the interview. Each interview started with a short introduction about the research that we were working on, the purpose of the interview, and an overview of the type of questions that the respondent could expect. All interviews were rather informal in-depth interviews with open-end questions and did not have a stringent structure. Usually, after the introduction and the first question the respondent would start talking and often address more questions than the one initially posed. The responses determined which question was posed next. The interviews with actors evolved around the following issues:

- The role of the actor in the energy planning process.
- The actor's interests and preferences concerning the energy infrastructure (i.e., what the actor perceives as important aspects).
- Which other actors the actor has to deal with.
- Problems, thresholds, conflicts, and opportunities encountered during the planning process.

Note that the questions concerning these issues are usually not posed directly, but framed in a polite and sometimes indirect manner as not to 'embarrass' or 'shock' the respondent. Furthermore, more specific questions are posed to the following actors:

Specific Questions for Municipalities

- How the energy planning process is initiated and which steps are followed.
- Whether the municipality has a specific energy plan for the development of the energy infrastructure at new building sites.
- What type of support the municipality gets from consultancy firms or support organizations.
- Whether more support or more information is needed.

- What the role of the municipality is when an energy company wants to install a new energy system that is not directly linked to local energy demand.
- Who pays for extra costs induced by energy related measures in new buildings.

Specific Questions for Energy Companies

- What the effects of the liberalization of the energy sector (presumably) will be for the energy company.
- When and how the energy company decides to install new energy infrastructure, and which requirements apply.
- What type of support the energy company gets from consultancy firms or support organizations.
- Whether more support or more information is needed.
- Who pays for extra costs induced by policy measures.

Specific Questions for Support Organizations

- The type of support that the organization offers, and during which steps of the planning process.
- Which actors are supported.
- The time it takes to support the process.

Specific Questions for Property Developers

- What the effects of the liberalization of the energy sector (presumably) will be for the property developers.
- Who pays for extra costs induced by energy related measures in new buildings.

Specific Questions for Consultancy Firms

- The type of support that the consultancy firm offers, and during which steps of the planning process.
- Which actors are supported.
- The time it takes to support the process.
- Which models are used, and for what purpose.
- Which aspects are included in the models and on which assumptions the model is based.

II. Interviews for the Brabant Field Study

Government (Municipalities & Province)

Biemans, Pieter (Gemeente Tilburg, Project manager Environment), interview d.d. June 15, 1999) in Tilburg.
Dörfel, Jack (Gemeente Boxtel), interview d.d. Sept. 15, 1999 in Boxtel.
Klaassen, Sjef (Gemeente Helmond, Dep. City Development), interview d.d. July 8, 1999 in Helmond.
Moerkerken, Albert (Provincie Noord-Brabant, Enviornmental and Energy Policy), interview d.d. June 3, 1999 in ‘s Hertogenbosch.
Schalk, Pieter (SRE/ Gemeente Eindhoven), interview d.d. Sept. 22, 1999 in Eindhoven.
Schipper, Margriet (Gemeente Boxtel), interview d.d. Sept. 15, 1999 in Boxtel.
Van Eupen, Marijke (Gemeente Breda, Environmental Policy Dep.), interview d.d. Aug. 18, 1999 in Breda.
Wirtz, Roel (Gemeente Boxtel), interview d.d. Sept. 15, 1999 in Boxtel.

Energy Companies

De Jong, Jan (EPZ), interview d.d. Aug. 25, 1999 in Eindhoven.
Krikke, Koen (PNEM Energy Systems, Chief Sustainable Energy), interview d.d. May 28, 1998, in ’s Hertogenbosch.
Leentvaar, Gezien (PNEM), interview by telephone d.d. Sept, 21, 1999.
Van Gestel, Jack (PMG, Energy sales), interview d.d. June 16, 1999 in ’s Hertogenbosch.

Support Organizations

Hamers, Walter (Novem, Process manager OEI), interview d.d. Sept. 2, 1999 in Sittard.
Van Huffelen, Alexandra (Project Bureau Energie 2050, Director), interview d.d. March 12, 1999 in ’s Hertogenbosch.
Visser, Arjan (Project Bureau Energie 2050, Manager), interview d.d. March 12, 1999 in ’s Hertogenbosch.

Consultancy Firms

Vrins, Evert (Energie Adviesburo W/E), interview d.d. Oct. 1, 1999 in Tilburg.

Property Developers

Lambrichts (Compagnie Brandevoort), interview d.d. Sept. 30, 1999 in Helmond.
Ad Theuws (Bouwfonds). Interview by fax d.d 14 Jan. 1999.

Experts in the Field of Energy

Correljé, Aad (Erasmus Universiteit), email correspondance d.d. Sept 1999 – March 2000.
Kers, Daan (Tennet), email correspondance d.d. Aug. 19, 1999.
Lysen, Erik (Universiteit Utrecht, Chief Utrecht Center for Energy Research), interview d.d. Aug. 8, 1998.
Zijdeveld, Chris (Consultant/ ECN), interview d.d.Sept. 14, 1999 in Utrecht.
Smulders, Paul (retired consultant), interview d.d. 4 May 1999 in Eindhoven.
Guimaraes, Joao (professor at the Institute for Social Studies) Interview d.d 13 Nov. 1998, The Hague.

III. Questions Posed in the Interviews for the Field Study in Huetar Norte, Costa Rica

The interviews for the Huetar Norte field study were held during the second (descriptive) visit in May-July 2001[1]. The interviews aimed to get better insight in how the local energy planning process evolves in a developing country, and whether the assumptions of the new method hold. The interviews were held in Spanish, and each respondent got a copy of the interview. Each interview started with a short introduction about the research that we were working on, the purpose of the interview, and an overview of the type of questions that the respondent could expect. All interviews were informal in-depth interviews with open-end questions, and did not have a stringent structure. Usually, after the introduction and the first question the respondent would start talking and often address more questions than the one initially posed. The responses determined which question was posed next. The interviews with actors evolved around the following issues:

- The role of the actor in the energy planning process.
- The actor's interests and preferences concerning the energy infrastructure (i.e., what the actor perceives as important aspects).
- Which other actors the actor has to deal with.
- Problems, thresholds, conflicts, and opportunities encountered during the planning process.

Note that the questions concerning these issues are usually not posed directly, but framed in a polite and sometimes indirect manner as not to embarrass or shock the respondent. Furthermore, more specific questions are posed to the following actors:

Specific Questions for Local Entrepreneurs & Local Habitants

- What type of support the entrepreneurs/ habitants get from consultancy firms, support organizations, or interest groups.
- Whether more support more information is needed.
- Whether more information is needed on a particular subject.

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[1] A third visit in November-December 2001 aimed to get feedback on the tool through interviews, but we only partly succeeded.

Specific Questions for Energy Companies

- What types of clients the energy company has, and how much they consume.
- For which purposes the clients demand energy.
- What type of energy systems the energy company operates, how much they costs (specified), and how much energy they produce each year.
- Which types of energy forms they supply to the end-users.
- The electrification rate in the area serviced by the energy company.
- How long the energy planning process takes, which steps can be distinguished and which decisions must be taken.
- What type of support the energy company gets from consultancy firms, support organizations, or interest groups.
- Whether more support more information is needed.
- Whether more information is needed on a particular subject.

IV. Interviews for the Huetar Norte Field Study

Government

Ramírez, Eduardo (ARESEP, Dirección de Energía, Consección de Obra Pública). Personal communication d.d 12 Dec. 2001, San José, Costa Rica.

Energy Companies

Alfaro, Arturo (Gerente Distribución Eléctrica de Coopelesca). Personal communication d.d. 11 Dec. 2001, Ciudad Quesada, Costa Rica and insight in electronic files.

Mora, B. (ARESEP, Dirección de Energía, Consección de Obra Pública). Personal communication and supply of data d.d 12 Dec. 2001, San José, Costa Rica.

Reyes, Isaac (Director de redes eléctricas de Coopelesca). Personal communication June 2001, Ciudad Quesada, Costa Rica.

Local Entrepreneurs

Gámez, Beatriz (Owner of hotel La Quinta, Sarapiquí, Heredia and member of CATUSA, the chamber of tourism for the canton of Sarapiquí) Personal communication d.d. 28 June 2001, Sarapiquí, Costa Rica.

Martínez, Alex (Owner of a hotel in Sarapiquí, and founder-member of ABAS) Personal communication d.d. June 28, 2001, Puerto Viejo de Sarapiquí, Costa Rica.

Local Habitants

see: Martínez, Alex
see: Gámez, Beatriz

Interest Groups/ Support Groups

ACOPE: Alvarado Mora, Mario (Director of the Association for Independent Power Producers ACOPE). Personal communication d.d. July 3, 2001, San José, Costa Rica.

Siteur, Joost (Biomass User Network). Email correspondence, July 2001.

Experts in the Field of Energy

Azofeifa, Roberto (Ministerio de Agricultura y Ganadería, Región Huetar Norte). Personal communication d.d. 28 Nov. 2001, San José, Costa Rica, and email correspondence.

Hengsdijk, H. (Plant Research International, Wageningen University). Personal communcation d.d. 25 Jan, 2002, Wageningen.

Jiménez Gómez, Roberto (Director of environmental planning of CENPE-ICE). Frequent personal communication during May-June-July and Nov.-Dec. 2001.

Saenz, Fernando ((researcher at CINPE-UNA). Personal communication d.d.26 Nov. 2001, Heredia, Costa Rica.

Vargas Alfaro, Leiner (Professor at the Centro Internacional de Política economía de Desarrollo Sostenible (CINPE) at the Universidad Nacional de Costa Rica). Frequent personal communication during May-June-July and Nov.-Dec. 2001.

Appendix F: Tool Assumptions & Formulas

This appendix addresses the assumptions and formulas used in the (hidden) sheets of the TOOL prototype, as discussed in Chapter 7 and Chapter 8 of this thesis. However, it does *not* address the formulas and values used to calculate the scores o the (sub-)indicators, as these are discussed in Appendix D.

The calculations in this appendix mainly concern the amount of the different energy forms demanded by the different types of clients, the required production of the energy systems, and the availability of the energy resources, in particular biomass residues. We will start with energy demand, as this is also the starting point of the TOOL.

Energy demand is largely determined by the input values concerning the demand scenario. These input values include the growth rates for:

- The number of residential
- Electricity demand per residential client
- Heat demand per residential client
- The number of other commercial clients
- Electricity demand per other commercial client
- The number of industrial clients
- Electricity demand per industrial client
- The number of luxury and eco-tourist
- The number of nights they spend in the area
- Electricity demand per hotel room
- Heat demand per hotel room

When the values for 2000 are determined, we can use the growth rates to calculate the values in other periods with the following general formula:

$$X_t = X_i \cdot (1 + r)^{(t-i)} \qquad \text{[Formula F-1]}$$

With X_t = Value of variable X at year t
X_i = Value of variable X at year i
r = Average annual growth rate
$t-i$ = Time period between year t and year i

The total energy demand of a particular type of client in a certain period can then be determined with:

$$E_{d,i} = N_i \cdot \left(e_{d,i} + h_{d,i}\right) \qquad \text{[Formula F-2]}$$

With $E_{d,i}$ = Total energy demand of client type i [kWh/yr]
N_i = Total number of clients of type i [-]
$e_{d,i}$ = Electricity demand per client type i [kWh/yr]
$h_{d,i}$ = Heat demand per client type i [kWh/yr]

Overall energy demand is then the sum of the total energy demand of the client types. Note that for the sake of simplicity, in our example we distinguish between electricity and heat demand only for households (residential clients) and hotels; the heat demand of other clients is met by using electricity. This brings us to the following issue. We can easily calculate the total energy demand of *tourists* (with the number of luxury and eco-tourists, their time of stay, and their respective energy demands per tourist type per day), but we need to know the total energy demand of (luxury and eco-) *hotels*. And for this we need to know the electricity demand per hotel $e_{d,H}$. To get from demand per tourist to demand per hotel we use the occupancy rate of hotels and the total number of hotels. The occupancy rate is the ratio of occupied rooms and the total number of available rooms taken over a certain period (e.g., a year), and is calculated with the following formula:

$$\tau_i = \frac{N_i \cdot D_i \cdot \left(s_i + \frac{1}{2} \cdot k_i\right)}{M_i \cdot 365} \qquad \textit{with} \quad s_i = 1 - k_i \qquad \text{[Formula F-3]}$$

With $\tau_{,i}$ = Occupancy rate of hotel type i (i.e. luxury or eco) [-]
N_i = Total number of tourists of type i (i.e. luxury or eco) [-]
M_i = Total number of rooms of type i (i.e. luxury or eco) [-]
D_i = Days of stay per tourist type i (i.e. luxury or eco) [days/year]
s_i = Percentage singles of tourist type i [-]
k_i = Percentage couples of tourist type i [-]
365 = Number of days in a year [days/year]

The number of tourists and the days of their stay depend on the demand scenario chosen. The number of rooms and hotels in the Coopelesca area are derived from data of ICT (1995a; 2000a). ICT states that in 2000 there were a total of 24 hotels and 737 rooms available in the canton of San Carlos and the tourist area of Sarapiquí, which together (more or less) cover the Coopelesca area. However, ICT only lists the hotels and rooms that are certified with a

'Declaratoria Turística'[1], which we will label as luxury hotels. But there are also many hotels without such a certificate. ICT states that about 80% of all hotels in Costa Rica do not have a declaratoria, so we will take this percentage to calculate the number of eco-hotels in the Coopelesca area, which amounts then to 97. ICT (2000a) also provides data on the average number of rooms per hotel in 2000. For eco-hotels (i.e., hotels *without* a declaratoria) this average is 10.5 rooms per hotel, resulting in a total number of eco-rooms of 1019. The average number of rooms per luxury hotel can then be calculated by dividing the number of rooms (737) by the number of hotels (24), which results in an average of 30.7 rooms per luxury hotel. We assume that the number of rooms per luxury and eco-hotels is constant for the entire 20-year period. Furthermore, we assume that 80% of the luxury tourists and 70% of the eco-tourists travel as couples, while the remaining fraction travels as single[2]. Based on these data, and given the number of tourists and the time spent in the area in 2000 (see § 7.3.2), we determine the occupancy rate to be 71.4% for luxury hotels and 59.9% for eco-hotels. We assume the occupancy rate is constant over the entire 20-year period. The number of hotels for each five-year period can now be calculated with:

$$H_i = \frac{N_i \cdot D_i \cdot \left(s_i + \tfrac{1}{2} \cdot k_i\right)}{\tau \cdot m_i}$$

[Formula F-4]

With $H_{,i}$ = Total number of hotels of type i (i.e. luxury or eco) [-]
$\tau_{,i}$ = Occupancy rate of hotel type i (i.e. luxury or eco) [-]
m_i = Number of rooms per hotel of type i (i.e. luxury or eco) [-]

The formula to calculate the electricity demand per type of hotel is similar to that for the heat demand per type of hotel, and is given by:

$$e_{d,Hi} = e_{d,Ti} \cdot \frac{N_i \cdot D_i \cdot \left(s_i + \tfrac{1}{2} \cdot k_i\right)}{H_i}$$

[Formula F-5]

With $e_{d,Hi}$ = Electricity demand per hotel of type i (i.e. luxury or eco) [kWh/yr]
$e_{d,Ti}$ = Electricity demand per tourist of type i [kWh/yr]

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[1] A 'Declaratoria Turística' indicates that a hotel complies with certain (voluntary) requirements set by the government.

[2] The eco-tourist is believed to also include the 'backpacker' type of tourist, who is believed to travel alone more often than the luxury tourist.

The amount of energy that the energy systems have to produce depends on the input values for the shares they contribute in meeting demand, and on distribution (and transmission) losses:

$$E_{p,i} = \frac{\lambda_i \cdot E_{d,tot}}{(1-\ell_i)}$$ [Formula F-6]

With $E_{p,i}$ = Required energy production by system i [MWh/yr]
$E_{d,tot}$ = Total energy demand (all forms of energy of all clients) [MWh/yr]
λ_i = Fraction of total energy demand supplied to the end-user by system i [-]
ℓ_i = Distribution (and transmission) losses associated with system i [-]

Remember that (PV and thermal) solar systems do not have distribution losses, while the losses of distributing biogas are also set at zero. And for the sake of simplicity, we assume that only the electricity imported form the national grid has transmission losses. The amounts of energy resources that are needed to supply the demanded amounts of energy are then determined by dividing the required production with the conversion efficiency of that system:

$$E_{s,i} = \frac{E_{p,i} \cdot 3.6}{\eta_i}$$ [Formula F-7]

With $E_{s,i}$ = Required amount of resources used by system i [GJ/yr]
$E_{p,i}$ = Required energy production by system i [MWh/yr]
η_i = Conversion efficiency of system i [-]
3.6 = Factor to convert MWh/yr into GJ/yr.

However, some resource potentials for electricity generating systems (e.g., hydropower, geothermal) are expressed in potential capacity that can be installed, implying that the required amount of resources can be calculated with the following formula:

$$E_{sp,i} = \frac{E_{p,i}}{CF \cdot 8760}$$ [Formula F-8]

With $E_{sp,i}$ = Part of resource potential used by system i [MW]
CF = Capacity factor of system i [-]
8760 = Number of hours in one year

The capacity factor is the time in a given period that the system operates at nominal capacity. Table F.1 lists the average conversion efficiencies and capacity factors of the energy systems, based on CEPAL (2001), Van Beeck (1998), and Van Helden (2001).

Table F.1. Average conversion efficiencies and capacity factors of energy systems.

Average Conversion & Capacity Factors	***Unit***	**2000**	**2005**	**2010**	**2015**	**2020**
Conversion Efficiency - Electricity						
Biomass - Regional	%	25%	25%	25%	25%	25%
PV Solar - Micro	kWh/kW$_p$	1,500	1,500	1,500	1,500	1,500
Conversion Efficiency - Heat						
Agro-Residues Digestion - Regional	%	30%	30%	30%	30%	30%
Wood Combustion - Regional	%	80%	80%	80%	80%	80%
Thermal Solar – Households and Eco-Hotels	GJ/m^2	2.5	2.6	2.8	2.9	3.0
Thermal Solar – Luxury Hotels	GJ/m^2	3.0	3.1	3.3	3.4	3.5
Capacity Factor						
Hydro - Local	-	0.40	0.40	0.40	0.40	0.40
Hydro - Regional	-	0.50	0.50	0.50	0.50	0.50
Geothermal - Regional	-	0.90	0.90	0.90	0.90	0.90

Of course, for each demand scenario we have to check whether the required amount of resource does not exceed the maximum available amount of resource. The PV solar potential is based on an estimated average of 4.11 hours of sunshine per day in the Huetar Norte region, implying 1500 sunhours per year, and thus –with an average irradiation of 1500 kWh/m^2/yr (DSE, 1994), an energy intensity of 1 kW/m^2. Given an estimated average conversion efficiency of PV systems of 10% in developing countries in 2000 (Van Helden, 2001), the capacity per m^2 of PV system is then 100 W$_p$/m^2. The specific capacity can then be calculated with the following formula:

$$\eta_{spec,PV} = \frac{h_{sun} \cdot \eta_c \cdot I}{c_p} \qquad \text{[Formula F-9]}$$

With $\eta_{spec,PV}$ = Specific efficiency of PV systems [kWh/kW$_p$]
η_c = Conversion efficiency of PV systems [-]
h_{sun} = Average hours of full sun in one year [hrs/yr]
I = Solar intensity [kW/m^2]
c_p = Capacity per m^2 [W$_p$/m^2]

So in 2000, each kW$_p$ will produce 1500 kWh/yr, which is the specific efficiency of PV systems. We assume that the specific efficiency is constant over the entire 20-year period, although we acknowledge that the specific efficiency may increase due to improvements in other parts of the PV system than the PV modules (e.g. better connections and invertors).

Note that the biomass potential is scenario dependent, as the scenarios determine the cultivated area and the marginal yield. The amount of biomass resources is also determined by the percentage of residues remaining after harvest and processing of the agro-products, the dry content of the residues, and the energy content of the residues. This is expressed in the following formulas for the resource potential of dry and wet biomass residues:

$$E_{s,biod} = A_i \cdot y_i \cdot v_i \cdot d_i \cdot \varepsilon_{i,dry} \qquad and: \quad E_{s,biow} = A_i \cdot y_i \cdot v_i \cdot \varepsilon_{i,wet} \qquad \text{[Formula F-10]}$$

With $E_{s,biod}$ = Resource potential of dry residues of agro-product i [GJ/yr]
$E_{s,biow}$ = Resource potential of wet residues of agro-product i [GJ/yr]
A_i = Cultivated area for agro-product i [ha/yr]
y_i = Marginal yield of agro-product i [ton/ha]
v_i = Percentage biomass residues of total yield of agro-product i [-]
d_i = Percentage dry content of biomass residues of agro-product i [-]
$\varepsilon_{i,dry}$ = Energy content of dry residues of agro-product i [GJ/ton$_{dry}$]
$\varepsilon_{i,wet}$ = Energy content of wet residues of agro-product i [GJ/ton$_{dry}$]

The values of the variables to determine the biomass resource potential in the Huetar Norte region in 2000 are listed in Table F.2. Note that some biomass residues may currently be used for other purposes than energy generation. For instance, Azofeifa (2001) states that residues from harvesting (among others) rice and beans are left behind on the land as a fertilizer. However, when digesting biomass residues, one of the digestion products –besides biogas– is compost, which can also be used to fertilize the land. In addition, Saenz (2001) states the agro-sector currently generates large amounts of residues that are not used for other purposes and are not disposed of in a proper way.

The residues in subsequent periods are determined by altering the growth rates for the cultivated area per agro-product and/or changing the values for the marginal yields of the agro-products. For the sake of simplicity, we assume that the shares of the cultivated area of the different agro-products is constant, so that their individual growth rates are all equal.

Table F.2. Values to determine the biomass resource potential in the Huetar Norte region in 2000.

Variable	**Unit**	**Banana**	**Sugar Cane**	**Oranges**	**Pineapple**	**Wood**	**Total**
A_i	ha	5,000[1]	7,100[1]	20,000[1]	5,700[1]	81,200[2]	**119,000**
y_i	ton$_{wet}$/ha	43[3]	127[4]	17[5]	55[4]	see note 2	
Yield	ton$_{wet}$/yr	215,000	901,700	340,000	313,500	36,628[6]	**1,806,828**
ν_i	%	60%[7,8]	40%[7,8]	20%[7,8]	60%[7,8]	65%[9]	
Total Wet Residues	ton$_{wet}$/yr	322,500	601,133	85,000	470,250	23,808	**1,502,691**
d_i	%	20%[8]	20%[8]	20%[8]	20%[8]	50%[8]	
Total Dry Residues	ton$_{dry}$/yr	64,500	120,227	17,000	94,050	11,904	**307,681**
$\varepsilon_{i,wet}$ (LHV$_{wet}$)	GJ / ton$_{wet}$	8[10]	8[10]	8[10]	8[10]	8[10]	**8**
$\varepsilon_{i,dry}$(HHVdry)	GJ / ton$_{dry}$	18[10]	18[10]	18[10]	18[10]	18[10]	**18**
$E_{s,biow}$	GJ/yr	2,580,000	4,809,067	680,000	3,762,000	190,463	**12,021,530**
$E_{s,biod}$	GJ/yr	1,161,000	2,164,080	306,000	1,692,900	214,271	**5,538,251**

Notes:

[1] Source: Ministerio de Agricultura y Ganadería (2001).

[2] According to OEA (1997), Huetar Norte accounts for 70% of the Costa Rican part of the San Juan river basin. Total (primary and secondary) forest area in the Costa Rican part of the river basin is estimated to be 116,000 ha. and annual sustainable wood supply 80,500 m3 assuming sustainable extraction rate with a 20 year cycle and a 20 m3/ha yield for primary forest and a 10 m3/ha yield for secondary forests. For the Huetar Norte region, this implies a cultivated area of 81,200 ha. and an annual wood supply of 56,350 m3.

[3] Assuming 1 box of bananas weighs 18 kilos, and assuming regional yield per ha is equal to national yield per ha. National yield is determined using data from SEPSA (2001). Consistent with data from Bouman et.al. (2000) for the region Huetar Atlántica.

[4] Source: MAG (1999).

[5] Yield value based on MAG (1995).

[6] Assuming the average bulk density = 0.65 metric tons per m3.

[7] Estimate based on opinion of experts of SEPSA (R. Azofeifa) and Plant Research International, Wageningen University (H. Hengsdijk).

[8] Estimate based on expert opinion of Plant Research International, Wageningen University (H. Hengsdijk)

[9] Assuming harvesting losses of 15% and sawing losses of 50%. (The latter is based on sawing losses mentioned in OEA (1997) and Estado de la Nación 4 (1998).

[10] Estimate based on data in Faaij (1997, p. 31).

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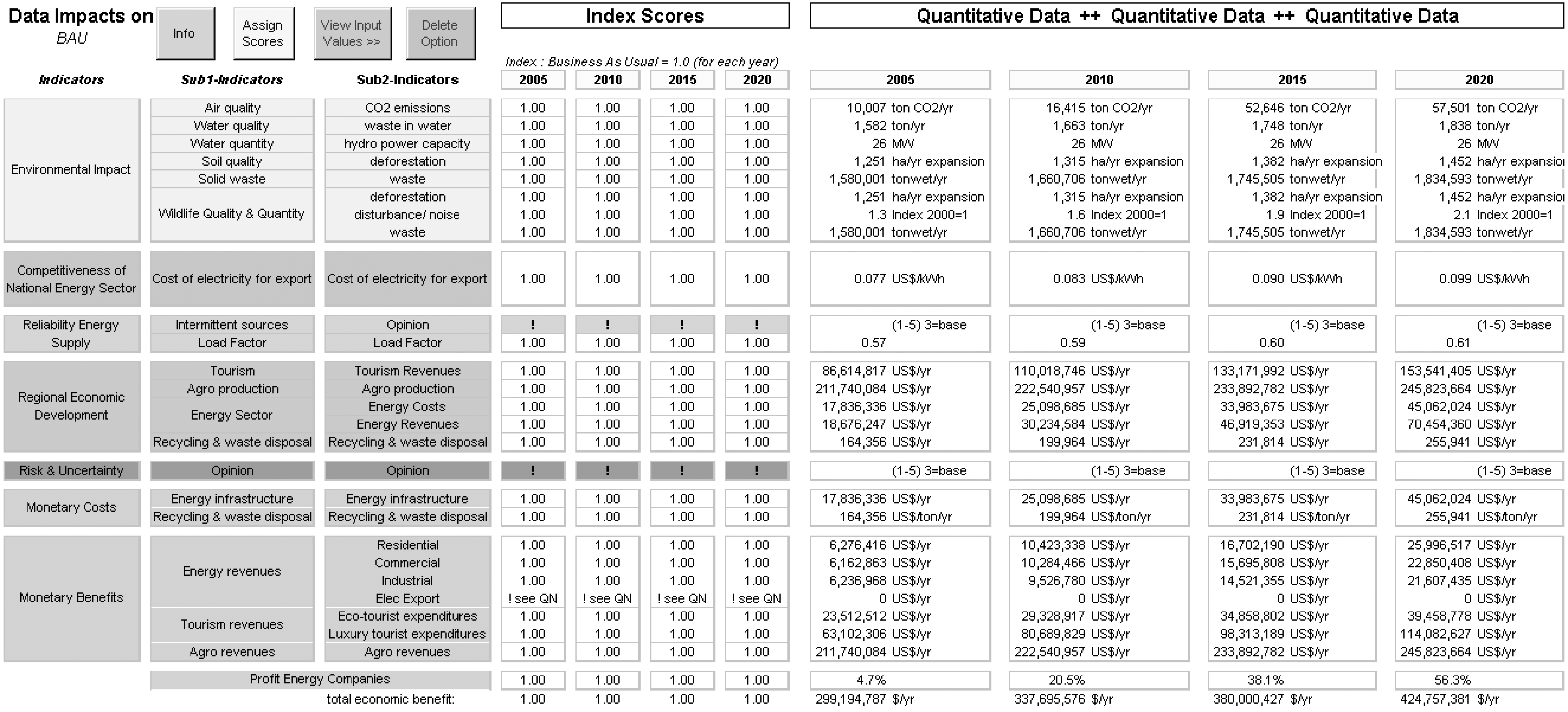
Appendix G Overview of Data Impacts Sheets

Data Impacts Sheet of the 'Business-As-Usual' Energy Infrastructure Option

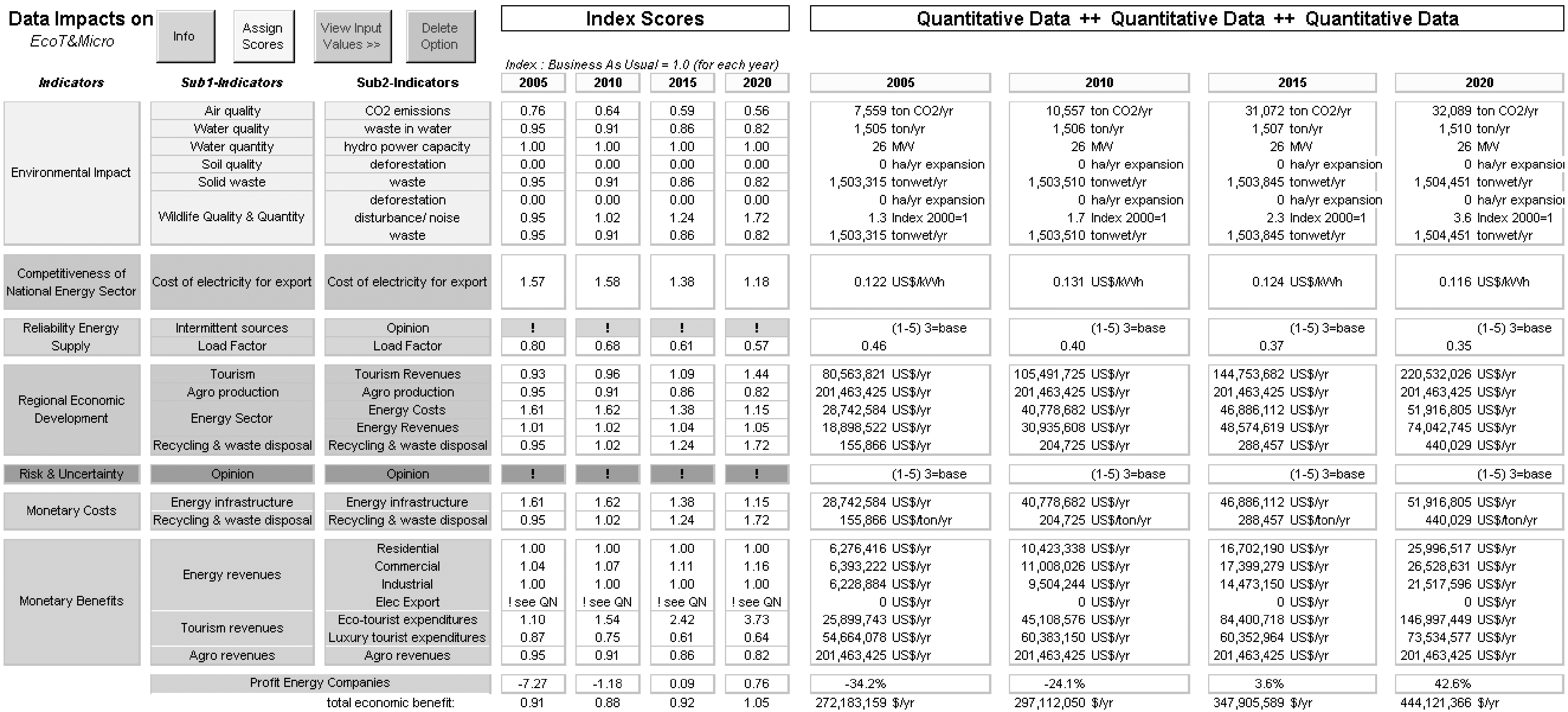


Data Impacts on
BAU

Index : Business As Usual = 1.0 (for each year)

Indicators	Sub1-Indicators	Sub2-Indicators	Index Scores				Quantitative Data ++ Quantitative Data ++ Quantitative Data			
			2005	2010	2015	2020	2005	2010	2015	2020
Environmental Impact	Air quality	CO2 emissions	1.00	1.00	1.00	1.00	10,007 ton CO2/yr	16,415 ton CO2/yr	52,646 ton CO2/yr	57,501 ton CO2/yr
	Water quality	waste in water	1.00	1.00	1.00	1.00	1,582 ton/yr	1,663 ton/yr	1,748 ton/yr	1,838 ton/yr
	Water quantity	hydro power capacity	1.00	1.00	1.00	1.00	26 MW	26 MW	26 MW	26 MW
	Soil quality	deforestation	1.00	1.00	1.00	1.00	1,251 ha/yr expansion	1,315 ha/yr expansion	1,382 ha/yr expansion	1,452 ha/yr expansio
	Solid waste	waste	1.00	1.00	1.00	1.00	1,580,001 tonwet/yr	1,660,706 tonwet/yr	1,745,505 tonwet/yr	1,834,593 tonwet/yr
	Wildlife Quality & Quantity	deforestation	1.00	1.00	1.00	1.00	1,251 ha/yr expansion	1,315 ha/yr expansion	1,382 ha/yr expansion	1,452 ha/yr expansio
		disturbance/ noise	1.00	1.00	1.00	1.00	1.3 Index 2000=1	1.6 Index 2000=1	1.9 Index 2000=1	2.1 Index 2000=1
		waste	1.00	1.00	1.00	1.00	1,580,001 tonwet/yr	1,660,706 tonwet/yr	1,745,505 tonwet/yr	1,834,593 tonwet/yr
Competitiveness of National Energy Sector	Cost of electricity for export	Cost of electricity for export	1.00	1.00	1.00	1.00	0.077 US$/kWh	0.083 US$/kWh	0.090 US$/kWh	0.099 US$/kWh
Reliability Energy Supply	Intermittent sources	Opinion	!	!	!	!	(1-5) 3=base	(1-5) 3=base	(1-5) 3=base	(1-5) 3=base
	Load Factor	Load Factor	1.00	1.00	1.00	1.00	0.57	0.59	0.60	0.61
Regional Economic Development	Tourism	Tourism Revenues	1.00	1.00	1.00	1.00	86,614,817 US$/yr	110,018,746 US$/yr	133,171,992 US$/yr	153,541,405 US$/yr
	Agro production	Agro production	1.00	1.00	1.00	1.00	211,740,084 US$/yr	222,540,957 US$/yr	233,892,782 US$/yr	245,823,664 US$/yr
	Energy Sector	Energy Costs	1.00	1.00	1.00	1.00	17,836,336 US$/yr	25,098,685 US$/yr	33,983,675 US$/yr	45,062,024 US$/yr
		Energy Revenues	1.00	1.00	1.00	1.00	18,676,247 US$/yr	30,234,584 US$/yr	46,919,353 US$/yr	70,454,360 US$/yr
	Recycling & waste disposal	Recycling & waste disposal	1.00	1.00	1.00	1.00	164,356 US$/yr	199,964 US$/yr	231,814 US$/yr	255,941 US$/yr
Risk & Uncertainty	Opinion	Opinion	!	!	!	!	(1-5) 3=base	(1-5) 3=base	(1-5) 3=base	(1-5) 3=base
Monetary Costs	Energy infrastructure	Energy infrastructure	1.00	1.00	1.00	1.00	17,836,336 US$/yr	25,098,685 US$/yr	33,983,675 US$/yr	45,062,024 US$/yr
	Recycling & waste disposal	Recycling & waste disposal	1.00	1.00	1.00	1.00	164,356 US$/ton/yr	199,964 US$/ton/yr	231,814 US$/ton/yr	255,941 US$/ton/yr
Monetary Benefits	Energy revenues	Residential	1.00	1.00	1.00	1.00	6,276,416 US$/yr	10,423,338 US$/yr	16,702,190 US$/yr	25,996,517 US$/yr
		Commercial	1.00	1.00	1.00	1.00	6,162,863 US$/yr	10,284,466 US$/yr	15,695,808 US$/yr	22,850,408 US$/yr
		Industrial	1.00	1.00	1.00	1.00	6,236,968 US$/yr	9,526,780 US$/yr	14,521,355 US$/yr	21,607,435 US$/yr
		Elec Export	! see QN	! see QN	! see QN	! see QN	0 US$/yr	0 US$/yr	0 US$/yr	0 US$/yr
	Tourism revenues	Eco-tourist expenditures	1.00	1.00	1.00	1.00	23,512,512 US$/yr	29,328,917 US$/yr	34,858,802 US$/yr	39,458,778 US$/yr
		Luxury tourist expenditures	1.00	1.00	1.00	1.00	63,102,306 US$/yr	80,689,829 US$/yr	98,313,189 US$/yr	114,082,627 US$/yr
	Agro revenues	Agro revenues	1.00	1.00	1.00	1.00	211,740,084 US$/yr	222,540,957 US$/yr	233,892,782 US$/yr	245,823,664 US$/yr
	Profit Energy Companies		1.00	1.00	1.00	1.00	4.7%	20.5%	38.1%	56.3%
		total economic benefit:	1.00	1.00	1.00	1.00	299,194,787 $/yr	337,695,576 $/yr	380,000,427 $/yr	424,757,381 $/yr

Data Impacts Sheet of the ‘Eco-Tourism & Micro Supply’ Energy Infrastructure Option

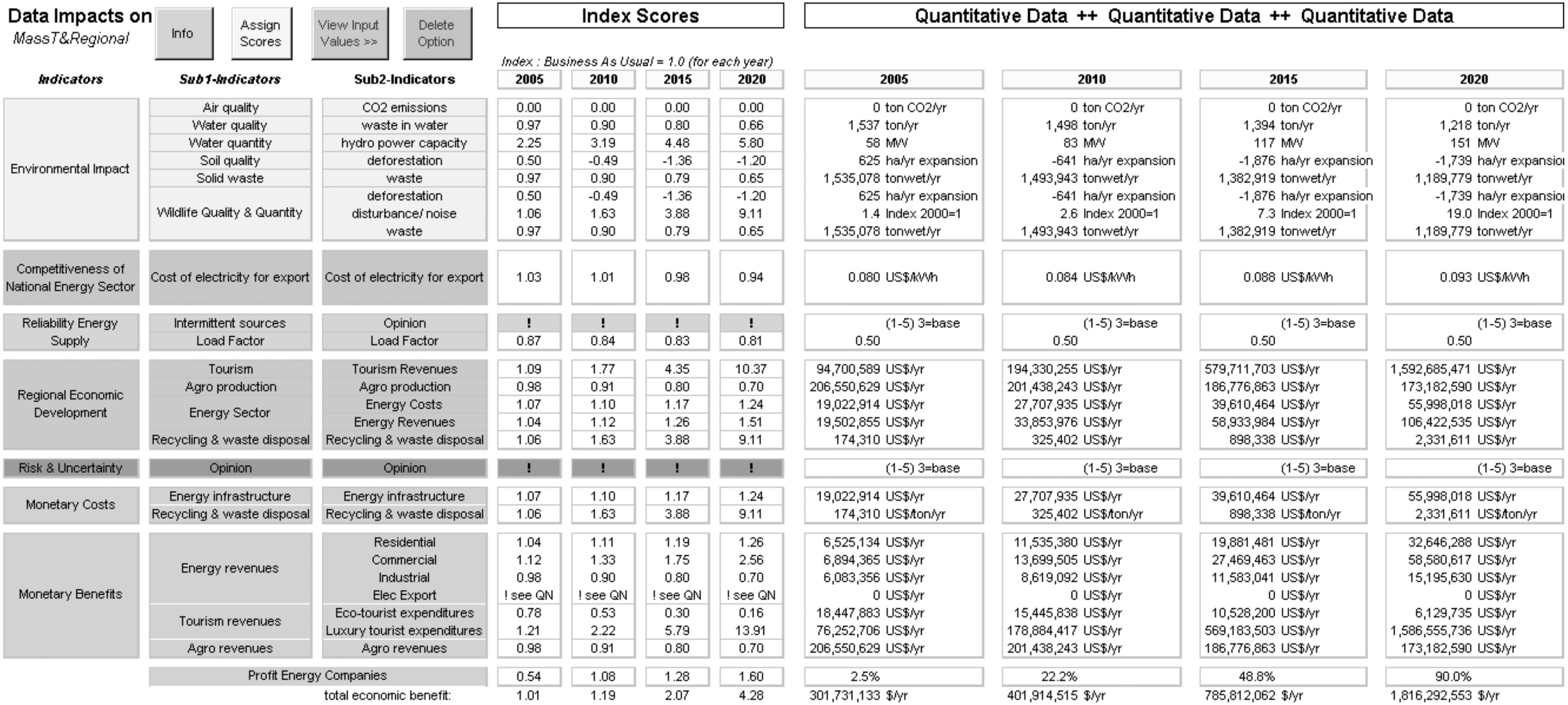


Data Impacts on
EcoT&Micro

Index : Business As Usual = 1.0 (for each year)

			Index Scores				Quantitative Data ++ Quantitative Data ++ Quantitative Data			
Indicators	***Sub1-Indicators***	**Sub2-Indicators**	**2005**	**2010**	**2015**	**2020**	**2005**	**2010**	**2015**	**2020**
Environmental Impact	Air quality	CO2 emissions	0.76	0.64	0.59	0.56	7,559 ton CO2/yr	10,557 ton CO2/yr	31,072 ton CO2/yr	32,089 ton CO2/yr
	Water quality	waste in water	0.95	0.91	0.86	0.82	1,505 ton/yr	1,506 ton/yr	1,507 ton/yr	1,510 ton/yr
	Water quantity	hydro power capacity	1.00	1.00	1.00	1.00	26 MW	26 MW	26 MW	26 MW
	Soil quality	deforestation	0.00	0.00	0.00	0.00	0 ha/yr expansion	0 ha/yr expansion	0 ha/yr expansion	0 ha/yr expansio
	Solid waste	waste	0.95	0.91	0.86	0.82	1,503,315 tonwet/yr	1,503,510 tonwet/yr	1,503,845 tonwet/yr	1,504,451 tonwet/yr
	Wildlife Quality & Quantity	deforestation	0.00	0.00	0.00	0.00	0 ha/yr expansion	0 ha/yr expansion	0 ha/yr expansion	0 ha/yr expansio
		disturbance/ noise	0.95	1.02	1.24	1.72	1.3 Index 2000=1	1.7 Index 2000=1	2.3 Index 2000=1	3.6 Index 2000=1
		waste	0.95	0.91	0.86	0.82	1,503,315 tonwet/yr	1,503,510 tonwet/yr	1,503,845 tonwet/yr	1,504,451 tonwet/yr
Competitiveness of National Energy Sector	Cost of electricity for export	Cost of electricity for export	1.57	1.58	1.38	1.18	0.122 US$/kWh	0.131 US$/kWh	0.124 US$/kWh	0.116 US$/kWh
Reliability Energy Supply	Intermittent sources	Opinion	!	!	!	!	(1-5) 3=base	(1-5) 3=base	(1-5) 3=base	(1-5) 3=base
	Load Factor	Load Factor	0.80	0.68	0.61	0.57	0.46	0.40	0.37	0.35
Regional Economic Development	Tourism	Tourism Revenues	0.93	0.96	1.09	1.44	80,563,821 US$/yr	105,491,725 US$/yr	144,753,682 US$/yr	220,532,026 US$/yr
	Agro production	Agro production	0.95	0.91	0.86	0.82	201,463,425 US$/yr	201,463,425 US$/yr	201,463,425 US$/yr	201,463,425 US$/yr
	Energy Sector	Energy Costs	1.61	1.62	1.38	1.15	28,742,584 US$/yr	40,778,682 US$/yr	46,886,112 US$/yr	51,916,805 US$/yr
		Energy Revenues	1.01	1.02	1.04	1.05	18,898,522 US$/yr	30,935,608 US$/yr	48,574,619 US$/yr	74,042,745 US$/yr
	Recycling & waste disposal	Recycling & waste disposal	0.95	1.02	1.24	1.72	155,866 US$/yr	204,725 US$/yr	288,457 US$/yr	440,029 US$/yr
Risk & Uncertainty	Opinion	Opinion	!	!	!	!	(1-5) 3=base	(1-5) 3=base	(1-5) 3=base	(1-5) 3=base
Monetary Costs	Energy infrastructure	Energy infrastructure	1.61	1.62	1.38	1.15	28,742,584 US$/yr	40,778,682 US$/yr	46,886,112 US$/yr	51,916,805 US$/yr
	Recycling & waste disposal	Recycling & waste disposal	0.95	1.02	1.24	1.72	155,866 US$/ton/yr	204,725 US$/ton/yr	288,457 US$/ton/yr	440,029 US$/ton/yr
Monetary Benefits	Energy revenues	Residential	1.00	1.00	1.00	1.00	6,276,416 US$/yr	10,423,338 US$/yr	16,702,190 US$/yr	25,996,517 US$/yr
		Commercial	1.04	1.07	1.11	1.16	6,393,222 US$/yr	11,008,026 US$/yr	17,399,279 US$/yr	26,528,631 US$/yr
		Industrial	1.00	1.00	1.00	1.00	6,228,884 US$/yr	9,504,244 US$/yr	14,473,150 US$/yr	21,517,596 US$/yr
		Elec Export	! see QN	! see QN	! see QN	! see QN	0 US$/yr	0 US$/yr	0 US$/yr	0 US$/yr
	Tourism revenues	Eco-tourist expenditures	1.10	1.54	2.42	3.73	25,899,743 US$/yr	45,108,576 US$/yr	84,400,718 US$/yr	146,997,449 US$/yr
		Luxury tourist expenditures	0.87	0.75	0.61	0.64	54,664,078 US$/yr	60,383,150 US$/yr	60,352,964 US$/yr	73,534,577 US$/yr
	Agro revenues	Agro revenues	0.95	0.91	0.86	0.82	201,463,425 US$/yr	201,463,425 US$/yr	201,463,425 US$/yr	201,463,425 US$/yr
	Profit Energy Companies		-7.27	-1.18	0.09	0.76	-34.2%	-24.1%	3.6%	42.6%
		total economic benefit:	0.91	0.88	0.92	1.05	272,183,159 $/yr	297,112,050 $/yr	347,905,589 $/yr	444,121,366 $/yr

Data Impacts Sheet of the ‘Mass-Tourism & Regional Supply’ Energy Infrastructure Option



Data Impacts on
MassT&Regional

Index Scores — *Index : Business As Usual = 1.0 (for each year)*

Quantitative Data ++ Quantitative Data ++ Quantitative Data

Indicators	*Sub1-Indicators*	Sub2-Indicators	2005	2010	2015	2020	2005	2010	2015	2020
Environmental Impact	Air quality	CO2 emissions	0.00	0.00	0.00	0.00	0 ton CO2/yr	0 ton CO2/yr	0 ton CO2/yr	0 ton CO2/yr
	Water quality	waste in water	0.97	0.90	0.80	0.66	1,537 ton/yr	1,498 ton/yr	1,394 ton/yr	1,218 ton/yr
	Water quantity	hydro power capacity	2.25	3.19	4.48	5.80	58 MW	83 MW	117 MW	151 MW
	Soil quality	deforestation	0.50	-0.49	-1.36	-1.20	625 ha/yr expansion	-641 ha/yr expansion	-1,876 ha/yr expansion	-1,739 ha/yr expansio
	Solid waste	waste	0.97	0.90	0.79	0.65	1,535,078 tonwet/yr	1,493,943 tonwet/yr	1,382,919 tonwet/yr	1,189,779 tonwet/yr
	Wildlife Quality & Quantity	deforestation	0.50	-0.49	-1.36	-1.20	625 ha/yr expansion	-641 ha/yr expansion	-1,876 ha/yr expansion	-1,739 ha/yr expansio
		disturbance/ noise	1.06	1.63	3.88	9.11	1.4 Index 2000=1	2.6 Index 2000=1	7.3 Index 2000=1	19.0 Index 2000=1
		waste	0.97	0.90	0.79	0.65	1,535,078 tonwet/yr	1,493,943 tonwet/yr	1,382,919 tonwet/yr	1,189,779 tonwet/yr
Competitiveness of National Energy Sector	Cost of electricity for export	Cost of electricity for export	1.03	1.01	0.98	0.94	0.080 US$/kWh	0.084 US$/kWh	0.088 US$/kWh	0.093 US$/kWh
Reliability Energy Supply	Intermittent sources	Opinion	!	!	!	!	(1-5) 3=base	(1-5) 3=base	(1-5) 3=base	(1-5) 3=base
	Load Factor	Load Factor	0.87	0.84	0.83	0.81	0.50	0.50	0.50	0.50
Regional Economic Development	Tourism	Tourism Revenues	1.09	1.77	4.35	10.37	94,700,589 US$/yr	194,330,255 US$/yr	579,711,703 US$/yr	1,592,685,471 US$/yr
	Agro production	Agro production	0.98	0.91	0.80	0.70	206,550,629 US$/yr	201,438,243 US$/yr	186,776,863 US$/yr	173,182,590 US$/yr
	Energy Sector	Energy Costs	1.07	1.10	1.17	1.24	19,022,914 US$/yr	27,707,935 US$/yr	39,610,464 US$/yr	55,998,018 US$/yr
		Energy Revenues	1.04	1.12	1.26	1.51	19,502,855 US$/yr	33,853,976 US$/yr	58,933,984 US$/yr	106,422,535 US$/yr
	Recycling & waste disposal	Recycling & waste disposal	1.06	1.63	3.88	9.11	174,310 US$/yr	325,402 US$/yr	898,338 US$/yr	2,331,611 US$/yr
Risk & Uncertainty	Opinion	Opinion	!	!	!	!	(1-5) 3=base	(1-5) 3=base	(1-5) 3=base	(1-5) 3=base
Monetary Costs	Energy infrastructure	Energy infrastructure	1.07	1.10	1.17	1.24	19,022,914 US$/yr	27,707,935 US$/yr	39,610,464 US$/yr	55,998,018 US$/yr
	Recycling & waste disposal	Recycling & waste disposal	1.06	1.63	3.88	9.11	174,310 US$/ton/yr	325,402 US$/ton/yr	898,338 US$/ton/yr	2,331,611 US$/ton/yr
Monetary Benefits	Energy revenues	Residential	1.04	1.11	1.19	1.26	6,525,134 US$/yr	11,535,380 US$/yr	19,881,481 US$/yr	32,646,288 US$/yr
		Commercial	1.12	1.33	1.75	2.56	6,894,365 US$/yr	13,699,505 US$/yr	27,469,463 US$/yr	58,580,617 US$/yr
		Industrial	0.98	0.90	0.80	0.70	6,083,356 US$/yr	8,619,092 US$/yr	11,583,041 US$/yr	15,195,630 US$/yr
		Elec Export	! see QN	! see QN	! see QN	! see QN	0 US$/yr	0 US$/yr	0 US$/yr	0 US$/yr
	Tourism revenues	Eco-tourist expenditures	0.78	0.53	0.30	0.16	18,447,883 US$/yr	15,445,838 US$/yr	10,528,200 US$/yr	6,129,735 US$/yr
		Luxury tourist expenditures	1.21	2.22	5.79	13.91	76,252,706 US$/yr	178,884,417 US$/yr	569,183,503 US$/yr	1,586,555,736 US$/yr
	Agro revenues	Agro revenues	0.98	0.91	0.80	0.70	206,550,629 US$/yr	201,438,243 US$/yr	186,776,863 US$/yr	173,182,590 US$/yr
	Profit Energy Companies		0.54	1.08	1.28	1.60	2.5%	22.2%	48.8%	90.0%
		total economic benefit:	1.01	1.19	2.07	4.28	301,731,133 $/yr	401,914,515 $/yr	785,812,062 $/yr	1,816,292,553 $/yr

Data Impacts Sheet of the 'Agro-Industry & Maximum Supply' Energy Infrastructure Option

Data Impacts on *Agro&Max*

Info | Assign Scores | View Input Values >> | Delete Option

Index : Business As Usual = 1.0 (for each year)

Indicators	*Sub1-Indicators*	Sub2-Indicators	Index Scores				Quantitative Data ++ Quantitative Data ++ Quantitative Data			
			2005	2010	2015	2020	2005	2010	2015	2020
Environmental Impact	Air quality	CO2 emissions	-5.89	-12.41	-11.62	-11.06	-58,939 ton CO2/yr	-203,696 ton CO2/yr	-611,629 ton CO2/yr	-635,948 ton CO2/yr
	Water quality	waste in water	1.02	0.80	0.90	0.92	1,615 ton/yr	1,325 ton/yr	1,572 ton/yr	1,683 ton/yr
	Water quantity	hydro power capacity	10.00	15.00	20.00	25.00	260 MW	390 MW	520 MW	650 MW
	Soil quality	deforestation	1.50	2.56	4.97	4.58	1,876 ha/yr expansion	3,368 ha/yr expansion	6,860 ha/yr expansion	6,649 ha/yr expansio
	Solid waste	waste	1.02	0.80	0.90	0.92	1,613,111 tonwet/yr	1,324,161 tonwet/yr	1,571,106 tonwet/yr	1,682,526 tonwet/yr
	Wildlife Quality & Quantity	deforestation	1.50	2.56	4.97	4.58	1,876 ha/yr expansion	3,368 ha/yr expansion	6,860 ha/yr expansion	6,649 ha/yr expansio
		disturbance/ noise	0.82	0.55	0.33	0.17	1.1 Index 2000=1	0.9 Index 2000=1	0.6 Index 2000=1	0.4 Index 2000=1
		waste	1.02	0.80	0.90	0.92	1,613,111 tonwet/yr	1,324,161 tonwet/yr	1,571,106 tonwet/yr	1,682,526 tonwet/yr
Competitiveness of National Energy Sector	Cost of electricity for export	Cost of electricity for export	0.38	0.35	0.32	0.27	0.029 US$/kWh	0.029 US$/kWh	0.028 US$/kWh	0.027 US$/kWh
Reliability Energy Supply	Intermittent sources	Opinion	!	!	!	!	(1-5) 3=base	(1-5) 3=base	(1-5) 3=base	(1-5) 3=base
	Load Factor	Load Factor	0.83	0.99	0.97	0.96	0.48	0.59	0.59	0.59
Regional Economic Development	Tourism	Tourism Revenues	0.82	0.55	0.33	0.17	71,355,091 US$/yr	60,836,946 US$/yr	44,477,701 US$/yr	26,376,148 US$/yr
	Agro production	Agro production	1.02	1.10	1.31	1.48	217,033,325 US$/yr	245,553,286 US$/yr	306,004,070 US$/yr	363,436,844 US$/yr
	Energy Sector	Energy Costs	2.47	6.61	6.58	6.50	44,102,111 US$/yr	165,936,646 US$/yr	223,763,734 US$/yr	292,767,312 US$/yr
		Energy Revenues	3.71	6.75	6.01	5.29	69,227,508 US$/yr	204,208,141 US$/yr	281,938,304 US$/yr	372,484,638 US$/yr
	Recycling & waste disposal	Recycling & waste disposal	0.82	0.55	0.33	0.17	135,400 US$/yr	110,574 US$/yr	77,423 US$/yr	43,967 US$/yr
Risk & Uncertainty	Opinion	Opinion	!	!	!	!	(1-5) 3=base	(1-5) 3=base	(1-5) 3=base	(1-5) 3=base
Monetary Costs	Energy infrastructure	Energy infrastructure	2.47	6.61	6.58	6.50	44,102,111 US$/yr	165,936,646 US$/yr	223,763,734 US$/yr	292,767,312 US$/yr
	Recycling & waste disposal	Recycling & waste disposal	0.82	0.55	0.33	0.17	135,400 US$/ton/yr	110,574 US$/ton/yr	77,423 US$/ton/yr	43,967 US$/ton/yr
Monetary Benefits	Energy revenues	Residential	1.00	1.06	1.17	1.23	6,276,416 US$/yr	11,086,711 US$/yr	19,549,241 US$/yr	32,089,389 US$/yr
		Commercial	0.92	0.85	0.79	0.74	5,649,245 US$/yr	8,702,266 US$/yr	12,437,996 US$/yr	16,984,983 US$/yr
		Industrial	1.03	1.10	1.31	1.48	6,393,668 US$/yr	10,517,033 US$/yr	19,023,510 US$/yr	32,006,820 US$/yr
		Elec Export	! see QN	! see QN	! see QN	! see QN	50,908,179 US$/yr	173,902,131 US$/yr	230,927,558 US$/yr	291,403,446 US$/yr
	Tourism revenues	Eco-tourist expenditures	0.82	0.55	0.33	0.17	19,370,097 US$/yr	16,217,980 US$/yr	11,642,383 US$/yr	6,778,436 US$/yr
		Luxury tourist expenditures	0.82	0.55	0.33	0.17	51,984,994 US$/yr	44,618,967 US$/yr	32,835,317 US$/yr	19,597,712 US$/yr
	Agro revenues	Agro revenues	1.02	1.10	1.31	1.48	217,033,325 US$/yr	245,553,286 US$/yr	306,004,070 US$/yr	363,436,844 US$/yr
	Profit Energy Companies		12.10	1.13	0.68	0.48	57.0%	23.1%	26.0%	27.2%
		total economic benefit:	1.05	1.02	1.08	1.11	313,513,788 $/yr	344,661,703 $/yr	408,656,315 $/yr	469,530,293 $/yr

Nederlandse Samenvatting

Dit proefschrift beschrijft de ontwikkeling en eerste toepassing van een nieuwe methode die energieplanners ondersteunt bij de selectie van een adequate lokale energie-infrastructuur voor regio's in ontwikkelingslanden met een sterke economische groei.

Energie is nodig voor praktisch alle economische activiteiten: historische trends laten een duidelijk verband zien tussen bijvoorbeeld het bruto nationaal product en de energie consumptie van een land. Een adequate energievoorziening is dus een noodzakelijke voorwaarde voor economische ontwikkeling. Echter, het is niet een voldoende voorwaarde: investeringen in de sociale infrastructuur en in riolering, irrigatie, telecommunicatie, rails en wegen zijn net zo belangrijk. Voor ontwikkelingslanden is het dus zaak de juiste investeringsbeslissingen te nemen, en daaraan ten grondslag ligt een juiste planning. Energieplanning richt zich op het afstemmen van de energievoorziening op de toekomstige (verwachte) energievraag. De huidige energieplanning in ontwikkelingslanden vindt veelal op nationaal niveau plaats en richt zich op grootschalige centrale productiesystemen. Maar de economische ontwikkeling –en de daarmee gepaard gaande stijging in energievraag– beperkt zich vaak tot enkele regio's in die landen. De respons van nationale energieplanning op de sterke regionale groei is daardoor vaak te traag en houdt geen rekening met lokale omstandigheden. Er is bovendien onvoldoende informatie beschikbaar over de mogelijkheden om via decentrale productie en regionale energiebronnen aan de regionale vraag te voldoen. Ook de instrumenten die gebruikt worden ter ondersteuning van de energieplanning zijn gericht op grootschalige centrale systemen. Het uitblijven van aan adequate respons op de regionale groei kan de verdere ontwikkeling in de regio ernstig belemmeren of zelfs teniet doen. De huidige centrale energieplanning is daarom niet geschikt voor regio's met een sterke economische groei, terwijl informatie en instrumenten voor de ondersteuning van een adequate regionale planning ontbreken.

Doel van dit proefschrift is dan ook het ontwikkelen van een nieuw instrument dat het proces van energieplanning transparanter maakt en regionale planners in staat stelt om weloverwogen beslissingen te nemen over de energie-infrastructuur voor de middellange termijn (± 20 jaar). Hierdoor worden de planners in staat gesteld de ontwikkeling van de regionale energie-infrastructuur in een gewenste richting te sturen. De centrale vraag die beantwoordt dient te worden in dit proefschrift is dan ook:

Welke methode is geschikt voor het analyseren van alle relevante energiebronnen en (decentrale) energie technologieën, en alle relevante aspecten om zodoende de selectie van geschikte lokale energie-infrastructuur voor regio's in ontwikkelingslanden met een sterke economische groei te ondersteunen?

De ondersteuning die de methode biedt zal in de eerste plaats moeten bestaan uit het verschaffen van informatie over de mogelijke energie-infrastructuur opties en de consequenties van die opties. Verder dient de methode een structuur te bieden voor het systematisch analyseren en vergelijken van de opties, en oog te hebben voor de verschillende voorkeuren van de belanghebbenden. Voor het ontwikkelen van de methode maken we gebruik van een aantal deelvragen die in de opeenvolgende hoofdstukken van dit proefschrift aan de orde komen:

I. Welke theorieën en instrumenten bestaan er op dit moment al voor het ondersteunen van de energieplanning, en welk type instrument sluit het best aan bij lokale energieplanning in ontwikkelingslanden? (Hoofdstuk 2)
II. Wat blijken in de praktijk de voornaamste drempels te zijn in het plannen van lokale energie-infrastructuur? (Hoofdstuk 3 en Hoofdstuk 6)
III. Zijn er nog andere theorieën –niet persé gelieerd aan energie– die bruikbare informatie leveren voor het sturen van de ontwikkeling van de energie-infrastructuur op de middellange termijn? (Hoofdstuk 4)
IV. Hoe kan de methode operationeel gemaakt worden? (Hoofdstuk 7 en Hoofdstuk 8)

Niet vernoemd bij de deelvragen zijn Hoofdstuk 1, dat een algemene inleiding geeft over de problemen rond energie in ontwikkelingslanden en het onderzoeksgebied nader omschrijft, en Hoofdstuk 5, waarin de nieuwe methode uitgebreid besproken wordt. Voor de beantwoording van eerste deelvraag geeft Hoofdstuk 2 een karakterisering van de bestaande methoden en modellen inclusief de voor- en nadelen per type methode of model. Merk op dat dit proefschrift een onderscheid maakt tussen een *methode* en een *model*: de methode levert het raamwerk voor de ondersteuning van het planningsproces, modellen dienen slechts als rekeninstrumenten die de uitvoering van stappen in een methode vergemakkelijken. De karakterisering van de bestaande methoden en modellen verschaft beter inzicht in wat voor type methode of model geschikt zou zijn voor de ondersteuning van lokale energieplanning in ontwikkelingslanden. Op basis van deze informatie construeren we vervolgens een eerste –voorlopige– versie van de nieuwe methode. Belangrijk bij de toepassing van deze methode zijn de belangen en voorkeuren van actoren. Actoren zijn gedefinieerd als de individuen en groepen (inclusief organisaties, bedrijven, etc.) in de samenleving die betrokken zijn bij of de gevolgen ondervinden van de resultaten van het planningsproces én dat proces kunnen beïnvloeden. De methode gebruikt de belangen en voorkeuren van de actoren als basis voor het construeren van indicatoren en de indicatoren worden op hun beurt gebruikt om de consequenties van de verschillende energie-infrastructuur opties in kaart te brengen en onderling te vergelijken. De methode maakt ook gebruik van een benadering die uitgaat van de energie*diensten* die verlangd worden, bijvoorbeeld het koken, het verwarmen van ruimte of tapwater, en het gebruik van huishoudelijke elektrische apparatuur. Beginnend bij de energiediensten wordt teruggewerkt naar de energievormen (elektriciteit, warmte gas) waarmee deze diensten kunnen worden geleverd, de technologieën waarmee de energievormen kunnen worden opgewekt, tot uiteindelijk de energiebronnen die als input dienen voor de technologieën. Op deze manier kan systematisch het scala aan energie-infrastructuur opties bepaald worden.

Doordat de methode gedurende het gehele planningsproces aan alle relevante actoren ondersteuning dient te bieden zal, op basis van het overzicht van bestaand methodes in Hoofdstuk 2, de nieuwe methode aspecten in zich hebben van zowel de ‘prescriptieve’ methodes als van politieke methodes. Overigens is ‘prescriptief’ in dit proefschrift enigszins afwijkend gedefinieerd in vergelijking met de meeste literatuur (zie § 2.5). Op basis van de karakterisering van de bestaande energiemodellen (§ 2.6) gaan we ervan uit dat de modellen die onderdeel van de nieuwe methode uitmaken in eerste instantie een modulair karakter en een zogenoemde ‘bottom-up’ benadering hebben, zodat de modellen makkelijk zijn aan te passen aan lokale omstandigheden en de verschillende technologieën duidelijk te onderscheiden zijn.

Het overzicht van de bestaande methoden voor energieplanning en de karakterisering van de bestaande energiemodellen geven een antwoord op de eerste deelvraag van het proefschrift. Echter, de literatuur die voor Hoofdstuk 2 gebruikt werd bevatte weinig informatie over *lokale* energieplanning; hoe die momenteel plaatsvindt of zou moeten plaatsvinden. Daarom is een (beschrijvende) veldstudie uitgevoerd naar het proces van lokale energieplanning. De studie richtte zich op het plannen van nieuwe energie-infrastructuur voor nieuwbouwlocaties in de Provincie (Noord) Brabant in Nederland. Het doel van de veldstudie was het verkrijgen van inzicht in wat er zich daadwerkelijk afspeelt tijdens het lokale planningsproces om zodoende te kunnen vaststellen of de opzet van de voorlopige methode realistisch is. De keuze voor Brabant als regio is gebaseerd op het feit dat deze regio in de afgelopen periode een snelle ontwikkeling liet zien, dat informatie relatief makkelijk was te verkrijgen, dat de informatie recent en betrouwbaar was, en dat communicatieve problemen tot een minimum beperkt konden blijven. Hierdoor kon in een relatief korte periode de benodigde data verzameld worden. Het nadeel van Brabant als regio is dat deze regio natuurlijk geen onderdeel is van een ontwikkelingsland. Niettemin verwachtten wij dat er genoeg algemene elementen in het lokale planningsproces zitten om als basis te dienen voor de situatie in ontwikkelingslanden. Wel is voor een verfijnde afstemming van de methode op de situatie in ontwikkelingslanden nader onderzoek in zo’n land essentieel, maar dit komt pas aan de orde in Hoofdstuk 6. De resultaten van de veldstudie in Brabant worden gepresenteerd in Hoofdstuk 3 en zijn op zichzelf niet onverwacht, maar geven wel de nodige feedback en inzicht wat betreft de aannames die voor de voorlopige methode uit Hoofdstuk 2 gebruikt zijn. De belangrijkste conclusie van de veldstudie is dan ook dat de opzet van de methode realistisch is, maar een aanpassing behoeft om explicieter de interactie tussen actoren en het leeraspect –die tijdens het planningsproces een belangrijke rol blijken te spelen– mee te nemen. Met deze aanpassing kan de methode de actoren tijdens het gehele planningsproces ondersteunen. Met deze conclusie levert de veldstudie in Brabant tevens een antwoord op deelvraag II van dit proefschrift.

Een probleem dat opdoemt bij de aanpassing van de methode is dat de huidige energie-literatuur nauwelijks informatie bevat over het opnemen van leeraspecten en interactie in het planningsproces. Daarom worden in Hoofdstuk 4 enkele theorieën beschreven die niet direct gelieerd zijn aan energie, maar wel beter inzicht bieden en nuttige instrumenten beschrijven voor de aanpassing van de methode. Een belangrijke theorie die een fundament biedt voor de nieuwe methode is de quasi-evolutionaire theorie. Deze theorie helpt te verklaren hoe de ontwikkeling van technologieën in het algemeen verloopt, hoe die kan worden beïnvloed, en wat de rol van leerprocessen en interactie (netwerkvorming) hierin is. Overigens sluiten we niet uit dat andere theorieën (bijvoorbeeld gebaseerd op het neoklassieke gedachtegoed met concepten als 'bounded rationality', transactiekosten, en leercurves) ook gebruikt kunnen worden als fundament voor het verklaren van ontwikkelingen in –of het maken van investeringsbeslissingen over– de energie-infrastructuur. Onze voorkeur gaat echter uit naar de quasi-evolutionaire theorie omdat deze theorie ook zonder economische achtergrond relatief eenvoudig te begrijpen is en de sociale factor in het planningsproces benadrukt.

Voor concrete hulp bij het opnemen van leeraspecten en interactie in de nieuwe methode maken we gebruik van verschillende typen Technology Assessment (TA) en de Participatory Technology Development (PTD) benadering. De TA typen geven structuur aan het analyseren van de effecten van bepaalde technologiekeuzes en bevatten nuttige informatie over het betrekken van alle relevante actoren in het planningsproces en hoe interactie bevorderd kan worden. Daarnaast bieden de TA typen een raamwerk om leerprocessen te stimuleren. Niettemin richten de TA typen zich over het algemeen op lange-termijn beslissingen op nationaal niveau in geïndustrialiseerde landen. Wat dat betreft biedt de PTD benadering aanknopingspunten. Deze benadering is juist geschikt voor de middellange termijn en heeft een duidelijk 'bottom-up' karakter, gericht op de toepassing van decentrale technologieën op lokaal niveau in ontwikkelingslanden.

Een ander concept dat goed aansluit bij de nieuwe methode is dat van 'appropriate technology'. Appropriate technology, en dan met name de school binnen appropriate technology die uitgaat van de *context* waarin de technologie wordt toegepast, verwerpt het gebruik van *vaste*, *vooraf gedefinieerde* criteria (of indicatoren) waar een technologie op wordt beoordeeld, omdat de geschiktheid van een technologie alleen kan worden bepaald in de context waarin ze wordt toegepast. En die context verschilt per geval. In hoofdstuk 2 kwam al aan de orde dat de nieuwe methode indicatoren gebruikt om de effecten van de energie-infrastructuur opties in kaart te brengen. En een van de kenmerkende aspecten van de nieuwe methode is dat de belangen en de voorkeuren van de actoren als basis dienen voor het construeren van deze indicatoren, en er dus geen vooraf gedefinieerde indicatoren gebruikt worden. Het concept van appropriate technology biedt dus een goede theoretische basis voor het gebruik van context-afhankelijke indicatoren in de nieuwe methode.

De aanvullende informatie van de theorieën in Hoofdstuk 4 geeft een antwoord op de deelvraag III van dit proefschrift en dient om de voorlopige methode uit Hoofdstuk 2 verder aan te passen. Wat die aanpassing precies oplevert is het onderwerp van Hoofdstuk 5, waarin de nieuwe methode voor lokale energieplanning uitgebreid wordt beschreven.

De nieuwe methode is niet puur normatief noch puur beschrijvend. Normatieve methoden verlangen dat actoren de regels van de methode nauwgezet opvolgen; de actoren dienen hun gedrag aan te passen aan wat de methode oplegt, zelfs (of met name) als de praktijk afwijkt van de voorgeschreven regels. De beschrijvende methoden geven slechts weer hoe het huidige planningsproces verloopt en wat de rol van de actoren op dit moment is, zonder te pogen het gedrag van die actoren of het proces zelf te veranderen. Naar aanleiding van ons onderzoek zijn wij er van overtuigd dat de actoren wel wat hulp kunnen gebruiken bij het plannen van de lokale energie-infrastructuur. Enerzijds kan de nieuwe methode inderdaad van de actoren verlangen dat zij hun gedrag aanpassen om de kwaliteit van de besluitvorming te verbeteren. Maar anderzijds erkennen we dat de complexiteit van de praktijk en de specificiteit van lokale situaties moeilijk in een algemeen toepasbare methode te vangen zijn. Daarom denken wij dat het soms beter is om een methode aan te passen aan de praktijk zodat werkelijke ondersteuning geboden kan worden, dan van actoren te verlangen zich in het keurslijf van een strikte methode te wringen, wat uiteindelijk kan uitdraaien op een totale verwerping van die methode en daardoor helemaal geen ondersteuning oplevert. Dus de methode die we in dit proefschrift presenteren moet gezien worden als een houvast of heuristiek voor energieplanners om geschikte energie-infrastructuur te selecteren en *niet* als een normatieve set van regels en procedures die strikt nageleefd dienen te worden.

In het kort kenmerkt de nieuwe methode zich door haar *triple-i* benadering: *informatief*, *interactief*, en *iteratief* zijn de sleutelwoorden van deze methode. Allereerst verschaft de methode op een gestructureerde manier *informatie* over het scala aan energie-infrastructuur opties en hun consequenties. Echter, voor een goede toepassing van de methode is *interactie* tussen de relevante actoren (o.a. via participatie in het proces) essentieel om de belangen en voorkeuren van de actoren duidelijk te krijgen. Die belangen en voorkeuren dienen vervolgens als basis voor het construeren van de indicatoren waarmee de effecten van de infrastructuur opties worden geanalyseerd, vergeleken en beoordeeld. Het *iteratieve* karakter, tenslotte, biedt ruimte aan actoren om te leren verwoorden wat hun belangen en voorkeuren precies zijn, ruimte om die voorkeuren aan te passen in het licht van nieuwe informatie, ruimte om de set van indicatoren te veranderen als daar behoefte aan blijkt, en ruimte om andere energie-infrastructuur opties (of variaties op eerdere opties) ook te kunnen analyseren.

De methode heeft een transparante structuur om opties te evalueren en te vergelijken, waarbij alle relevante energiebronnen en decentrale energietechnologieën een eerlijke kans krijgen in de analyse. De methode stelt de actoren in staat om weloverwogen beslissingen te nemen, en ondersteunt hen bij het selecteren van geschikte energiebronnen en energietechnologieën in een regio. En daarmee kan de ontwikkeling van de energie-infrastructuur in een wenselijke richting worden gestuurd. De methode biedt géén 'optimale' of 'beste' oplossing aan: aan het einde van iedere iteratie van de methodestappen zullen de actoren zelf moeten beslissen welke infrastructuur opties meegenomen worden in de volgende iteratie, totdat er uiteindelijk voldoende draagvlak ontstaat voor een bepaalde optie om als 'geschikt' te worden gekozen.

De nieuwe methode dient natuurlijk ook getest te worden op bruikbaarheid. In Hoofdstuk 6 gaan we hier dieper op in. Een echte toetsing van de methode bleek onmogelijk binnen het kader van het onderzoek, omdat het proces van lokale energieplanning al snel vijf jaar in beslag neemt en die tijd niet beschikbaar was. Wel hebben we de aannames waarop de methode gebaseerd is getest, en dan met name of deze aannames realistisch zijn voor snel ontwikkelende regio's in ontwikkelingslanden (overigens is een deel van de aannames ook al getest tijdens de veldstudie in Brabant, beschreven in Hoofdstuk 3). Voor het testen van de aannames is een tweede veldstudie verricht, dit keer in de regio Huetar Norte in Costa Rica (zie Hoofdstuk 6). Deze regio heeft de laatste jaren een sterke economische groei laten zien, met name in de agrarische sector en in toerisme. De resultaten van de veldstudie laten zien dat de economische ontwikkeling zich in Costa Rica inderdaad beperkt tot bepaalde regio's. Verder toont de veldstudie aan dat als relevante actoren worden buitengesloten van het planningsproces, dit ernstige belemmeringen kan opleveren nog tijdens het planningsproces of gedurende de implementatie van de geselecteerde energie-infrastructuur. Ook blijkt uit de veldstudie dat actoren verschillende belangen en voorkeuren hebben, en zij de nadruk leggen op verschillende aspecten bij het evalueren van de infrastructuur opties. Duidelijk is dat meer dan alleen technische en financiële aspecten een rol spelen en dat veel aspecten moeilijk direct te kwantificeren zijn. Veel actoren lieten tijdens de veldstudie ook blijken dat er een gebrek aan kennis bestond wat betreft het scala aan infrastructuur opties en de mogelijke consequenties van die opties.

Door tijdgebrek bleef de veldstudie beperkt tot een beschrijvende studie; er was dus geen inmenging in het bestaande planningsproces door bijvoorbeeld het verstrekken van informatie en een structuur om deze informatie te verwerken. Daardoor was het niet mogelijk te bepalen of de nieuwe methode resulteert in een verbetering van de kwaliteit van de beslissingen. Bovendien kan niet worden nagegaan hoe leeraspecten het planningsproces beïnvloeden. Dit zal nader onderzocht moeten worden in vervolgonderzoek.

Een zwak punt dat aan het licht kwam tijdens de veldstudie in Costa Rica betreft het kiezen van een regio, mede door de manier waarop we in Hoofdstuk 1 een regio gedefinieerd hebben (i.e., onafhankelijk van het oppervlak of de populatie). De beginkeuze van Huetar Norte als regio werd later aangepast (verkleind) tot het gebied Coopelesca om zo over betrouwbare en gedetailleerde data omtrent de energievraag te kunnen beschikken. Vervolgens werd de regio nog verder verkleind tot Sarapiquí om de relevante actoren te kunnen identificeren. Vervolgonderzoek is nodig om na te gaan hoe een regio het best gekozen kan worden.

Hoofdstuk 7 geeft een voorbeeld van hoe de methode operationeel gemaakt kan worden, daarbij zoveel mogelijk gebruik makend van de data uit de Costa Rica veldstudie. Hoofdstuk 8 geeft vervolgens een demonstratie van de operationele 'tool'. Echter, de tool is niet daadwerkelijk getest in een praktijksituatie en is daardoor een prototype. De tool is een 'bottom-up' model van het type spreadsheet en maakt gebruik van scenario's voor zowel de toekomstige energievraag als het mogelijke energieaanbod om energie-infrastructuur opties te construeren. De scenario's beslaan een periode van 20 jaar en zijn opgebouwd uit subperiodes van ieder 5 jaar. Allereerst dient een zogenaamde 'Business-As-Usual' (BAU) energie-infrastructuur optie geconstrueerd te worden, bestaande uit een scenario voor de energievraag en een voor het energieaanbod. Deze BAU scenario's beschrijven een situatie waarin historische trends worden doorgetrokken naar de toekomst en dienen als basis voor de constructie van andere vraagscenario's. De BAU scenario's dienen ook als referentie bij het vergelijken van de effecten van de andere infrastructuur opties. Iedere energie-infrastructuur optie is dus opgebouwd uit een (door de actoren gekozen) combinatie van een bepaald *vraag*scenario met een bepaald *aanbod*scenario. De vraagscenario's beschrijven verschillende socio-economische ontwikkelingen die de toekomstige vraag naar energie bepalen. Dus de keuze voor een bepaald vraagscenario impliceert automatisch de keuze voor een bepaalde richting in de socio-economische ontwikkeling. (Niettemin zal in de praktijk de uitkomst van het planningsproces –door externe invloeden– zelden exact hetzelfde zijn als de situatie beschreven in het gekozen scenario.) De aanbodscenario's reflecteren het scala aan energiebronnen en –technologieën die beschikbaar zijn. Met uitzondering van de BAU infrastructuur optie zullen de opties in eerste instantie 'extreme' opties zijn, waarbij een ontwikkeling wordt weergeven die een breuk impliceert met de huidige trends. Door extreme opties te kiezen worden de verschillen tussen de opties duidelijk naar voren gebracht. In latere iteraties van de methode zullen de opties waarschijnlijk worden aangepast totdat uiteindelijk slechts een aantal varianten van één of twee infrastructuur opties overblijft, waaruit tenslotte een breed gedragen, geschikte energie-infrastructuur gekozen kan worden.

De consequenties of effecten van een energie-infrastructuur optie worden weergegeven door de scores van die optie op de indicatoren. Vaak hebben indicatoren verschillende subindicatoren (of zelfs sub-subindicatoren) waarvan de scores ieder op hun eigen manier bepaald worden. Daardoor is het moeilijk om tot een totale score te komen voor de algemene hoofdindicator. In de meeste gevallen laat de methode daarom de actoren totaalscores toekennen aan de algemene indicatoren, maar biedt ze de actoren wel een duidelijk overzicht van de scores op de subindicatoren om ze te helpen bij het bepalen van die totaalscores. De scores op de indicatoren zijn dus quasi-kwantitatief: er zijn kwantitatieve data aanwezig voor het bepalen van de scores, maar de uiteindelijke scores (toegekend door de actoren) op een indicator zijn ordinaal.

Omdat de huidige energieplanning in de meeste gevallen wordt geïnitieerd door de overheid of het energiebedrijf zal één van deze twee actoren een voor de hand liggende initiatiefnemer zijn voor de toepassing van de nieuwe methode. Niettemin kan een (onafhankelijke) intermediair een belangrijke rol spelen in het planningsproces door zorg te dragen voor een succesvolle uitvoering van de methode. Het voornaamste doel van de intermediair is het verbeteren van het besluitvormingsproces. De intermediair kan de actoren ondersteunen door bijvoorbeeld experts te interviewen om informatie te verkrijgen; door de actoren te interviewen om de belangen en voorkeuren in kaart te brengen, maar ook door de communicatie tussen de actoren te verbeteren, of te bemiddelen in conflicten en eventueel wantrouwen weg te nemen. En de intermediair is ook de aangewezen actor om de methode operationeel te maken voor de lokale situatie en zorg te dragen voor een goed gebruik van de tool.

Zoals reeds opgemerkt dient de nieuwe methode nog getest te worden, maar op basis van de resultaten van het huidige onderzoek verwachten wij dat de methode het besluitvormingsproces omtrent regionale energieplanning in ontwikkelingslanden zal verbeteren. Echter, het kan zijn dat de actoren die in het verleden de energieplanning voor hun rekening namen de nieuwe methode in eerste instantie 'lastig' vinden, omdat zij een deel van de controle over het planningsproces verliezen. Maar het uitsluiten van relevante actoren levert slechts een schijncontrole op; de praktijk in zowel Brabant als Huetar Norte toont aan dat de conflicten die optreden tussen de huidige energieplanners en de buitengesloten actoren nu vaak pas aan het licht komen aan het einde van het planningsproces of bij de implementatie, als veel beslissingen niet meer terug te draaien zijn. De conflicten kunnen echter wel een ernstige belemmering vormen voor een goed functioneren van de nieuwe energie-infrastructuur. De kosten die deze conflicten met zich meebrengen (zoals de kosten van het aanpassen van deels geïnstalleerde energie-infrastructuur) zullen in eerste instantie niet worden toegeschreven aan slechte planning. Wij beweren echter dat ze met een goede planning wél voorkomen hadden kunnen worden door de (conflicterende) belangen van alle relevante actoren al vanaf het begin van het planningsproces mee te nemen. En aangezien de belangen en voorkeuren –door leerprocessen– tijdens het planningsproces kunnen veranderen, is het noodzakelijk om niet alleen de belangen van die actoren in het proces mee te nemen, maar die actoren zelf te laten participeren in het proces.

Een punt van aandacht bij het toepassen van de methode is het nationale kader van regels en wetten waarbinnen ieder regionaal initiatief of plan dient te passen. Zo'n kader dient ervoor te zorgen dat het geheel van regionale activiteiten op elkaar afgestemd is, maar zeker in ontwikkelingslanden kan het nationale kader nieuwe regionale activiteiten belemmeren, ook als die de maatschappij als geheel ten goede zouden komen.

Vanuit wetenschappelijk oogpunt draagt dit proefschrift bij aan een beter inzicht in de complexe interacties en processen die zich afspelen bij de selectie van lokale energie-infrastructuur in snel ontwikkelende gebieden van ontwikkelingslanden. De integrale, multidisciplinaire benadering die we bij het ontwikkelen van de methode hebben gebruikt maakt duidelijk dat er meer manieren zijn om het planningsprobleem te benaderen. Door theorieën uit verschillende disciplines te gebruiken slaat de nieuwe methode een brug tussen die verschillende benaderingen. Bovendien biedt de methode een manier om aspecten die moeilijk zijn te kwantificeren toch mee te nemen in de analyse, via quasi-kwantitatieve scores. Het vernieuwende van de methode moet dan ook vooral gezocht worden in de *eclectische* aanpak, waarbij een synthese wordt gevormd van bestaande theorieën en niet wordt getracht een van die theorieën verder te verdiepen.

Hoewel de nieuwe methode voor iedere situatie wordt geoperationaliseerd in een specifieke tool kunnen bestaande modellen –die slechts een beperkt aspect van het planningsproces belichten– gebruikt worden als onderdeel van de tool (bijvoorbeeld om de toekomstige energievraag te bepalen, of de economische effecten van opties te berekenen). De nieuwe methode kan dus gezien worden als *complementair* aan bestaande modellen, waarbij de nieuwe methode vooral gericht is op het ondersteunen van het *totale* planningsproces.

Een aspect dat tot nu toe weinig aandacht heeft gekregen is dat de methode uitgaat van de participatie van en de interactie tussen actoren. Deze voorwaarde zou kunnen impliceren dat de toepassing van de methode beperkt blijft tot regio's waar participatie en discussie mogelijk zijn, zoals in de meeste democratieën. Zowel Brabant als Huetar Norte (de twee regio's gebruikt in de veldstudies) zijn democratische regio's waar een open discussie mogelijk is en veelal gezocht wordt naar consensus. Vervolgonderzoek zal moeten aantonen voor welke regio's de nieuwe methode wel of niet geschikt is.

Een ander punt is dat de methode bedoeld is voor regio's in ontwikkelingslanden met een sterke economische groei, maar is ontwikkeld door iemand uit een Westerse cultuur. Als we de quasi-evolutionaire theorie doortrekken naar ons eigen onderzoek, dan zou je kunnen zeggen dat de nieuwe methode tot stand had moeten komen via onderlinge coöperatie met en participatie van de mensen in die regio's. Echter, door de specifieke voorwaarden waaronder het onderzoek is verricht was zo'n opzet niet mogelijk. Toch hebben we via de interviews die gehouden zijn de opinies van de mensen in die regio's proberen mee te nemen.

Zoals met zoveel onderzoek het geval is roept ook dit proefschrift veel nieuwe vragen op. Een aspect dat extra aandacht verdient in vervolgonderzoek is in de eerste plaats een gedegen toetsing van de nieuwe methode: case studies waarbij de nieuwe methode volledig wordt toegepast gedurende het gehele planningsproces moeten laten zien of de methode daadwerkelijk de kwaliteit van de besluitvorming verbeterd én de actoren beter ondersteunt dan bestaande methoden en modellen. Een ander punt voor vervolgonderzoek is de keuze van de regio. De veldstudie in Costa Rica liet al zien dat deze keuze problemen op kan leveren. Daarnaast kan de cultuur of de staatsvorm een probleem vormen (participatie en discussie moeten mogelijk zijn). Ook zou vervolgonderzoek kunnen ingaan op de vraag of regio's die zich nog niet snel ontwikkelen toch gebruik kunnen maken van de nieuwe methode om hun energie-infrastructuur te verbeteren, met als doel de economische ontwikkeling op gang te brengen. Verder zijn case studies nodig om de effecten van leren te bepalen en zal nader ingegaan moeten worden op andere aspecten (zoals communicatievaardigheden, motivatie en betrokkenheid bij de actoren, en machtsposities) die buiten het huidige onderzoek vielen, maar die de kwaliteit van de besluitvorming en een effectieve toepassing van de methode kunnen beïnvloeden. Tenslotte dient meer aandacht te worden besteed aan de manier waarop de consequenties van energie-infrastructuur opties worden gepresenteerd, met name wat betreft de 'framing' van de indicatoren en de schaalkeuze bij het weergeven van de scores op de indicatoren.