A roadmap for energy transition in Suriname: Backcasting scenarios for a sustainable electricity generation by 2040

DELFT UNIVERSITY OF TECHNOLOGY

Ravikiran Sandeep Punwasi

A roadmap for energy transition in Suriname

Backcasting scenarios for a sustainable electricity generation by 2040

Ravikiran Sandeep Punwasi

Student number: 4281454

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Thesis committee:

1st Supervisor:	dr. ir. J.N. (Jaco) Quist
2nd Supervisor:	dr. A.F. (Aad) Correljé
Chair:	prof. Kornelis Blok
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Delft University of Technology

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Summary

On a global level, an increasing number of countries are taking actions towards the mitigation of climate change by taking actions towards less carbon emissions coming from different domains, for example from the energy generation.

Suriname is a country on the continent of South America and is considered as a Small Island Development State (SIDS) since it represents all the main characteristics of SIDS. Although its renewable power capacity share is around one third at the moment, Suriname faces challenges for the future with regards to the energy demand: a growing energy demand one hand and a relative lower electricity output from the hydropower plant as result of extreme droughts. The interesting part here is that due to its geographical location of Suriname, there is a significant potential for solar energy. Moreover, local studies have also elaborated on other renewable energy sources such as hydropower. That makes it even more interesting to emphasize on the current energy system in order to develop scenarios and transition pathways towards a fully sustainable energy supply.

By using the five step backcasting framework of Quist as a backbone and reinforced with policy packaging, a combined theoretical framework is developed which will be used to answer the main research question in this study:

How can Suriname achieve a sustainable energy system by 2040?

In order to answer the main research question, several steps have been identified along with the key activities in each of the steps. First of all, the five steps backcasting methodology have been rearranged and merged into four steps in this study. Step one deals with analyzing the current energy system, elaborative stakeholder analysis and the potential of different renewable energy sources. The second step aims at developing future visions for Suriname. In the third step the necessary changes and interventions for a successful transition are discussed. The last step (step four), elaborates on the transition pathways and the implementation timeline.

The desired vision in this thesis is defined as meeting the energy demand, in terms of power and for the transportation sector for 100% by 2040 with locally produced renewable energy.

Comparable to other SIDS, the current energy demand of Suriname is significantly relying on fossil fuels. However, the energy (diesel and HFO) is mostly produced locally by the State-owned company, NV Staatsolie. Just around one third of the electricity demand is covered by hydropower. Current electricity infrastructure is regionalized and supplies consumers in the coastal region with electricity (85% grid connected).

Based on the current energy system, for the desired vision it is assumed that by 2040 the applications of fossil fuels (e.g. for diesel generators, the transportation sector and cooking) will be fully replaced by electricity. By analyzing the growth of population and consequently the

energy demand, the basis for scenario development is set towards a centralized electricity system or remain having a regionalized electricity system. By using the potentials of the different energy sources, the configuration of the energy mix in both scenarios are determined. Although solar PV and hydropower are dominating the energy mix, it is interesting to observe to what extent these technologies are used in each of the scenarios.

Based on the identification of the technical scenarios, the “What-How-Who” analysis is used to have a better overview of which cultural, structural and technical changes are necessary to achieve the future vision. Enforced with policy packaging, policy packages are developed which aims at answering the “How and Who” part of the analysis. The outcome provides policy makers and actors in the energy sector a clear overview of which interventions are needed towards a fossil free generation of electricity and the penetration of electric vehicles on the market.

In anticipation of how the transition in Suriname can occur, it has been envisioned that the EPAR region (where currently 80% of the power demand is generated) would be a good start to begin. This region already is fed by hydropower; by already installing solar PV plants the amount of thermal power plants installed would no longer be necessary. However, the grid network needs to be upgraded to handle the future capacity. A centralized grid enables interconnectivity of different regional grids and minimizes the storage costs for the intermittent energy sources.

Finally, achieving a 100% sustainable energy supply in Suriname by 2040 is technically feasible. The renewable energy potentials are higher than the required for the installed capacities in 2040 with regards to the electricity supply for households, industry and road transportation system. The economic feasibility highly depends on the construction of a second hydropower plant in West – Suriname. However, the technical solutions can only be achieved with the support of the social and institutional commitments discussed in chapter 7.

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Chapter 1 Introduction

The consequences of climate change are showing increasingly serious forms in the Caribbean: longer period of droughts and hurricanes together with a rising sea level (Food and Agriculture Organization of the United Nations, 2016). Small Island Development States (SIDS) in the Caribbean have been facing similar challenges and are more vulnerable for the consequences of climate change (Simpson et al., 2010) compared to developed nations as climate change directly impacts their biodiversity (fishery and corals), the agricultural sector and water management. Moreover, the economy of these nations is often based on non-sustainable resources such as fossil fuel exploration and minerals. The shift towards a more sustainable energy generation enables these nations to minimize their carbon footprint and to achieve more control over their growing energy demand. Suriname, the smallest country on the South American continent, and being part of the Caribbean community, generates for about one third of its electricity supply by hydropower (Els, 2012), which is a sustainable energy source. However, extreme droughts have resulted in lower electricity output of the hydropower plant, especially during drought seasons. The rest of the power for baseload is delivered by diesel generators. However, with the growing demand of electricity and the country's shift towards renewable energy generation, the current energy mix will not be able to satisfy the demand in the next ten years.

1.1 Problem Statement

The electricity in the capital and the coastal districts is supplied by the state – owned N.V. Energie Bedrijven Suriname (EBS), a utility company that owns and operates all the country's transmission and distribution of electricity. Besides hydropower, electricity generation is also supplied by Staatsolie, the state – owned oil company. In 2016, Suriname's grid connected generation capacity amounted to 503 MW with oil and diesel accounting for around two thirds. (Raghoebarsing et al., 2019). The remaining part is supplied by the Afobaka hydropower plant with an installed capacity of 189 MW. The N.V. EBS is responsible for the design, construction, operation and maintenance of the country's electric transmission and distribution network (milieustatistieken ABS, 2016). About 85% of the population have access to grid-connected electricity. In the rural villages, electricity is mostly generated by small diesel generators and seldom by small-scale PV solar panels (INDC, 2015). Given the fact that there will be an increased demand of electricity in the near future on one hand and on the other hand the effects of climate change minimizing the potential of current energy system, the country should commit towards a fully sustainable energy system.

Moreover, Suriname has committed to the Millennium Development Goals (MDG's) aiming at eight specific targets. Although these MDG's do not directly address energy, it is acknowledged that access to sustainable energy contributes directly to realizing all MDG's (Energypedia, 2014). During the 41st Special Meeting of COTED (Council for Trade and Economic Development) where Suriname is part of as member state of the CARICOM (Caribbean Community) the target of realizing 47% renewable power capacity and at the same time CO_2 reductions of 36% in the power sector by 2027 is agreed upon (IRENA, 2015).

1.2 Brief on Suriname

Suriname, a developing nation and a former Dutch colony, is a country located in the northern part of South America with neighboring countries Brazil, French Guyana and Guyana. The North of Suriname is bordered by the Atlantic Ocean. With a population of around 560,000 inhabitants on an area of 163,821 km² the country has the lowest population density rate compared to the other countries on the continent of South America (less than 4 persons per square kilometer) (climatescope, n.d.). On the other hand, Suriname is categorized as a High Forest cover, Low deforestation country (HFLD) with a forest coverage of 93% and a deforestation rate below 0.22% annually (Project Management Unit, 2019).

Around 250,000 ("World Population Review," 2018) people live in the capital, Paramaribo, which is also the most populated city of Suriname. According to census data (ABS, 2016), between 2004 and 2012 a significant growth of around 10% in eight years' time was found. Menke (2016) explains that this increase is the result of improved measuring tools provided by the United Nations. Moreover, there are better logistical conditions to visit the interior part of the country and migration increase from neighboring countries and abroad. Menke (2016) concludes in his study a 3.7 % annual growth rate, although this rate is difficult to assess since there were different methods and definitions used in the past during census. Given this, it is expected that this rate will remain stable in the coming years. This indicates that the electricity demand will also increase in the coming years.

1.3 Suriname compared to SIDS

Since Suriname has no energy exchange with its neighboring countries, its energy system can easily be compared to an Islands' one. According to Romano et al. (2016) Suriname resembles the main characteristics of SIDS. The main characteristics are:

- Unpredictable global factors including economic and environmental calamities
- Relatively high costs for transportation and energy services
- Heavily depending on fossil fuel imports
- Limited control over the sustainable usage of resources

- Lack of economies of scale
- Increasing demographic putting more pressure on natural resources and the ecosystem

Given this, studies carried out for SIDS will also be consulted. The main difference is that Suriname has the potential to sell its locally produced excess of energy to its three neighboring countries relatively cheaper compared to what Islands seldom can manage because of the high transmission costs of energy. Lachman (2011) discusses in his study about a scenario-specific strategy where the import and export of energy is considered as a option for decentralized produced renewable energy in Suriname. To ensure quality and competitive prices for energy, the current supply chain needs to be reformed: power generation and transmission and/or distribution needs to be seperated and not carried out by the same actor.

1.4 Research objective and knowledge gaps

Earlier studies conducted for the Caribbean Islands did not consider the scalability for Suriname as it is also comparable to SIDS. Furthermore, no concrete studies and articles about possible pathways for sustainable energy transition for Suriname were found, even though renewable energy potentials can be extracted from reports published by the International Energy Agency (IEA). Local studies focused more on the potential and the effect of individual technologies on the energy mix of Suriname, instead of sketching an integrated overview of how the future energy scenario might look like. Moreover, research conducted by Lachman (2009) considers the future energy security of Suriname by making use of scenario planning methodology. His study identifies and discusses several policy elements. The intention of this study is to provide an integrated approach (technical and policy related tools) towards the energy transition in Suriname. Hence, this research will focus on filling those knowledge gaps by making use of proper research methodologies and applying available and trustworthy data.

1.5 Research questions

Based on the research objective, the following main research question can be defined:

How can Suriname achieve a sustainable energy system by 2040?

The main research question is supported by the following sub-questions:

1. How does the current energy system of Suriname look like?
2. What is the potential of different renewable energy sources in Suriname?
3. How will the demand for energy change towards the desired vision in 2040 and how will the desired future look like?
4. What kind of intervention are needed to achieve the desired future?
5. How can these interventions contribute to the proposed energy transition towards 2040?

1.6 Thesis outline

This thesis has the following structure: the introduction in chapter 1 is followed by the theoretical framework in chapter 2, containing the literature review for this thesis. Chapter 3 builds upon the key concepts emphasized on in the second chapter in order to build a methodological framework for this research. In chapter 4 the activities involved in the first step of backcasting framework are executed. Chapter 5 deals with development of future visions and modeling for scenario development. Then, backcasting for selected scenarios are assessed in chapter 6. Chapter 7 concludes this thesis with a reflection and discussion on the methods and framework used during this research.

Chapter 2 Theoretical framework

In order to achieve the desired goals and thus answering the research questions of this thesis, an academic approach is necessary. This enables us to approach and solve the problem based on scientifically approved studies. In this chapter, literature study will be executed based on previous studies and literature. This helps to modify and build a suitable methodological framework which can be applied to this specific research to develop strategies for achieving a sustainable energy system for Suriname. The literature study involves understanding of key concepts such as backcasting analysis, transitional pathways and scenario development.

Based on Verschuren et al. (2010) the research design of this project is schematically illustrated:

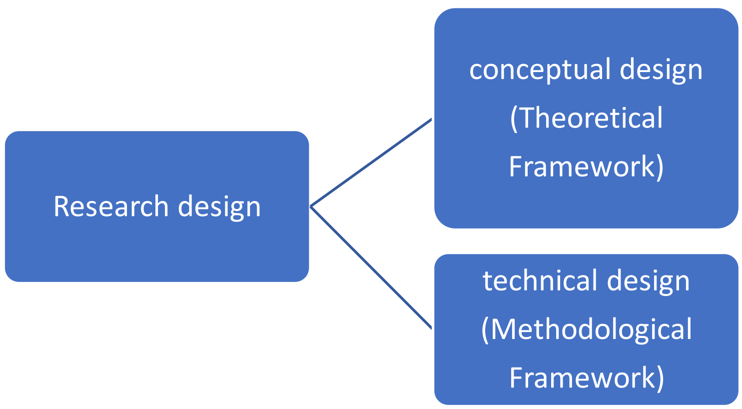


Figure 2.1: Schematic overview of research design

Derived from this model, chapter 2 emphasizes on the understanding and insights of the literature and key concepts regarding this research (*figure 2.1*). In chapter 3 the synergies between the concepts discussed in this chapter will be evaluated to build a comprehensive methodological framework for this research.

Literature review forms the basis for the theoretical framework (*figure 2.1);* in this chapter literature study will be carried out based on existing literature with the aim to select a suitable scientific framework to address the problem statement of this research. Previous studies carried out by Vallabhaneni (2018) and García Nodar (2016) are used as references for identifying the conceptual framework. Both studies started with backcasting analysis combined with a transitional pathway to achieve the research objective.

Scientific literature in online databases included the keywords: “backcasting”, and “backcasting + energy”. The following online databases are used: Elsevier’s ScienceDirect, Scopus and Google Scholar and the TU Delft education and research repository.

2.1 Backcasting analysis

According to Quist and Vergragt (2006), "*backcasting is a method which starts by defining a desirable future vision or normative scenario and subsequently looking back at how this desirable future could be achieved*".

Originally backcasting dates back to the 1970's, when Lovins (1976) proposed backcasting as an alternative planning methodology for electricity supply and demand (Quist, 2007). Lovins believed that it would be beneficial to describe a vision of a desired future and then assess how that future can be realized, instead of assessing futures based on forecasting. The main idea behind this was that after the desired future have been described together with the strategic objectives, it would be possible to work backwards to determine what policy measures should be taken into consideration to guide the energy industry in its transformation towards that future (Quist, 2007).

Energy backcasting introduced by John Bridger Robinson (1982) is a method to analyze future energy systems and how desirable futures can be attained. This method has been applied on long-term complex-issues where the focus is mostly on societal problems of great importance (Prosperi et al., 2014). Although backcasting can be used in a wide variety of studies (Wilson et al., 2006), there are specific approaches depending on the country and traditions used. Robinson developed a generic six-step methodology (*figure 2.3*), which was used as an outline for analyses oriented to environmental issues. However, there are many backcasting approaches found in literature. In this section the most common approaches for this research will be described.

Weaver et. al (2000) describe in their article that backcasting can be used as a tool for implementing future visions of a desirable future state. However, they emphasize that backcasting can be used "to define feasible short-term actions that can lead to trend-breaking change, in other words putting vision into action" (Jansen,2005; Quist, 2007).

In *appendix A-1*, the background of future studies is described along with the following backcasting approaches: the Robinson approach, the Natural Step approach (TNS), Sustainable Technology Development approach (STD). These approaches were comprehensively reviewed and further developed to the participatory backcasting approach by Quist (2007).

<u>The Quist's approach</u>

In his doctoral dissertation Quist (2007) describes and compares the four backcasting approaches as mentioned earlier in this section and proposes a fifth approach based on the existing approaches: the five steps backcasting framework. Accordingly, all additional steps mentioned in the earlier approaches can generally fit into one of these 5 steps, which can be seen in *figure 2.2*. One of the arguments Quist (2007) mentions about is the presence of a dynamic nature in a backcasting experiment; this implies that having stakeholder involvement not only affects their stakes, but they also have essential knowledge and vital resources. The dynamic nature also considers that stakeholders come and go as they are not forever bound to an organization.

The first step deals with analyzing the main problem and setting up normative assumptions and goals based on stakeholder participation. Noteworthy is that not all activities were carried out in the same order during the cases; in few of them the assumptions and targets were set up before analyzing the main problem. In the second step alternative future visions are developed based on the outcome of the problem orientation in the first step. In the next step, step 3, backcasting is carried out by looking backwards in search for ideas to overcome the identified barriers between the present and the desired future. In the fourth step further assessment and feasibility study of the ideas in step 3 are carried out; these are crucial as follow up for realizing the future vision. The final step deals with embedding the results and agenda of the previous step and stimulate follow-up by the stakeholders (Quist, 2007).

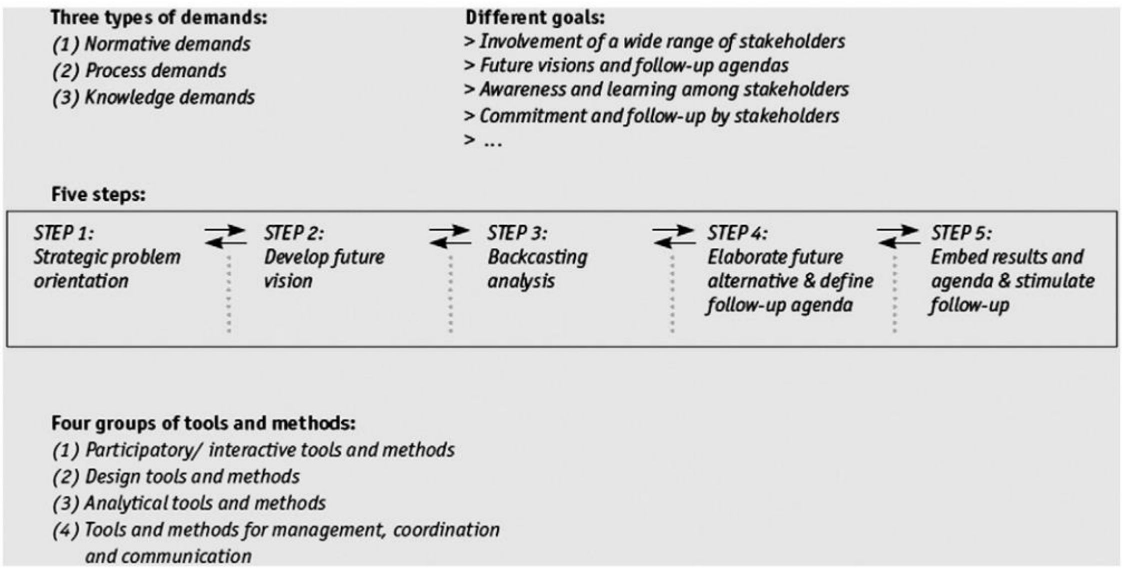


Figure 2.2: Overview of the Quist backcasting framework (Quist et.al, 2011)

Quist (2016) further elaborates on this backcasting framework by describing the relevant activities that will be performed in a non-participatory backcasting:

Table 2.1: list of activities assigned in each step within the framework (Quist, 2016)

Step 1	Strategic problem orientation
1A	Setting requirements, criteria, basic assumptions, process plan, methodology
1B	System and regime analysis
1C	Stakeholder analysis
1D	Trend and problem analysis
Step 2	Generating future visions
2A	Detailed (normative) standards and criteria
2B	Idea articulation and elaboration
2C	Generation of one or several visions
Step 3	Backcasting analysis
3A	What-how-who analysis part 1: technological, cultural-behavior, organizational and structural institutions.
3B	What-how-who analysis part 2: required actions and stakeholders.
3C	Drivers and barriers analysis
Step 4	Evaluation and follow-up
4A	Scenario elaboration (turning vision into quantified scenario)
4B	Scenario sustainability analysis
4C	Generation of follow-up agenda and proposals
4D	Develop transition pathway
Step 5	Embed results and stimulate follow-up
5A	Dissemination of results and policy actions
5B	Stimulate follow-up activities
5C	Stakeholder learning evaluation

Based on Quist (2007), Agarwala (2017) and Vallabhaneni (2018) compared the five backcasting approaches with each other and schematically bullet pointed *(table 2.2)* their key assumptions, methodology and method used for each approach.

Table 2.2: Overview of the five backcasting approaches (Quist, 2007: Agarwala, 2017; Vallabhaneni, 2018)

	Robinson Approach	**The Natural Step Approach**	**STD Approach**	**Sushouse Approach**	**Quist Framework**
Key Assum-ptions	• Criteria for social and environmental desirability are set externally to the analysis • Goal-oriented • Policy-oriented • Design-oriented • System Oriented	• Decreasing resource usage • Diminishing emissions • Safeguarding biodiversity and ecosystems • Fair and efficient usage of resources in line with the equity principle	• Sustainable future need fulfilment • Factor 20 • Time horizon of 40-50 years • Co-evolution of technology and society • Stakeholder participation • Focus on realising follow-up	• Sustainable participation • Factor 20 • Sustainable households in 2040 • Social and technological changes are needed • Achieving follow-up is relevant	• Stakeholder participation • Goal-oriented • Stakeholder learning • Achieving follow-up is relevant
Metho-dology	1. Determine objectives 2. Specify goals, constraints and targets. Describe present system and specify exogenous variables 3. Describe present system and its material flows 4. Specify exogenous variables and inputs 5. Undertake scenario construction 6. Undertake scenario impact analysis	1. Define a framework and criteria for sustainability 2. Describe the current situation in relation to that framework 3. Envisage a future sustainable situation 4. Find strategies for sustainability	1. Strategic problem orientation 2. Develop sustainable future vision 3. Backcasting- set out alternative solutions 4. Explore options and identify bottlenecks 5. Select among options and set up action plan 6. Set up cooperation agreements 7. Implement research agenda	1. Problem orientation and function definition 2. Stakeholder analysis and involvement 3. Stakeholder creativity workshop 4. Scenario construction 5. Scenario assessments 6. Stakeholder backcasting and strategy workshop 7. Follow-up and implementation	1. Strategic problem orientation 2. Develop future visions 3. Backcasting analysis 4. Elaborate future alternatives & define follow up agenda 5. Embed results and agenda & stimulate follow-up
Method Used	• Social impact analysis • Economic impact analysis • Environmental analysis • Scenario construction • System analysis and modelling • Material flow analysis and modelling	• Creativity techniques • Strategy development • Employee involvement • Employee training	• Stakeholder analysis • Stakeholder workshops • Problem analysis • External communication • Technology analysis • Construction of future visions • System design and analysis	• Stakeholder analysis • Function & system analysis • Backcasting analysis • Stakeholder workshops • Scenario construction • Scenario evaluation (consumer acceptance, environmental, economic)	• Scenario construction and analysis • Stakeholder Workshops • Backcasting Analysis • Process Design • Communication and management methods

In their article Kishita et al. (2017) proposed a method for designing backcasting scenarios for resilient energy futures by using Japan as case study. According to Fiksel (2006), resilience can be defined as “*the capacity of a system to tolerate disturbances while retaining its structure and function”*. Thus, in terms of energy system, resilience can be defined as the capacity for the energy sector to adapt to new energy technologies and grow at the same time while facing socio-technical challenges.

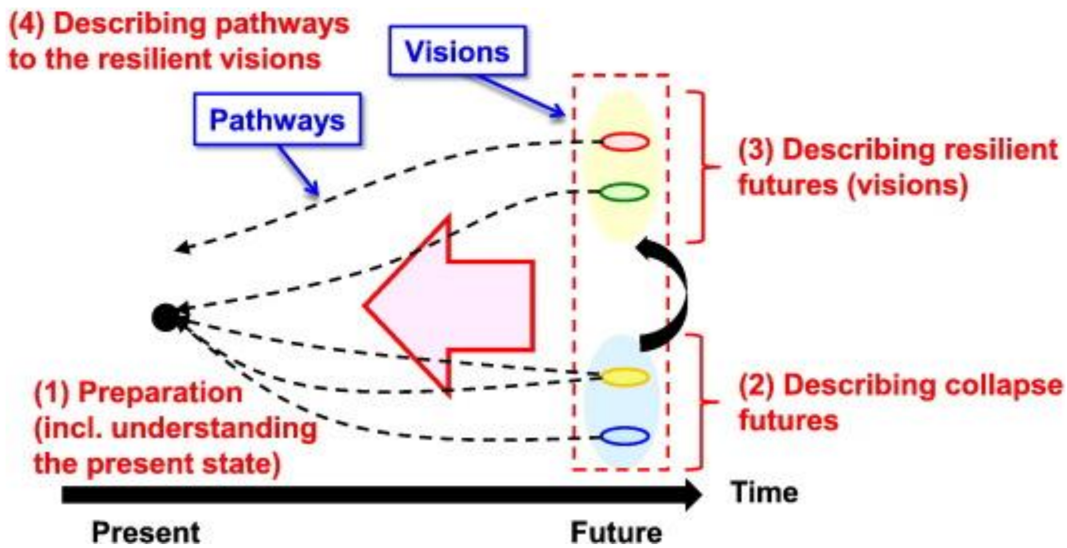


Figure 2.3: concept of backcasting scenario design for resilient futures: the numbers correspond to the steps in the scenario design process (Kishita et al., 2017)

Kishita et al. (2017) used the Fault tree analysis (FTA) as a tool to think “backward” to achieve the long-term goals during the case studies (*figure 2.3*). They claimed that this method was valid and worked well during their expert workshops in order to draw transition toward resilient energy systems in Japan. However, they did not involve various stakeholders in the scenario design process during the participatory backcasting. While looking back at this study, the Fault tree analysis is a top-down method which may work in particular cases but cannot be used as a generic tool for scenario development.

This section aimed at in-depth literature review based on different backcasting approaches found in literature and scientific database. The five-steps methodological framework described by Quist (2007), is found to be the most appropriate to be used as a backbone for this research. With his research Quist (2007) developed the five steps approach (including the activities per step) to cover the “*full range of participatory backcasting approaches found in the literature*”. Previous studies found in literature successfully integrated this framework with different theories and approaches to build a strong methodological framework to achieve the future visions they proposed in their research.

2.2 General Morphological Analysis as tool for developing scenarios

In this section the focus is on exploring theories and methods found in literature to be applied in the 5 steps backcasting framework of Quist. The second step of the 5 steps backcasting framework deals with generating future visions.

Based on Vallabhaneni (2018) scenario development was studied by Börjeson et.al (2006) in order to classify the types of scenarios. Börjeson et.al (2006) distinguished three types for scenario generation during their study: generation, integration and consistency of scenarios (*figure 2.4).*

Scenario types	Techniques		
	Generating	Integrating	Consistency
Predictive			
Forecasts	• Surveys • Workshops • Original Delphi method	• Time series analysis • Explanatory modelling • Optimising modeling	
What-if	• Surveys • Workshops • Delphi methods	• Explanatory modelling • Optimising modeling	
Explorative			
External	• Surveys • Workshops • Delphi modified	• Explanatory modelling • Optimising modeling	• Morphological field analysis • Cross impact
Strategic	• Surveys • Workshops • Delphi methods	• Explanatory modelling • Optimising modeling	• Morphological field analysis
Normative			
Preserving	• Surveys • Workshops	• Optimising modeling	• Morphological field analysis
Transforming	• Surveys • Workshops • Backcasting Delphi		• Morphological field analysis

Figure 2.4: The three techniques for scenario development (Börjeson et.al, 2006)

The in *figure 2.4* illustrated scenario types along with the techniques used to assess them give an overview of scenario development in general. Generating techniques are most suitable for this research as the deliverable of this project will not focus at the integration and consistency of the projected scenarios. However, for non-participative scenarios (backcasting), it is found that these techniques do not satisfy the criteria, as there is no active stakeholder participation involved during the scenario development in this study. The General Morphological Analysis (GMA), however, is a valid scientific method which can be used for scenario development.

According to (Ritchey, 2018), the General Morphological Analysis (GMA) is a method for "*structuring a conceptual problem space - called a morpho space – and, through a process of existential combinatorics, synthesizing a solution space*". This means that this non-quantitative method defines the problem space as a set of discrete categories variables; there are no metric relationships involved, except of the scaling property utilized in classical morphological modelling which is in a "rank order". The General Morphological Analysis (GMA) first introduced by the Swiss astro-physicist Fritz Zwicky aiming at investigating the total set of relationships within multi-dimensional, non-quantifiable complex problems. (Garcia Nodar (2016); Zwicky, 1969).

In his article Ritchey (2018), refers to five modelling types used in the General Morphological Analysis *(figure 2.5)* which can be applied in different research fields depending on its nature. These modelling types are recognized by their relationship's nature: discrete variables, undirected connections, non-quantified connections, cyclic connections and non-causal connections. Based on the research objective of this thesis, the aim is to build and develop a transition pathway which include socio-political elements. Therefore, the non-quantified connections will be crucial to further elaborate on in the morpho space.

Variable type	Directedness of connections	Quantification of connections	Cyclicity of connections	Nature of connections between variables
Continuous variables	Directed connections	Quantified connections	Cyclic connections	Causal: deterministic (mathematical-functional)
Discrete variables	Undirected connections	Non-quantified connections	Acyclic connections	Causal: probabilistic
Black-box variables (Unspecified domains)				Non-causal: (e.g. logical/modal/normative)
				Unspecified connections

Figure 2.5: Morphological model of modelling types, consisting of five modelling properties (Ritchey, 2018).

The GMA consists of two stages, where in the first stage a morphological box, known as the Zwicky box and today also called as the morpho space (Ritchey, 2018) is created. It starts with identifying and defining the parameters that influence a system to be used in a Zwicky box. This box consists of a matrix with where each cell contains a value which corresponds to the defined parameter.

In the second step, all parameter values in the morphological space are compared to each other to achieve consistency. This is called the Cross-Consistency Assessment (CCA) and is performed on a cross-consistency matrix *(figure 2.6).* This step is crucial to remove any configurations that are mutually inconsistent. The three primary types of inconsistencies that must be removed are the purely logical contradictions, empirical inconsistencies and normative inconsistencies. According to (Ritchey, 1998) empirical inconstancies and normative inconstancies are excluded due to unacceptable social preferences. Thus, the logical inconsistencies are the configurations that are mutually repealing (Nodar, 2016; Ritchey, 1998).

		Variable type			**Directedness**		**Quantification**		**Cyclicity**	
		Continuous	Discrete	Black-box	Directed	Undirected	Quantified	Non-quantified	Cyclic	Acyclic
Directedness	Directed									
	Undirected									
Quantification	Quantified									
	Non-quantified	1								
Cyclicity	Cyclic									
	Acyclic									
Nature of connections	Causal: deterministic			4		5		6		
	Causal: probabilistic							7		
	Non-causal									
	Unspecified	2	3							

Figure 2.6: Cross-Consistency Assessment for the morphological meta-model by Ritchey (2018)

2.3.1 Policy packaging

Backcasting enables an approach to develop policy packages aiming at the implementation of the targeted objectives. As Quist (2007) mentioned in his research about the dynamic role of stakeholder engagement, this section deals with the underlying theories where policy implications are developed and recommended for stakeholders in the follow-up phase of participatory backcasting. Therefore, this section deals with the underlying theory of policy implementation.

According to Fearnley et al. (2011) policy packaging is defined in Optic (2010): *A 'policy package' is a combination of individual policy measures, aimed at addressing one or more policy goals. The aim is to get better impacts of the individual policy measures, minimizing negative side effects and improving implementation and acceptability.*

Through literature survey it is found that policy packaging is often used as a policy framework in the transportation sector. No studies were found approaching (future) energy scenarios with the policy packaging framework. This can be explained by the fact that that policy packaging in the energy sector is more complex: it requires a good understanding of who are really the actors and stakeholders in this field and what stakes and influences they have towards each other and towards the desired program.

2.3.2 Policy package theoretical framework

In order to select a suitable framework for policy packaging, various studies were consulted where this method is applied. Studies done by researchers for the transportation sector show that there was active involvement of stakeholders during the execution of the program (Soria-lara, 2017). Accordingly, a participatory process was developed to deal with policy implementation gaps by having active involvement of policy makers, researchers and practitioners.

A crucial aspect during this study is the fact that there is no active involvement of stakeholders, since this would require a couple of consultations and workshops to actively involve all the parties within the energy sector to finally develop implementation pathways. This will be further explained in the discussion section of this study.
Given this, it is crucial to select such a framework which can be adapted to the conditions here, in within the scope of this study.

In Optic (2010), the policy package process is described in six steps (Fearnley et al, 2011). The authors describe the different steps within this framework *(figure 2.7)*.

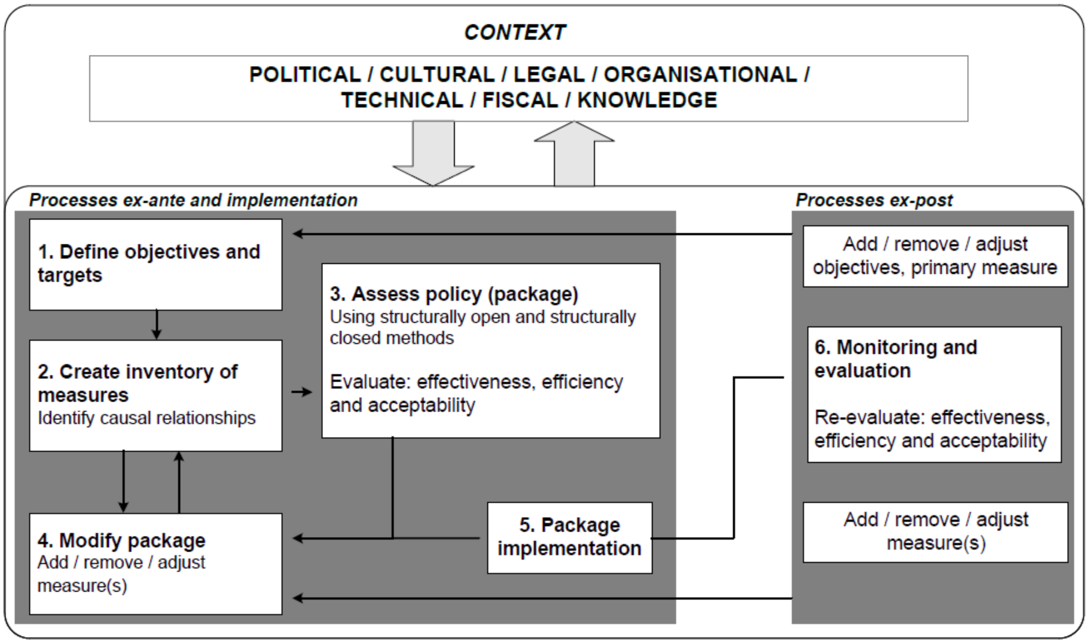


Figure 2.7: Generic Framework of Policy Packaging (Fearnley et al., 2011)

This generic framework consists of two parts: the first part, the *"processes ex-ante and implementation"*, deals with the following steps:

1. Defining objectives and targets: Objectives should be precise and concrete, achievable, realistic and time-dependent *(Fearnley et al., 2011).* Accordingly, objectives should be defined in such way that they can be quantifiable in the future. On a country level, objectives are developed through a democratic process where multiple actors and stakeholders are participating. This mainly includes:
    - Politicians / decision makers
    - Public administration
    - Stakeholders: NGO's, citizen, industrial representatives and public authorities.

    Targets, on the other hand, are much more condensed and specific; they may even include a concrete quantification. Based on Fearnley et al. (2011), targets should be formulated concretely. Moreover, they are connected to specific indicators that measure the achievement or progress of targets set.

2. The second step within the first part deals with the identification of potential primary measures. With measures Fearnley et al. (2011), refer to actions in the form of policy interventions. First, a number of potential primary measures are created. Awareness should be taken into account since major policy interventions create synergetic as well as contradictory relationships. It should be mentioned that there are no exclusive criteria present in this stage and that innovative ideas and best practices are part of the measures.

The measures are selected based on the policy objectives and targets defined in the first stage. Accordingly, the following questions are used as guidance for creating the inventory:

- ***Policy objective****: What is the major objective and concrete targeting to achieve with the policy?*
- ***Policy type****: What type of policy is referred to? This is important, as the type of policy tells something about potential unintended effects, e.g. a reduced acceptance.*
- ***Expected effects****: What is the direction of effects (e.g. stimulate use of public transport, restrain the use of cars, i.e. both resulting in a different modal split) and are there experiences with the expected (or observed) effectiveness of the policy?*

In this step it is crucial to identify and consult the stakeholders and detect relationships between them. This results into more comprehensive policy interventions which form the basis for the next steps.

3+4. Steps 3 and 4 are dealing with the assessment of policy package. These are further evaluated in terms of “effectiveness, efficiency and acceptability”. In this phase, modelling and in-depth analysis of possible outcomes are determined via qualitative and quantitative methods. The outcome of this analysis are used to quantify (if possible) the effectiveness of policy interventions. The analysis is usually carried out by experts in this field (modelers and analysists) who ensure that the following conditions are met *(Fearnley et al., 2011)*:

- Primary measures are identified and clearly shaped.
- Methods and tools for assessing the cause – effect relationships related to the measures.
- Required resources (time, monetary expenditures) for the assessment are estimated against the available resources.

Step 4 (package modification step) is combined here, because of its iteration effect: in the process of assessing the primary set of measures, it may occur that some of them will not be effective in practice or can be empowered by other measures. Therefore, step 4 enables one to modify, add or remove a set of measures defined in the second step *(figure 2.12).* Although this iteration helps to refine the process of policy package, it cannot continue for long, due to time limitation and restriction of resources.

In summary, the steps 3 and 4 form the core of the policy packaging process. The actual package is established after (multiple) iterative processes have been applied with regards to the effectiveness, efficiency and acceptance of measures. Although barriers may appear within the policy packaging process (e.g. the targeted modal shift is not met) or outside this process (e.g. resistance by stakeholder(s)), modification of the package is the solution to resolve these issues.

1. Implementation step: this step can be seen as the transition between the process ex-ante and the ex-post. Fearnley et al. (2011) mention in their study that even though the previous steps represent the key of policy package, the implementation step remains crucial as issues as e.g. (public) acceptance can affect the desired outcome. In conclusion, step 5 enables the identification of elements for a successful implementation of policies.

   The second part of this framework; the "*processes ex-post*" deals with the following step:

2. Monitoring and evaluation; actions taken after the implementation. In this phase it is important to measure to which extent the set of policy objectives and targets have been successfully implemented. If necessary, the primary measures are subjected to adjustments in order to meet the desired outcome. According to Fearnley et al. (2011), the primary measures are often kept or only adjusted, but not entirely removed. Here, politicians are most likely the one to take a decision. Accordingly, the actual monitoring is conducted by experts in the field who assess the effectiveness and efficiency of the package.

2.4 Conclusion of applied theoretical framework

This section briefly summarizes the different aspects in the theoretical framework used in this thesis.

Starting with the literature foundation on future studies and backcasting approaches, it is found that the five Steps backcasting framework of Quist (2007) will be used as backbone theoretical framework for this thesis. Moreover, the general morphological analysis will be considered as tool for developing scenarios. Finally, the policy packaging will be integrated into the five steps backcasting framework of Quist (2007).

Given the fact that this research deals with backcasting analysis and that policy packaging will be used as part of the backcasting analysis, a modified policy package will be proposed based on the theoretical framework of Fearnley et al. (2011).

In this research, the steps 1 and 2 of the policy package framework by Fearnley et al. (2011), will be integrated in step 4 (Backcasting) of the research framework discussed in the methodological framework (Chapter 3).

In Optic (2010) tools on how objectives and targets should be defined are presented. This means that since no consultations with stakeholders and policymakers were made, it is still possible to formulate clear objectives and targets to use within policy packaging.

First, an in-depth stakeholder analysis will be performed, with the aim to understand the interrelations between parties. This will be carried out by making use of the field study conducted by Hisschemoller et al. (2009) regarding the energy policy of Curacao. Since Curacao and Suriname have a common situation regarding the energy transition (similar to other Small Island

Development States in the Caribbean), this study helps to identify and the recognize relationships between actors and stakeholders in the energy sector. This adds additional value to the execution of the first two steps of policy packaging.

Schematically, the simplified policy packaging framework used in this research is illustrated in *figure 2.13*.

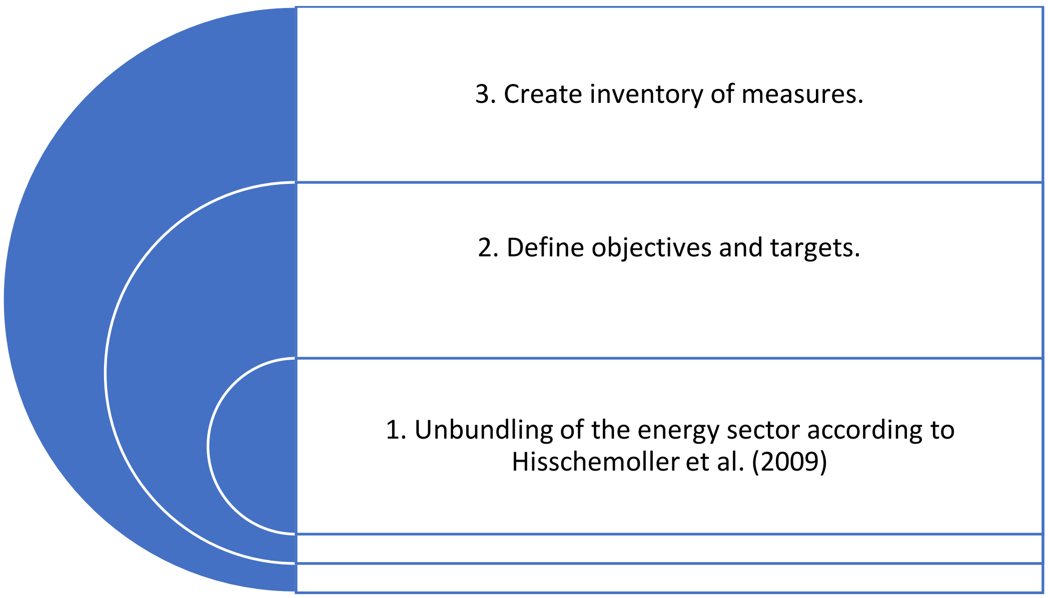


Figure 2.8: overview of the modified framework for policy packaging based on Fearnley et al. (2011).

The shape in *figure 2.8* implies that the base of this method lies in the "Unbundling" of the actors and stakeholders in the energy sector. This helps to identify the parties responsible for execution of objectives and targets. At last, an inventory (i.e. package) of measures will be proposed as part of the backcasting analysis.

Figure 2.9 illustrates an overview of the incorporation of the theoretical framework discussed in this chapter.

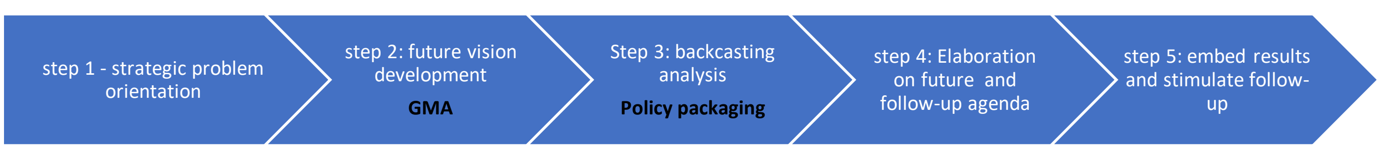


Figure 2.9: Overview of the theoretical framework used in this thesis, based on the 5- steps theoretical framework by Quist (2007).

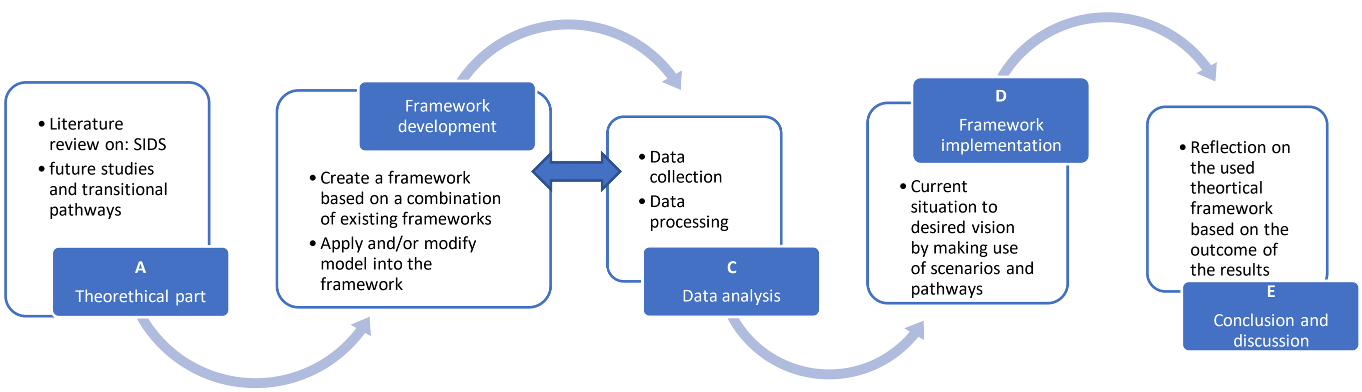
Chapter 3 Methodological framework

In this chapter the synergy between the key concepts elaborated on in the theoretical framework will be further developed in order to build a strong methodological framework for this research which aims at answering the research questions. Furthermore, activities of each step within the framework will be addressed.

3.1 Backcasting framework for this research

The 5-steps backcasting framework of Quist (2007) can be applied in both cases; participatory and non-participatory. Therefore, this framework will be used as a backbone to develop a strong vision on future energy scenarios for Suriname. The main benefit of using this framework is that it accommodates stakeholders and is beneficial for social groups are companies, research bodies, government, public interest groups and the public themselves (Vallabhaneni, 2018). Simultaneously, by combining this methodology with other relevant theories (mentioned in chapter 2), the framework can be modified and suitable for new challenges in likewise regions and situations. In order to address and define the interventions needed to achieve the desired future vision, theories regarding future scenario's and transition pathways are consulted.

The following scheme illustrates the research framework of this thesis:



A. The first step includes the literature review based on the research objectives and scope and the academic theories that can be consulted to perform the proposed research. In this step the most suitable frameworks and theories are identified in order to be applied in the next step, step B. Literature review covers backcasting and future studies done on SIDS, since Suriname also meets the criteria of the main characteristics of SIDS.

B. + C.

As mentioned earlier the backbone for this research will be based on the five-steps framework of (Quist et.al, 2011). The initial step within this framework is used to describe and present the current situation in order to understand the shortcomings that could be addressed in the research. Here, the identification and interaction between an actor and stakeholder can also be understood. This step corresponds to the first sub-question for this research: the business as usual scenario. The second step creates future visions and scenario's: by the identification of the shortcomings in the current energy system, better visions and scenarios can be developed. Then, the backcasting analysis can be performed which involves the required interventions and changes from present towards the future scenario. The following step identifies the drivers and barriers and elaborates on how they can create a transition pathway. The final step involves a follow-up agenda wherein the action plan for each stakeholder is illustrated. Although this framework seems to have a linear character, it is an iterative process. Further elaboration on the method and the activities involved within are described in step B.

The analytical framework section elaborates on the selection and application of existing frameworks in order to create a modified framework with possible changes and adapted to the conditions of the assessed region. This step is merged with the data analysis part, because of the activities identified in each of the steps within the framework.
Outcomes of the first step (step A) help to identify and select proper academic theories to build the customized framework for this research. One of the main benefits of the Quist framework is that it can be combined with other methodological frameworks: this helps to emphasize on the collaboration of different actors and stakeholders to work on a transition pathway. Section B concludes with the backcasting framework used for this research considering the boundary conditions. Based on Quist, J. (2016), and cited by Vallabhaneni (2018) there can be concrete activities identified in each of the 5 steps based on the Quist's framework:

<u>Step 1:</u> Strategic problem orientation: In this part of the study, the strategic problem orientation will be assessed, starting with the current energy situation in Suriname.

The following activities are part of this step:

- Describe current energy system of Suriname:

Through desk research the current energy system of Suriname will be described. Data will be mainly retrieved from the International Energy Agency (IEA), the Energy Information Administration (EIA) and additionally from the state – owned utility company, EBS. Data on energy generation, supply and transmission will be obtained from local institutions in Suriname.

- Stakeholder analysis: In this part, stakeholder analysis based on Miron et al. (2009) will be applied to identify the stakeholders in Suriname's energy sector. Accordingly, stakeholders are classified in different categories with respect to their interest, power and resources to influence a program. This is necessary for the steps later in this research. Moreover, the stakeholders in the energy sector will be mapped and their interrelationship will be further discussed (Hisschemoller et al., 2009), which helps to identify the responsible actor in case changes will be necessary to achieve the future vision.

- PESTEL analysis: PESTEL analysis consists of various factors that influence the energy sector. PESTEL is also referred as external environmental analysis. Each letter in the acronym signifies a set of factors. These factors can affect the energy industry directly or indirectly. Based on Dočkalíková et al. (2014) and applied by Vallabhaneni (2018) this method will be used to get more insight of the external environment within the energy landscape of Suriname.

- Identification and defining exogenous variables: The Robinson's approach will be for the energy industry as described in the Energy Backcasting by Robinson (1982). Part of this step is also the identification of exogenous variables, which are independent from other variables during this analysis, for instance the GDP of the country.

- Moreover the renewable energy potentials of Suriname will be calculated, based on geographic and climatic databases (Noguchi, et al., 2013) and previous studies done assessing different renewable energy potentials of Suriname.

So, this step provides all the essential ingredients for the next step to build possible scenarios.

<u>Step 2</u>: Generating future visions:

After the desired vision is formulated in the previous step of this framework and getting detailed information on the current energy landscape more insight will be gained in generating future scenarios.

The General Morphological Analysis (GMA) by Zwicky as proposed by (Ritchey, T. (2011)) will be used as backbone to develop future scenarios. This will be done by using a Zwicky morphological box as proposed by Garcia Nodar (2016).

Based on a spreadsheet model, outcomes from the General Morphological Analysis will be used as input variables to develop future energy scenarios of Suriname. Specific input parameters of this model will be based on the future energy demand and the available potentials. The main purpose of using this model is that it gives insight in the share of each renewable energy potential for the desired future. In this research 100% renewable energy share will be considered in the model (as criteria). The results of this step will be used for the next step (backcasting analysis).

Step 3: Backcasting analysis: this step within the 5 steps – framework analysis of Quist, involves the following activities:

The What, how and who – analysis: this task starts with understanding "what" technological, cultural-behavior, organizational and structural changes are necessary to achieve a 100% sustainable energy system? This is the first step to create transition pathways and answering the sub research question "what needs to be done".

Followed by the identification of "What" changes are necessary, the – modified policy packaging framework in this research based on Fearnley et al. (2011)(Soria-lara & Banister, 2017). – will be assessed: the outcome (policy measures) will be answering the "how" part as well as the "who" part within the What-How-Who analysis. During the policy package assessment, the interrelationship of actors and stakeholders (Hisschemoller et al., 2009) within the energy sector will be considered to develop complete and measurable policy packages. The outcome will not only consist of indicators how the proposed measures will be evaluated, but by integrating the policy package framework into the "traditional" what – how – who analysis, a more holistic approach towards the backcasting will be provided resulting into clear and logical pathways to achieve the desired vision.

D. Framework implementation; this section corresponds with **step 4 and step 5** of the Quist's five steps backcasting framework and mainly answers "by when" can these changes happen. Based on the identified changes in the previous steps, long- and short-term actions can be derived which will help to build transition pathways for a sustainable energy system of Suriname. Activities in this step consists of depicting the current situation, making use of the elaborative stakeholder analysis, energy balances and future scenario analyses methods to draw a pathway towards the desired outcome. For each scenario the possible future energy mix will be presented and discussed. By making use of the pathways, different scenarios will be assessed and compared to each other in order to select the best-case scenario.

E. This step applies backcasting to the scenarios formulated in the previous step. Based on the results found in part D the necessary interventions for each scenario will be discussed. Then, the transition pathways and implementation timeline will be constructed for the selected scenarios for Suriname. This section concludes with an implementation timeline of the transition towards 2040 for Suriname. Conclusion and discussion: in this section the answers to the research questions will be addressed and reflection on the used theoretical framework will be provided based on the outcome of the results.

3.2 Activities within the research framework

In short, the abovementioned research approach is illustrated in *table 3.1* which was also used by the studies done by Agarwala (2017) and Vallabhaneni (2018) and based on Quist (2016).

Table 3.1: overview of methodological framework including activities

Backcasting step	Activities	Research method and techniques	Framework used
Step 1: Strategic problem orientation	➢ Describe current energy system of Suriname ➢ Stakeholder Analysis ➢ Unbundling of the energy sector ➢ External environment assessment ➢ Renewable Energy Potential ➢ Identification and defining exogenous variables	● Desk Research ● Desk Research ● Desk Research ● PESTEL analysis ● Estimations using meteorological data. ● Desk Research	Quist's 5 steps backcasting framework in combination with Robinson's approach. "Unbundling" by (Hisschemoller et al., 2009)
Step 2: Develop future vision	➢ Specify the desired goal and targets ➢ Development of scenarios & generation of one or several visions ➢ Renewable energy share in each scenario	● Desk Research ● General Morphological Analysis by Fritz Zwicky ((Zwicky 1966, 1969)) ● Spreadsheet model	Quist's framework Spreadsheet model
Step 3: Backcasting analysis	➢ What are the (cultural, structural and technical) changes? • Define objectives and targets • Create inventory of measures	• What – How – Who analysis combined with: • policy packaging framework as proposed in *Chapter 2.5.2*	Policy packaging framework proposed by Fearnley et al. (2011)
Step 4+5: Elaboration and follow-up agenda And embed results	➢ Develop transition pathway ➢ Generation of follow-up agenda and proposals	• Desk Research • Desk Research	Quist's framework

The next chapter will deal with the first step within the activities listed in *table 3.1*: The Strategic problem orientation. From here on, all the successive steps will be performed in this thesis.

Chapter 4 Strategic problem orientation

This chapter first deals with the geography, demographics and economy of Suriname, followed by the assessment of the current energy system in Suriname. Then, the technical aspects regarding the energy supply and demand will be presented, followed by the actors and stakeholders in the energy sector. Finally, the problem analysis will be assessed through a PESTEL analysis of the current energy system.

4.1 Location Study

In the introduction, a brief overview of Suriname is presented with the focus on the geographical location of this country on the continent of South America and its very low population density.

Figure 4.1: Map of Suriname with international borders, the national capital Paramaribo, districts capitals, major towns, villages, and resorts. (Nationsonline, 2019)

Suriname has, because of its geographical position, an equatorial climate featuring a hot and humid weather throughout the year. However, there is a rainy season from December to August with a relative decrease in February and March and a peak rain season in May and June. A relative dry season follows from late August to mid-November. These climate conditions are favorable for the tropical rain forest in Suriname. According to the (Forest Legality Initiative, 2019) approximately 94% of the country's surface area is covered with tropical rain forest, of which about 91% consists of primary forest. As *figure 4.1* indicates, the coastal region facilitates most of the inhabitants: this can be observed from the district capitals and cities on the coastal side compared to the relatively small numbers of cities and villages in the interior part of Suriname. The capital, Paramaribo, and the area within the blue circle (*figure 4.1*) is the region where the majority of the inhabitants live in Suriname. The dashed areas (east and west) in the southern part of the country are disputed areas, where the government still needs to negotiate for with its neighboring countries. Suriname can be divided into the coastal (low land) area in the north followed by a narrow strip of savanna landscape and the tropical rain forest covering the remaining part of the country. The coastal zone, about 364 km long (measured from the eastern border to the western border) consists of sandbanks, mudbanks and other sediments deposited by the southern equatorial currents (Guyana stream) from the area surrounding the mouth of the Amazon river in Brazil (Chin et al., 2019)

Therefore, this coastal area is known as very fertile land and was also cultivated since colonization period to produce crops such as sugar cane, cotton, cacao, coffee and tobacco. Later, with the arrival of immigrants from Asia, rice became the main crop cultivated in the coastal region. Nowadays not only rice, but also bananas and tropical vegetables are produced for export purposes. Export focuses mainly on the European market and the CARICOM region. The southern part of the country consists of hilly areas, which is home for the tropical rain forest. The highest summit is the Juliana Top in the Wilhelmina mountains with a height of 1230 meters above sea level. Suriname is divided into 10 districts of which 7 of them are in the coastal zone; the capital, Paramaribo, forms a district on her own.

4.2 Demographics

According to (Menke, 2016), the total population of Suriname from the census of 2012 was found to be 541,638. According to his study, an increasing trend is noticeable between the census held in different years (*figure 4.2*). However, it should be mentioned that the timeframe between the census held is not constant. Furthermore, the highest absolute population growth was in the period 1950 – 1964 while between 1972 and 1980 there was a decrease in the population. This was the result of many people leaving the country right after the independence of Suriname in 1975 (*Appendix A-2*).

Based on the MDG progress report 2014 (Government of the Republic of Suriname, 2014), an average population growth rate of 1.2 % per year is presented (*Appendix A-2).* This growth rate is comparable to other Small Island Development States in the region (UN-OHRLLS, 2014), so this growth rate will further be used in this research.

As mentioned in *section 4.1*, Suriname has 10 districts. Menke (2016) observes that the population in the districts Paramaribo (at the same time the capital of Suriname) and Wanica together facilitates around 66% of the total population of Suriname (*Appendix A-3*). In *figure 4.1*, the blue circle on the map indicates where the majority of the population is concentrated.

Furthermore, Menke (2016) found that in the last five to ten years, there has been an increase of people moving to the neighboring districts of Paramaribo. Especially to the neighboring districts Wanica, Commewijne and Para increased significantly while there was a small decrease of people living in the capital, Paramaribo. This can be explained by the fact that many companies chose to set up their business in the districts around Paramaribo to avoid unnecessary traffic jam and growing operating expenses within Paramaribo, while still be within a 30 minutes driving distance from the capital, where all major services and governmental institutes are located.

4.3 Economy

Suriname's economy mainly depends on the extractive industry with the exports of gold and oil products accounting for around 75% of the exports in 2017 (OEC, 2019.). These are non – sustainable ways of harvesting natural resources on one hand while being highly vulnerable for changes in world prices of gold and oil products on the other hand. Precious metal scraps (Copper and steel), Rough wood and the export of bananas and rice are the other export products contributing to the government revenues. In 2017 the GDP of Suriname per capita was $15,200 (OEC, 2019), about one third of the GDP per capita in the Netherlands.

<u>Oil</u>

At the moment, it is known that oil has proven reserves (about 87 million barrels) until the early 2030's, based on a production rate of maximum 6.3 million barrels per annum. Hereafter, the production rate will decrease (IMF, 2018). The proven reserves are present in the nearshore exploration area. The State-owned oil company, Staatsolie NV, is responsible for the exploration of crude oil and the refinery process. This relatively small refinery has a production capacity of 17,000 barrels per day. It is expected that with the exploration of wells in the territorial waters of Suriname, Staatsolie will draw a 100 million dollars in foreign direct investment inflows (Indexmundi, 2019). However, no feasible offshore reserves are found yet. In *chapter 4.4.2* this will be discussed in more details.

Gold

The interior area of Suriname is used for gold mining and for timber harvesting as main economic activities. Gold deposits are especially present in the Guyana shield, a geological formation that stretches out across 415,000 km^2 of Venezuela, the Guyana's, and Brazil (Heemskerk et al., 2016). The mining and refinery of gold is carried out by the Canadian multinational IAMGOLD and the US-based NewMont, accounting for a total of 65% of the gold production in 2017 (IMF, 2018). Accordingly, in September 2018, IAMGOLD extended their contract with the republic of Suriname until 2033, since they have proven and probable reserves of up to 5.5 million ounces in their exploration area. NewMont's projection for the next 10 years is also guaranteed with an average annual production of 0.5 million ounces in the Merian gold mine. The remaining 35% is produced (explored and refined) by small-scale producers and a few mechanized operated companies (e.g. public enterprise Grassalco). Unfortunately, there are many informal operators present in this production segment. The local government is concerned about illegal mining of gold, where mercury is still used in the processing and governmental tax is not paid for exploration activities. The mercury pollution leads to serious health issues when it comes in the ecosystem (from fish to persons). Besides that, the deforestation in and around these illegal mining is often not considered. Heemskerk et al. (2016) mention in their report that a recent REDD+ report suggests, according to satellite images, that gold mining induced deforestation in Suriname has doubled between 2008 and 2014 compared to the years before.

Although the coastal area is very fertile and ideal for producing crops such as bananas and rice on large-scale, the government does very little to stimulate farmers and agricultural enterprises to produce on a larger scale as there's an increasing demand on these crops in the region. As mentioned earlier, rough wood is one of the export products of Suriname, accounting for 2.5 percent of the total export income of Suriname in 2017 (OEC, 2019). This wood is harvested in the interior of Suriname. In terms of energy this means that, there are wood residues present which currently do not have an economic value. However, this could be considered as fuel for small biomass installations which could supply the interior villages with electricity, especially in the evening.

In summary, it can be observed that the largest extractive industries will remain active until at least 2030. This means that the government of Suriname can already anticipate on this and switch towards (stimulating) more sustainable – less extractive – industries.

4.4 Current energy system

In this section the current energy system of Suriname is described. Crucial part of this system are the energy supply and the energy demand of the country. In the next subsections more emphasis will be given on these two aspects. As mentioned earlier, around 85% of the population in Suriname has access to the electricity grid. Suriname has a grid operating frequency of 60 Hz. The grid voltage supplied to households is standard 127 Volts and additionally households and local business can apply for a 220V connection. Noteworthy is to mention that in the last few years small-scale mini and micro grids are installed in the interior of Suriname, mainly supplied by solar PV panels.

4.4.1. Energy Balance of Suriname

The energy balance as result from an energy analysis forms a crucial part for further action, such as an energy savings plan or an energy management system (Blok, et al., 2016). Thus, for assessing the current energy system of Suriname, the energy balance first needs to be addressed in order to get a better understanding of the share of each source in the energy supply and observe relevant energy indicators from the energy balance, obtained from the IEA (2016).

Table 4.1: The energy balance for 2016 (all units in PJ)

Supply and consumption	Crude oil	Oil products	hydro	Biofuels/ waste	Electricity	Heat	Total
Total primary energy supply (TPES)	31.95	-12.6	4.14	1.13		0	24.62
Electricity plants		-11.14	-4.14		7.29		-7.99
Oil refineries	-16.33	15.45					-0.88
Total final consumption (TFC)		14.32		1.13	6.36	0	21.81
Transport (by road + non-specified)		8.54			0		8.54
Industry		0.84		0.17	3.05		4.06
Other (residential, commercial; agriculture/forestry)		4.94		0.96	3.31		9.21

Table 4.1 gives an overview of the total primary energy supply (TPES); this includes the production, import and export of energy in terms of crude oil and oil products. Moreover, hydropower and biofuels/waste are also considered. For hydropower the current hydropower plant delivers around 4.14 PJ of energy while the biofuels/waste energy (energy from biomass; used as wood for stoves) has an energy content of 1.13 PJ. Per net amount, more oil products are exported than imported. The total powerplant losses for the conversion of hydro and thermal power into electricity was around 8 PJ.

Besides the local production of oil and oil products, Suriname also imports energy in the form of liquid petroleum gas (LPG). This gas is mainly used as stove gas for residential and small businesses (e.g. restaurants). LPG is imported by Ogane Suriname, a subsidiary of the state's owned utility company, the N.V. EBS. Partly is supplied to the state oil company, Staatsolie, to use in the refining process. The other customer segment are the households and local businesses where this gas is mainly used as fuel for gas stoves. According to Starnieuws (2016), Ogane Suriname facilitates 900 metric tonnes (MT) of LPG (liquified petroleum gas) of which 45 MT is weekly supplied to Staatsolie. With the current capacity the gas supply is guaranteed till 2020, taking into account an annual increase of 3% of stove gas. However, no exact data could be obtained for the gas consumption.

The energy balance (in *table 4.1*) indicates zero for the total final consumption in terms of heat production in Suriname; energy in terms of heat generation will therefore not be considered during this research.

4.4.2 Energy supply and distribution network

After Cuba and Trinidad and Tobago, Suriname is the third largest oil producer in the Caribbean, with a daily production of around 17,000 barrels (Espinasa et al., 2013). Oil is explored onshore/near shore of Suriname. The exploration area is divided into different blocks *(figure 4.2).*

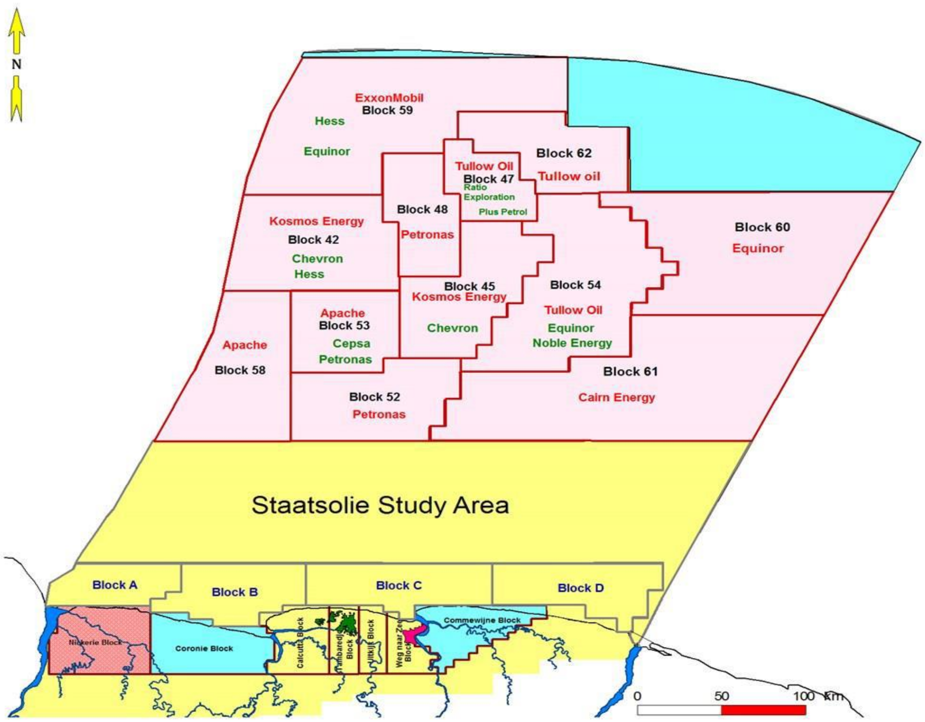


Figure 4.2: Locations of the oil drilling explorations in the Exclusive Economic Zone of Suriname. (Staatsolie, 2019)

The state oil company Suriname, Staatsolie, established in 1980 is engaged in the exploration, drilling, production, refining, marketing, sales and transport of crude and refined products. The crude oil production is around 17,000 barrels per day, while the refinery capacity is approximately 15,000 barrels per day (since 2016). Staatsolie is responsible for the exploitation of hydrocarbon potential, contracting and monitoring activities of other oil companies on behalf of the State of Suriname. Products on the market are crude oil, fuel oil (HFO), gasoline, diesel and bitumen. The refined diesel, gasoline, fuel oil and bitumen cover the local markets, while the fuel oil (HFO) is exported to Guyana, Antigua and Barbados for their power generation. The bitumen is used in all major paving projects in Suriname (Staatsolie, 2019).

Currently, the Staatsolie Study Area (*figure 4.2)* is being used by the Staatsolie to trace the presence of hydrocarbons and to check if they can also have an economic value for the exploration. Further offshore, Staatsolie NV has consulted large multinational contractors to study that area for the presence of economically feasible hydrocarbons. However, no economically viable deposits of hydrocarbons have been discovered until now, whereas in Guyana the British company, Tullow Oil, have made enormous hydrocarbon discoveries in the Guyanese Exclusive Economic Zone. In case, Guyana decides to explore the hydrocarbons, this could lead to business opportunities for Suriname. With a good geographical location for Guyana, Suriname can help processing the crude oil coming from the Guyanese explorations, which could result into additional revenues for Suriname.

The Staatsolie Power Company Suriname N.V. (SPCS) operates as a subsidiary of Suriname's state oil company Staatsolie. The SPCS owns and operates a 62 MW Tout Lui Faut thermal plant, which was expanded in 2015 to a 96 MW installed capacity power plant in order to cover the growing demand of electricity (in the EPAR region) and especially for the refinery expansion which became operational in 2016.

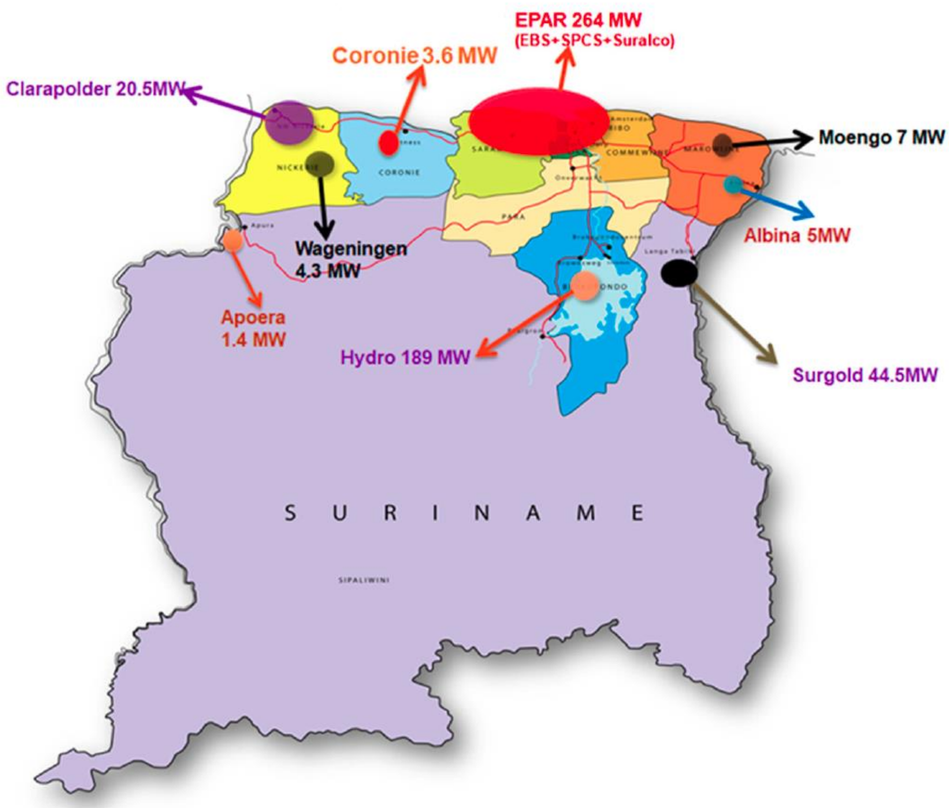


Figure 4.3: locations of the installed electric power plants in Suriname. Source: (NV EBS, 2016)

From *figure 4.3* it can be observed that Suriname has a distributed electricity generation: based on the coverage of the population and economic activities various electricity producing plants are installed. The major electricity grid is in the EPAR (Electricity Supply Paramaribo and Surroundings) region. This region is supplied with electricity generated by the hydropower plant (189 MW installed capacity) and administrated by the Suralco llc. The remaining power is delivered from the thermal powerplants owned by NV EBS and the thermal power plant by Staatsolie Power Company Suriname (SPCS), subsidiary of the State oil company, Staatsolie. Noteworthy is to mention that all thermal power plants use HFO (Heavy Fuel Oil) or diesel as fuel to produce electricity.

It can also be observed from *figure 4.3*, that Surgold (partnership between Newmont Mining and the government of Suriname) has the second largest installed capacity. However, electricity is here generated by HFO engines for the refining of gold. Additionally, each district has a substation which is run by diesel or HFO engines and in ownership of the state company, NV EBS. Currently, there is no grid interconnection between the different power plants.

Electricity is transmitted over long distances through High Voltage lines of 161 kV and distributed over 33 kV, 12.6 kV and 6.3 kV distribution lines to residential and industrial consumers.

Renewable energy

Apart from the 189 MW installed capacity hydropower plant, Suriname is developing and integrating other renewable energy systems in its energy mix. During a recent study by (Raghoebarsing et al., 2019) it is found that around 130 villages are provided with diesel generators (gensets) with a total installed capacity of approximately 4.5 MW while most of them only run for 4–6 h during the evening. Fuel for these generators is delivered on regular basis by the ministry of Natural Resources (NH), which has a subdivision: Department for Rural Energy (Dienst Electriciteit Voorziening (DEV)) focusing especially on the energy needs in the interior part of Suriname.

Additionally, a 27 kWp solar PV system is installed at the headquarters of the State Oil Company Suriname to provide electricity for offices. The main intention of this pilot project is to promote and demonstrate grid connected solar PV system in Suriname and get improved technical insight on grid connected PV systems (Raghoebarsing et al., 2019).

According to NV EBS (2016) it was found that the contribution of solar powered micro grids in the interior of Suriname was 1% (*NV EBS, 2016)*. Hydro power contributes to around 35% of the total energy generation while diesel/HFO fueled thermal plants dominate the electricity market with a share of 64%.

The first largest renewable energy project for the interior (villages) of Suriname has been operational since January 2018 in the village Atjoni; this power plant has a capacity of 500 kW and consists of 1680 solar PV panels (each 300 Wp) and a group of 8 battery banks with a total capacity of 8000 Ah. However, this power plant uses diesel generators as backup in case the batteries deliver insufficient power during the night. In collaboration with the InterAmerican Development Bank (IDB) as financing partner and the local communities, the government aims at scale-up for similar projects in the interior of the country to stimulate economic and social development of these isolated communities (Abadal et al., 2018).

Based on the Energy Balance, presented earlier, it was found that the total electricity consumption in Suriname in the year 2016 was 6.36 PJ. It can be observed that the generated electrical energy in Suriname is for around 48% consumed by the industry (e.g. gold refineries, metal scrap processing companies, sawmills) and the remaining 52% is delivered to residential customers and small commercial companies.

From *table 4.2* it can be observed how the monthly electricity bill for the different categories of consumers is determined. While the actual electricity costs vary between USD 0.13 and USD 0.20/kWh, the final price consumers must pay for electricity is heavily subsidized by the government to an average of around USD 0.04/kWh for households. Moreover, large commercials and industrial customers benefit from the reduced electricity price as well, which is quite unique compared to other parts of the Caribbean.

Table 4.2: Electricity tariffs for the consumer segments (NV EBS, 2016).

Customer type	Monthly Consumption (kWh)	Tariff (USD/kWh)	Subscription fee (USD) (depending on phase)
Residential	< 150 - 800	0.02 – 0.17	1.44 – 2.42
Social		0.05	1.44 – 2.42
Small commercial		0.07	1.44 – 2.42
Large commercial		0.07	2.84
Industrial customers		0.07	10.29

4.4.3 Electricity demand

According to Mehairjan,et al. (2010) the energy demand in terms of electricity in Suriname increases by 6 to 10% per year due to increasing economic activities and population growth. The power demand is mainly concentrated in the EPAR region (*figure 4.3*) followed by the district Nickerie. Although it is known that there is an electricity deficiency which is growing annually, no exact numbers could be obtained from the NV EBS as electricity distributor and grid operator. Because of the increasing shortage of electrical energy load-shedding is applied; especially in the EPAR region. This practice is very inconvenient for companies and households as it significantly decreases the reliability of electricity supply in the country.

However, the projections made by Mehairjan, et al. (2010) were based on historical trends. Over the years, the correlation between energy consumption and economic growth have been studied by researchers. Lachman (2018) emphasizes on this aspect: Although many studies show that an increase in energy consumption usually leads to an increase in GDP. However, there are examples of developed countries where this statement does not stand (Lachman, 2018).

According to the Energy Balance (IEA, 2019), the total electricity consumption in 2016 was 6.36 PJ; this included the industry and the residential, commercial as well as the agricultural sector. Based on personal communication with Stella (September 2019), an annual average increase of around electricity demand between 2 and 5 percent is observed in the last three years. This increase is mainly due to the electrification of several off-grid regions to the distribution network of the NV EBS, followed by an increased demand of industry and residential segments as well as street lighting.

4.4.4 Transportation sector

Transport is here defined as the movement of people and/or goods (Algemeen Bureau voor de Statistiek (ABS), 2016). This can be through road, water or air. From the Energy Balance *(table 4.1)* it can be observed that the transportation sector consumes about 40% of the total energy demand in Suriname.

The total consumption of oil products related to the transportation sector was 8.54 PJ (IEA, 2019). The demand for transportation sector in terms of energy is significantly higher than initially was expected; however, this is not surprising compared to the world energy demand where 67% of the energy demand comes from the transportation sector (Rafiee et al., 2019).

Based on the statistics found (ABS, 2016), the road transportation is dominated by passenger cars (146,000), followed by trucks/lorries (34,434) and buses (3,608) in 2015. Consequently, these transportation types require energy (in terms of oil) to drive on. Since there are no commercial electrical, or fuel cell vehicles registered in Suriname, it can be considered that the whole road transportation sector is depending on oil.

According to a study conducted by Lachman (2018), historical statistical data showed out that there is an annual increase of 1.3% in the number of vehicles on the road. This will be taken into the calculations for determining the future energy demand for the transportation sector.

4.4.5 Heating and cooling demand

Since Suriname has a tropical and humid climate, there is significantly less demand for heating purposed compared to the cooling demand. Based on ABS (2014), there are 8657 boilers installed in buildings; no specific data is present how much of them are solar powered or electrified, although it is found that solar powered boilers are rarely applied in buildings (Lachman, 2018).

According to ABS (2014), there are a total of around 135,000 residential buildings in Suriname of which one third of them have an installed and working air conditioning system (Lachman, 2018). Accordingly, it can be assumed that commercial, industrial and public buildings have more installed air conditioning systems. Lachman (2018) found that 40% of the energy consumption in buildings is used for air conditioning.

Given this, a sustainable way for maintaining climate systems for commercial, industrial and public buildings is also considered in this research. Based on Green (2008), cold water is pumped from a lake or ocean through a deep water intake pipe and transported to a cooling station where heat transfer takes place: hot air coming from the buildings is cooled down by the cool water from the lake or ocean. The cooled down air then recirculates to the buildings, while the slightly warmed water is pumped back to the lake or ocean. *Figure 4.4* illustrates how a conventional air conditioning system is replaced by a Seawater AC. (Green, 2008)

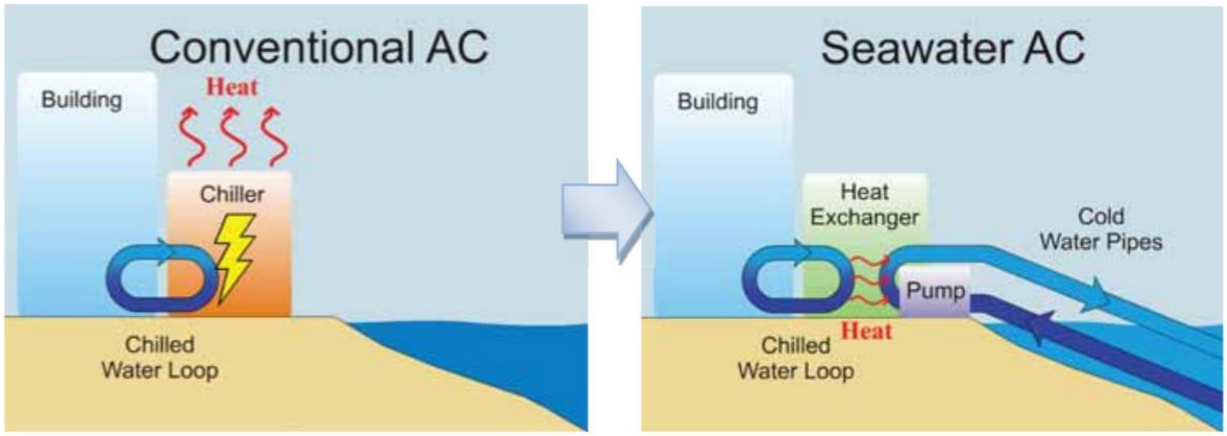


Figure 4.4: overview of the components in conventional AC versus seawater AC (SWAC) (Green, 2008).

Since there are many hotels, resorts, restaurants and industrial buildings located near the shore of the Suriname river, the focus is on developing a cooling distribution network within a range of 5 kilometers. Since the Suriname river is the nearest water "deep water" reservoir, it technically can be used in the SWAC or SDC system. However, given the depth (and the related temperature difference between the surface and the "deep water") of the Suriname river, it is not viable to build an SDC or SWAC system. It is found that the Suriname river is very shallow with depths of around 6 meters (Starnieuws, 2012). No specific data was found on temperature measurement in this river.

Since the coast of Suriname consists of mud banks and other sediments, there is a shallow coastal profile (which is different compared to other islands in the Caribbean (Coelho et al., 2009). Therefore, projects like the SWAC or SDC will only work if deep sea water from the exclusive economic zone (EEZ) is pumped land inwards, which will be very costly given the high investment costs for the large infrastructure required.

4.5 Stakeholders

This section deals with the identification of the most relevant actors in the current energy sector of Suriname. By assessing the role and interests of each group of stakeholders, relevant information can be obtained which provides input for the backcasting analysis of this research. Furthermore, stakeholders play an important role in the transition pathways which will be later in this thesis discussed.

Based on a study conducted by Miron et al. (2009) about the Romanian energy sector, it was found that stakeholder analysis should be focused on three main elements:

- Interest of actors in formulating and describing the objectives of the program
- Power of actors over the proposed program
- Quantity and type of the resources to influence the proposed outcome of the program

Consequently, according to Miron et al. (2009), in a general stakeholder analysis, three kinds of stakeholders can be identified:

1) **Key Stakeholders:** the actors who can influence the success of the project or the program.

2) **Primary Stakeholders:** the actors who are directly affected by the project or the program.

3) **Secondary Stakeholders:** the group of actors who can or cannot take part in the decision-making process or also could be affected by the project or the program.

In order to categorize the stakeholders, it is important to first start with the policymakers: the government of Suriname. The ministry of Natural Resources (NH) is responsible for meeting the energy demand. Their role is therefore "continuous availability of affordable reliable electrical energy for the total population and for the projected economic growth" (Gov.sr, n.d.)

The Ministry of NH has the following institutes as a work arm to take care of this:

- The Energy Companies Suriname N.V. (E.B.S.) is responsible for the electricity supply in the urban and semi-urban areas;
- The Electricity Supply Department (D.E.V.) transferred to N.H. is responsible for the electricity supply in the interior;
- Staatsolie Power Company Suriname (S.P.C.S.). With the construction of a new power station of 28 MW, Staatsolie Maatschappij N.V. can generate thermal energy.

Key Stakeholders:

The key stakeholders are classified as those who can significantly influence or are important for the realization of a program or project. The ministry of Natural Resources (NH) and its division DEV in partnership with the ministry of Regional Development (RO) are responsible governmental actors for the electrification of Suriname: in the cities and the remote and non-urban areas (*figure 4.5*). This involves the small-scale solar PV installation in villages in the interior part of Suriname. Their goal is to achieve 24 hours access to electricity in the country. DEV is responsible for the interior of Suriname. The Energy Authority Suriname (EAS) acts as supervisory body ensuring the reasonableness and fairness of electricity tariffs paid by consumers. The government, through the Ministry of Natural Resources, has a Power Purchase Agreement (PPA) with Suralco (administrator of the hydropower plant) of USD 0.004/kWh. Surgold as multinational is involved in the exploration and refining of gold. They have an installed capacity of 5 MWp to be served for their refinery (Raghoebarsingh et al., 2019). The DEV is working towards electrification of villages in the interior of Suriname where solar PV panels are backed up by diesel generators (for peak load and during intermittency). Their first project in collaboration with the IDB is delivered in January 2018: a 500 KW solar PV farm which provides electricity to about 400 homes (Cuervo, 2018).

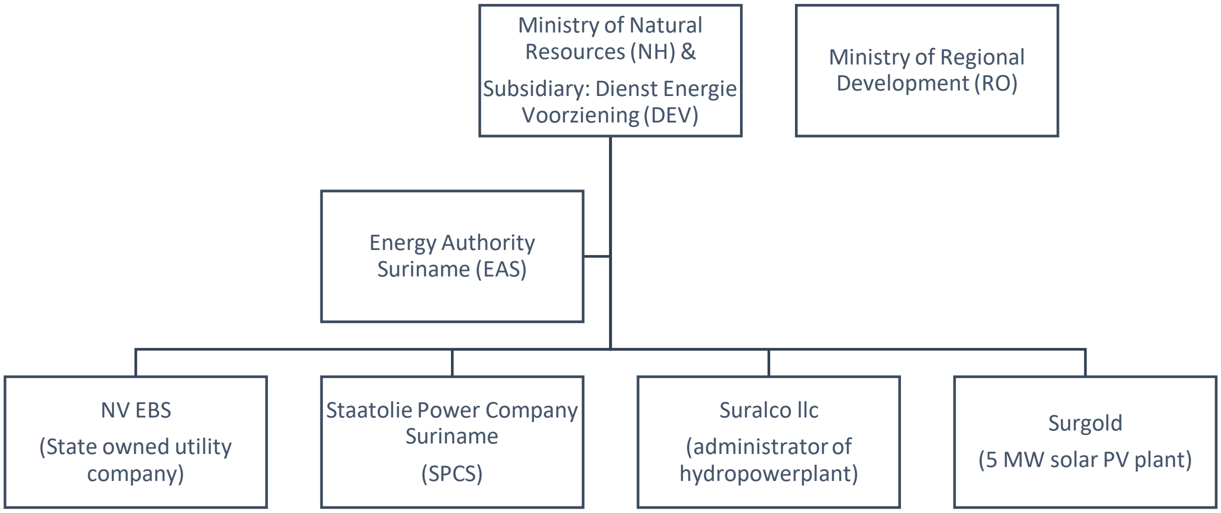


Figure 4.5: organization chart of the governmental institutions active in the energy sector

Most of the public owned investments made in the energy sector are financed by the government of Suriname, where the responsibility lies in the hand of the ministry of NH. However, for large-scale projects carried out by the Staatsolie Power Company Suriname or the NV EBS, loans are often provided by the Inter-American Development Bank (IDB). Besides, the government of Suriname identified Foreign Direct Investment (FDI) as primary source for future economic development. This includes both bilateral and multilateral as well as private foreign investors (IBP, 2016). Noteworthy is that the government took debts (in 2016) from the Islamic Development Bank (ISDB), Caribbean Development Bank (CDB) and Inter-American Development Bank (IDB) for a total of US$ 156.7 million, of which a portion is intended for the development of the energy sector (NU. CEPAL, 2013).

Moreover, it is noteworthy to mention that the end-consumers should also be considered as key stakeholders, since they are the party who can change the demand for electricity. The fact that the end-consumers are not united yet is one of the reasons why they are not closely involved in the electrification program of the government.

Primary Stakeholders

Primary stakeholder are actors who have a direct stake in the organization and its success (Miron et al., 2009); at first the power producers which fall directly under the ministry of Natural Resources. The second category are the end-consumers.

As power producers, the following companies are identified:

- State's owned company NV EBS.
  The NV EBS is apart from the network and grid operator also power producer with decentralized thermal power plants (HFO and diesel); mainly in Paramaribo and the coastal districts. Given the power and influence of the NV EBS, it is evident that this actor has an important stake in the success of the desired outcome.
- Staatsolie Power Company Suriname (SPCS)
  The SPCS is a subsidiary of Staatsolie NV and delivers electricity through its thermal power plant with an installed capacity of 96 MW.
- Suralco llc through a PPA to the state of Suriname; the Suralco llc delivers electricity to the grid of NV EBS, generated by the hydropower plant. The installed capacity here is 189 MW.

The end consumers are divided into two segments to highlight each of their role: industrial consumers and residential consumers.

<u>Industrial consumers:</u>
This group of consumers consists of representatives of the gold mining refineries (so called "large scale consumers"), the agriculture and wood refineries. Since this group of consumers have their businesses outside the city, due to environmental requirements, it is obvious to involve them (as primary stakeholders) within the analysis. Furthermore, the industry solely is responsible for around half of the electricity consumption (IEA, 2019). Therefore, they have a major role in the electricity sector as it comes to the electricity demand.

<u>Residential consumers:</u>

The end-consumers of electricity mainly consist of grid connected small businesses and households. These group of consumers are largely inactive in the energy landscape. They are also not aware of the way they should use electricity in a sustainable way: very poor isolated buildings with high energy consuming air conditioning systems are one of the examples. In the almost static electricity market in Suriname, they are not even united in a union. The recent act of the establishment of the Energy Authority Suriname (EAS) takes the monopoly position away from the power producers to produce electricity. Households and small businesses can generate their own electricity through solar PV panels for example. However, with the heavily subsidized electricity price for households, the payback time for the solar PV investments makes it less interesting for households and small businesses to invest in sustainable electricity sources.

As result of the increasing demand of electricity in the EPAR and the Clara polder region, there are often blackouts and load shedding. In case of load shedding, the NV EBS prioritized critical loads (fire and police services and hospitals) from the less critical ones (residential). This often leads to many disappointed end-consumers.

Secondary Stakeholders

Under the secondary stakeholders Non-Government Organizations (NGO's) and research institutes are identified.

Research Institutes

The Anton de Kom University of Suriname (AdeKUS), founded in 1966, has been identified as the highest research institute of Suriname. The university published as of 2019, 354 scientific papers, employs over 400 researchers and facilitates over 3700 students. The university works in close collaboration with governmental institutions and department to find solutions for e.g. climate mitigation and reforestation of mangrove vegetation on the coastal shore. The university of Suriname also works with other research institutions (abroad) on academic field addressing aspects of sustainable development. However, there remains a significant shortage of expertise, graduates and postdocs (academic staff) to ensure the quality of education, especially when the number of students admitted to the university annually keeps increasing.

Non-governmental Organizations (NGO)

The NGO's in Suriname have a work field varying from environmental concerns towards waste management and sustainable tourism. The following socio-environmental NGO's have been identified as relevant for this research (*table 4.4*):

Table 4.4: List of relevant socio-environmental NGO's in Suriname.

Name of NGO	**Main activities**
National Institute for Environment and Development in Suriname (NIMOS)	- national environmental legislation and regulation - monitoring of compliance
Conservation International (CI)	- Biodiversity - Climate change - Deforestation & REDD+ (sustainable forestry)
Stichting Suwama	- Waste management; recycling - Awareness raising
Amazon Conservation Team (ACT)	- Indigenous community development - Cultural conservation and education - Land use mapping

NGO's play an important role in convincing people and making them aware of climate change effects. Because of their zero interest in profit or money, and while fully focusing on the social benefits of people and the environmental benefits for the climate NGO's are considered to be the "messenger" between the key actor (government) and the population. Their large network and knowledge can therefore be utilized in different regions of the country during the energy transition.

4.6 Unbundling of the energy sector: interrelationships between actors

In the previous chapter, the governmental stakeholders were illustrated in *figure 4.5*; this is meant more towards the generation and supply of energy: electricity to the grid connected end-consumers and fuel for generators in the interior of Suriname.

Since there is no regulatory framework present for the energy sector in Suriname, this section will emphasize deeper on the actors and stakeholders in the energy landscape of Suriname. The interrelationships within the energy sector are derived from the study of Hisschemoller et al. (2009). Accordingly, the term "Unbundling" was used. With regards to the energy sector, it means the separation of the segments of a system or value chain, whether there is competition or not. Since this study scopes down to the future electricity demand and supply, the interrelationship within the electricity market will be discussed into further detail. Moreover, the unbundling of the electricity landscape will be based on the following fundamental aspects of sustainable electricity supply. This involves a social, ecological and economical component:

- Social: affordable and reliable electricity for the local communities; whether they are in the coastal region or in the interior of Suriname.
- Ecological: clean generated electricity i.e. electricity generated by sustainable energy sources keeps emissions low and prevents air pollution. Moreover, it is important to shift towards sustainable energy generation, without destruction of flora and fauna (preserve as much tropical rainforest as possible)
- Economical: a good energy policy or sets of policies forms a boundary condition for reliable and affordable electricity. This results in more applications of innovations and entrepreneurship.

In the interrelationship analysis used here, the actors and stakeholders are clustered to have a better overview on how they are related with each other.

However, there is still unbundling applied to the different working areas and/or responsibilities within individual actors.

- Electricity generation companies: Currently, NV EBS, SPCC (subsidiary of Staatsolie NV), Suralco powerhouse (administrator of Afobaka hydropower plant).
  Although this group represents the electricity generation, distribution and transmission chain, generation should be separated from distribution and transmission: the NV EBS needs to uncouple their thermal power plants from the other divisions. This means that another entity (company) should be in charge for the distribution and transmission of electricity.

Staatsolie is exploring crude oil; partly is refined to HFO and diesel (for the local market and export to the Caribbean islands). Moreover, bitumen as (energy) byproduct is sold to the local market for pavement projects. Staatsolie Power Company (SPC) therefor has stakes in buying relatively cheaper fuel from Staatsolie NV, as they are also operating on the same site as the refinery. It is proposed that the SPC will also be uncoupled from the refinery and under ownership of another company not related to Staatolie NV.

Since all these power companies, except the Suralco powerhouse, are (in) directly under control of the government, it makes it better to cluster these power companies into one entity. It is assumed that this will help to accelerate the energy transition towards renewables.

- Monetary institutions: monetary institutions are one of the key partners in development and execution of relatively large (energy) projects: it can be observed that the government of Suriname has a couple of on-going energy related projects which are funded through loans from the Interamerican Development Bank (IDB) (InterAmerican Development Bank, 2016). Moreover, the International Monetary Fund (IMF) and the Islamic Development Bank (IsDB) are involved in financing community projects. Therefore, there is a control and audit relationship between the monetary institutions and the governmental institutions.

- End-users: this group plays an important role in the energy demand and the future energy demand, especially in terms of electricity. However, at the moment, the end-consumers for electricity are not united; therefore, it is advisable to establish a union which represents both: the industrial consumers and the small and medium residential consumers. In this way they can better influence the electricity generation companies and governmental institutions towards their future power demand.

- Governmental institutions: the major key partners within this category are the Ministry of Natural Resources, the Dienst Energie Voorziening (DEV) responsible for the (electrical) energy supply respectively in the coastal region and the interior of Suriname. Although these organizations are politically oriented, it is important to mention that once the legislation are set, it is up to these ministries to execute the by law set regulations and policies. Currently, the Energy Authority as entity is monitoring over these ministries. It is proposed that the Energy Authority will be part of the independent Energy Institute, thus moving from the governmental institutions towards the Energy Institute Suriname.

- The NGO's: refer to the NGO's mentioned earlier (*table 4.4);* they play a crucial role in guiding the end-consumers and have an influential role towards the governmental institutions and the power generation companies.

With a complete and elaborative overview of the actors and institutions involved in the energy system of Suriname results into a more comprehensive follow-up as part of this research. Moreover, this helps to create better policy packages aiming at achieving the future vision of this study. In *figure 4.6*, an overview of the technical, economic and institutional energy system in Suriname is presented. This figure is used as a backbone for recognizing the actors in the backcasting analysis.

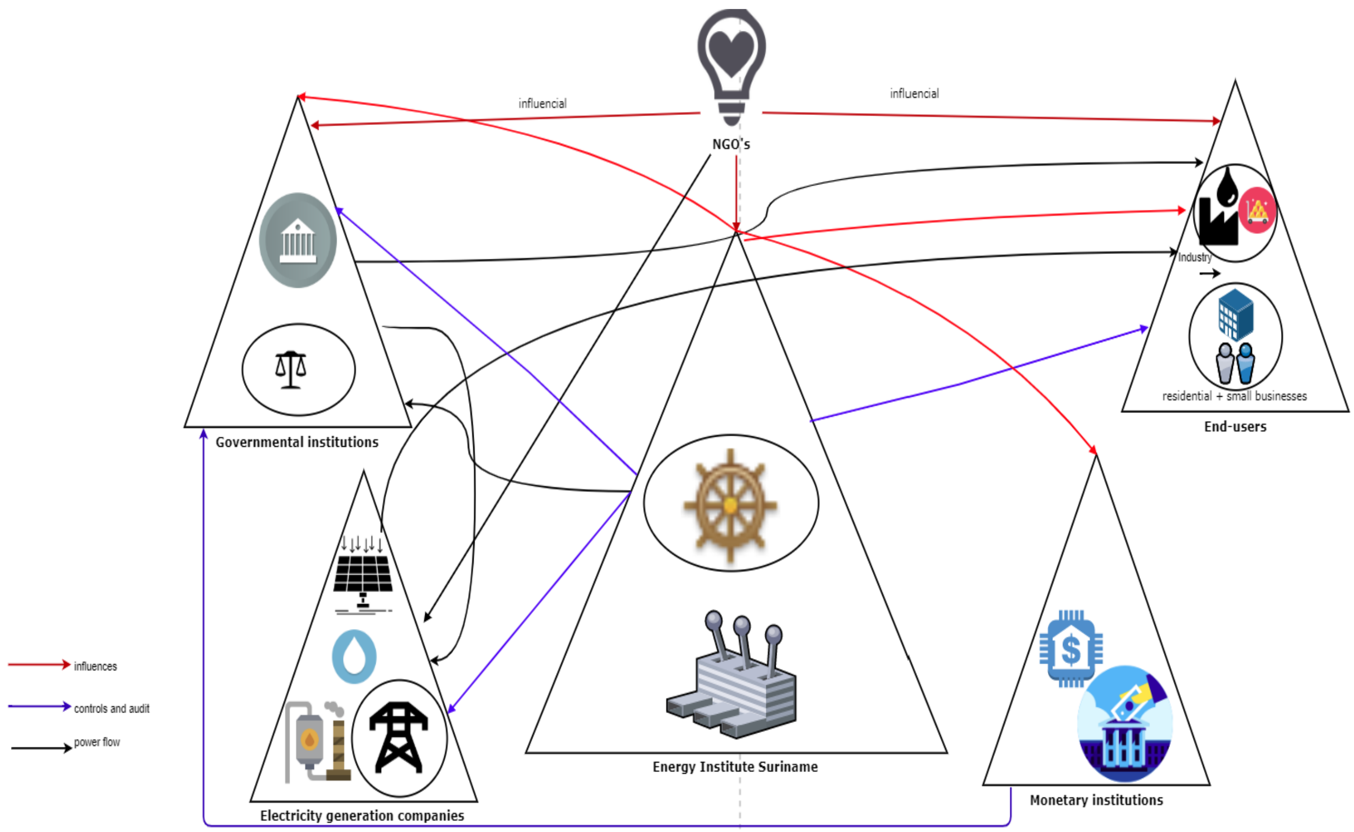


Figure 4.6: relationships within the energy sector in Suriname

Having a complete and elaborative overview of the actors and institutions involved in the energy system of Suriname results into a more comprehensive follow-up as part of this research. Moreover, this helps to create better policy packages aiming at achieving the future vision of this study. *Figure 4.6* is used as a backbone for recognizing the actors in the backcasting analysis.

4.7 PESTEL analysis

PESTEL analysis will be used as a tool for the problem analysis for this research: by analyzing the external environment regarding Suriname's energy sector one can get a better understanding on how the energy transition might be influenced.

PESTEL analysis consists of six factors: Political, Economic, Technological, Environmental and Legal assessment. Here follows the analysis regarding these six factors.

Political:

The Ministry of Natural Resources acts as the main responsible government institution for the development and implementation of Renewable Energy. This ministry works in partnership with the ministry of Finance and other regional institutions to achieve the Renewable energy targets. During the 41st Special Meeting of COTED (Council for Trade and Economic Development) where Suriname is part of as member state of the CARICOM (Caribbean Community) the following targets were agreed upon; based on the Caribbean Sustainable Energy Roadmap and Strategy (C-SERMS):

- 20% renewable power capacity by 2017,
- 28% renewable power capacity by 2022,
- 47% renewable power capacity by 2027,
- 33% reduction in energy intensity by 2027,
- Power sector CO_2 emission reductions of 18% by 2017,
- Power sector CO_2 emission reductions of 32 percent by 2022 and
- Power sector CO_2 emission reductions of 36 percent by 2027 (IRENA, 2015)

Based on the power share of the hydropower plant (about 36%), this agreement does not encourage Suriname to move faster towards a renewable energy system: with the current scenario Suriname will have to consider the increase of 36% RE share (2019) to 47% RE share by 2027. Besides, Suriname has signed the Paris agreement as well (which unfortunately has not been ratified yet). According to Raghoebarsing et al. (2019) Suriname is currently documenting an Intended Nationally Determined Contribution (INDC) which will include the renewable energy targets.

Suriname emits about 3.63 metric tons CO_2 per capita (2014), of which is the majority comes from the combustion of fossil fuels in the transportation and electricity sector (Worldbank, 2016). *Figure 4.7* illustrates a quite stable emission per capita in the last 10 years.

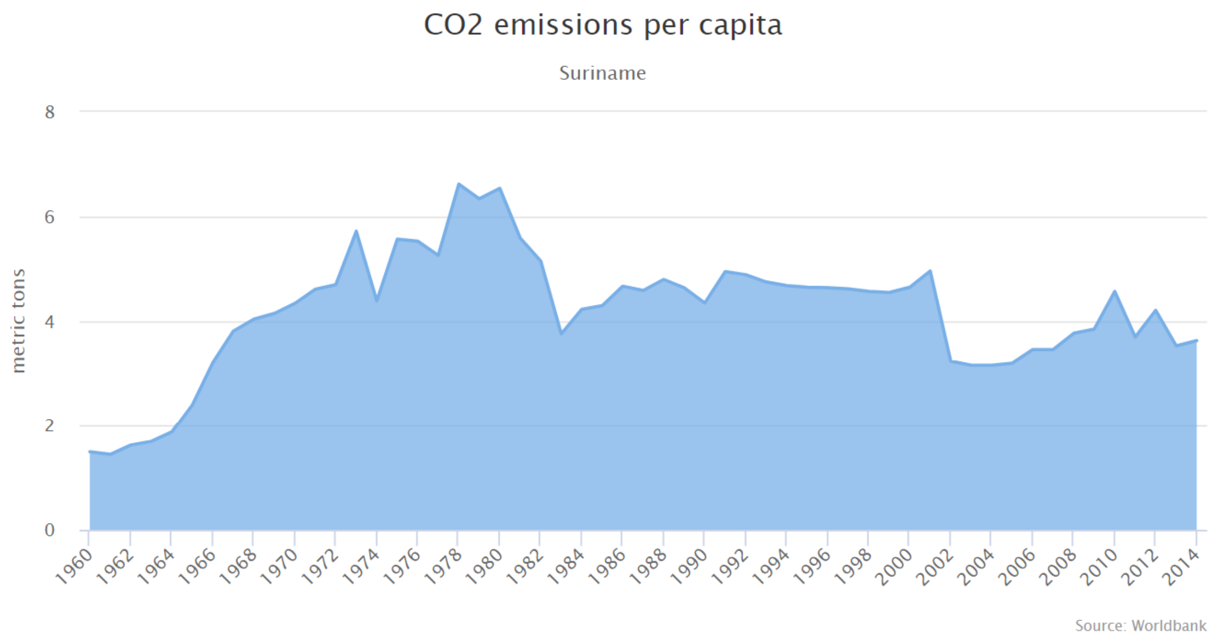


Figure 4.7: Historical data of CO_2 emission per capita in Suriname (Worldbank, 2016)

A recent visit to the International Solar Alliance (ISA) in India by the minister of Natural Resources (NH) resulted in a commitment made by the ISA to install solar panels and 250 solar pumps for government buildings in Suriname (Waterkant.net, 2019). Additionally, the request was made to the ISA to finance 133 micro grids for Suriname through the credit-line India made available for Suriname.

There seems to be a lack of local involvement of entrepreneurs in RE projects initiated by the government, however, the government (Investment and development Corporation Suriname) is looking for foreign investors to invest in Renewable Energy projects. (San A Jong, n.d.)

Regarding the transportation sector there are currently no policy initiatives towards electric vehicles, nor is the government currently considering a reduction of diesel fueled vehicles.

<u>Economic:</u>

Given the economical insights of Suriname, discussed in *chapter 4.3,* it can be concluded that Foreign Direct Investments (FDI) play an important role in the Surinamese economy. Since it is expected that the commodities from oil and gold will remain more less stable, there will be more energy required to shift from extractive industries towards more inclusive and agriculturally based industries.

One of the transitional changes is that Suriname already tries to attract foreign investors to invest in the solar energy sector. According to the Investment and Development Corporation Suriname (IDCS), (San A Jong, n.d.), Suriname offers a wide range of incentives for foreign investors. These are:

- *"Tax based incentives under the Suriname Investment Act including a nine-year tax holiday that can be extended for an additional year for large investments of at least US$ 13 million: results in reduction of corporate income tax due, if any;*
- *In terms of non-tax incentives, a license can be granted by the authorized institution regarding the repayment of the equity capital obtained from abroad to finance the investments;*
- *Licenses will also be granted to investors by the authorized institution for residence and settlement of foreign personnel, occupation of foreign personnel, establishment of a company and import and export of goods and services."*

Although this seems to be very attractive for foreign investors, it is often found that the number of authorities and institutes a potential investor must deal with is very high and makes it less attractive because of its time-consuming nature. Therefore, it is suggested to have a central independent coordinating authority installed which will serve as a one-stop-shop for investors. (Nannan, et al. , 2016)

Generally, enabling incentives help to promote and let Renewable Energy penetrate in the energy mix, as they help to reduce the costs for investors. Unfortunately, no governmental incentive is available for local companies, businesses and households for investments in Renewable energy projects (e.g. solar PV installation).

Noteworthy is to mention that in Suriname the electricity price is heavily subsidized by the government: cost price for electricity in the EPAR region is USD 0.13/kWh, while the districts solely rely on HFO/diesel, which makes the cost price even higher: USD 0.20/kWh. In 2016 the government decided to reduce the subsidy on the electricity price, resulting in increased electricity bills for consumers. However, the interior part of Suriname has waived electricity bills due to a fully subsidized scheme for this part of the country. The intention is to further reduce the subsidy on electricity in the coming years.

Between 2015 and 2016 Suriname encountered an economic crisis as result of the alumina refinery closure (a 10.4% decrease of GDP in 2016). Financial aid from the International Monetary Fund (IMF) was necessary to cover the minimal import costs of the country. On the other hand, the first steps were taken for decreasing the subsidy on electricity as one the measures to control the governmental expenses.

Social

Regarding the social aspects, the involvement of local communities in workforces is crucial; this helps to make them aware of the negative effects on the climate from using primitive fuels, such as wood and fossil fuels. Besides that, it will make them aware of how to change their social behavior in a way that it contributes to energy efficiency. In the interior part of Suriname, the traditional authority is always involved in the decision making and execution process of projects. However, there is a lack of awareness of how to use energy carriers in a more sustainable way. Besides, in order to stimulate renewable energy generation, the government must cut significantly on subsidies. This might affect a portion of households with low income might not be able to pay for the electricity. Therefore, the government needs to prepare for and able to facilitate this under a so called "social safety net". However, "cutting" subsidies on fossil fueled powered electricity generation on one hand and providing subsidies for sustainable generated electricity on the other hand maintains in balance.

Technological:

The technological aspects regarding the current energy sector have been discussed in the section "Current energy system". The NV EBS is responsible for the grid connection and maintenance in the EPAR region and the coastal districts. One of the challenges for this utility company is the growing demand of electricity on one hand while increasing the grid capacity on the other hand. Moreover, with the stimulation of electricity generation by solar PV panels (prosumers), this company must invest in smart meters and measuring tools.

In the rural areas (interior of Suriname), microgrids are a successful implementation for hybrid systems: solar PV combined with diesel generators. This enables consumers in the remote areas to have electricity 24 hours a day instead of 4-6 hours a day (Raghoebarsing et al., 2017).

Moreover, Suriname is favorable for Sustainable Energy technologies: due to its geographical location, Suriname has a large potential for solar PV energy. Besides, energy from biomass is available to serve as base load, especially in the rural areas (villages) in the interior of the country. Hydropower has a larger potential than what is currently harvested from the Afobaka hydropower plant (REEEP, 2012). In-depth analysis on the renewable energy potentials will be performed in section 4.8 of this research.

Environmental:

Even though Suriname's tropical rainforest stores about 11 gigatons and absorbs more than 8.8 million tons of forest carbon annually, it is highly vulnerable to the effects of climate change (INDC, 2015). The over 80% of the population living on the coastal side are fragile for floods when the sea level will rise. Current projections for sea level rise will result in severe damage to the coastal ecosystems; the mangrove forests and agricultural land. Furthermore, the coastal area contains freshwater aquifers which are distributed as potable water for people living in and around the capital, Paramaribo. According to (INDC, 2015), possible damage affects over 40% of the country's GDP and the lives of more than 80% of the inhabitants. In the last decade, people living in the interior part of Suriname also have experienced unusual flooding in their village caused by extreme water level in the rivers (where most villages are located). Besides this, human contribution also plays an important role: illegal gold mining and timber activities leads to illegal forest exploitation. Moreover, the use of HFO/diesel engines accounts for 59% of the Greenhouse gas emissions in Suriname. (Raghoebarsing et al., 2019)

Legal:

The investment climate in Suriname contains too many hassles to make it attractive enough for investors to invest in the energy sector. As mentioned earlier in the economic aspects, the government is working towards a one-stop window, avoiding the long time to wait for establishing and setting up a business. In order to make it attractive for foreign investors to invest, the government provides tax and non-tax-based incentives (mentioned in the Economic part of the PESTEL analysis).

On the other side, the parliament of Suriname recently approved and established the Energy Authority Suriname (EAS) aiming at meeting compliance of the national electricity strategy and the electricity sector plan, including the reasonableness and fairness of electricity tariffs (Raghoebarsing et al., 2019). As result of this act, local people (residentials) and private businesses can generate their own electricity. However, they cannot generate more electrical energy than they annually consume to avoid that they become net electricity producers. With this act, the government intends to promote Renewable Energy generation by households and companies. However, for the average household, the costs for a solar PV system are too expensive to afford. Besides, there are no financial schemes or subsidies present to stimulate this.

4.8 Exogeneous Variables

Based on (Miola, 2008) exogeneous variables are referred to elements which are not included in the backcasting itself, but which are important to describe the context within which the analysis takes place. This is especially relevant as these variables may (in)directly act as input for the scenario analysis.

The following input assumptions are part of the exogenous variables:

- Economic growth (in terms of GDP): It is found that Suriname has experienced economic growth until 2014, thereafter the economic growth started to decrease until 2017 (Tradingeconomics, 2019). Mehairjan et al. (2010) explains that the economic growth in Suriname can be explained due to the development of the oil industry, refinery process, and growth in the mining sector especially the gold sector.

- Demography: population growth is proportional to the energy consumption per capita (OECD/IEA, 2011). It is found that with a growing population the energy demand will increase as energy. A population growth of 1.3% per year will be considered in this study.
- Prices of fossil fuels: since prices of fossil fuels have a very huge volatility, it will be considered as an exogenous variable.
- International relationship: it is assumed that the international relationship between Suriname and the rest of the countries will not affect the scenario development.

4.9 Renewable Energy Potential of Suriname

In this section the renewable energy potentials of Suriname will be determined. Outcomes of this assessment will be crucial to develop future scenario's on. All Renewable energy sources will be considered. Subsequently, storage facilities to meet the intermittent character of renewables will also be considered.

4.9.1 Data collection

Data used to determine the technical potential of the renewable energy type is derived from meteorological data as well as studies and researches done on the energy sources and potential present in Suriname. Apart from these data, data from international institutions such as the IRENA and NASA are used in this analysis.

4.9.2 Solar Energy

The geographical location of Suriname already reveals that this country is in favor of the Sun. Data obtained from SolarGIS *(2018)* confirms that, showing an annual irradiance of around 1790 kWh/m^2 which is almost twice as much compared to the Netherlands (1000 kWh/m^2).

Key parameter for solar PV is the Global Horizontal Irradiance (GHI): this is the amount of irradiance which comes directly from the sun and is received on a horizontal surface on Earth. Raghoebarsing et al. (2019) mention in their study the fluctuations of the GHI in Suriname during all seasons throughout the year. Hglobal per month varies from 3.72 $kWh/m^2/day$ (in February) to 6.02 kWh/m2/day (in October). The annual Hglobal is 1791.85 $kWh/m^2/year$. Changes in these values are the result of rain season (between December and May) and the dry season (between June and November) respectively.

Solar PV parameters:

Table 4.5: Assumptions made in the calculations (Calculations described in Appendix A-4)

Available Area:	Irradiance:	Solar panel:	Module efficiency:	Balance of a system (BoS)	Grid efficiency	Capacity factor:
9,360 km^2 out of the total 156,000 km^2 Land use factor of 6%.	1790 kWh/m^2	Bluesun Solar BSM280M-60 (280W)	17.12%	92%	91%	17.6 % (IRENA, 2018)

In this case a Bluesun Solar BSM280M-60 (280W) solar panel is considered with an efficiency of 17.12 %. Based on (IRENA, 2018), the capacity factor for solar PV is found to be 17.6%. Given the geographical distribution where the people in the city, districts and the villages in the rural part of Suriname are located, the solar panels can be installed centralized and decentralized. Since there is no data available on the available area designated for projects like solar PV, it may be assumed that this is a parameter which is "abundantly" present. Unfortunately, no data could be obtained indicating rooftop areas of industrial and governmental buildings and residences. From the total land area of Suriname (156,000 km^2) 90% is forest (PAHO, 2015). The built environment has an area of approximately 15,600 km2; this is largely the area in the Northern (Coastal region) of Suriname which is cultivated. In his master's thesis García Nodar (2016) used a factor of 60% to determine the roof area which can be used for the installation of solar PV panels. Counting in 60% of the cultivated area for rooftop solar PV installations as well as ground-mounted solar PV systems, the total area would be 9,360 km^2. Since Suriname is committed to the REDD+ program (less than 0.22% deforestation per year) (PMU, 2019) additional area from the 90% forest area is not considered in this calculation.

Other assumptions made here are a Balance of System efficiency of 92% due to the losses of cables, charge controller, inverter and other system losses. A Land Utilization Factor (LUF) of 6% (9,360 km^2) is considered. LUF refers to the percentage of designated for the solar PV modules.

Based on the assumed area, the efficiencies and the capacity factor, the potential solar PV energy has been calculated by taking the lowest measured daily average of 3.72 kWh/m^2 per day (figure 4.12): 32,210 GWh or 116 PJ.

Solar thermal

Concentrating solar power (CSP) utilizes the Sun's rays and with the use of mirrors high temperature heat is generated to use in a steam turbine which finally delivers electricity. This technology offers an efficiency of around 13% (IRENA, 2018). Given the fact that its efficiency is lower compared to the solar PV for delivering electricity and that hot water is not considered as desired output of this system (since there are no exact numbers for heat demand in Suriname), the solar thermal potential will not be considered in this research.

4.9.3 Hydro energy

In the past 10 years, there have been many speculations going on about the execution and feasibility potential hydropower projects (Mehairjan et al., 2010).

- The Tapa-Jai project: based on the expansion of the existing hydropower plant: water infrastructure will be built to connect the Jai-Tapanahony river (*Appendix A-4*). This project leads to an additional installed capacity of 116 MW, bringing the total installed capacity of the HPP (hydropower plant) to 305 MW.
- The Kabalebo Hydro Power Project (also known as the West Suriname Hydro Power Project) was already initiated in 1977. The projected installed capacity will be around the 350MW to 650MW. A more recent study in 2014 was conducted to assess environmental impacts upon realization of this hydropower plant in the Western part of Suriname. The results of this research show significant changes of the hydropower potential as impact of flows in the river between 2050 and 2100 (Donk P. et al, 2014). The hydropower river basin will be covering an area of roughly 9450 km^2 (Appendix A-4)

It is noteworthy to mention that the real hydropower potential could be much larger than these projects show out. Since no other study was found regarding the hydropower capacity of Suriname, this thesis will consider these projects as starting point. Moreover, by considering already carried out local (feasibility) studies, the accuracy is better than making estimations based solely on climatological data.

When the 2 hydro projects will be executed than nearly 560 MW extra hydro capacity will be available (Mehairjan,et al., 2010). This involves the expansion of the current hydropower plant and the realization of the Kabelebo hydropower plant. The total installed capacity of both hydropower plants will be around 750 MW. With a capacity factor of 0.65 for hydropower (currently the case in Suriname), the annual electricity generation will be 4415 GWh or 16 PJ.

4.9.4 Biomass potential

Biomass provides the baseload when utilized in a renewable energy system. A recent study carried out by (Nannan et al., 2016), elaborates on the potentials of various biomass potentials in Suriname which can be used as biofuels. The total potential energy from biomass is 1.14 PJ.

Table 4.6: Overview of the potential energy from biomass in Suriname

Energy from biomass source (feedstock)	Installed capacity
Rice husk	4 MW
Rice straw	4 MW
Wood waste	30 MW

4.9.5 Wind energy potential

Based on climatological data, Suriname has very low winds speeds ranging between 2 and 4 m/s *(WeatherOnline, 2019).* Therefore, harvesting wind energy through wind turbines not only becomes a technological challenge, but will also result in high Levelized costs of electricity (LCOE). In their study Ramsingh et al. (2016), use Regional Climate Model (RCM) simulations to determine whether wind energy would be efficient to use in the future. With wind speeds below 4.5 m/s (lower than the cut in wind speeds for commercial wind turbines on the market) and a capacity factor between 7.5 and 18.4% found, this study concludes that on long-term basis wind energy would not be efficient for large scale generation.
Therefore, wind energy will not be considered as a potential energy source in this research.

4.9.6 Geothermal Energy

According to IRENA, Suriname has a neglectable potential of geothermal energy since there are no active volcano's compared to other east Caribbean islands such as Dominica, Grenada, St. Kitts/Nevis, St Lucia & St. Vincent/Grenadines (Muñoz Cabré et al., 2015). No other data or studies show relevant geothermal energy projects for Suriname.

4.9.7 Ocean Thermal Energy conversion (OTEC)

An important requirement for feasible exploration of OTEC energy is the temperature difference of around 20 degrees Celsius between the surface water and deep ocean water. It is found that the EEZ has a total area of 96,238 km^2 and therefore a total energy potential of 24 TW. Based on an overall theoretical efficiency of 6% for OTEC, the total estimated OTEC potential would be

1440 MWe (Strok, 2015). However, given the large distance from shore to the proposed OTEC plant, the installation of OTEC power plants are not considered as viable within current conditions.

4.9.8 Wave Energy

Wave energy is harvested as a result of interactions between the wind and the ocean, where waves tent to increase as they propagate (TU Delft, 2018). Compared to other types of renewable energy sources, wave energy tent to be more predictive and therefore is better suitable as a source for baseload. According to the study conducted by Mørk et al. (2010), the Exclusive Economic Zone of Suriname has a wave energy potential around the 10 – 15 kW/m (*Appendix A-4*). From this study, the best wave energy conditions (red to brown dots) are found in medium-high latitudes and deep waters (from 40 meters deep on) (Alcorn, 2013). Accordingly, wave energy farms in these regions (China, Australia, Norway etc.) achieve a levelized costs of electricity between EUR 330-630/MWh, which are already higher than other types of renewable energy sources. Compared to the wave conditions found for Suriname, the potential implies that this technology is (economically) not viable and thus will not be considered in this research.

4.9.9 Tidal Energy

Tides are the waves caused by the gravitational interaction of the moon and the sun. As result, energy can be harvested from the mechanical movement. According to a study conducted by Rambaran Mishre (2015) to harvest tidal energy in Suriname, measurements were taken in the Nickerie river, which is located in the North-Western part of the country.

Since no technical dimensions for the free flow turbines and all the rivers in Suriname having their outfall in the ocean could be found, it is estimated that the total installed capacity for harvesting tidal energy will be around the 60 – 100 kW per turbine. This is based on the width of around 100 meters for small rivers and more than 1500 meters for the large rivers. These turbines deliver the estimated power wherever the water velocity is around the 0.67 m/s (Rambaran Mishre, 2015). Accordingly, especially the rural communities could benefit from the generated electricity, since these consumers live near the riverbanks in the interior part of Suriname and the costs for transmission would be significantly lower.

Although there is a technical feasibility for this technology, this study will not consider tidal energy as a potential energy source since this kind of (low) technical potential is (economically) not yet viable.

4.9.10 Energy savings potential in Suriname

This subsection elaborates on the possible savings on energy in the following categories: residential, industrial and transportation. Data obtained for this summary is heavily derived from the study conducted by Lachman (2018). He tried to cover as much data as possible from local institutions (statistical data) as well as internationally published data. The study elaborates on the energy efficiency and savings by assessing a top-down analysis in combination with a bottom-up analysis. The Top-down analysis consists of a numerical tool from the American Council for an Energy- Efficient Economy (ACEEE) that "uses metrics for policy and performance in order to determine the extent an economy uses energy efficiently" (Lachman, 2018). Based on his analysis, Suriname scored 27 out of a total of 100 points. Compared to industrialized country e.g. Germany, a scorecard of 72.5 points is earned (Eichhammer, et al., 2016). This implies that there is a need for improving the energy efficiency in Suriname. In the bottom-up analysis Lachman (2018) emphasizes on the energy consumption per sector: transportation sector, electricity market and the LPG market (stoves). However, since this study already emphasizes on the transition towards electric vehicles, the energy savings here cover the following areas: street lighting, more efficient transformers in the distribution chain, housing and appliances. The total amount of energy saving potentials here is 0.3 PJ per year.

4.9.11 Storage potential

Energy storage systems play an important role in Renewable energy systems as they have an intermittent character (Díaz-González et al, 2012). Accordingly, there are many storage technologies available on commercial size:

• Solid State Batteries – this includes electrochemical storage solutions (batteries and capacitors)

• Flow Batteries – these are batteries where the energy is stored in the electrolyte solution for longer cycle life and quick response time.

• Flywheels – stored rotational energy to deliver immediate electricity

• Compressed Air Energy Storage - utilizing compressed air to create a potent energy reserve

• Thermal - capturing heat and cold to create energy on demand

• Pumped Hydro-Power – using large-scale reservoirs of energy with water

Given the fact that the current hydro reserve can be expanded with an additional 116 MW capacity (Mehairjan et al., 2010), this provides a great potential for Pumped Hydro Storage. Besides, the capital costs are significantly lower compared to other storage technologies: 10 – 20 Euros/kWh (Díaz-González et al, 2012). Therefore, this technology will be assessed as storage potential in this research.

Pumped hydro systems build potential energy by storing water in a reservoir (van Blommestein lake) in case of excess energy. The potential energy is then converted into electricity when there is a demand. The following equation is used to calculate the energy storage capacity of a PSH system: $E = 9.81 * \rho_{water} V_{res} h_{head} \eta$; where

E is the energy stored in Joules
ρ_{water} is the density of water, usually about 1000 kg/m^3.
V_{res} is the volume of the reservoir in cubic meters.
h_{head} is the head height in meters.
η is the efficiency of the energy conversion, and must consider losses like turbine efficiency, generator efficiency, and hydrodynamic losses.

The reservoir volume is 46,800,000,000 m^3 with a head of 54 meters and efficiency of 0.65, the total storage capacity is 1,6 PJ => 456 GWh. Based on an average electricity consumption of 1950 GWh per annum (IEA, 2014), the storage capacity would be enough to store electricity for roughly 80 days. However, this storage potential can only be fed to the main region, the EPAR region in Suriname, as there is no grid interconnection with the other regions. As described in this section, the total potential of Renewable Energy sources in Suriname are estimated. Based on calculations and estimations, it is found that the major sources of Renewable energy are solar PV followed by Hydropower and biomass (*figure 4.8*).

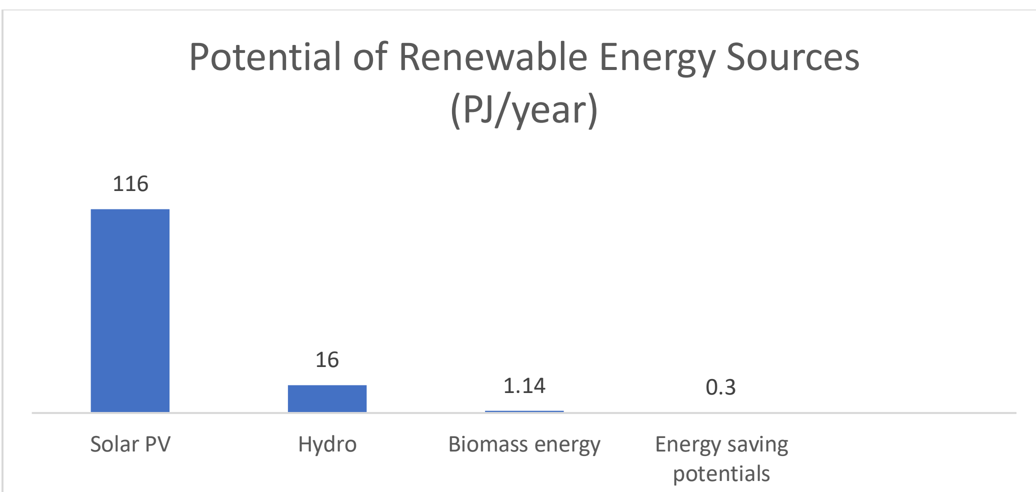


Figure 4.8: Overview of the estimated Renewable Energy Potentials in Suriname (PJ/year)

In the next chapter the future vision and scenario development will be performed based on the findings of current chapter.

Chapter 5 Future Vision and Scenario development

The future vision and scenario development will be performed in this chapter. This part is derived from an earlier study conducted by Vallabhaneni (2018). Having the current energy system described in the previous chapters, this chapter will deal with the future vison and the necessary changes for the transition from the current system to the desired one.

As mentioned earlier in the methodological framework, the General Morphological Analysis (GMA) approach is intended to use in this research. The following parameters are assessed to address the future vision:

- **The energy demand:** the growing demand for energy (in terms of electricity) as result of the increasing number of households connected to the grid as well as the population growth and economic growth.
- **Energy markets:** the nature of energy markets is an important parameter that can influence the nature of competitiveness and value for business opportunities.
- **Energy sources:** this parameter is depending on the assessment of renewable energy potentials and the plausible conventional energy sources. This can be divided into the following subcategories:
    - **Conventional energy sources:** based on the existing energy sources that are currently being used: oil and oil products
    - **Baseload Energy sources:** these are the renewable energy sources that can provide a constant energy output, such as biomass and hydropower.
    - **Intermittent energy sources:** renewable energy sources that heavily depend on the meteorological conditions, such as solar PV.
- **Infrastructure changes:** This parameter represents all the infrastructure changes that might be required to transform the existing energy systems. Given the current situation, the electricity throughout the country is generated in a decentralized way; different powerplants delivering the power to the distribution network. The distribution and transmission networks are therefore regionalized.
- **Key actors:** this domain includes all relevant stakeholders regarding the future development of the energy system in Suriname; such as the government of Suriname and the energy companies.
- **Storage**: possible storage options which can be considered.

According to Ritchey (2013), the GMA enables the identification and investigation of a total set of possible relations or configurations; thus also in the future energy mix of Suriname.

Table 5.1: representation of the Morphological box

Energy demand	**Energy markets**	**Conventional energy sources**	**Baseload energy sources**	**Intermittent energy sources**	**Infrastructural Changes**	**Key actors**	**Storage of energy**
increase	Competitive	Diesel	hydropower	Solar PV	Centralized generation	Government	Pumped Storage hydro (PSH)
stable	Monopoly	LPG	biomass		Decentralized generation	Energy and Utility companies	Batteries (Li-ion)
decrease	Combined	none				Users and local communities	

In *table 5.1*, the parameters of the morphological box are presented (Zwicky box). Although there are a great number of configurations possible based on this box, there are some inconsistencies possible as outcome since there are no conventional energy sources expected to be in the energy mix in the future vision (third column in the table). Based on the findings of the renewable energy potentials, in combination with the parameters in *table 5.1,* individual scenarios will be developed which then will be modelled to determine an entirely renewable electrical energy system for Suriname in 2040. Noteworthy is to mention that *table 5.1* does not consider cultural and structural elements, as the future scenarios are initially approached from a technical perspective. However, in the discussion (chapter 7), the cultural and structural aspect regarding the morphological analysis will be discussed.

5.1 Future Energy Demand

The future energy demand has a two-fold character and can be divided into the transportation sector and the electricity demand.

According to the IMF (2018), resource-rich countries like Suriname are dealing with a significant volatility regarding their commodity revenues. That is also the reason for the instable GDP share; ranging from 11% in 2011 to 3% in 2016. The high government spending and low revenues are almost equally important for the case of Suriname. Given that, the IMF predict the following long-term variables: GDP growth rate of 3 percent, inflation of 3 percent, and real interest rate of 5 percent beyond 2023 IMF (2018).

The population growth rate is found to be 1.2% annually according to the MDG progress report (UN-OHRLLS, 2014). This means that Suriname will have 945,000 inhabitants by 2040.

The transportation sector

Transportation by road has the largest share in terms of energy consumption. Based on the energy balance of 2016 (IEA, 2019), the current energy consumption for transportation is found to be 2373 GWh.

Given the predictions of the IMF (2018), in terms for road transportation, it means that there will be additional energy required for agricultural and tourism purposes, as Suriname wants to shift towards more sustainable sources of income (rather than be depending on the volatile price of extractive industries). Based on the current annual growth of vehicles (Appendix A-3), it is estimated to be around 2% average per year. This is highly depending on the economic situation in that particular year. If the current energy demand is converted into electricity, it is expected that by 2040, the transportation sector will require a total of 4,653 GWh in terms of energy. However, there are efficiency changes when converting fossil fuel energy demand into (battery stored) electricity demand.

Based on the models developed by Gustafsson et al. (2015), the total efficiency (fuel to wheel) for internal combustion engines (ICE) is found to be around 28.5%. (figure 5.1)

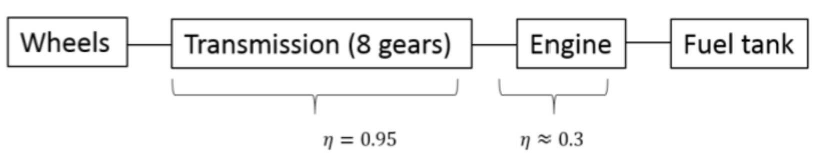


Figure 5.1: Schematic view of the ICE model (Gustafsson et al., 2015)

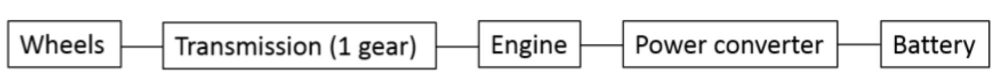


Figure 5.2: Schematic overview of the BEV model (Gustafsson et al., 2015)

The individual efficiencies in the BEV model are 98% for the transmission efficiency and an engine efficiency of at least 50%, with a maximum of 95% (figure 5.2). Based on the estimated efficiencies of the battery Electric Vehicle, the overall battery – to wheel efficiency is at least 49% (Gustafsson et al., 2015). This efficiency can only be higher since this is calculated on a worse-case scenario, assuming an engine efficiency of 50%.

This implies, that the total energy demand required for the transportation sector will be almost half since the efficiency of BEV is almost twice the efficiency of ICE.

Thus, in case the transportation sector would be fully electric driven (today), the energy demand for fossil fuels (2373 GWh), would be equivalent to 1356 GWh of electricity demand. Extrapolating this demand toward the desired vision with a BEV growth of 2% delivers a total BEV electricity demand of 2181 GWh.

Moreover, since the transportation sector involves zero electricity consumption at the moment (no electric vehicles present), it is assumed that this demand in terms of oil products will shift towards electricity.

Electricity demand

The energy balance illustrated in *table 5.2* is assumed as the starting point for determining the future electricity demand, since the future energy demand will not consider heat and oil products in the supply and consumption chain.

Table 5.2: The energy balance for 2016 (IEA, 2016); all values in PJ

Supply and consumption	Crude oil	Oil products	hydro	Biofuels/ waste	Electricity	Heat	Total
Total primary energy supply (TPES)	31.95	-12.6	4.14	1.13		0	24.62
Electricity plants		-11.14	-4.14		7.29		-7.99
Oil refineries	-16.33	15.45					-0.88
Total final consumption (TFC)		14.32		1.13	6.36	0	21.81
Transport (by road + non-specified)		8.54			0		8.54
Industry		0.84		0.17	3.05		4.06
Other (residential, commercial; agriculture/forestry)		4.94		0.96	3.31		9.21

Referring to Mehairjan, et al. (2010) a growth rate of 6 to 10% peak electricity demand was expected per annum, as result of the prediction of high income growth and commercial activities. However, this amount seems to be much higher compared to historical data found for the last 3 years where on average 3% growth is found (The World Bank, 2019). The population growth is found to be 1.2% per annum, which is in the range of other countries in the Caribbean region. The GDP growth is on average 2% per annum. Previously, it is already discussed that GDP growth does not have to mean explicitly that the electricity demand will also change in that order. Considering that, since 85% of the end consumers are already grid connected and that for the remaining part consists of users in the hinterland (around 9%) and 6% are spread out in the coastal region (Raghoebarsing, 2019), it is unlikely that there will be 100% grid connected consumers in the coming 5 to 10 years, so no large growth due to electrification is expected in the coming years.

Taking all these considerations, an annual growth of 3% will be sustained (derived from the historical trends) until 2030. Based on this, the future electricity demand estimated here will be probably higher than it will really occur on the electricity market. From 2030 to 2040 an electricity growth rate of 2% will be considered, since it is expected that smart devices will then be fully integrated in the local market resulting into more energy efficient consumption.

The values found based on historical data and the future annual growth rates based on the above-mentioned assumptions are tabulated in *table 5.3*.

Table 5.3: Average annual growth rates for the energy demand

	2000 – 2019 (historical)	2019 – 2030	2030 – 2040
Electricity demand – power generation	3%	3%	2%

Based on the energy balance found for 2016 (*table 5.3*), the future energy demand is determined.

The following table summarizes the boundary conditions for determining the future energy scenario.

Table 5.4: indicators used to determine future electricity demand

Indicators	2016	2040
power demand – excluded BEV	1768 GWh	6359 GWh
Transportation demand (BEV)	2373 GWh (oil equivalent) 1356 GWh (electricity equivalent)	2181 GWh (electricity equivalent)
Electricity growth rate	3 % until 2030 and 2% from 2030 to 2040.	
Electricity Transmission and distribution losses	9 %	
Energy conversion efficiency from ICE to BEV (fuel switch factor)	57 %:	

The total primary energy supply (TPES) is the sum of all energy produced. Storage changes (if there are), conversion efficiency and transmission losses are not included. The TPES minus the losses due to conversion and transmission provides the total final consumption (TFC) (*figure 5.3*). However, in case of solar PV and hydroelectricity, the energy is already converted into the desired forms. Therefore, transmission and distribution losses will be taken into account.

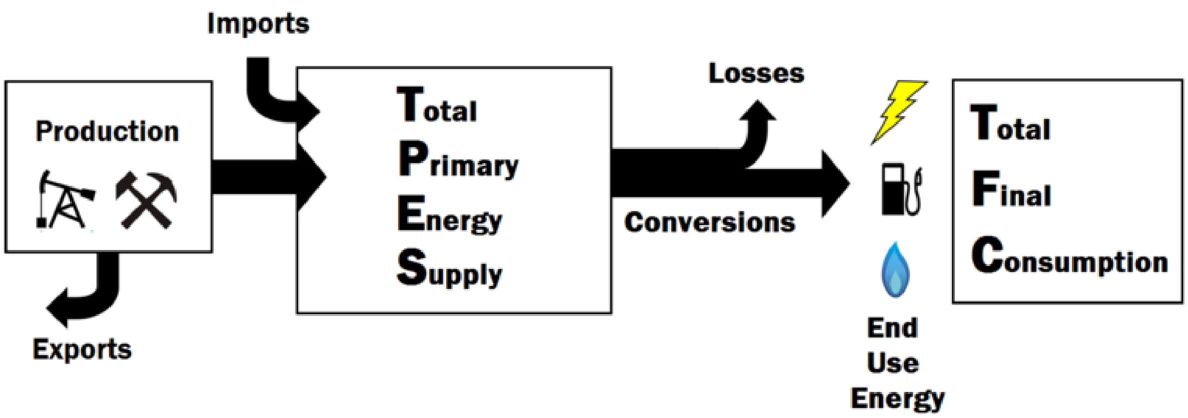


Figure 5.3: Schematic overview of the relation between the TPES and the TFC mentioned in the energy balance (Hanania, 2017).

Table 5.5: The energy balance for 2040 (PJ/year):

Supply and consumption	Crude oil	Oil products	hydro	Biofuels/ waste	Electricity	Heat	Total
Total primary energy supply (TPES)	-	-	-	-	30.75	-	30.75
Oil refineries	-	-					-
Total final consumption (TFC)		0		-	23.4	-	23.4
Transport (by road + non-specified)		0			8.6		8.6
Industry and residential, commercial & agriculture/forestry		0			14.8		14.8

From *table 5.5* it can be observed that the total primary energy supply for 2040 will be 30.75 PJ. This is the sum of the electricity demand for including for the road transportation sector. For biofuels/waste there is uncertainty about how this will manifest in 2040; in the ideal case all bio waste is converted into electricity via biomass energy systems. Electricity (TPES) will be generated from solar PV systems and biomass energy systems. The demand for oil is assumed to be zero in the sectors mentioned before.

Taking into account the transmission and distribution losses, the TFC amounts to 23.4 PJ. From this amount, about 37% goes to the electricity demand with respect to the transportation sector (BEV). The electricity demand for the industry and residential will be 14.8 PJ.

In *figure 5.4*, the forecast suggests that the total electricity demand-except for the transportation sector by 2040 will be almost twice the electricity demand in 2016.

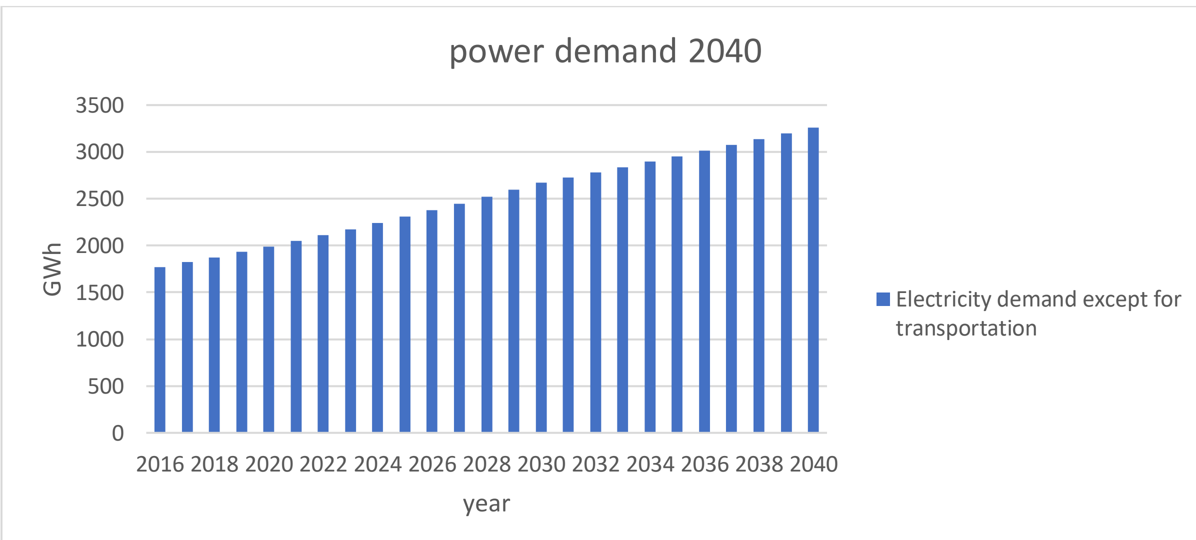


Figure 5.4: Electricity demand for Suriname

In the next section, the possible scenario's will be outlined.

5.2 Scenario development

Although, the GMA was initially intended to use for developing scenarios, this method considers one parameter per column in combination with single parameters from other columns (*table 5.1*) as they are related to each other. In this way numerous scenarios are possible. However, since in this specific study multiple options can be considered per parameter (depending on the geographical location), there will be a deviation from the GMA analysis, leading towards a "so called" – customized model. Therefore, further analysis, such as the cross-consistency analysis (CCA) as part of the GMA will not be considered during this study.

Scenario 1: Solar PV - Hydropower - Storage for a centralized electricity grid

Since the current decentralized electricity generation and distribution network is concentrated in the coastal zone *(figure 5.5a),* it is likely that this network will increase by 2040. This will also enable an even better spreading of local residences and commercial activities throughout the districts with minimal traffic congestion.

Connecting the regional grids within the districts with the main electricity grid (EPAR region) means that the NV EBS (as solely transmission operator) will have more control on the distribution and a higher grid capacity to meet the demand by 2040.

This first scenario is based on a centralized electricity grid especially for the coastal region, since the largest power electric power plants are in this region. To meet the desired vision, the potential renewable energy available will be utilized to meet the future demand. Looking at the energy sources, solar PV is the one with an intermittent character. Currently, the largest PV system is installed by the Gold refining multinational, Rosebel Gold Mine Company (5 MWp). The second largest PV grid connected system is installed at Atjoni (village in the interior) with a 500-kW installed capacity hybrid system (PV combined with batteries and diesel as backup) (Raghoebarsingh, 2019).

For the baseload supply biomass has a relative low potential, whereas tidal has an even lower potential in combination with an even lower technological maturity. Hydropower has a significant large potential with a high maturity level (operational in Suriname since 1964).

As far as it concerns to the storage facilities, pumped storage hydroelectricity (PSH) will here be considered as alternative. Moreover, as the hydropower plants are in the hinterland, additional infrastructure for distributed generation will be required to connect to the existing grid.

Scenario 1	Solar PV	Hydropower	Energy saving potential	Storage
Centralized electricity system	32,210 GWH/year	4,415 GWh/year	83 GWH/year	Pumped storage hydroelectricity (PSH)

Table 5.6: Scenario 1 with the available potentials for energy supply

The values for the potentials listed in *table 5.6* indicate the quantity of the renewable energy potentials used in the first scenario. In this scenario, the total solar PV energy output refers to the energy generated by solar PV panels in the coastal region. Besides the expansion of the current hydropower plant (*shown in figure 5.5a),* an additional hydropower plant is considered in the West- Suriname region (shown in *figure 5.5b),* adding up to 4,415 GWh per year. *Figure 5.2b* illustrates the new transmission line from the new hydropower plant joining the existing transmission line. In this scenario energy saving potential will be used until all vehicles will be electric driven.

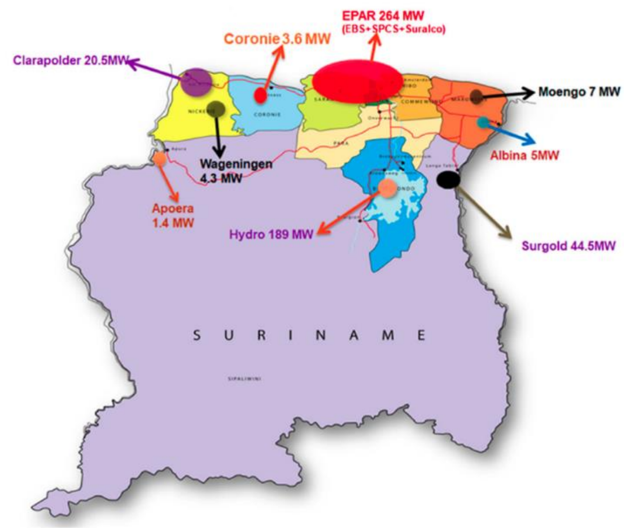


Figure 5.5a: locations of the installed power plants in Suriname. Source: (NV EBS, 2016)

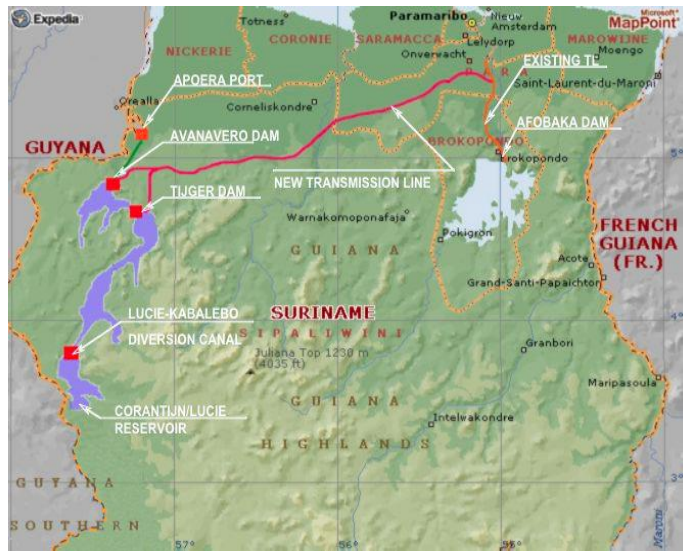


figure 5.5b: the proposed hydropower plant and the transmission lines as proposed. (Weitzner, 2008)

Scenario 2: Hydropower - Solar PV – Biomass - Storage for a decentralized electricity grid.

This scenario has a two-fold character and mainly builds on the current decentralized power plants combined with relative lower technological costs: while the largest region (the EPAR region) will be supplied with solar PV and existing hydropower (as baseload), the coastal districts and interior part will be supplied by distributed generation (small-scale and micro grids) powered by solar PV and biomass as baseload. With regards to storage, pumped storage hydroelectricity (PSH) will be considered in the EAPR region and Lithium-ion batteries will be used in all other regions.

Most of the villages in the interior of Suriname are located near the shore of rivers in the South-eastern part of Suriname. In this region the small-scale gold mining activities are also very active.

Although the different tribes have their own traditional authority, they fall under the supervision the Ministry of Regional Affairs. However, this research does not consider the interconnection of the different microgrids per village, since it would be an intercultural affair to involve parties in the different villages.

Scenario 2	Solar PV	Hydropower	Energy saving potential	Biomass	Storage
De-centralized electricity system	32,210 GWH/year	1,730 GWh/year	83 GWh/year	315 GWh/year	Li-ion batteries + pumped storage hydroelectricity

In scenario 2, the total electricity demand will be covered by the generated solar PV, which is the same in scenario 1 as the total area for solar PV remains the same, regardless where it will be installed. Since the current hydropower is specifically fed to one region, the EPAR region (*figure 5.2a*), scenario 2 takes only the expansion of the current hydropower plant in consideration. Thus, the total installed capacity will be 189 + 116 MW = 305 MW (1730 GWh per annum). In scenario 2 biomass is also taken into the energy mix as the interior and the districts produce most of the biomass. This can be beneficial to meet the deficit of electricity, especially during the evening and night when solar PV is unable to do so. As storage, there are 2 options available: for the EPAR region, pumped hydro (PSH) will be considered and for the other regions, Li-ion batteries are proposed as storage facility.

Based on these two proposed scenarios, the input for the spreadsheet model have been defined. The results of these scenarios will be further discussed in the next section.

5.3 Spreadsheet model

This part of the study emphasizes on modelling where the main objective is to find out how the energy mix will look like in the desired future.

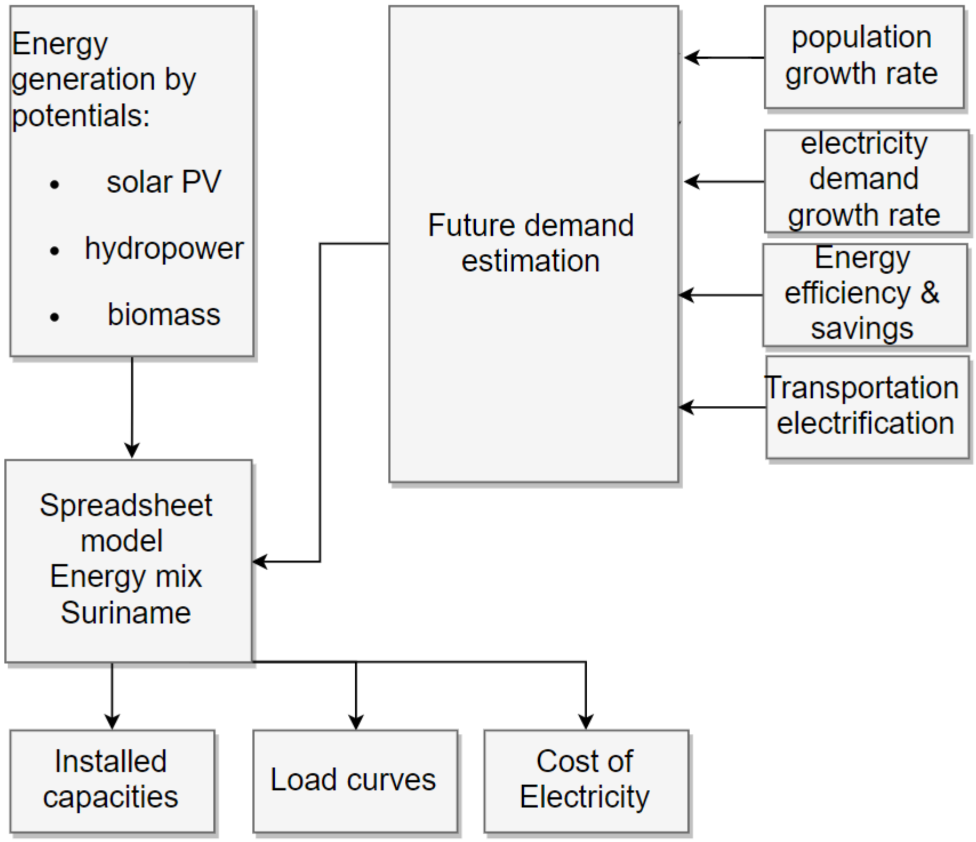


Figure 5.6: Spreadsheet model used in this approach

The modelling process, as explained in *figure 5.6*:

1. At first, the future demand of electricity and fuels is calculated based on historical trends.

This amount of energy will be supplied by the potentials calculated earlier in this study. The amount of energy efficiencies will also be considered. The available energy is divided into electricity and fuels (transport).

2. The available energy will be transformed to electricity, assuming that the transport sector will be fully substituted by electric vehicles.

3. In the energy demand scheme, the demand and the supply towards 2040 should be in balance. This will be done by extrapolating the current energy patterns towards 2040.

Model properties:

• **Timeline:** Since the model is supposed to represent the energy mix at the end of the backcasting period, the time period of 2040 will be used. This requires a proper estimation of the future energy consumption patterns and the energy demand profiles.

• **100% Renewable Energy:** The main vision of this study is to achieve 100% renewable energy transition in Suriname. For that reason, conventional energy sources (such as diesel and HFO) have not been considered in this model.

• **Energy Sources:** In order to suit the model for Suriname, local energy potentials will be considered.

• **EV technology:** Since the energy used in the transportation sector requires more than 40% of the total energy demand, EV implementation has been considered in this study. Assuming that there will be 100% EV powered vehicles in the road transportation. Transportation by air and water are not considered in this study since specific data required in these segments could not be obtained from institutions.

During the analysis of the renewable energy technology penetration in the energy mix, the merit order principle will be used. According to Jensen et al. (2002), renewable energy generation appears at the base of the merit function. It is found that an increase in intermittent sources generation (e.g. solar PV) "would put a downward pressure on the spot electricity market price by displacing high fuel-cost marginal generation" (Benhmad et al., 2018). The renewable energy systems are very capital – intensive but have almost zero marginal costs and are delivered with a certainty to meet demand.

5.4 Model results and discussion

In this part the results and discussion of the spreadsheet model will be presented.

Scenario 1:

In this scenario, the electricity grid throughout whole country will be connected; starting from connecting the current powerplants with each other. The existing hydropower plant will be expanded (the so called "Tapa-Jai project"), while the new hydropower plant will be built in West – Suriname (Kabelebo project). These hydropower plants can be controlled over time to meet demand. This option also provides the ability to meet demand at possible deficit from intermittent sources (solar PV). The dominant source used in this scenario is solar PV.

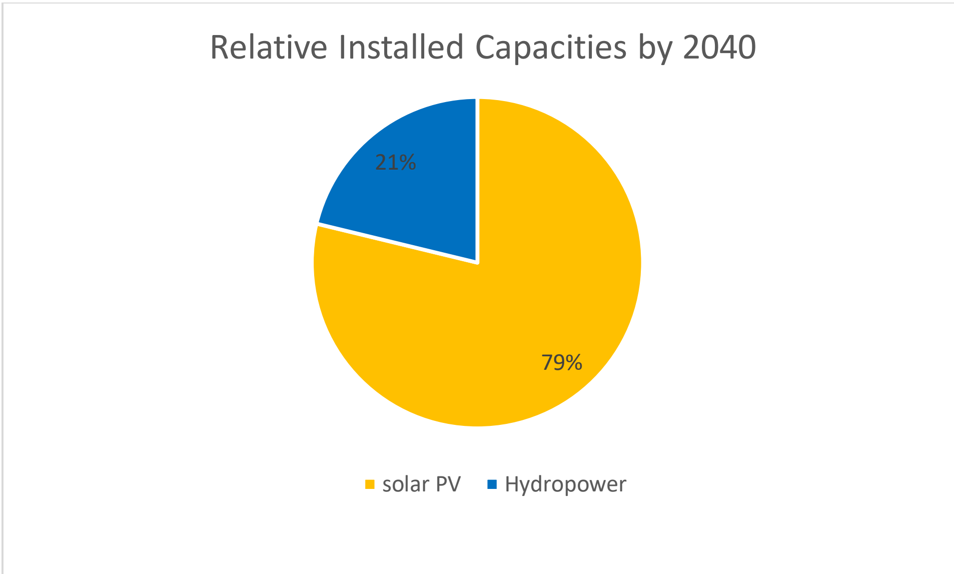


Figure 5.7: Relative installed capacities of renewable energy sources in scenario 1.

Figure 5.7 illustrates the high amount of solar PV as energy source (intermittent source). This also requires storage facilities to be in place. Based on the calculations made for the pumped storage hydroelectricity (456 GWh) at the existing hydropower reservoir (*figure 5.8*), there will be enough energy stored energy for at least 2 weeks.

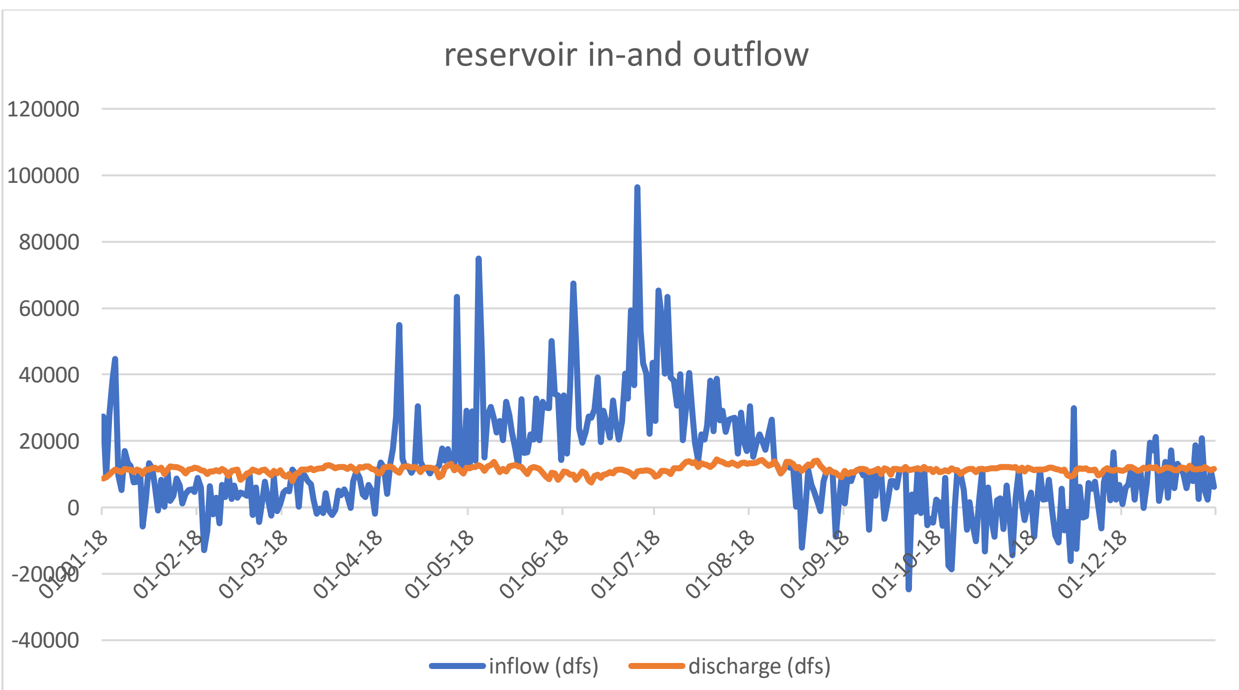


Figure 5.8: the in- and outflow of water in the current hydropower lake. Source: personal communication with Suralco (2019).

Figure 5.8 shows an almost constant reservoir outflow rate throughout the year which is ideal to produce the desired (maximum) output of energy. The inflow is calculated based on the outflow and how much foot (height) the reservoir has dropped. So, there may be situations in which more water flows out than flows in. Then the inflow contribution is negative. This occurs more often in the dry season.

Based on the electricity demand in the whole country; the installed peak power required by 2040 will be 1850 MW. This value is calculated by adding up the future demand for electricity in each of the individual regions (*figure 5.9*). In this figure the EPAR (Paramaribo and district Wanica) is the largest one to grow. The installed capacity is calculated in the spreadsheet by applying the capacity factors of the corresponding technologies from the primary energy production.

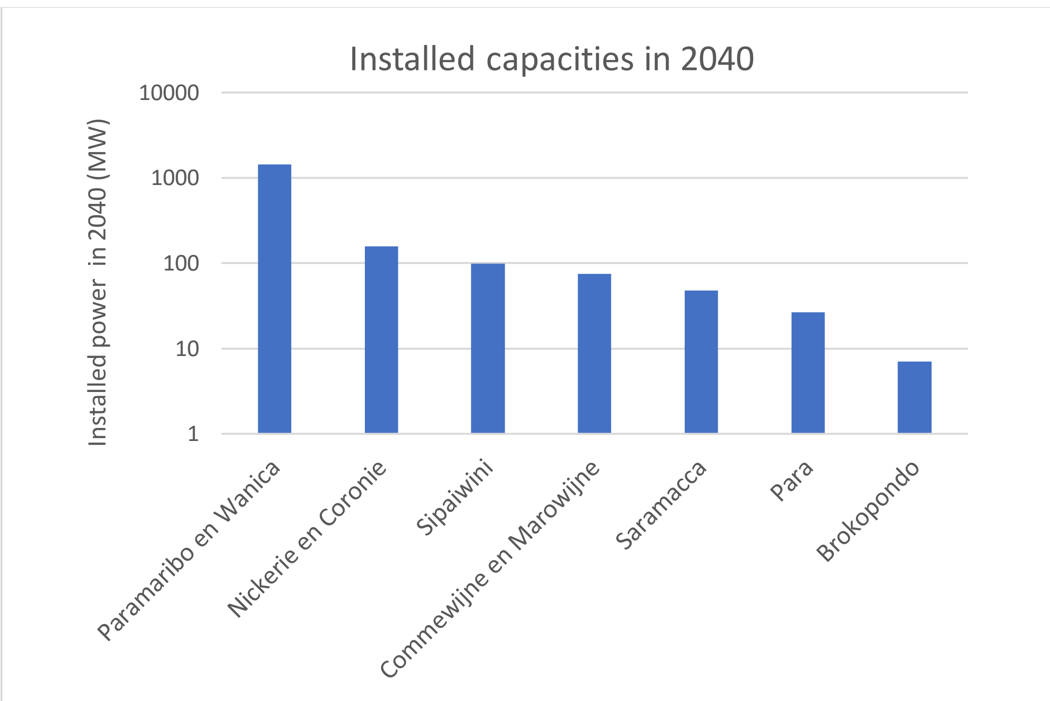


Figure 5.9: power growth in each of the power plant regions in Suriname. (Personal communication with S. Stella, 2019).

On the country scale it means that, the total power demand must be met with solar PV and hydro power.

In order to obtain the load curve for the whole country, the starting point here is made on the available data for the EPAR region (largest region): *figure 5.10* shows out how the demand for electricity varies during the day.

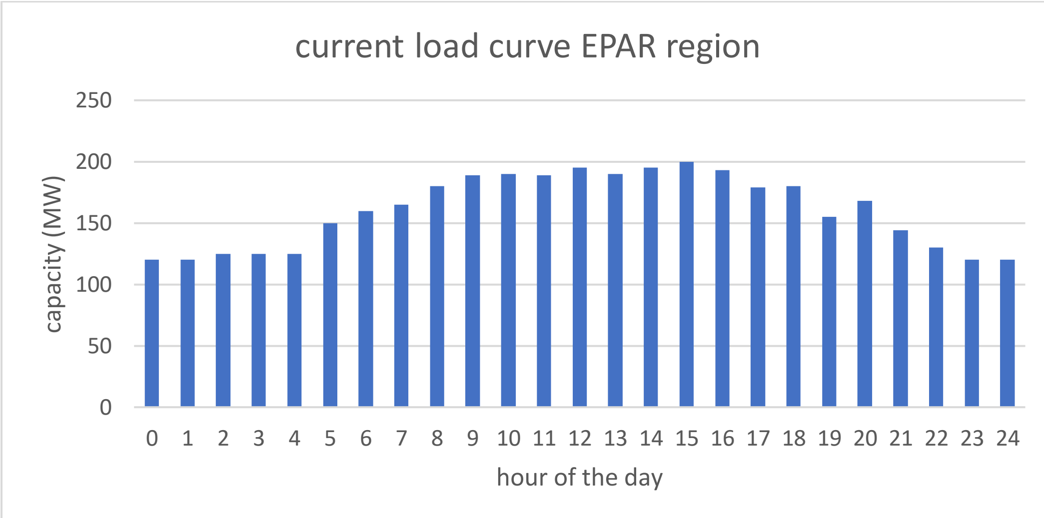


Figure 5.10: load curve for the EPAR region (Stella S., personal communication, June 17, 2019).

From *figure 5.10* it can be observed that the load varies between 120 MW and 200 MWe peak during the day on average in the EPAR region. The load curve projected for 2040 is established by multiplication of factor 1.4 as earlier analysis justified this factor. It should be noted that *figure 5.7* only implies the demand for electricity for residential and industry. For the future demand, the electricity for the mobility sector will also be included. Based on the pattern of the load curve, this has been assumed as the load curve or the whole country as the EPAR region accounts for around 80% of the electricity produced and consumed. In addition, the first scenario is built on this basis in combination with the available power generated by solar PV panels and hydropower.

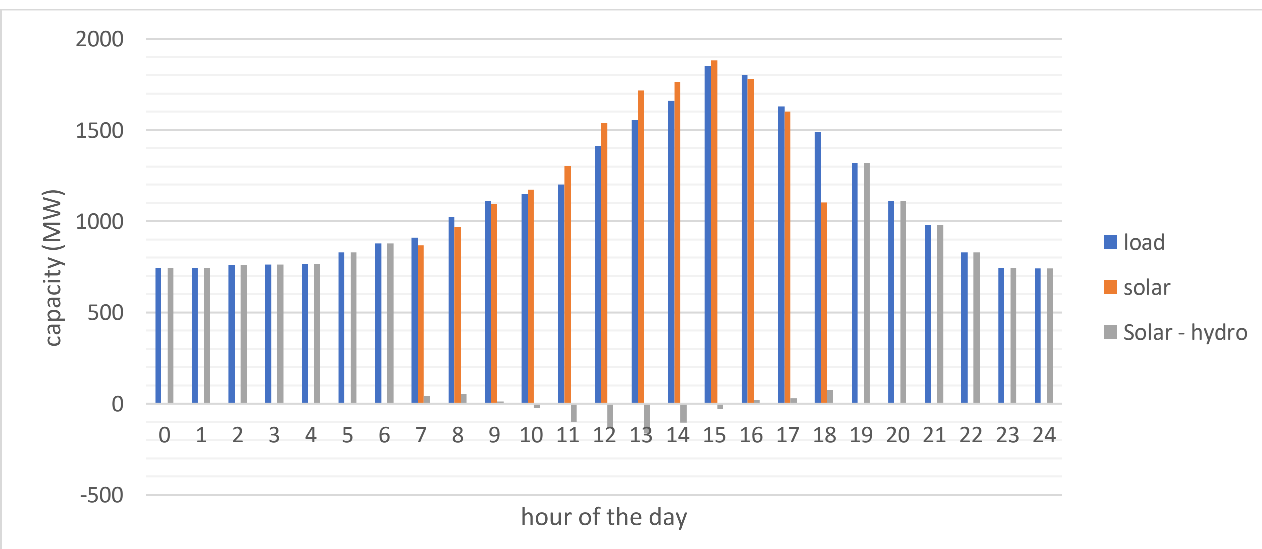


Figure 5.11: the load curve combined with the generated solar PV and hydropower for 24 hours in Suriname.

From *figure 5.11* it can be concluded that in the first scenario, there will be enough hydropower to meet the demand during the time that solar PV panels will not operate. Solar PV panels will produce more electricity than required between 10 o'clock and 3 p.m. This excess of electricity can be used for pumped storage hydroelectricity (PSH) during that time of the day. The total capacity in terms of storage will be 547.4 MW on daily basis.

<u>Scenario 2:</u>

In this scenario, the current powerplants remain to have their individual distribution grid, however, the electricity will be generated by renewable energy sources. Especially for the districts and interior region solar PV farms are considered. In addition, biomass will also be used in this energy mix as the feedstock for biomass are often produced in the districts themselves. Regarding to the EPAR region, there will be only a hydropower plant expansion considered (Tapa-Jai project) which will deliver hydroelectricity. Moreover, the hydro lake is also reserved as reservoir for pumped storage hydroelectricity (PSH) for the EPAR region.

The relative installed capacities for this scenario (clustered) are illustrated in *figure 5.12*:

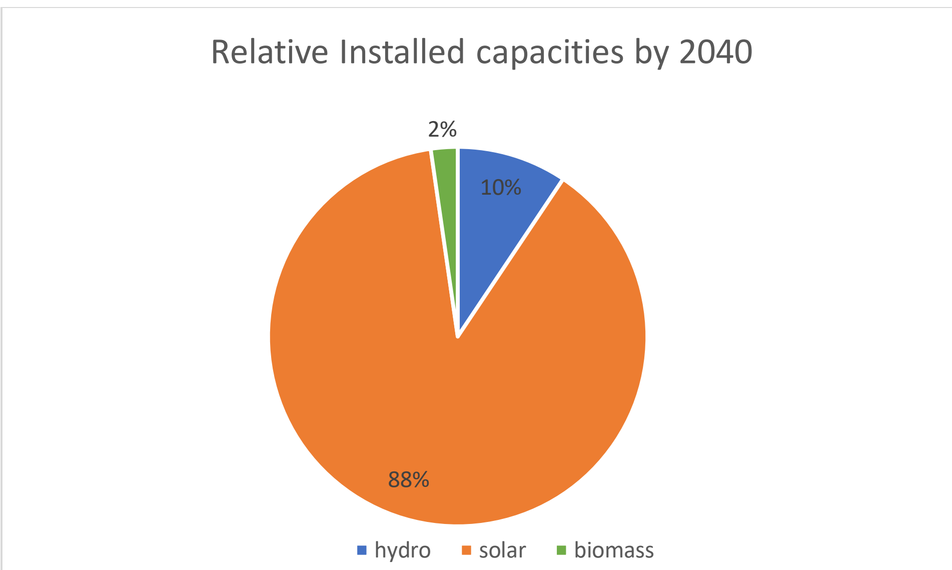


Figure 5.12: Relative installed capacities of renewable energy sources in scenario 2

This scenario will assess the penetration of renewables separately in the individual regions as the availability of renewables differ in each of the regions.

Based on the available data, which could be obtained, the EPAR region has been evaluated based on the second scenario:

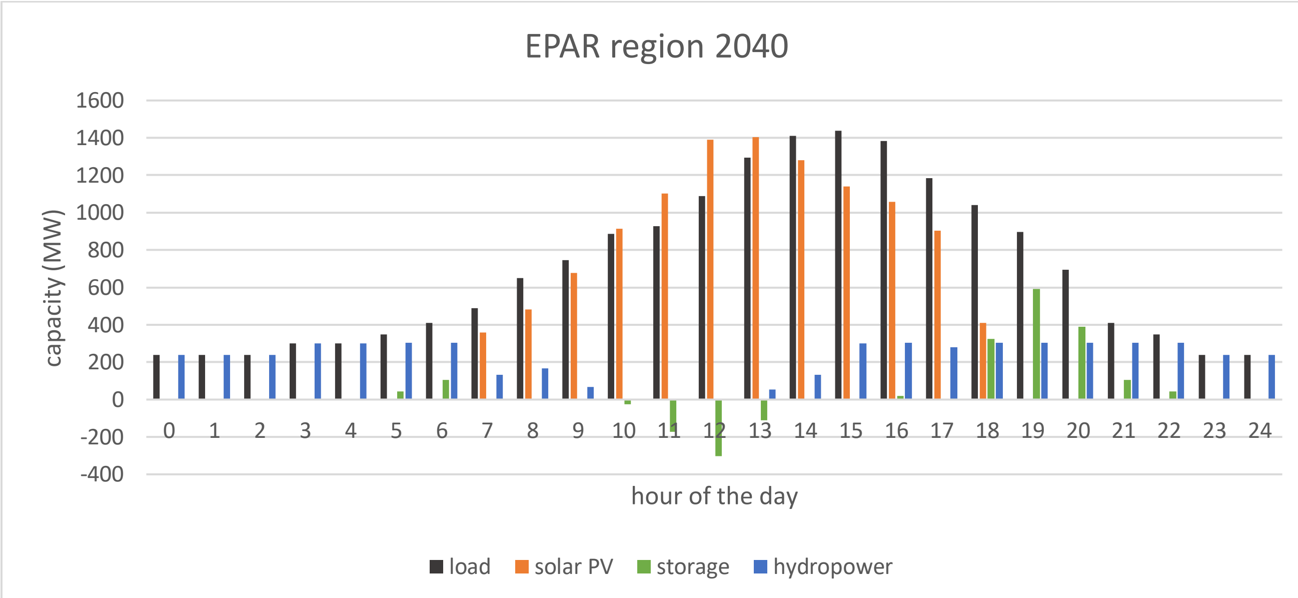


Figure 5.13: Solar PV penetration in the desired vision of the EPAR region.

Figure 5.13 shows out how the renewable energy mix for the EPAR region would look like in the desired vision: Since hydropower will be limited to the expansion of the current hydropower plant, an installed capacity of 305 MW can be achieved. Moreover, solar PV as dominant renewable energy source in this energy mix reduces the production of hydroelectricity significantly during its peak production time. This even enables a potential to store electricity during the day: about 610 MW, which can be used again especially in the evening. Battery storage would be recommended to use in this scenario, since pumped hydro would be more expensive for this amount of energy store.

5.5 Discussion regarding the comparison of the scenarios

In the first scenario, hydropower is present (2 hydropower plants), resulting in a high baseload, which corresponds well with the future electricity demand. Given the capacities for solar and hydropower, it would meet the future energy demand. Solar PV installations throughout the whole coastal area cause for high overcapacities, especially around the afternoon. These overcapacities can be limited by extracting the excess power and utilizing it for pumped hydro storage. The presence of the infrastructure for a pumped hydroelectricity makes it relatively easier to store excess electricity in the hydropower lake. With regards to the costs, large investments are needed to rebuild and interconnect the grid between existing regions and the construction of a new High Voltage transmission line from the Kabelebo powerplant to Paranam (existing one). Moreover, because of the long transmission distance, transmission losses must be considered.

The second scenario, however, is based on the replacement of all HFO/diesel thermal generators with solar PV panels and biomass reactors. In this scenario, the EPAR region has been elaborated on, as this region demands for around 80% of the total electricity production. Without the hydropower plant in West Suriname (Kabelobo power plant), the total installed capacity was only 305 MW. The area designated for solar PV panels is not in proportion with the total area in the first scenario as the area in and around the EPAR region is smaller. This resulted in lower generated output power, compared to what was achieved in the first scenario: in the first scenario the place where the solar PV farm would be installed did not matter as long as it would be throughout the coastal area where the centralized grid would connect to. In the second scenario, the EPAR region would require much more area since it is the largest electricity consuming region; this means that the solar PV farms would be installed in other neighboring districts to meet the demand. In the second scenario there is need for batteries or else the demand cannot be met in the evening. This was not the case in the first scenario, where outside the peak demand hydropower delivered enough electricity. In terms of costs, the second scenario does not have high investments costs of a hydropower plant and transmission lines, but the costs for storage (batteries) should be considered in this scenario. Alternative would be a semi-centralized grid network; this implies an expansion of the EPAR region.

Chapter 6 Backcasting Analysis

In this chapter the backcasting analysis will be performed; this covers the last three steps of the backcasting analysis presented in the research framework of this study. Step 3 regards the identification and addressing the necessary interventions to achieve the desired vision. In the methodological framework, policy packaging has been mentioned as the framework which will be assessed during the backcasting analysis. The policy package has previously been used in the transportation sector, but not in the energy sector. Therefore, this method will be applied here to find out "how" the proposed changes will happen over time. Moreover, steps 4 and 5 have been merged and represent the implementation or "by when" the proposed changes can occur. The changes proposed in step 3 can then be presented into short-term and long-term actions.

The backcasting analysis (step 3) refers to the method proposed by Quist (2016): the What – How – Who analysis:

- What regards the necessary changes to achieve the desired future. This often covers the identification of the technical, social and cultural / behavior changes.
- How refers to the activities in order to meet the proposed changes; this can regard measures for knowledge development, regulatory and policy changes
- Who represents the actors or parties who are responsible for the execution of the activities. Often, most of the actors are already identified in the stakeholder analysis.

The basis for executing the policy packaging (PP) framework is explained in the methodology (chapter 2.5.2) and consists of two major subsequent steps based on the initial policy packaging framework by Fearnley et al. (2011). The modified policy packaging framework in this study will be assessed empowered by the approach conducted by Hisschemoller et al. (2009) for the case study of the energy vision in Curacao. In order to develop policy packages, the objectives and targets must be defined first. Hereafter, the measures for each of the objectives and targets will be defined.

1. Defining objectives and targets; the focus here is to determine which major objectives and concrete targets are met in case of successful implementation of a policy.
2. identification of potential primary measures; in this step actions regarding policy interventions and/or recommendations are proposed. Based on Howlett et al. (2003), Fearnley et al. (2011) mention that the following categories of measures can be distinguished:
   • *regulatory measures* (coercive): relies on physical sanctions
   • *economic measures* (remunerative): depends on controlling resource allocation
   • *informative measures* (normative): based on persuasion, manipulation and suggestion

In summary, the backcasting analysis performed in this chapter, consists of 3 sub-steps (*figure 6.1)*

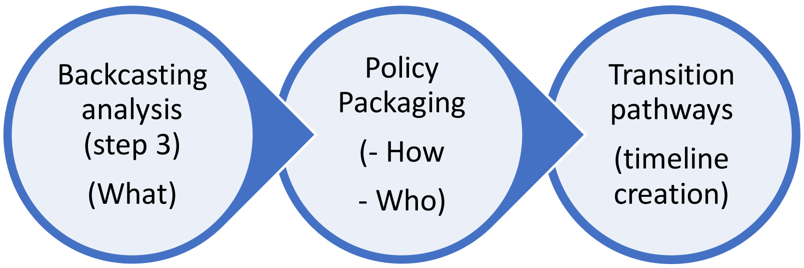


Figure 6.1: overview of the backcasting process

Figure 6.1 illustrates how the process discussed in this chapter looks like. Since the policy packaging framework emphasizes on the measures (How) and responsible actors (Who), the What – part will first be performed for both scenarios, followed by the policy packages (PP). The chapter concludes with the transition pathways and timeline creation (*section 6.4*).

The What – How – Who analysis is allocated to necessary changes regarding the future visions and have been categorized in technical, cultural and structural changes. First the technical changes will be discussed, followed by the cultural and structural changes (Visman, 2019).

- Technical changes: these changes involve production change, infrastructural change as well as application changes.
- Cultural changes: this covers the necessary behavioral and educational changes.
- Structural changes: regards the institutional, organizational, legal and economic changes.

Since the How – and Who – analysis is now part of the policy packaging, the technical, cultural and structural changes will be first discussed for each scenario, followed by the policy packages (how and who part). The intention is to connect the different technical, cultural and structural changes to the policy packages for each scenario.

6.1 Backcasting for scenario 1

First, the technical, cultural and structural changes regarding the first scenario will be discussed (What – part). Then, policy packages will be developed to answer the How- and Who- analysis as described earlier in this chapter. The objectives and targets refer to the technical, cultural and structural changes mentioned in *table 6.1*.

Table 6.1: technical, cultural and social changes regarding the first scenario

What – Technical changes	What – Cultural changes	What – Structural changes
Infrastructure: construction and connection of a centralized electricity grid. (T-1)	Behavioral: consumer behavior changes: adopt to efficient technologies and practices. (C-1)	Institutional: governmental direction towards renewables; institutional monitoring entities. (S-1)
Production: replacement of fossil fuel powered thermal plants to solar farms and hydropower plants. (T-2)	Educational: knowledge on renewable energy technologies and efficiency (C-2)	Legal: set emission standards (S-2)
Application: smart grids; demand side management (DSM) and Electric vehicles infrastructure (T-3)	Behavioral: social acceptance (C-3)	Economic: set carbon tax for emissions in the power and the mobility sector. (S-3) Provide incentives to accelerate the EV development (S-4) Pricing tool as part of DSM (S-5)
		Organizational change: include smaller actors and representatives of small-scale end-consumers. (S-6)

The changes proposed in *table 6.1* will be embedded in the policy packages; some of the changes will be coupled to each other, while others might not be integrated into the packages, but will be discussed at the end of this section.

Table 6.2 provides an overall summary of the policy packages developed for the first scenario. In this table the indicators refer to instrumental indicators; they are used to measure the impact of a certain policy or set of policies and the desired outcome(s). Moreover, the measurements refer to "tangible" measurements regarding the policy implementation.

In principle, indicators do not automatically lead to changes in policymaking (Pintér et al., 2006). However, accordingly, they are used to provide an overview of concepts. There are different indicator sets that can lead to changes in policymaking (e.g. political use, symbolical use, tactical use etc.). In this analysis, the instrumental indicators are used to reveal a direct relationship between the change of policies and the desired outcome.

Table 6.2: overview of the proposed policy packages for scenario 1.

Scenario 1: towards a centralized grid			
	description	Indicators	Measurements
Policy package 1	CO_2 reduction from thermal power plants	share of renewables in gross final consumption	Measurement of CO_2 reductions from powerplants.
Policy package 2	hydropower integration in the power generation	Construction and operation of Kabelebo hydro power plant	Share of renewables in energy mix
Policy package 3	from low emission vehicles to zero emission vehicles	Comparing data for emissions before and after policy change	Emission measurements and transparency regarding imported vehicles.
Policy package 4	Smart grids and Demand Side Management (DSM)	Energy efficient practices	Smart energy solutions and automation tools
Policy package 5	Effective institutional monitoring and steering	"Unbundling" of the energy sector	Meeting the deadlines for proposed targets according to timelines.

An elaborative discussion on the policy packages (*table 6.2*), follows here.

Objectives and targets:

The desired future requires a couple of technological changes; first, the construction of a hydropower plant in the Western part of Suriname (Kabelebo region), followed by largescale applications of solar PV panels and (grid) infrastructure changes: from a fossil fuel based one to a renewable energy one (T-1 & T-2). Moreover, demand side management (DSM) will be considered here as well. The transportation sector will be fully electric driven; this means that a total of around 250,000 internal combustion vehicles will be replaced by electric vehicles. Gas for cooking will be replaced by electric stoves. The current energy landscape dominated by fossil fuels will be shifted towards a 100% electricity landscape.

Policy Package (PP) 1: CO_2 reduction from thermal power plants (i.e. diesel generators); this package has a short-term and a long-term character. Short-term, because it considers the transition time for building a new hydropower plant in West-Suriname and connecting it to the national grid, and long-term, because it already sets the required changes and measures in terms of policy and regulations for the future scenario.

Objective:
Significantly reduce electricity generated by fossil fuels by installing solar PV farms on one hand and increase the power capacity of current hydropower plant on the other hand. On short-term: by harvesting the power generated by solar PV panels, the electricity from diesel generators will be only necessary during the night and during peak demand of electricity (T-1).

Targets:
Increase the installation of solar PV panels and solar PV farms to such extent where diesel generators will only be needed during the night within the next 10 years: reduction of CO_2 emissions from thermal power plants.

Measures:

In order to significantly reduce the CO_2 emissions from thermal power plants in the next 10 years, there has to be movement going by the following key stakeholders: the ministry of Natural Resources and the NV EBS. The government (on behalf of the ministry of Natural Resources) must have a transparent agenda towards renewables. In order to measure the emissions, a governmental entity or institute must be set up who will measure and publish the measured data from all (thermal) power plants. Moreover, the NV EBS as solely distribution and transmission operator plays an important role in purchasing electricity from power plants and sell it to the consumers. However, an organizational change within the NV EBS is crucial: resulting in the fact that they will not anymore be responsible for the generation of thermally generated power (S-6). In this way, they can only buy electricity from power plants which produce electricity within certain emission standards (to be determined by the monitoring entity). Thus, one of the indicators used here is the CO_2 emission decrease (S-1 and S-2).

Economic: set carbon emission tax (S-3); since the power producers will have to maintain their power production within certain emission standards, the emission tax scheme for consumers will stimulate and drive consumers towards a cheaper and environmentally friendly option to consume electricity (T-3). Especially, (low efficient) air - conditioners are considered to be one of the largest power consuming devices in households and small businesses. Furthermore, this act will also affect the transportation sector: towards less polluting vehicles on the road and thus reduction of carbon dioxide emissions from the transport sector. Responsible actors and stakeholders involved are the power producers: Staatsolie Power Company (SPC) and the NV EBS in collaboration with the ministries of Natural Resources and the ministry of Finance. Important here is the collaboration of small and large-scale consumers throughout the country.
Moreover, through this emission tax system, the government can accelerate the solar PV integration the national grid by stimulating the prosumers in this field: small consumers with large rooftops and/or privately-owned land and large consumers with the ability to generate their own electricity; eventually, their net-emission can be reduced significantly.

From a cultural perspective, PP 1 regards the consumer behavior: by educating end consumers on how to deal with energy efficient practices, household appliances can be bought in a more conscious way: consumers will not only look at the price before buying any appliances, but also understand what is meant with the energy label on appliances (C-1 and C-2).

Indicators regarding PP 1 are the assessment of the share of renewables in the gross final energy consumption: this should increase as result of the policy changes made as discussed here. Moreover, measurement tools here are related to the CO_2 emissions, primarily from power plants.

PP 2: hydropower integration in the power generation

Objective: Expansion of the current hydropower plant and the construction of a new hydropower plant in the Kabelebo region.

Targets: Within the first 10 years a new hydropower plant will be build and the existing hydropower plant will be expanded, delivering a total power capacity of around 750 MW (T-2). Moreover, this will be carried out in such a way that the flora and fauna remain preserved as far as possible.

Measures:
While the current hydropower plant will be expanded to a maximum of 305 MW capacity, the construction and the operation of the Kabelebo hydropower plant will be executed (T-2). Monitoring institutions here are the government of Suriname in collaboration with the financing institutions (e.g. InterAmerican Development Bank, IDB) and the Suralco Power Company. The NV EBS will be responsible for the setup of a new grid infrastructure, connecting the new hydropower plant with the existing grid infrastructure (T-1). Moreover, the environmental related NGO's and the environmental institutions incorporated over ministries. Since there is no specific environmental law in Suriname, the oldest law in force with environmental-related provision is the Police Criminal Law of 1875. This explains why there is no ministry of environmental affairs yet in Suriname. The NIMOS (National Institute for Environmental Development Suriname), as NGO is therefore an important institute to be involved in these projects: monitoring and re-allocating the flora and fauna is very crucial for the ecological system. Besides that, implementation of the proposed hydropower plant requires migration of local communities living in and around the neighborhood of the planned hydropower lake. Social acceptance is crucial here since this change directly affects people (C-3). Responsible actors here are the government of Suriname, NGO's and local communities for the migrations of people and preserving as much as possible of the flora and fauna.
Moreover, the IDB and the International Monetary Fund (IMF) are likely to be involved in this project, since they are considered as the financing partners of the government of Suriname (S-1 and S-6)

Indicators regarding PP 2 are related to the (baseload) share of renewables in the energy mix. Moreover, the construction and operation of the Kabelebo hydro power plant is "tangible" indicator in this case.

PP 3: from low emission vehicles to zero emission vehicles

In the first policy package the emission tax is proposed; this tax also influences the mobility sector in Suriname. This does not drive consumers directly towards electric vehicles, but more towards driving more efficient and thus low emission vehicles (C-1 and C-2). However, to further significantly reduce the emissions and drive consumers toward Electric Vehicles (EV), the infrastructure should be in place (T-3).

Objective: Significantly reduce the emissions from internal combustion vehicles on the road.

Targets: Develop infrastructure for electric vehicles on one hand and on the other hand stimulate public transportation in and around the city of Paramaribo within the next 10 years.

Measures:
Aiming at 100% emission free vehicles on the road transportation system in Suriname means that this needs to start with the development of a proper infrastructure to facilitate electric vehicles (EV's) in the future (T-3). The Ministry of Transportation is responsible for the monitoring and the implementation of the EV charging stations. Moreover, the NV EBS will be responsible for the setup of the electricity infrastructure. While this will be carried out, the public and governmental authorities responsible for the import of vehicles should monitor that only low emission vehicles are imported into the country (S-1). The government can, in collaboration with consumers and the NV Staatsolie (State Oil Company) come with a scheme which stimulates the tradeoff of heavy polluting vehicles to low emission vehicles. Here, also the institutions for monitoring the emissions from the road transportation system should report the progress in order to modify or change the proposed policy package. One of the economic measures could be a legal tax exemptions for EV owners (S-4): main economic incentives used in European countries are the VAT exemption upon the purchase of an EV and annual tax exemptions (Yang, et al., 2016). Accordingly, many governments provide rebates (subsidy) which reduce the price for EV in the country.
Another aspect mentioned in the targets is to stimulate reliable public transportation in and around the capital, Paramaribo. Providing reasonable (reliable and affordable) alternatives for car owners who use their vehicle most of the time to get to work and drive on average less than 10 km a day to work significantly will decrease the number of cars in and around the city. Since this change regards not only structural, but also cultural (behavior and educational) aspects, a multidisciplinary group should be involved in this transition regarding transportation sector: the ministry of Transportation, the consumers (car owners) and NGO's (C-1 and S-1).

Indicators regarding PP 3 are focusing on the effectiveness of the policy change by comparing data of greenhouse gas emissions before and after implementation of PP 3 to reflect on the progress towards the desired vision.

PP 4: Smart grids and Demand Side Management (DSM)

Smart grids generally refer to the integration of information technology (IT) in the (existing) traditional grids. This enables a more communication driven and consumer – involved system (Gudi, et al., 2012). Moreover, smart grids have the ability to monitor the usage through the electricity network by using computer – based applications in order to have a two- way interaction instead of a one-way interaction through the traditional grid.

Smart grids are applied in different phases of the chain: from generation to the consumption of electricity:

- Generation: the first scenario involves a centralized grid network, using different renewable energy sources including intermittent ones (solar PV). Smart grids effectively help to connect these sources and generate electricity on demand. Moreover, it allows consumers and prosumers to monitor how much electricity is consumed and how much excess electrical energy is fed back into the grid.
- Distribution: integrating IT in the existing grid enables the NV EBS to remotely monitor and control their assets (e.g. the transmission lines and substations). It also allows a real time detection of load demand changes and can accordingly respond to that.
- Consumption: this part of smart grid enables the consumer segment to have a better overview and control over their power consumption.

Gudi et al. (2012) refer to Demand-Side Management (DSM) as the implementation of policies and measures to control, regulate, and reduce energy consumption. The aim here is manage the demand on the customer side and not on the supply side (producers). One of the common techniques used in DSM is based on load shifting. According to Gelazanskas et al. (2014) DSM has been initiated since the early 1980's. It enables DSM techniques such as peak clipping, strategic conservation, valley filling, strategic load growth, load shifting and flexible load shape *(figure 6.2).*

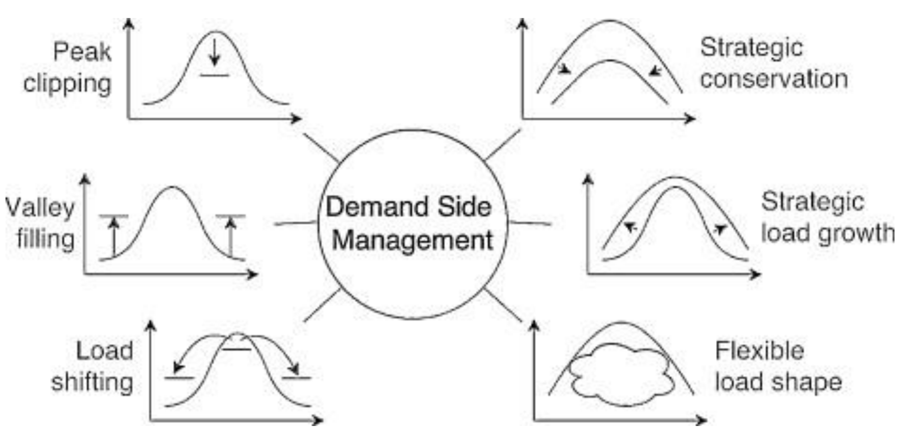


Figure 6.2: Load shaping techniques adapted from Gelazanskas et al. (2014) based on (Gellings, 1985).

From *figure 6.2*, six commonly used balancing techniques are illustrated. Based on the outcome of the first scenario, the load shifting technique would fit the best, since the projected load demand curve resembles the shape in *figure 6.2*. The aim here is to allow consumers a time-shift demand; either through behavior change or automation, in response to the real-time conditions of the electricity system (Yilmaz et al., 2019). This can be achieved by applying the following strategies:

- Energy saving solutions such as proper isolation buildings: this will have an energy saving effect on air conditioners for industry and office and public buildings, which finally results into lower peak demands.
- Pricing as tool: this can drive consumers towards behavior change: by having cheaper electricity prices during the off-peak hours, consumers will change their traditional routine and utilize more electricity during the off-peak hours.
- EV penetration: once Electric Vehicles (EV) are fully integrated in the transportation system, this will allow a small fall back of the peak loads during office hours when passenger cars are mostly parked.
- Automation: having appliances which can be controlled during a specific time of the day e.g. washing machines set at a specific time to do the laundry.

Given this, the following objective and targets are defined:

Objective: establishment of smart grids with active Demand Side Management (DSM)

Targets: By starting with the smart grid implementation in the EPAR region, the NV EBS will have around 70% of the total load demand under its control (T-3).

Measures:
The success of policy package (pp) 4 depends on the active interaction of the key stakeholders involved in the energy sector in Suriname: the ministry of Natural Resources (on behalf of the government of Suriname), the NV EBS (as only grid operator), financial institutions and the whole consumer segment. The economic measures here involves the pricing tool as part of the DSM (S-6). Indicators to quantify the progress here are real-time energy consumption statistics from the utility company, NV EBS. Moreover, informative measures identified here refer to the behavior change of consumers with regards to the electricity consumption (C-1). This change not only consider the behavior change, but also refers to educational changes (C-2): being aware of how renewables work and their awareness towards the pricing method. In short, smart grids allows consumers to change their way of utilizing electricity from the grid.

Moreover, Feed in Tariff (FiT) is a policy tool which is often used to promote renewable energy technologies (S-1 and S-4) and are also designed to support renewable energies in off-grid areas (mini-grids). This will result in a lower per kWh price for solar PV produced electricity price. There are various ways of how this could work. In developing countries, a renewable energy fund (FiT

fund) is also proposed which can be funded by the local government as well as international donors (Jacobs, 2009).
Policy measures recognized here includes education and awareness towards the consumers (especially the small consumers). This can be achieved in active collaboration between the NV EBS, the Ministries of Natural Resources and Regional Development and the NGO's involved in the energy sector (S-5).

Indicators regarding PP 4 are the practices towards more energy efficient use of appliances and successful implementation of energy saving potentials. These can be measured by smart energy solutions (e.g. sensors) and automation tools.

PP 5: Effective institutional monitoring and steering
As mentioned earlier, in order to make large technological changes occur successfully, effective steering from institutions dealing with cultural and structural aspects is required.

Objective: all institutions working together on achieving the desired vision

Targets: Establishment of an independent Energy Institute (EI)

Measures:

Suriname's energy sector includes many actors and has common ground with other policies. Therefore, Lachman (2009) highlights the importance of properly defining the roles and responsibility of all actors followed by the processes and affiliated procedures. Since the current energy supply to the coastal area is under supervision of the ministry of Natural Resources and the hinterland under the supervision of the Ministry of Regional Affairs (subsidiary: DEV), there is a need and must to reformulate the current legislation (especially in the case of the first scenario with a centralized grid). Lachman (2009) refers in his study to the institutionalizing of the energy sector. This initiative was also brought up during the case study of Curacao (Hisschemoller et al., 2009). Accordingly, an energy law is proposed which states:

- The objectives and instruments of the energy policy
- The actors in energy policy with their responsibilities
- Procedures for policy making, policy implementation and active involvement of actors in the energy policy.

The Energy Authority Suriname (EAS) was established in 2016 to ensure fair electricity prices for consumers on one hand and the guarantee for reliable electricity supply, while on the other hand lower risks at acceptable level for investors in the energy sector (Wet Energie Autoriteit, 2016). However, the supervisory board of the EAS consists of political related representatives from different ministries. Dalipi et al. (2016) mention in their study the importance of the independency of institutions, especially protecting them from political influences. Additionally, a few institutions will be established to support the energy policy. This includes:

- The energy institute (EI) as proposed by Lachman (2009); this institute should operate in an autonomous way so that political influences are minimized as far possible. Since the energy institute will only focus on the energy sector and aim towards achieving the desired vision, this means that energy policies regarding the legislation and technology can be defined in a more concrete way. Furthermore, responsibilities regarding the electrification and energy supply of the interior and the coastal area of Suriname can be integrated (i.e. centralized) in this energy institute instead of having different department under various ministries.

- Reformation of the existing Energy Authority Suriname (EAS); this authority can be transformed into a fully advisory institute for the government. The role of the EAS towards the government will be one which advise the government and parliament to change and improve existing policies regarding the energy sector.

- An Energy Policy Implementation Agency that will focus on technical implementation aspects: the progress of solar PV installations and hydropower plant construction as well as the gradual phase out of internal combustion engines from the road transportation system. Moreover, measures regarding energy efficiency will considered.

Indicators referring to PP 5 are related to the unbundling and reorganization of the current energy sector in order to prevent conflict of interest among actors and stakeholders.

6.2 Backcasting for scenario 2

Based on the results obtained from the second scenario (at least for the EPAR region), it can be observed that in this scenario supply from storage facilities is crucial to ensure that the future electricity demand can be met. Although this scenario does not involve large technological changes compared to the first scenario, it is also important to look at the cultural changes as well as the structural ones. Given this, *table 6.3* outlines the necessary changes with respect to each of these categories. It can be observed that the cultural and structural changes identified here are almost similar to the first scenario.

Table 6.3: technical, cultural and social changes regarding the second scenario

What – Technical changes	What – Cultural changes	What – Structural changes
Infrastructure: upgrade of decentralized electricity grid (T-4)	Behavioral: consumer behavior changes: adopt to efficient technologies and practices. (C-1)	Institutional: governmental direction towards renewables; institutional monitoring entities. (S-1)
Production: expansion of current hydropower plant (T-5). Solar PV powered systems (T-6) Biomass energy systems (T-7)	Educational: knowledge on renewable energy technologies and efficiency (C-2) Educational: entrepreneurship opportunities (C-3)	Legal: phase out of fossil fuels in power and transportation sector. (S-2)
Application: power balancing (T-8)	Behavioral: social acceptance (C-4)	Economic: set carbon tax for emissions in the power and the mobility sector. (S-3) Provide incentives for electric vehicles (S-4) Pricing tool as part of DSM (S-5)
Storage: Li-ion batteries as storage facility (T-9)		Organizational change: include smaller actors and representatives of small-scale end-consumers. (S-6)

Moreover, some of the policy packages developed in the first scenario apply to the second scenario as well. These policy packages have common goals, independent from either a centralized grid or a regionalized one. First, the common policy packages will be summarized which are applicable for both scenarios. Then, additional policy packages regarding the second scenario will be discussed in this section.

Table 6.4 summarizes the proposed policy packages regarding the second scenario. In this table the first four policy packages are similar to the policy packages proposed in the first scenario.

Table 6.4: overview of the proposed policy packages for scenario 2.

Scenario 2: towards a decentralized grid			
	description	Indicators	Measurements
Policy package 1	CO_2 reduction from thermal power plants	share of renewables in gross final consumption	Measurement of CO_2 reductions from powerplants.
Policy package 2	from low emission vehicles to zero emission vehicles	Comparing data for emissions before and after policy change	Emission measurements and transparency regarding imported vehicles.
Policy package 3	Smart grids and Demand Side Management (DSM)	Energy efficient practices	Smart energy solutions and automation tools
Policy package 4	Effective institutional monitoring and steering	"Unbundling" of the energy sector	Meeting the deadlines for proposed targets according to timelines.
Policy package 5	Power balancing of the individual grids	Reliable stand-alone systems	Realtime demand and supply monitoring; enabling a reliable regional grid.
Policy package 6	Encourage entrepreneurship opportunities	Development of local communities	Measurement of economic activities, especially from local communities in Suriname.

The following policy packages remain the same for the second scenario:

- PP 1: CO_2 reduction from thermal power plants: since the desired vision aims at a 100% sustainable electricity generation, it is obvious that power generated from thermal power plants will be replaced by renewable energy sources, regardless whether there will be a centralized or a decentralized grid system.
- PP2: Smart grids and DSM: the objective and targets defined in this package refer to the integration of IT in the traditional grid and the policies regarding the demand side management. These interventions are also applicable and beneficial for a decentralized grid.
- PP3: Effective institutional monitoring and steering; the initiative of institutionalizing the energy sector is not only beneficial for a centralized grid system, but also for a decentralized one since this institute will monitor on country level.

- PP4: from low emission vehicles to zero emission vehicles; this package also applies to this scenario as the aim is minimize internal combustion (IC) engines on short-term and only have Electric driven vehicles in the desired vision. A decentralized grid; powered by decentralized power station does not affect the EV integration, as the charging stations infrastructure are based on the concentration of EV.

Additionally, the following packages are developed regarding scenario 2:

PP 5: Power balancing of the individual grids (T-8)

Since the future demand in the EPAR region can not only be met with hydropower and solar PV, there is a need for storage facilities which will supply additional power during peak demand. Biomass was not included in this region, as the availability of biomass in this area is minimal and thus not viable to generate energy from biomass. Interventions regarding the transition of the mobility sector remain the same compared to the first scenario. However, balancing intermittencies and loads remain a challenge. This can be optimized by using stationary systems (batteries; PSH system) or Vehicle to Grid (V2G) technology.

Objective: Guarantee of reliable electricity generation and supply in the regional grids

Targets: With the ability to easily adjust between the renewable energy sources in each power station, the NV EBS can ensure reliable electricity generation.

Since every power station with its decentralized grid is responsible for the electricity generation for that specific region, it is possible to combine and determine the energy mix for that specific region. The EPAR region remains the largest one with supply from the Afobaka hydropower plant, solar PV installations and/or solar farms and as storage the PSH at the Afobaka lake is proposed. It is noteworthy to mention that this lake provides PSH storage capacity of over 80 days based on the current electricity demand delivered in this region.

For the implementation of the technical changes (T-5, T-6 andT-8), the primary measures here include economic measures: Lachman (2009) refers to tax holidays, subsidies, loans, grants and other financial incentives to ensure sufficient return on investments from renewable energy projects (Sawin, 2004). Since renewable energy sources are often location – dependent (in this case energy from biomass), decentralized generation and distribution can be very beneficial. Especially, in the interior of Suriname, where biomass comes from the timber activities. These villages could become self-sufficient by solar PV – and biomass powered systems, backed up by batteries. This package provides opportunities for local communities to invest in small-scale solar PV farms (community or private owned) (C-2 and C-3). Regulatory measures here are controlled via the energy institute as proposed in an earlier mentioned policy package (S-1 and S-6).

Indicators referring to PP 5 are the stable and reliable electricity supply for each region. This can be made physical by real-time monitoring of the power supply by the power plants, considering the intermittent sources, as well as the baseload and storage facilities.

PP 6: Encourage entrepreneurship opportunities

The interior of Suriname has been isolated for a long period; many governments and politicians did not provide tools and facilitate resources to get the interior (or hinterland) of Suriname to a higher development level. Most of the inhabitants here are poorly educated and are involved in the informal sector: illegal mining of gold and services in this chain.

Hence, the **objective**: Stimulate entrepreneurship, especially for local communities

Targets: By educating local communities and involving them in the transition for Renewable Electricity generation, the entrepreneurship and local initiatives will be stimulated (C-2, C-3 and S-1)

Measures:

Building on the previous policy package (PP 5), this policy package does not only aim at inhabitants living deep in the interior of Suriname, but also villages and other rural communities in the coastal region, who are not yet grid connected. Since the education level is poor within these communities, it is more than necessary for the government to create such energy policies which will work in favor for the local community in the rural areas (C-2 and C-3), for example to become self-sufficient in terms of electricity supply. There must be enough electricity available at affordable prices to provide the essential needs. This enables fell-behind communities to catch up and develop further with tools as education and awareness: having a proper and working energy policy (S-1 and S-6) in the country, it will (in)directly contribute to the prosperity of Suriname: local production and entrepreneurship will be stimulated. Informative measures here are the education and awareness creation in collaboration with NGO's, the government, the NV EBS and local communities.

The role of the government here is to facilitate these communities, in collaboration with NGO's and financial institutions: by educating the people and awakening their entrepreneurial spirit (through ideation) and standing as guarantee for them to provide loans.

Indicators regarding this policy package are related to the development of the local communities in terms of economic activities: access to affordable and reliable electricity stimulates the processing of for example agricultural products, such as cassava.

6.3 Comparison of the Backcasting Analyses

Based on the backcasting analyses performed in the previous sections for both scenarios, this section provides a schematic overview of what changes are identified for each scenario and how the policy packages contribute to a successful implementation of the proposed changes. In *table 6.5,* an overview of the changes is given along with the policy package(s) related to each of these changes.

Table 6.5: summary of the changes in the ***first scenario***

Changes:	What	How (measures)	Who
Technical	• Construction of new hydropower plant and upgrade of existing one • Building solar PV farms. • Grid infrastructure for power and EV • DSM method • Storage in case of excess electricity	PP-1 and PP-2, PP-3.	Power producers; governmental institutions; Energy Institute Suriname; end-consumers
Cultural	• Adopt to efficient technologies. • Public acceptance for new technologies.	Awareness on energy saving practices and RE technologies	End-consumers, NGO's and the governmental institutions
Structural	• Governmental steering; • Legislation to promote renewables; • Carbon emission tax; • Organizational change within existing actors (unbundling)	PP 4 and PP 5	Governmental institutions, NGO's, monetary institutions, power producers and end-consumers

Based on the changes identified in each category (technical, cultural and structural), the changes over time are discussed in this section.

To start with, the implementation of the first scenario primarily requires the structural and cultural changes to be in place before the technical changes can be carried out. Thus, the first step would be to set emission standards by law (S-2) and set up institutions for monitoring and reporting the emissions (S-1).
At the same time, it is important to carry out organizational changes within the current actors and stakeholders: referring to the unbundling of the energy sector and reorganizing the power producing companies (mostly state-owned) from the transmission and distribution chain. This

helps to monitor and control these companies by the governmental institutions and minimizes conflict of interest in the power supply chain (policy package 5).

Consequently, the government of Suriname can initiate legislation towards the exit of the locked-in fossil fuel economy: by setting emission taxes (S-3), primarily for the power sector, followed by the transportation sector. With regards to the transportation sector, incentives for the purchase of electric vehicles should be made available (S-4), to help consumers in buying electric cars (policy package 3). Although the emission taxes can have a spinoff effect on the whole service providing sector, it is important to monitor that access to goods and services remain affordable for consumers.

Simultaneously, the cultural changes need to be addressed as well in the same phase: by educating people (end-consumers) on the purpose of the legal acts and learning them how to adopt to more sustainable and thus less polluting practices in their daily life (C-1 and C-2). By guaranteeing them that there will be affordable and reliable public transportation made available, alternatives are provided for avoiding paying emission taxes when using their own vehicles.

These acts form the structural and cultural foundation for the implementation of the technical changes. The technical changes can be seen as the result of having good and working institutions and cultural support.

Initially, the upgrade of the existing grid in terms of capacity handling and integration of IT to become smart grids forms the basis for the next step: installation of solar PV farms. With the installation of solar PV farms, less capacity from thermal power plants will be needed, thus also less emissions from the power companies (policy package 1). Since this scenario aims at the interconnection of the regionalized grids towards a centralized grid (T-1), the major baseload electricity supply will be operational after the construction of the hydropower plant in West – Suriname. Since this will require approximately 10 years from now on, the short-term power production changes are focusing on the solar PV installation and the hydropower expansion of the current hydropower plant (policy package 2). Moreover, Demand Side Management (DSM) tools such as load shifting methods allow the consumers to utilize the generated power in such way that there is less pressure on the demand during the "normal" peak hours (policy package 4).
Another technical change which is mentioned in *table 6.3* is the storage facility. Since this scenario aims at a centralized grid, there won't be any additional storage in the current regions necessary. The current hydropower lake has the potential for storing excess of solar PV generated electricity in the form of PSH. However, no explicit policy package(s) are created for this technical change since it can be seen as part of the other technical challenges proposed.

Overall, the changes with regards to the time are described in a top-down approach, since this starts with the bigger picture (future vision), breaking down into smaller segments (changes).

The interventions regarding the second scenario are tabulated in *table 6.4*:

*Table 6.6: summary of the changes in the **second scenario***

Changes:	What	How (measures)	Who
Technical	• Expansion of hydropower plant • Construction of Solar PV farms. • Upgrade grid infrastructure for power and EV • Storage facilities	Referring to policy packages 1, 2, 4 and 5.	Power producers, governmental institutions, Energy Institute Suriname
Cultural	• Adopt to energy efficient technologies • Public acceptance for new technologies.	• Awareness on energy saving practices and RE technologies • Active participation of end-consumers in energy transition	End-consumers, NGO's and the governmental institutions
Structural	• Governmental steering; • Legislation to promote renewables; • Carbon emission tax; • Organizational change within existing actors (unbundling)	PP 4 and PP 5	Governmental institutions, NGO's, monetary institutions, power producers and end-consumers

According to the changes tabulated in *table 6.4*, the changes over time for the second scenario are discussed here.

As mentioned earlier, there are common interventions required for both scenarios. These primarily involve the structural changes: governmental steering and legislation towards renewables. Moreover, the cultural changes regarding the education, behavior (adapt to sustainable practices) also holds for this scenario.

However, the from a technical perspective, the changes are different compared to the first scenario. Over the time, the following technical changes are crucial in order to achieve the desired vision: the upgrade of the current distribution grid. This upgrade enables the handling of larger capacities which will be necessary in the future. Since the generated power will be distributed over smaller regions, real time monitoring, and thus the integration of IT (smart grids) plays an important role in power balancing. On a regional level, storage should also be considered. For the EPAR region, the generated electricity will come from solar PV plants (rooftops in the city) and solar farms outside the city. The expansion of the hydropower plant will deliver the additional electricity during intermittency and peak load demand. Moreover, the hydropower lake will be used as storage facility when excess of electricity is produced by the solar PV panels. In the other regions, solar PV will be used in combination with biomass power plants. As backup, Li-ion batteries will be used for the individual regions. With regards to the transition time, initially solar PV and diesel generators will be used in order to gradually generate electricity from renewable energy sources (policy packages 1, 2, 4 and 5).

Apart from the technical changes, this scenario also supports the cultural and structural changes regarding the entrepreneurial activities related to renewable energy generation (policy package 6).

6.4 Some of the capital costs

In this section, a brief capital costs overview is presented based on the outcome of the scenarios with regards to the installed capacities needed in the future scenarios.

In the first scenario the following technical changes are proposed:

- Installation of solar farms with a total capacity of 2785 MW
- Expansion of the current hydropower plant with an additional capacity of 116 MW
- The construction and operation of a new hydropower plant in West-Suriname: 450 MW
- The construction of a high voltage transmission line from West-Suriname to the grid in the EPAR region along with the interconnection of the individual grids in the districts with each other.
- Pumped hydroelectricity as storage

In the second scenario, the following technical changes are proposed:

- Installation of solar farms with a total capacity of 2785 MW
- Expansion of the current hydropower plant with an additional capacity of 116 MW
- Biomass installations with an installed capacity of 72 MW
- Batteries as storage for the individual grid regions

The installed costs for these technical changes are tabulated in the following *table 6.5*. The assumptions and calculations are described in Appendix A-5.

Table 6.5: estimated installed costs

	Solar PV costs	Hydropower plant and / or upgrade of existing one	Construction of large transmission line	Biomass installations	Storage facilities	Estimated total costs
Scenario 1	USD 7,8 billion	USD 2.3 billion	USD 3.5 million		Pumped hydro: USD (0.16/kW): USD 12.8 million	USD 10.12 billion
Scenario 2	USD 7,8 billion	USD 87 million		USD 252 million	Li-ion Batteries: USD 273/kWh: USD 124.5 million	USD 8.26 billion

This overview presented in *table 6.5* is meant to give a general insight in the installation costs of the proposed technical changes. It can be observed that scenario 1 needs a significantly higher investment since the hydropower construction in West-Suriname is quite expensive. The costs for solar PV are accumulative cost and can therefore be executed in phases, while for hydropower a prompt investment is needed. Moreover, in terms of storage, scenario 1 provides the cheapest storage facility (*appendix A-8*).

6.5 Scenario Selection

Previously, the necessary interventions in terms of policies have been analyzed for both scenarios. This section deals with the most suitable scenario for the future electricity generation of Suriname.

Based on scenario 1, there will be a centralized grid which will connect the current individual grid with each other. It can be observed that the majority of the power stations are in the coastal part of the country. Thus, interconnecting them means that there will larger control over the demand and supply. A major investment here is the construction of the hydropower plant, Kabelebo. Besides, the electricity infrastructure will need a major upgrade and a new transmission line needs to be constructed from the new hydropower plant to the connect with the existing grid. In this scenario, storage facilities are not required. However, there might be large number of overcapacities; thus, storage for excess electricity generation must be considered.

Scenario 2, however, does not involve major investments, beside the fact that storage must be taken into account. For each individual grid, storage is necessary: in the EPAR region pumped Storage hydroelectricity is proposed, while for the other regions Li-ion batteries can be considered.

Based on the future electricity demand and the reliability of the electricity supply, the first scenario would give more guarantee. Nevertheless, scenario 2 could be adapted for the rural regions far more in the Southern part of the country.
Scenario 1 provides higher baseload capacity from the hydropower plants; therefore, investments in batteries is not necessary; the storage costs for PSH are significantly lower than Li-ion batteries. Moreover, scenario 1 offers the possibility for electricity trade with the neighboring countries, French – Guyana and Guyana in the future.

6.6 Pathway for the first scenario

This section deals with the transition pathways and implementation timeline based on the selected scenario: scenario 1. This section will conclude with a timeline which summarizes the activities for each of the identified phases.

Based on the transition model created by William Bridges (1991) about managing transitions, the transition towards the desired vision in this study is divided into 3 phases:

Phase 1: 2019 – 2025: Ending, Losing and letting go.
This phase is often characterized by resistance and emotional disruption as people are letting go of something that they are familiar with. In this case, the letting go of fossil fuels used for generating electricity as well as for the transportation sector. Accordingly, people must be informed and educated so as they can accept the disastrous effects of fossil fuels on our climate and ecosystem. Moreover, the fact that fossil fuels as non-renewable energy source, eventually will deplete in the future. Therefore, the timeframe for this phase is chosen in such way that crucial interventions and the first initiatives for the transition can be realized.

Phase 2: 2025 – 2035: The Neutral Zone
Although this stage is mostly experienced as “bitterness” towards a new direction, it means that by means of strong regulations and control the direction can still be sustained. Nevertheless, this implies that the foundations and directions developed in the first phase should work well in practice. Depending on its progress, new systems and new ways of working will be required: a fully centralized smart grid; integration of EV in the electricity grid and hydropower and solar PV in the energy mix.

Phase 3: 2035 – 2040: The new beginning

The last transition phase represents the acceptance and energy: in this phase the instrumental indicators, mentioned during the policy packaging process, will show the success of the policy interventions and the decisions made towards the desired vision. Moreover, once this stage is reached, people will start to realize the advantage of the steps (i.e. set of activities) in the first phase. In this stage all the technological, social and institutional interventions are implemented and working already according to the desired vision.

Phase 1:

In this phase the policy packaging framework as proposed earlier in this thesis will have to be developed further and carried out. While the energy institute is set up with the supporting institutions, the technological challenges will be faced. Activities here include the gradual phase out of internal combustion engines vehicles from the road and integration of EV into the grid. The smart grid infrastructure and the construction of the Kabelebo powerplant are part of the technological activities in this phase. In the first 5 to six years, the new hydropower plant might not be operational yet, thus solar PV will have to be integrated first in the energy mix. The thermal power plants will have to be operated during peak demand and during the intermittent hours of solar PV. Additionally, storage for surplus electricity during the day must be considered as well. In this phase it is also important to use the energy saving potential to meet the growing demand. A commission in charge of the control and regulation of EV should be operative and drastically minimize the import on high emission vehicles. On the other hand, EV can be stimulated by different subsidies and incentive schemes from the government. Based on estimations, around 40% of the total electricity demand will be generated from renewable energy sources (existing hydropower plant and solar PV).

Phase 2:

In this stage, the second hydropower will be operational (by 2029) and deliver the required installed capacity. With the policy interventions (taken in the first stage) and developments, policy instrumental indicators will already show improvements in this stage. The transmission line connecting the new hydropower plant with the existing grid will be operational. Furthermore, the Electric Vehicles will be well integrated in the transportation sector and there should be clear indicators present which show the phase out of internal combustion vehicles. In this stage around 80 percent of EV penetration in the market is expected.

It is expected that from 2029 on, diesel generators will no longer be required to meet the electricity demand. At least for the coastal regions. For the hinterland, there might be diesel generators required to meet the demand during the night where biomass energy systems are not yet installed. Micro financial schemes for the local communities can help to ensure a reliable and sustainable energy supply in the rural areas. Nevertheless, a 100 percent renewable electricity generation in the coastal and interior part of Suriname is achievable by the end of this phase (in 2035).

Phase 3:

The new beginning: in this stage, energy in terms of electricity is generated by renewable energy sources (total installed capacity of 1850 MW). Although the selected scenario aims at a centralized grid, connecting all the individual grids, it is expected that the microgrids will play a crucial role in the southern part of Suriname. In these remote areas, decentralized generated electricity from Solar PV panels and biomass energy systems will be distributed through microgrids. The proposed energy institute should be in charge for providing the permit and legislation for the operation of these mini grids to make sure that no diesel generators are used anymore. Moreover, this stage represents a fully diffused EV in the electricity grid and the road transportation system.

Figure 6.3 illustrates the three different stages recognized within this transition along with the key activities within every stage.

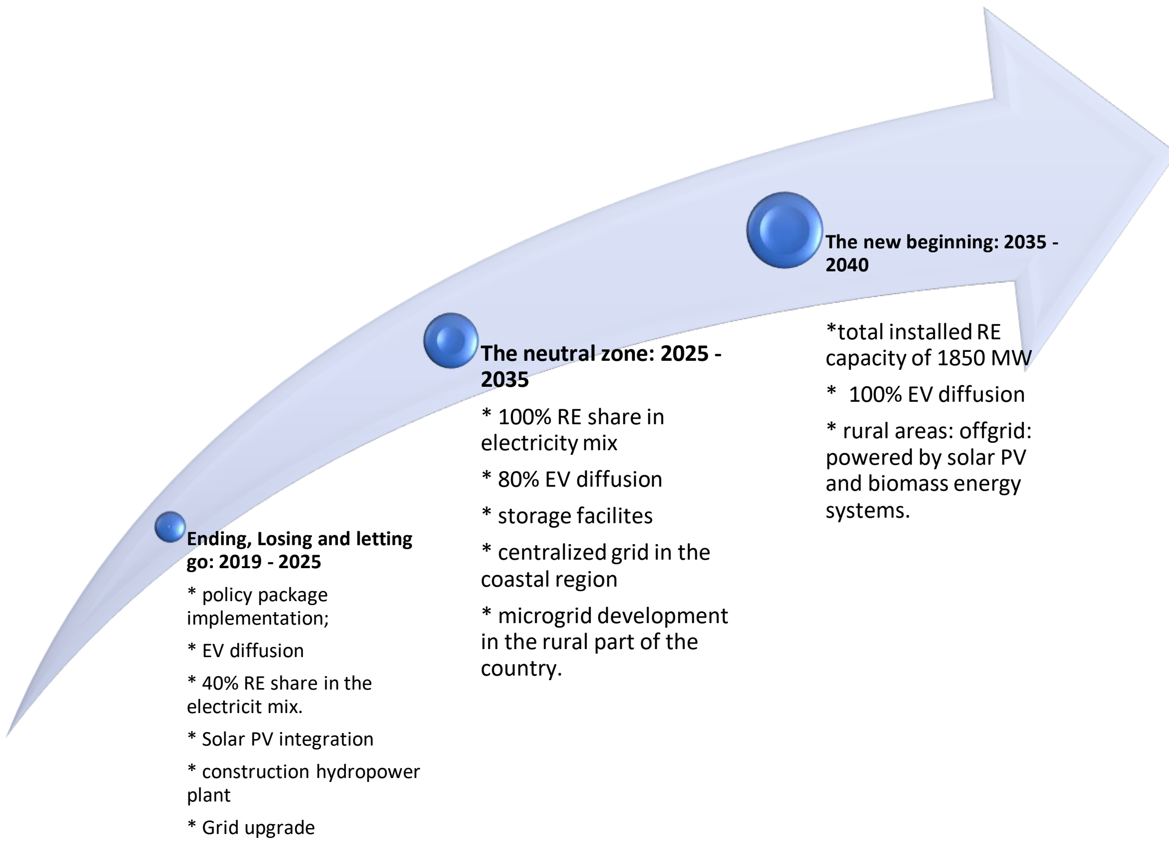


Figure 6.3: the key activities within the implementation timeline of the proposed transition.

Chapter 7 Discussion and Reflections

In this chapter the limitations on the methodologies and the model used in this study will be discussed. This is followed by reflections on the results obtained from the used model(s).

7.1 Discussion on used methods

Future energy scenario

In this study, the starting point for developing future energy scenarios was first to analyze the current energy system in Suriname. For this purpose, the energy balance for Suriname is used as boundary condition. In order to determine the future energy demand, the two major energy consuming sectors have been used: the power generation and the road transportation sector. Based on factors as GDP growth and historical energy demand, the future energy demand has been estimated in terms of electricity, assuming that by 2040 the road transportation will be fully electric driven. To develop scenarios for the future energy system, the General Morphological Analysis (GMA) is initially proposed. However, during the execution of the analysis it was found that the location played an important role in scenario development: a lot of combination could be found by adjusting the location. Since Suriname is in terms of energy supply divided into two where the inhabitants live: the coastal region and the interior, the GMA has been adjusted and finally two scenarios could be derived based on the technical change: whether to centralize the country's grid in the future or to remain it regionalized. Therefore, the scenario development has been made by a modified GMA analysis.

Policy packaging

Another interesting part of this thesis is the integration of the policy packaging into the "traditional" What – How – Who analysis as part of the backcasting. First the policy packaging framework has been adjusted to a level where no stakeholders involvement is necessary. Then, this framework has been applied in the backcasting: the changes (What -part), were done separately, although there was an overlap with the objectives (also aiming at what changes are necessary). The How- and Who- part were formulated and translated into policy actions (policy packages) for each scenario. Although there seemed to be a kind of overlap between the objectives defined and the changes on cultural, structural and technical ground, this study aims at improving the backcasting by enforcement of policy packages.

7.2 Limitations

This study performs backcasting analysis based on the 5 steps method of Quist (2009). The unique part of this study is that the backcasting performed here is combined with a quite complex policy packaging framework in order to develop transitional pathways for the desired energy system in Suriname by 2040. However, there are shortcomings in this thesis: although the Quist framework is a participative backcasting framework, this study could not conduct all the steps and activities involved within the framework due to limited access of resources and stakeholder's active engagement (thus, a non-participatory backcasting).

Limitations on data quality

For this study, data was obtained from different sources, ranging from international institutions (e.g. IEA and IRENA) to locally produced reports and studies. In some cases, there were inconsistencies in data: international reports sometimes interpret data in a different way. Therefore, in some cases the local institutions have been consulted to gather data from since it is more direct. Furthermore, data from the NV EBS (about the electricity demand and supply) could not be obtained directly. Therefore, estimations have been made based on historical data to predict the average growth. Furthermore, since no specific data for other transportation methods (besides road transportation) could be obtained, this thesis only considers the electricity and road transportation sector to estimate the final energy consumption. In conclusion, lack of concrete data directly from the issuing (or measuring) institutes caused for slightly less accurate data for the analysis used. Therefore, data obtained directly from local institutes and companies (e.g. NV EBS) could significantly improve the accuracy and thus quality of the data obtained.

Limitations on data collection: persons and sources

Another limitation which regards the backcasting methodology is that stakeholders' perspectives and opinions have not been considered. This shortcoming mainly manifests in the policy packaging framework (as part of the backcasting) is that the steps 1 and 2 within this framework were not carried out in collaboration with stakeholders. Nevertheless, the simplified framework allows the active involvement of stakeholders in the following steps (3 and 4) to adjust and/ or develop new policy packages. There are practical limitations in the policy package framework present, since the assessment of the policy package (from step 3 on) requires active involvement of stakeholders and experts and time to measure whether the primary measures delivered the desired outcome. That is the reason why the first two steps of policy packaging are carried out and at the same time, the outcome satisfies the backcasting criteria of this study. If the participative backcasting approach was used here, probably more relevant and practical pathways could have been developed. Ideally, a series of workshops with representatives from all actors and stakeholders in the energy sector would add more value to the backcasting approach.

Another shortcoming identified is the usage of an MS Excel model which could only provide the results for 24 hours load curves. The costs for using a specific technology is not integrated in this not integrated into the model. Therefore, this model could not be used for optimization as other studies did. So, in order to incorporate the Levelized Costs of Electricity (LCoE) for each scenario, the model of Fuchs (2017) could be used as a good starting point to reflect on the costs.

7.3 Reflection on research methodology and novelty

To start with, the location of this study is unique and already adds value to the study: although Suriname is not an island, it is considered as a SIDS because of its characteristics (discussed earlier). The country is a developing one with one of the largest preserved tropical rain forests on earth. Unlike many other island studies conducted, Suriname uses a different combination in its future energy mix, dominated by solar PV and hydropower. Another aspect here is that hydropower is a more mature technology, compared to other technologies used in island studies for baseload supply, for example OTEC.

Another interesting aspect in this thesis is the incorporation of policy packing in the backcasting framework: earlier studies conducted for SIDS did not apply this combination. Moreover, no other studies were found where this was applied together, beside studies which dealt with backcasting for the transportation sector.

Reflecting on the methodology used, first a scan of on the backcasting methods was conducted by Agarwala (2017) and Vallabhaneni (2018). After the selection for the 5 steps backcasting framework of Quist (2007) was made, other underlying theories were consulted to enforce the theoretical framework: The General morphological Analysis (GMA) and the policy packaging were found suitable to add additional value to the theoretical framework. Although is was found that the GMA was not really applicable for the case of Suriname, the initial policy package framework is quite successfully integrated into the backcasting (What, How, Who analysis)

However, it is found that sensitivities and assumptions are very important in the scenario analysis. A more thorough research on all policy mechanisms involved the energy sector would be recommended to analyze how the policy interventions are influenced by other economic variables (e.g. oil prices). Additionally, the incorporation of an optimization model, for example the model by Fuchs (2017) would add additional value to the modified framework used in this thesis.

Reflecting on the novelty of this research, it can be concluded that this study fills the knowledge gaps, discussed in the first chapter. By adding additional value to the research framework, a more comprehensive framework is developed which emphasizes more on the policy implementation side rather than the technical optimization side.

Reflecting on the broader literature, this study uses the five steps backcasting framework of Quist (2007) and is further shaped and modified to include and assess all the essential steps and activities. While the aim of this thesis was to use the generic backcasting approach, the use of this approach has been used in a limited way in this thesis, since no participatory backcasting has been used. However, compared to existing literature, this study additionally adds value by the integration of the interrelationship analysis and the policy packaging in the backcasting analysis. This enables a more comprehensive set of policy measurements towards developing the transitional pathways. Moreover, the modified framework in this thesis can be scaled up for assessing other countries and regions.

7.4 Implications and broader relevance

Based on the findings during this research, the following implications are proposed for the follow up and broader relevance.
From a social and structural perspective, the energy transition (as proposed) triggers changes from different perspectives:

<u>Environmental awareness</u>: educating people what renewables are and how they can contribute to less environmental damage: less greenhouse gas emissions leads to less pollution and improved water and air quality. However, it is important to understand that heavy deforestation should not be the result of the implementation of solar PV farms and hydropower. All the interventions must be made within the limits so as the flora and fauna remains preserved as much as possible.

<u>Social acceptance</u>: the view is a matter of getting used to. Since there will be lots of solar farms necessary, the site can be chosen in such way that it does not bother (view and reflection) the local inhabitants. Since large-scale solar PV is new for Suriname, people will gradually get used to seeing solar PV rooftops and farms. Moreover, the new hydropower plant will not be constructed in a large populated area, so that urbanization will be minimal. However, since there are tribal rights, the government of Suriname needs to involve them as a key stakeholder from the beginning on.

<u>Focus on the transition:</u> this is crucial for the government and all stakeholders in the current energy sector. The large discoveries of crude oil in the territorial waters of Guyana provides business opportunities; especially for the Staatsolie refinery to process and refine more crude oil in the future. Despite the economic advantages which can be gained from the fossil fuel sector, the main focus should be to develop business models in such way that the profits from the fossil fuel industry should be used for the economical costs of the sustainable energy transition. Therefore, institution such as the proposed Energy Institute should be independent from political influences and renewable energy targets proposed in the transition pathway should be fixed by law. Moreover, this creates a secure business environment for foreign investors.

Chapter 8 Conclusions

In this section the sub research questions, and the main research question have been answered.

Sub research questions:

- How does the current energy system of Suriname look like?

Based on the energy balance, obtained from the IEA (2019), the main energy carriers are liquid fuels, electricity and a small portion of biofuels (waste). Liquid fuels (diesel, gasoline and LPG) are mainly used for the transportation sector and for thermal power plants (HFO for generators) and the LPG for cooking as well. In the rural areas, waste (wood) is used for cooking. There is a lack of awareness in the field of energy savings (consumers side) and involvement in the energy system. Inefficiency is present from the generation and transmission side (NV EBS) as well as the consumer side (inefficient air conditioning systems). The electricity market is dominated by the government owned NV EBS, responsible for the thermally produced electricity and distribution; the Staatsolie Power Company for thermal produced electricity and though Power Purchase Agreement administered Suralco Power Company (hydropower). Although there are pilot projects carried out for renewable energy initiatives (e.g. solar PV farms), there is a fossil fuel lock-in presence. Local initiatives and investments in the sustainable energy field are absent. Rural communities often invest in diesel generators instead of solar PV panels, because of lower investment costs. Therefore, strong interventions are required to break the fossil fuel "lock-in".

- What is the potential of different renewable energy sources in Suriname?

During the RE potential analysis all possible renewable energy sources have been assessed for Suriname. During this analysis, accessible data as well as unpublished studies have been analyzed to get a thorough overview of the RE potential in Suriname. Moreover, the technical feasibility of each of these sources are considered.
It is found that Solar PV dominates over all the other Renewable energy sources, followed by hydropower and biomass. Additionally, energy saving potentials were also considered. In order to successfully create a landscape which will be dominated by these renewables, the energy policies need to be considered as well as the institutions for implementing these technologies.

- How will the demand for energy change up to 2040 and how will the desired vision look like?

In the future, electricity will become the main energy carrier. This means that, apart from the electricity demand, the energy demand for the road transportation sector as well as the demand for gas and firewood have been converted into future electricity demand.
To determine the future energy demand, parameters as growth rate and historical electricity growth demand have been used. Based on this, the final electricity consumption in 2040 is

around 36 PJ for Suriname. The configuration for the scenarios have been made based on the availability of the potentials and the grid interconnection (infrastructure).
Based on the results found, the electricity system in Suriname will be 100 percent sustainable by 2040, which will consist of a centralized grid, interconnecting all the current regional grids with each other and a hydropower plant in West – Suriname (Kabelebo). For the small villages in the interior (Southern part) of Suriname, micro grids have been proposed which will be powered by solar PV and biomass.

- What kind of intervention are needed to achieve the desired future?

In order to achieve the desired future, strong interventions are necessary: these have been identified in chapter 6 of this thesis. In this chapter, the policy interventions are included in the so- called policy packages. These interventions (measures) are considered to be the boundary conditions for a successful implementation of the proposed transition.
The policy interventions are closely related to the technological changes to facilitate the transition. Moreover, these interventions affect the consumer behavior and awareness.

Main research question: How can Suriname achieve a sustainable energy system by 2040?

The main research question is supported by the sub research questions. Thus, answering the main research question combines the answers given to the sub research questions. Therefore, only the most important points will be discussed here.
To achieve the desired vision in 2040, a strong policy framework is crucial. The involvement of the following actors are necessary: the policymakers (government: De Nationale Assemblee and the ministry of Natural Resources), public administration, NGO’s and the end consumers.
The initial steps here would be to establish an independent energy institute which would create and facilitate an investment friendly climate for the energy sector. Presence of strong and independent institutions are one of the boundary conditions for investors to invest in e.g. the electricity infrastructure and solar PV farms. Moreover, transparency from the NV EBS (as monopolist in the electricity transmission and distribution) is required to monitor the progress of different energy related interventions.

Chapter 9 Recommendations

The government of Suriname has signed and agreed upon the Caribbean Sustainable Energy Roadmap and Strategy (C-SERMS), the target of achieving 47% renewable electricity generation by 2027. This report also anticipates on the sustainable generation of electricity and in this study specific policy packages which include policy interventions have been developed in two scenarios. The following recommendations have been identified towards policy makers and stakeholders especially in the energy landscape.

The government of Suriname

Unbundling and reallocating resources: To start with the current energy landscape; there are necessary changes required which can lead to successful implementation of the transition pathways. At first, the energy sector needs to be transparent; power generation should be uncoupled from the distribution and transmission. The ministry of Natural Resources must re-allocate the power producing companies into one entity. This enables the NV EBS to focus more on the transmission and distribution network and to upgrade the existing grid to a smart grid. Furthermore, with the integration of Electric vehicles (EV), the NV EBS will be in charge with setting up the grid infrastructure for EV.

By having a national Energy Institute, the monitoring of the renewable energy progress will be two – folded: ensuring that the generated electricity is shifting from conventional sources to renewable energy sources and on the other hand developing strategies for Electric vehicle diffusion on the transportation market.

Government, local communities and NGO's, Small and Medium Enterprises, research institutes

Stimulating local initiatives: With the opportunities in the renewable energy market, local communities and households can participate in solar PV (rooftop) projects in order to make themselves self-sufficient. In order to do so, the governmental subsidies on electricity generated by fossil fuels need to shift towards Renewable energy. Energy transitions start with niches: once the government facilitates and creates business opportunities (e.g. by enabling loans for community funds and Small and Medium Enterprises), the transition towards a 100% sustainable electricity generation will be embraced by the majority of the inhabitants. Therefore, education (learning people about the opportunities in the energy transition and how to make business plans), active interactions between research institutes and the government and NGO's for more sustainable and energy efficient practices is crucial.

Government, companies and research institutes

Active stakeholder involvement is one of the boundary conditions to develop and deploy the proposed policy packages further in the consecutive steps as proposed by Fearnley et al (2011). This will lead to a clear and structured way of implementation of the proposed changes. Moreover, it is necessary to get out of the fossil fuel -locked in economy: by having active roles of stakeholders and actors, an emission tax can be a good way to make a shift towards sustainable energy sources. It is proposed that emission tax should be in such way implemented that foreign investors and industries will not be affected by this act. For the local people there is already governmental tax on fuels (used in vehicles). By reallocating resources, this governmental tax could be replaced to emission tax, which will make consumers more aware of why they are paying the tax for.

Recommendations on applied methods

Since this study incorporated policy packaging in the backcasting framework, the outcomes of this study tend to go more on the policy related changes. It would be highly recommended for future studies using a similar kind of framework to involve key partners, especially when developing pathways to achieve the future vision.

Although in this research the renewable energy potentials are mostly based on local produced reports and studies to obtain as accurate as possible data, another aspect which could complement this study is the use of a simulation model as proposed by Fuchs (2017). This would deliver better insights on the costs related to each of the scenarios (Levelized Costs of Electricity).

Another recommendation would be the availability of more consistent data; since data acquisition from local institutes in Suriname is quite a challenge and international published data are sometimes outdating, it would be again, very helpful to start a network first of representatives of institutions identified in the stakeholder analysis.
Therefore, I encourage future researches to consider these notes on this topic in order to provide more in-depth and structured recommendations and transition pathways.

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Appendices:

Table of Contents

Appendix A-1 Background of future studies and backcasting approaches

In this appendix, the background of future studies with respect to backcasting are described, followed by the elaboration of different participative backcasting approaches.

A-1.1 Future studies

In the process of conceptualizing and implementing changes in the future, a set of processes are necessary for determining what and where you want to be in the future (Stewart, 1993). Therefore, future studies give more insight into the processes involved within a backcasting method. Forecasting, exploratory scenarios and backcasting have been identified as the most popular approaches (Garcia Nodar, 2016). Forecasting is a way to predict the most likely future based on observations and facts of the past. According to Dreborg (1996), forecasting is based on dominant trends, which results in solutions that are unlikely to break them. However, it is questionable whether forecasting the future of energy systems take into account all actors and stakeholders involved in the energy sector to overcome possible barriers in the future (*figure A-1*). Literature survey shows out that forecasting is efficient for determining the future energy demand and load by using forecasting models as proposed by Debnath et al. (2018). This is also the reason why forecasting works in tandem with backcasting.

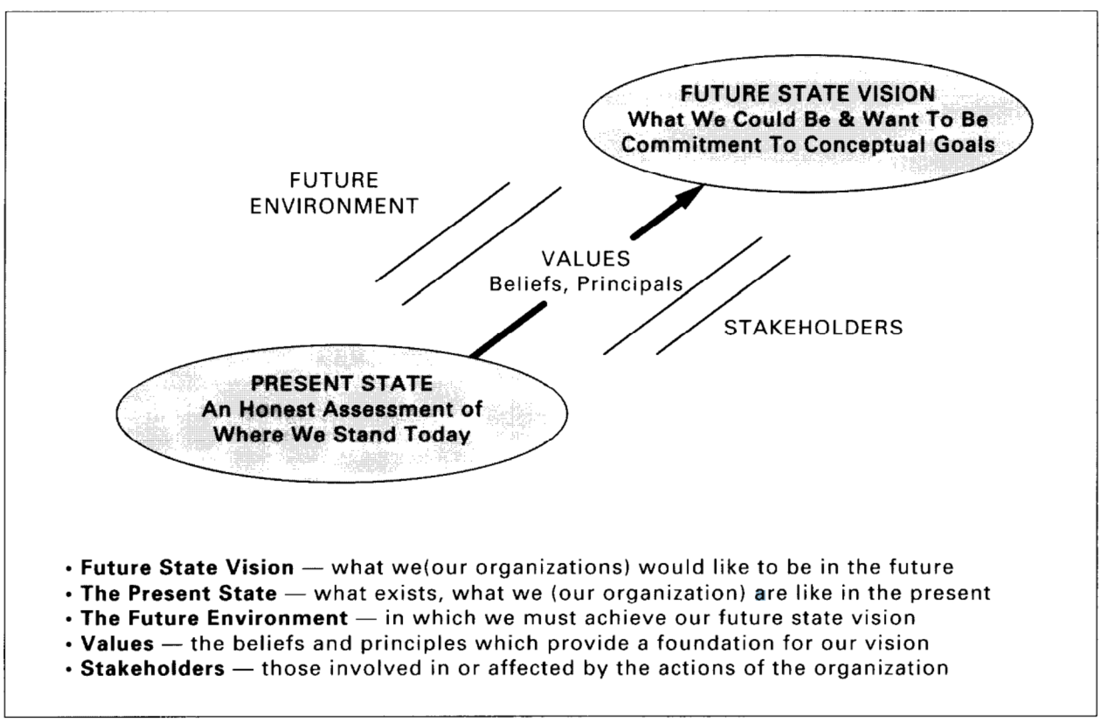


Figure A-1: the future state visioning (FSV) process by Stewart (1993).

In his paper (Stewart, 1993), describes the development of FSV into a process methodology: it describes each of the steps in the visioning process: defining the stakeholders; assessing the future environment; creating a vision; assessing the present state; and expressing a set of values (*figure 2.2*). This paper therefore gives a deep insight of how future studies help to achieve a future vision. However, this was a more process-oriented approach, while other studies specifically dealt with energy transition.

In his master thesis Garcia Nodar (2016) refers to the backcasting method of (Quist & Vergragt, 2006): "b*ackcasting is a planning method which starts by defining a desirable future vision or normative scenario and subsequently looking back at how this desirable future could be achieved"*. In his article (Quist, 2013) emphasizes on the transition from a fossil fuel-based economy towards a sustainable energy system assessing a variety of renewable energies based on the backcasting method described in his article. So, backcasting has proved to be a reliable method to help policy makers and stakeholders envisioning and designing a desirable future energy system. This is illustrated in *figure A-2*, where clearly different milestones during time intervals between the future vision and the present can be observed.

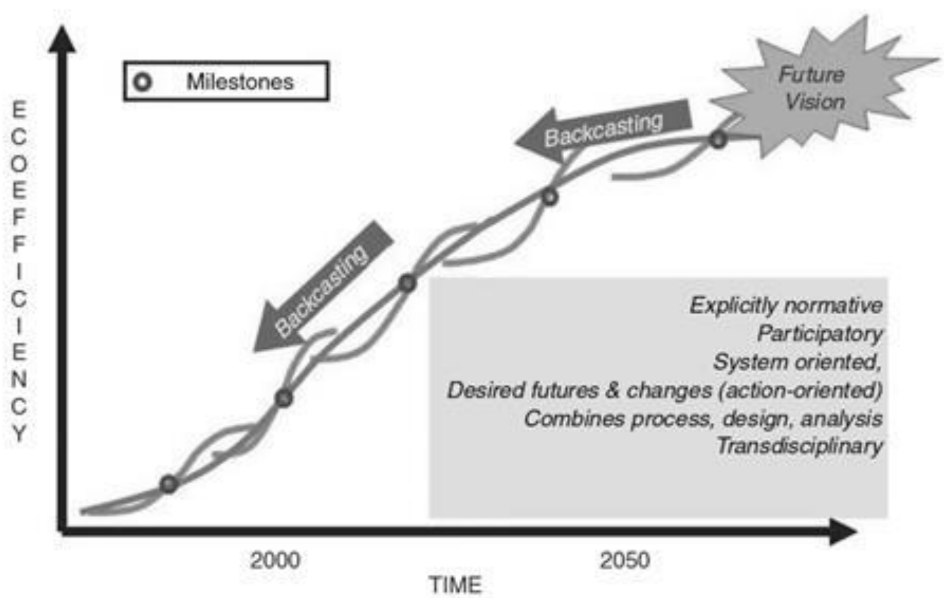


Figure A-2: the principle and key characteristics of backcasting (Quist, 2013)

A-1.2 Participative Backcasting and Backcasting approaches

Participatory backcasting dates back to the 1990's in the Netherlands. The Dutch government has been applying this approach, combined with Constructive Technology Assessment (Dreborg, 1996), as part of the philosophy of programs such as Sustainable Technology Development (STD) which ran from 1993-2001 and Strategies towards the Sustainable Household (SusHouse) which ran from 1998-2000 (Quist, 2007).

Through literature survey and backcasting studies performed by Vallabhaneni (2018), García Nodar (2016) and Agarwala (2016), five most common backcasting approaches have been identified. These are the Robinson approach, the Natural Step approach (TNS), Sustainable Technology Development approach (STD) and the Quist approach. Additionally, a study done by Kishita et al. (2017) for designing backcasting scenarios for resilient energy futures has also been consulted.

The model of Robinson (2003) has a normative nature and forms a fundamental approach for design-oriented research. This model contains of six steps *(figure 2.4);* in the first step the desirable future goals and constraints are defined. This forms the basis of performing the backcasting analysis. According to Anderson (2001) the timeframe of 30 – 50 years in the future would give an appropriate outcome of this analysis (Vallabhaneni, 2018). In the steps hereafter scenarios are assessed based on socio-economical, policy, physical and technological feasibility. From *figure 2.4* it can be observed that this analysis requires multiple iterations to resolve the inconsistencies and to rectify the adverse impacts revealed in the previous iterations (Vallabhaneni, 2018).

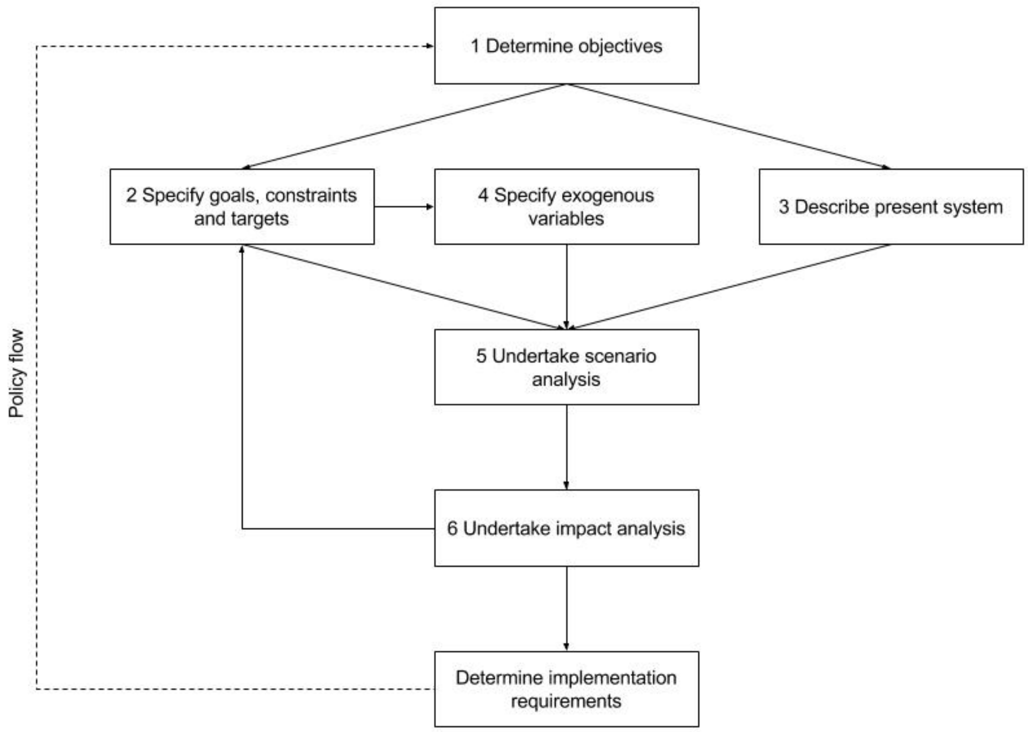


Figure A-3: Outline of generic backcasting method. Adapted from Robinson (1990).

The six-step methodology suggested by Robinson (1982) is as follows:

1) Specify goals and constraints

2) Describe current energy consumption and production

3) Develop outline of future economy

4) Undertake demand analysis

5) Undertake supply analysis

6) Determine implications of the analysis.

<u>Sustainable Technology Development approach (STD):</u>

The STD program was initiated by the Dutch government that ran from 1993-2001 aiming at achieving innovative solutions towards sustainability by using a backcasting approach that included a broad stakeholder participation, future vision or normative scenarios combined with creativity to achieve the desired goal. The program covered several social needs such as nutrition, water, mobility and housing (Quist et.al, 2004).

This approach is described by Weaver et.al (2000) in seven steps, which is illustrated in *figure A-4:* in the first three steps the outline the main problem is addressed, and the long-term visions are developed, necessary to achieve a sustainable goal. Steps 4-5 emphasize on defining short-term solutions that can lead to the desirable futures, forming joint action, required research and development (R&D) and supporting policies. In the last 2 steps the implementation phase is described by an action plan with the involvement of various stakeholders and establishing cooperation amongst them. This approach does not only involve stakeholder participation in the implementation phase, but also in the follow-up of the development of visions of sustainable futures (Weaver et al, 2000; Quist, 2007).

Develop long term vision
1 Strategic problem orientation and definition
2. Develop future vision
3. Backcasting
Develop short term actions
4. Explore solution options
5. Select among options: set up action plan
Implementation
6. Set up cooperation agreement-define roles
7. Implement research agenda

Figure A-4: an outline of the STD backcasting approach (Quist et al., 2006)

<u>The Sushouse approach:</u>

Primarily derived from the Sustainable Technology Development (STD) approach, the Sushouse program (1998-2000) aimed towards developing and testing strategies for sustainable households in the Netherlands. This approach was more centered towards the demand side by focusing on 3 primary household functions: clothing care, shelter and nutrition. Quist (2007) mentions in his doctoral thesis that the backcasting techniques, participatory methods, analytical methods, design methods and management and communication methods were all applied as part of this backcasting approach. From *figure A-5* it can be observed that this approach follows an iterative cycle during steps 4-6 which allows improving and adjusting the created scenarios in step 4 by assessing them during step 5 and step 6.

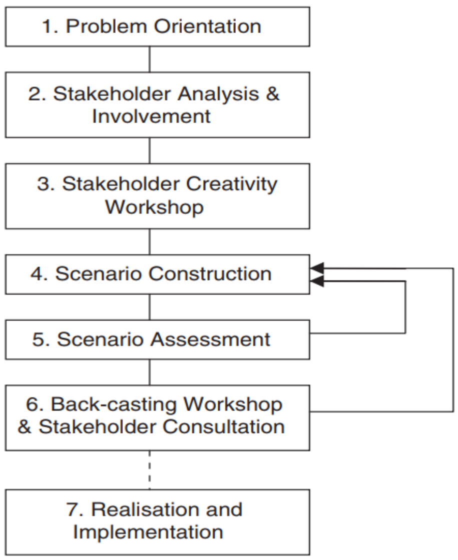


Figure A-5: an outline of the Sushouse backcasting approach (Quist et.al, 2006)

The Natural Step (TNS) backcasting approach is a method originally developed by (Holmberg, 1998; Quist 2007) in Sweden for strategic sustainability planning towards organizations and consists of the following four steps:

1. Define the relevant sustainability criteria based on key assumptions
2. Analyze the current situation of the organization and the supply chain where the organization is part from; this step enables identification of possible bottlenecks.
3. The future options for the organization are created by active involvement of employees at all levels in the organization
4. Strategies development from the present towards the future vision.

Noticeable is that this approach does not contain a separate backcasting step compared to the Sushouse and the STD approach and has a more operational-oriented character (Quist, 2007).

Appendix A-2: Population facts Suriname (MDG progress report)

Indicator	Value	Year	Value	Year
Population Mid-Year	517,052	2008	541,638	2012
Average population growth	1.2 %	2008	1.2%	2012
Total Fertility Rate	2.4	2007	2.56	2012
Life expectancy at birth (in years) males	67.7	2007	69.3	2012
Life expectancy at birth (in years) females	71.9	2007	75.0	2012
Infant mortality rate (per 1000 live births)	17.9	2008	14.6	2012

Source: ABS

Figure A-6: Population facts as indicator for the MDG progress report. (Government of the Republic of Suriname, 2014).

Appendix A-3: Census population data of Suriname

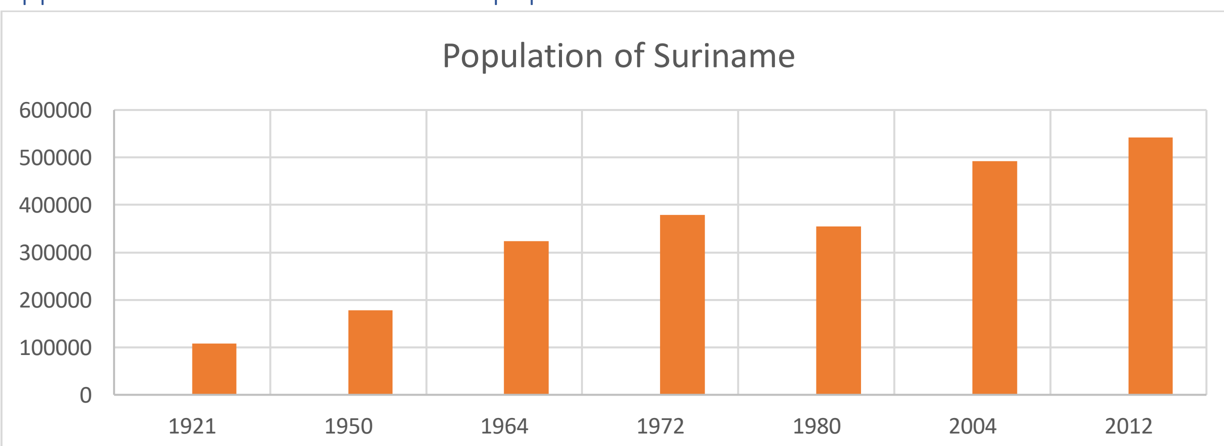


Figure A-7: the total population of Suriname census between 1921 and 2012 (Menke, 2016)

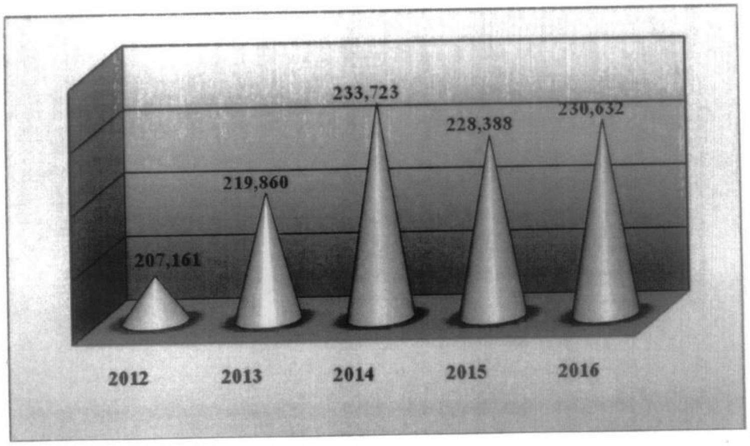
Appendix A-4: Energy balance of Suriname

Thousand tonnes of oil equivalent											
SUPPLY AND CONSUMPTION	Coal	Crude oil	Oil products	Natural gas	Nuclear	Hydro	Geotherm./ Solar/ etc.	Biofuels/ Waste	Electricity	Heat	Total
Production	-	846	-	-	-	117	-	29	-	-	992
Imports	-	-	479	-	-	-	-	18	-	-	497
Exports	-	-	-749	-	-	-	-	-	-	-	-749
Intl. marine bunkers	-	-	-50	-	-	-	-	-	-	-	-50
Intl. aviation bunkers	-	-	-	-	-	-	-	-	-	-	-
Stock changes	-	-	-	-	-	-	-	-	-	-	-
TPES	**-**	**846**	**-320**	**-**	**-**	**117**	**-**	**47**	**-**	**-**	**690**
Transfers	-	-517	575	-	-	-	-	-	-	-	58
Statistical differences	-	76	2	-	-	-	-	1	-	-	78
Electricity plants	-	-	-253	-	-	-117	-	-	187	-	-182
CHP plants	-	-	-	-	-	-	-	-	-	-	-
Heat plants	-	-	-	-	-	-	-	-	-	-	-
Blast furnaces	-	-	-	-	-	-	-	-	-	-	-
Gas works	-	-	-	-	-	-	-	-	-	-	-
Coke/pat.fuel/BKB/PB plants	-	-	-	-	-	-	-	-	-	-	-
Oil refineries	-	-402	384	-	-	-	-	-	-	-	-18
Petrochemical plants	-	-	-	-	-	-	-	-	-	-	-
Liquefaction plants	-	-	-	-	-	-	-	-	-	-	-
Other transformation	-	-	-	-	-	-	-	-	-	-	-
Energy industry own use	-	-3	-3	-	-	-	-	-	-3	-	-9
Losses	-	-	-	-	-	-	-	-	-16	-	-16
TFC	**-**	**-**	**385**	**-**	**-**	**-**	**-**	**48**	**168**	**-**	**601**
INDUSTRY	**-**	**-**	**24**	**-**	**-**	**-**	**-**	**5**	**81**	**-**	**110**
Iron and steel	-	-	-	-	-	-	-	-	-	-	-
Chemical and petrochemical	-	-	-	-	-	-	-	-	-	-	-
Non-ferrous metals	-	-	-	-	-	-	-	-	-	-	-
Non-metallic minerals	-	-	-	-	-	-	-	-	-	-	-
Transport equipment	-	-	-	-	-	-	-	-	-	-	-
Machinery	-	-	-	-	-	-	-	-	-	-	-
Mining and quarrying	-	-	-	-	-	-	-	-	-	-	-
Food and tobacco	-	-	-	-	-	-	-	-	-	-	-
Paper pulp and printing	-	-	-	-	-	-	-	-	-	-	-
Wood and wood products	-	-	-	-	-	-	-	-	-	-	-
Construction	-	-	10	-	-	-	-	-	-	-	10
Textile and leather	-	-	-	-	-	-	-	-	-	-	-
Non-specified	-	-	14	-	-	-	-	5	81	-	100
TRANSPORT	**-**	**-**	**225**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**225**
Domestic aviation	-	-	-	-	-	-	-	-	-	-	-
Road	-	-	141	-	-	-	-	-	-	-	141
Rail	-	-	-	-	-	-	-	-	-	-	-
Pipeline transport	-	-	-	-	-	-	-	-	-	-	-
Domestic navigation	-	-	-	-	-	-	-	-	-	-	-
Non-specified	-	-	84	-	-	-	-	-	-	-	84
OTHER	**-**	**-**	**136**	**-**	**-**	**-**	**-**	**43**	**87**	**-**	**266**
Residential	-	-	15	-	-	-	-	37	55	-	107
Comm. and public services	-	-	10	-	-	-	-	6	31	-	47
Agriculture/forestry	-	-	112	-	-	-	-	-	-	-	112
Fishing	-	-	-	-	-	-	-	-	-	-	-
Non-specified	-	-	-	-	-	-	-	-	-	-	-
NON-ENERGY USE	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
in industry/transf./energy	-	-	-	-	-	-	-	-	-	-	-
of which: chem./petrochem.	-	-	-	-	-	-	-	-	-	-	-
in transport	-	-	-	-	-	-	-	-	-	-	-
in other	-	-	-	-	-	-	-	-	-	-	-
Electricity and Heat Output											
Electr. generated - GWh	**-**	**-**	**821**	**-**	**-**	**1359**	**-**	**-**	**-**	**-**	**2180**
Electricity plants	-	-	*821*	-	-	*1359*	-	-	-	-	*2180*
CHP plants	-	-	-	-	-	-	-	-	-	-	-
Heat generated - TJ	-	-	-	-	-	-	-	-	-	-	-
CHP plants	-	-	-	-	-	-	-	-	-	-	-
Heat plants	-	-	-	-	-	-	-	-	-	-	-

Figure A-8: Energy Balance Suriname 2016 (IEA, 2019)

Appendix A-5 Transportation statistics in Suriname

Grafiek 26a: Het totale aantal verzekerde motorrij- en voertuigen, 2012 - 2016
Graph 26a: The Total Number of Insured Motor Vehicles and Passenger Cars, 2012 – 2016



Tabel 2.01: Het totale aantal verzekerde motorrij- en voertuigen naar soort, 2012 - 2016
Table 2.01: The Total Number of Insured Motor Vehicles by Kind, 2012 – 2016

Soort motorvoertuig/ *Kind of Motor –Vehicle*	2012	2013	2014	2015	2016
Personenauto/ *Passenger Car*	125,590	134,335	144,789	146,110	149,560
Vrachtauto/ *Lorry*	32,392	33,223	35,350	34,434	34,046
Autobus/ *Bus*	3,368	3,487	3,756	3,608	3,590
Motorfiets/ *Motor-bike*	1,461	1,535	1,794	1,752	1,798
Bromfiets/ *Moped*	43,370	46,235	47,056	41,504	40,708
Tractor/ *Tractor*	980	1,045	978	980	930
Totaal/*Total*	**207,161**	**219,860**	**233,723**	**228,388**	**230,630**

Bron: Centrale Bank van Suriname/ Source: Central Bank of Suriname

Grafiek 26b: Het totale aantal verzekerde personenauto's en vrachtauto's, 2012 - 2016
Graph 26b: The Total Number of Insured Passenger Cars and Lorries, 2012 – 2016

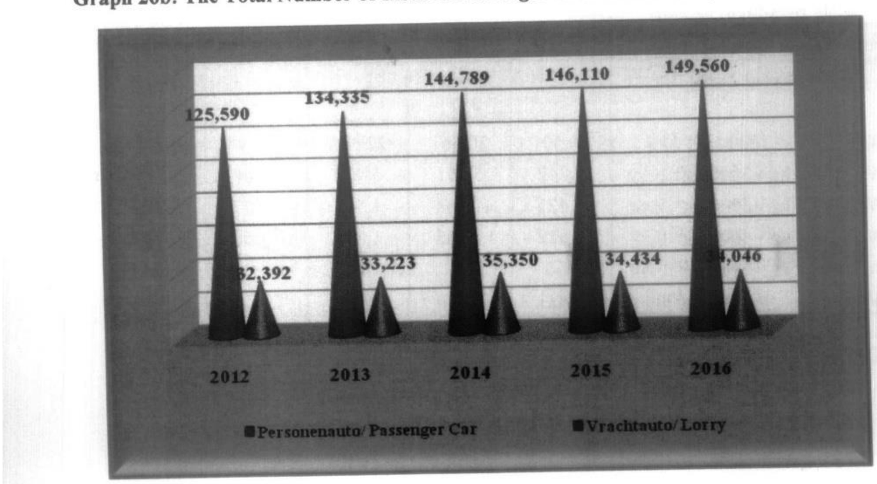


Figure A-9: ABS (2016) publication showing the transportation statistics in Suriname

Appendix A-6: Calculations for the Energy potentials

In this section the calculations, made for the various renewable energy potentials is calculated.

A-6.1 Solar PV

The geographical location of Suriname already reveals that this country is in favor of the Sun. Data obtained from SolarGIS *(figure A-10)* confirms that, showing an annual irradiance of around 1790 kWh/m^2 which is almost twice as much as the case in the Netherlands (1000 kWh/m^2). Furthermore, the it can be observed from this figure that the coastal area has a uniform irradiance profile. As there are many ways to harvest this energy from the sun, at first the potential of solar Photovoltaics (PV) will be assessed followed by the potential for solar thermal energy.

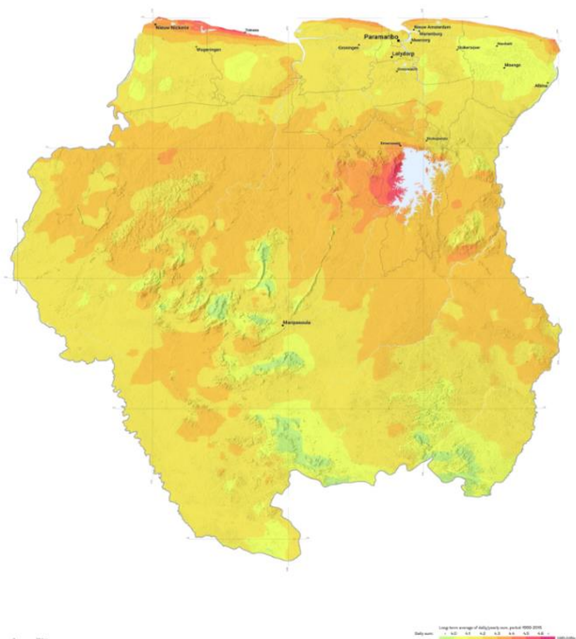


Figure A-10: Solar power potential of Suriname (Worldbank Group, 2017)

Key parameter for solar PV is the Global Horizontal Irradiance (GHI): this is the amount of irradiance which comes directly from the sun and is received on a horizontal surface on Earth. Raghoebarsing et al. (2019) mention in their study the fluctuations of the GHI in Suriname during all seasons throughout the year.

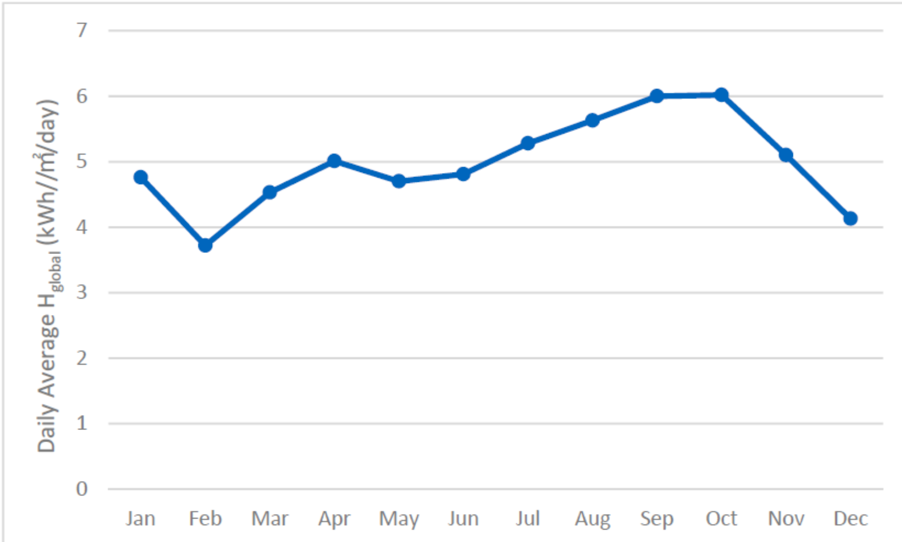


Figure A-11: Daily average global horizontal irradiation spanned over a year. (Raghoebarsing, et al., 2019)

In *figure A-11*, the Hglobal per month varies from 3.72 kWh/m^2/day (in February) to 6.02 kWh/m2/day (in October). The annual Hglobal is 1791.85 kWh/m^2/year. Changes in these values are the result of rain season (between December and May) and the dry season (between June and November) respectively.

The following calculation is used for determining the total solar PV yield:

$$Ppv = Amod * \int \eta(Tm, Gm)(t) * \eta BoS * Gm(t)$$

$$\eta\ (25^{\circ}C, Gm) = Pmpp/(Gm * Amod)$$

$$\eta\ (Tm, Gm) = \eta(25^{\circ}C, Gm) * (1 + k(Tm - 25^{\circ}C))$$

$$Tm = Tamb + (Gm/\ GNOCT) * (NOCT - 20^{\circ}C)$$

Where,
- $Amod$= Area of modules in total (m^2)
- $\eta(Tm,Gm)(t)$ = Efficiency at Temperature (Tm) and irradiation (Gm)
- ηBoS = Efficiency of balance of system
- $\eta(25^{\circ}C,Gm)$= Efficiency at Temperature ($25^{\circ}C$) and irradiation (Gm)
- $Pmpp$= Power at maximum power point = 187.2 W
- Gm= Irradiation (W/m2)
- k = temperature coefficient = -0.06
- $Tamb$= Ambient Temperature ($^{\circ}C$)

- $GNOCT$ = Irradiation at NOCT conditions (800 W/m^2)
- $NOCT$= NOCT temperature = 46 ˚C (Nominal operating Cell temperature)

Standard Test Conditions (STC): air Mass (AM) 1.5; irradiance of 1000 W/m^2 and cell temperature of 25 ˚C.

A-6.2 Solar thermal

Concentrating solar power (CSP) utilizes the Sun's rays and with the use of mirrors high temperature heat is generated to use in a steam turbine which finally delivers electricity. This technology offers an efficiency of around 13% (IRENA, 2018). Given the fact that its efficiency is lower compared to the solar PV for delivering electricity and that hot water is not considered as desired output of this system (since there are no exact numbers for heat demand in Suriname), the solar thermal potential will not be considered in this research.

A-6.3 Hydropower

In the past 10 years, there have been many speculations going on about the execution and feasibility potential hydropower projects (Mehairjan et al., 2010).

The Tapa-Jai project: this project is based on the expansion of the existing hydropower plant: water infrastructure will be built to connect the Jai-Tapanahony river (*figure A-7)*. This project leads to an additional installed capacity of 116 MW, bringing the total installed capacity of the HPP (hydropower plant) to 305 MW.

Figure A-12: Schematic illustration of the Tapa-Jai project (Mehairjan et al., 2010).

The Kabalebo Hydro Power Project (West Suriname Hydro Power Project) was already initiated in 1977. The projected installed capacity will be around the 350MW to 650MW. A more recent study in 2014 was conducted to assess environmental impacts upon realization of this hydropower plant in the Western part of Suriname. The results of this research show significant changes of the hydropower potential as impact of flows in the river between 2050 and 2100 (Donk P. et al, 2014). The hydropower river basin will be covering an area of roughly 9450 km^2 *(figure A-13).*

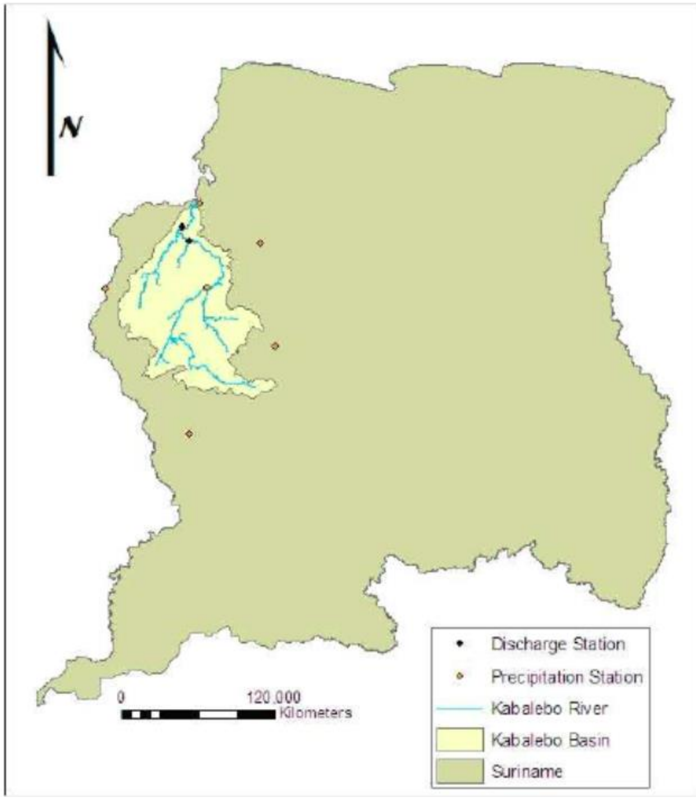


Figure A-13: Location of the Kabalebo river basin in district Sipaliwini, Suriname. (Donk P. et al, 2014).

When the 2 hydro projects will be executed than nearly 560 MW extra hydro capacity will be available (Mehairjan,et al., 2010). This involves the expansion of the current hydropower plant and the realization of the Kabelebo hydropower plant. The total installed capacity of both hydropower plants will be around 750 MW. With a capacity factor of 0.65 for hydropower, the annual electricity generation will be 4415 GWh or 16 PJ.

A-6.4 Biomass Energy

The following calculations have been performed to determine the biomass energy potential:

- Rice husk:

Accounting for the fact that:

– 1 ton of rice paddy produces 220 kg rice husk
– 1-ton rice husk is equivalent to 410- 570 kWh electricity
– Calorific value = 15.6 MJ/kg
– Moisture content = 5 – 12%

The amount of annual production is of the order of 55,000 metric ton. From this feedstock, a thermal power plant can be developed (in Nickerie) using an organic Rankine cycle engine as utilization technology for the generation of 4–5 MWe power (Nannan et al, 2016)

- Rice straw:

Accounting for the fact that:

– 1 ton of rice paddy produces 290 kg rice straw
– 290 kg rice straw can produce 100 kWh of power
– Calorific value = 10 MJ/kg

The production is of the order of 72,500 metric ton per annum. From this feedstock, a thermal power plant can be developed using an organic Rankine cycle engine as utilization technology for the generation of 4–5 MWe power. (Nannan et al, 2016)

- Wood waste:

Unfortunately, no record is kept of wood waste production. However, Nannan et al. (2016) found that the wood waste is estimated to be of the order of 150,000 m3 /year. This can be converted into thermal power using gasification or conventional combustion delivering a potential around 30 MW power. A total potential energy from biomass equivalent to 315 GWh (1.14 PJ) is found.

A-6.5 Wind energy potential

Based on climatological data, Suriname has very low winds speeds ranging between 2 and 4 m/s *(WeatherOnline, 2019)*. Therefore, harvesting wind energy through wind turbines not only becomes a technological challenge, but will also result in high Levelized costs of electricity (LCOE). In their study Ramsingh et al. (2016), use Regional Climate Model (RCM) simulations to determine whether wind energy would be efficient to use in the future. Measurements were taken from three different locations along the coast of Suriname: Nieuw Nickerie (district Nickerie), Paramaribo (the capital) and Galibi (district Marowijne) (*figure A-14).*

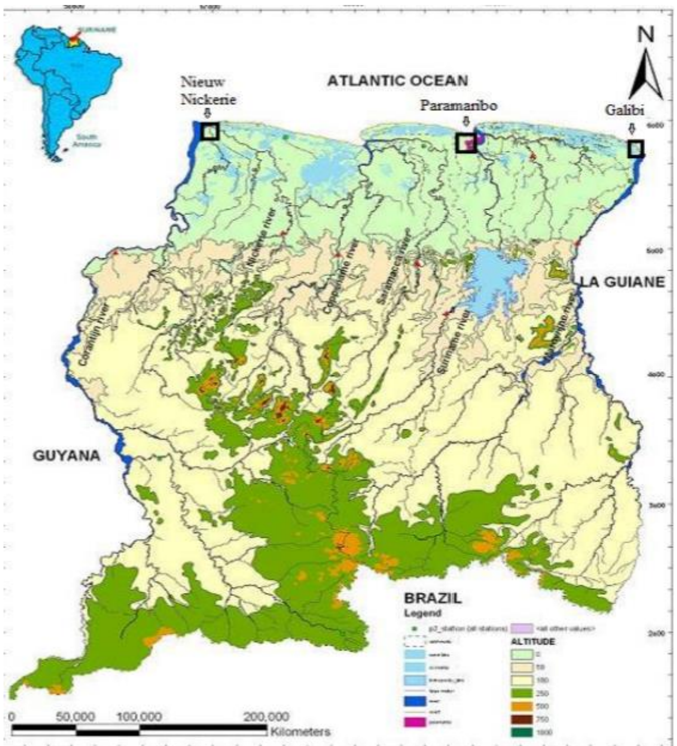


Figure A-14: three locations along the coast of Suriname where measurement are taken for the wind energy potential in Suriname (Ramsingh et al.,2016)

The study was based on the (current) measurements and extrapolation for future wind velocities on these three locations and the power that could be generated by wind turbines. Different GCM (General Circulation Model) outputs and SRES (Special Report on Emissions Scenarios) were used to determine whether the wind velocities in the future (due to climate change) would be in favor for Suriname to harvest wind energy on utility scale *(Ramsingh et al.,2016).* Unfortunately, the models showed out that for future scenarios (till 2100) wind speeds at different heights (10, 30, 50, 70, 90 and 110 m) would be insufficient to install wind turbines in these regions. With wind speeds below 4.5 m/s (lower than the cut in wind speeds for commercial wind turbines on the market) and a capacity factor between 7.5 and 18.4% found, this study concludes that on long-term basis wind energy would not be efficient for large scale generation. Therefore, wind energy will not be considered as a potential energy source in this research.

A-6.6 OTEC:

An important requirement for feasible exploration of OTEC energy is the temperature difference of around 20 degrees Celsius between the surface water and deep ocean water. According to Vega L.A. (2012), this condition is present within the exclusive Economic Zone (EEZ) of Suriname (*figure A-15*).

Figure A-15: The exclusive Economic Zone (EEZ) of Suriname (Strok, 2015).

Strok (2015) designed in his study a 1 MWe closed cycle OTEC plant at a distance of 300 km from the shore of Suriname: from this distance on the desired temperature difference (around 20 degrees Celsius) can be achieved. It is found that the EEZ has a total area of 96,238 km^2 and therefore a total energy potential of 24 TW. Based on an overall theoretical efficiency of 6% for OTEC, the total estimated OTEC potential would be 1440 MWe (Strok, 2015).

However, given the large distance from shore to the proposed OTEC plant, the installation of OTEC power plants are not considered as viable within current conditions.

A-6.7 Wave Energy

Wave energy is harvested as a result of interactions between the wind and the ocean, where waves tent to increase as they propagate (TU Delft, 2018). Compared to other types of renewable energy sources, wave energy tent to be more predictive and therefore is better suitable as a source for baseload. According to the study conducted by Mørk et al. (2010), the Exclusive Economic Zone of Suriname has a wave energy potential around the 10 – 15 kW/m (*figure A-16)*

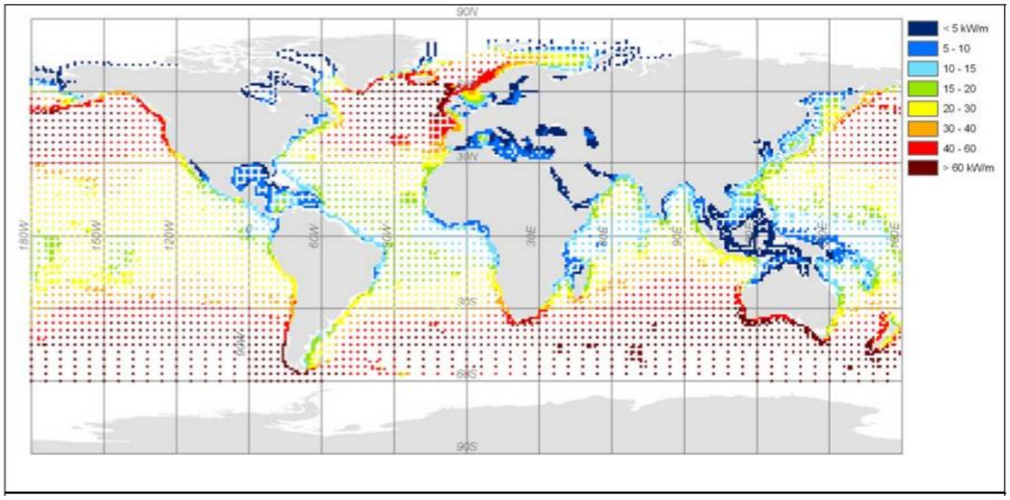


Figure A-16: Annual global theoretical wave energy potential.

From this study, the best wave energy conditions (red to brown dots) are found in medium-high latitudes and deep waters (from 40 meters deep on) (Alcorn, 2013). Accordingly, wave energy farms in these regions (China, Australia, Norway etc.) achieve a levelized costs of electricity between EUR 330-630/MWh, which are already higher than types of renewable energy sources. Compared to the wave conditions found for Suriname, the potential implies that this technology is (economically) not viable and thus will not be considered in this research.

A-6.8 Tidal Energy

Tides are the waves caused by the gravitational interaction of the moon and the sun. As result, energy can be harvested from the mechanical movement. According to a study conducted by Rambaran Mishre (2015) to harvest tidal energy in Suriname, measurements were taken in the Nickerie river, which is located in the North-Western part of the country. *Figure A-17* shows the tidal influences in the Nickerie River between the 1st of January 2015 till 28th of February 2015. The maximum water level difference found here was around 3 meters: the higher the water level difference is, the greater the incoming and outgoing water flow will be (Rambaran Mishre, 2015).

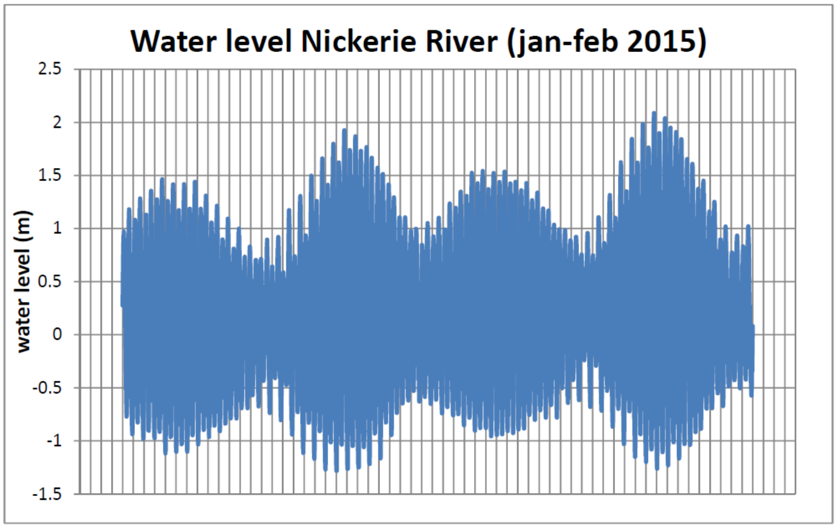


Figure A-17: Water level variation in the Nickerie River. Source: Professor S. Naipal (Rambaran Mishre, 2015).

Considering that all major rivers in Suriname have their outfall in the Atlantic Ocean and experience tidal influences mean that there is a huge potential resource of energy present to be harvested. Consequently, free flow turbines are the most ideal option to harvest tidal energy in the rivers of Suriname as this technology does not need expensive tidal barrage and has less environmental impacts compared to conventional tidal plants. Based on experimental data found by Rambaran Mishre (2015), the selected turbine could deliver 2 kW of continuous power for 2 periods of 5.5 – 6 hours a day. The delivered (mechanical) power of 2 KW corresponds with a water velocity of 0.67 m/s (*figure A-18*).

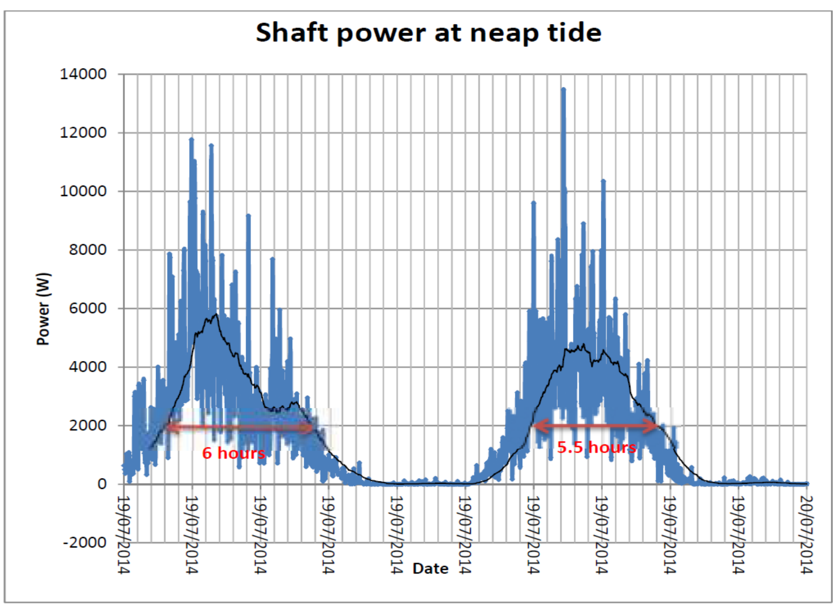


Figure A-18: Delivered shaft power in 24 hours' time (Rambaran Mishre, 2015)

However, since no electrical conversion of this harvested mechanical power was executed during this research, the electrical power conversion must be considered yet. According to the IRENA report written by Alcorn (2013), it is technically possible to build and construct free flow turbines based on the water velocity.

Since no technical dimensions for the free flow turbines and all the rivers in Suriname having their outfall in the ocean could be found, it is estimated that the total installed capacity for harvesting tidal energy will be around the 60 – 100 kW. This is based on the width of around 100 meters for small rivers and more than 1500 meters for the large rivers. These turbines deliver the estimated power wherever the water velocity is around the 0.67 m/s (Rambaran Mishre, 2015). Since most of the energy consumers live along the rivers (villages in the interior part of Suriname) and in the coastal area, the advantage here is that transmission costs will be significantly lower.

Although there is a technical feasibility for this technology, this study will not consider tidal energy as a potential energy source since this kind of (low) technical potential is (economically) not yet viable.

A-6.9 Energy savings in Suriname

This subsection elaborates on the possible savings on energy in the following categories: residential, industrial and transportation. Data obtained for this summary is heavily derived from the study conducted by Lachman (2018). He tried to cover as much data as possible from local institutions (statistical data) as well as internationally published data. The study elaborates on the energy efficiency and savings by assessing a top-down analysis in combination with a bottom-up analysis. The Top-down analysis consists of a numerical tool from the American Council for an Energy- Efficient Economy (ACEEE) that "uses metrics for policy and performance in order to determine the extent an economy uses energy efficiently" (Lachman, 2018). Based on his analysis, Suriname scored 27 out of a total of 100 points. Compared to industrialized country e.g. Germany, a scorecard of 72.5 points is earned (Eichhammer, et al., 2016). This implies that there is a need for improving the energy efficiency in Suriname.

In the bottom-up analysis Lachman (2018) emphasizes on the energy consumption per sector: transportation sector, electricity market and the LPG market (stoves). This analysis covers the following areas:

- transportation sector: by using traffic intensity figures from the NEA (2010). Lachman (2018) also used other studies to assess through empirical data how much fuel can be saved by introducing more fuel-efficient cars, car sharing and tools which result in minimizing traffic congestion.
- Street lighting: from the current system switching to a more energy efficient streetlight infrastructure. This can be achieved by replacing the conventional light bulbs with energy saving LED lights and motion activated lights.
- Housing: using statistical data from ABS (2014) on the amount and types of houses in Suriname, combined with the quantified benefits of efficiency saving measures, the amount of energy that can be saved is calculated
- Appliances: using data on appliances in use (ABS, 2014), and the average gap between best performing appliances and these appliances in use the energy efficiency potential is estimated.

Overview of the average annual energy savings potential per sector:

Sector	**Sub-system**	**Intervention**	**Energy savings per annum**
Electricity system	Street lighting (NV EBS)	Switching to LED	19 GWh
		Light dimming and switching	Between 2 GWh and 7 GWh
	NV EBS (utility company)	Replacing old transformers with new ones	54 GWh
	Electricity generation	Switching from diesel to Heavy Fuel oil (HFO)	56 GWh
Housing (residential)	Appliances	Behavior interventions (plugging off while not in use)	4.5 GWh
Transportation	Road transportation	Traffic intensity monitoring Car – sharing Eco- driving	727 GWh

Table A-1: Energy savings potential in different sectors in Suriname (Lachman, 2018).

Based on the estimated energy saving potential per year in each of the systems / sectors (*table A-1)*, the transportation sector has the largest share of energy savings potential.

Appendix A-7: Historical data on electricity consumption in Suriname

Figure A-19 was consulted (IEA, 2014) to estimate the historical electricity demand.

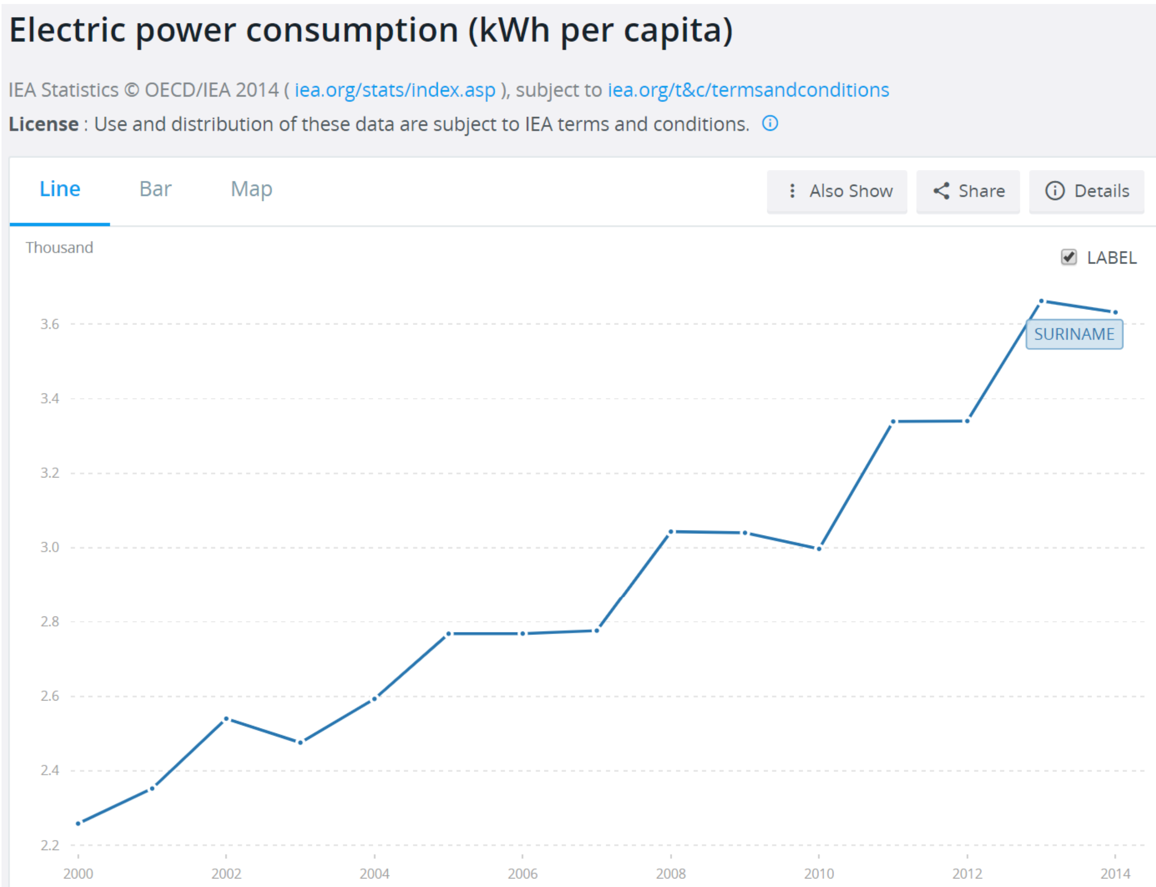


Figure A-19: overview of the overall- growing electricity demand between 2000 and 2014 in Suriname.

Appendix A-8: Costs estimations

In this appendix, the assumptions for calculating the installed costs of the proposed technical changes is described.

Based on IRENA (2012), the following values are used to calculate the installation costs regarding the hydropower plant(s) (*figure A-20*).

	Installed costs (USD/kW)	Operations and maintenance costs (%/year of installed costs)	Capacity factor (%)	Levelised cost of electricity (2010 USD/kWh)
Large hydro	1 050 – 7 650	2 – 2.5	25 to 90	0.02 – 0.19
Small hydro	1 300 – 8 000	1 – 4	20 to 95	0.02 – 0.27
Refurbishment/upgrade	500 – 1 000	1 – 6		0.01 – 0.05

Figure A-20: costs of installed hydropower plants (IRENA, 2012)

According to the IRENA (2012), large hydropower plants are plants with an installed capacity of at least 100 MW.

Total Transmission Line Cost = [(2014 Base Transmission Cost) x Conductor Multiplier) x (Structure Multiplier) x (Re-conductor Multiplier) x (Terrain Multiplier) + (ROW Acres/Mile) x (Land Cost/Acre)] x (# of Miles)

The total length of the new transmission line will be around 350 km (roughly 220 miles) in the first scenario. Based on the formula of the total transmission line costs, the estimated average is around $16,000/mile based on a single 138 kV line.

Storage selection:

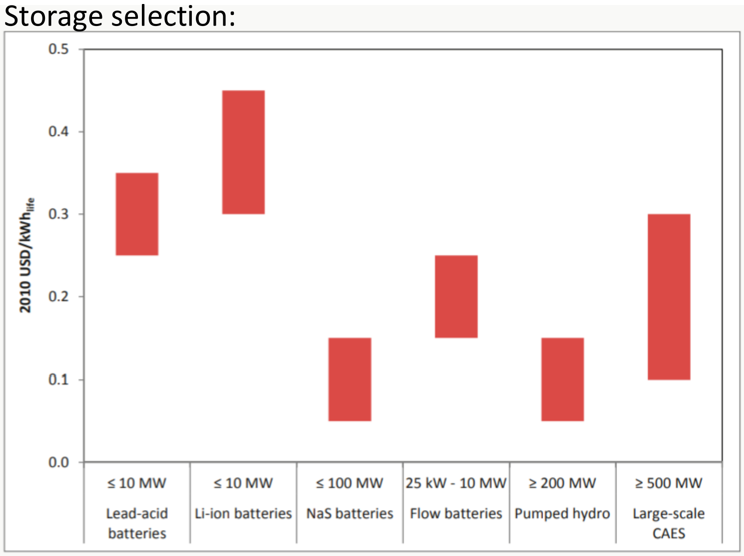


Figure A-21: lifecycle costs comparison of different electricity storage systems. Source: (IRENA, 2012)