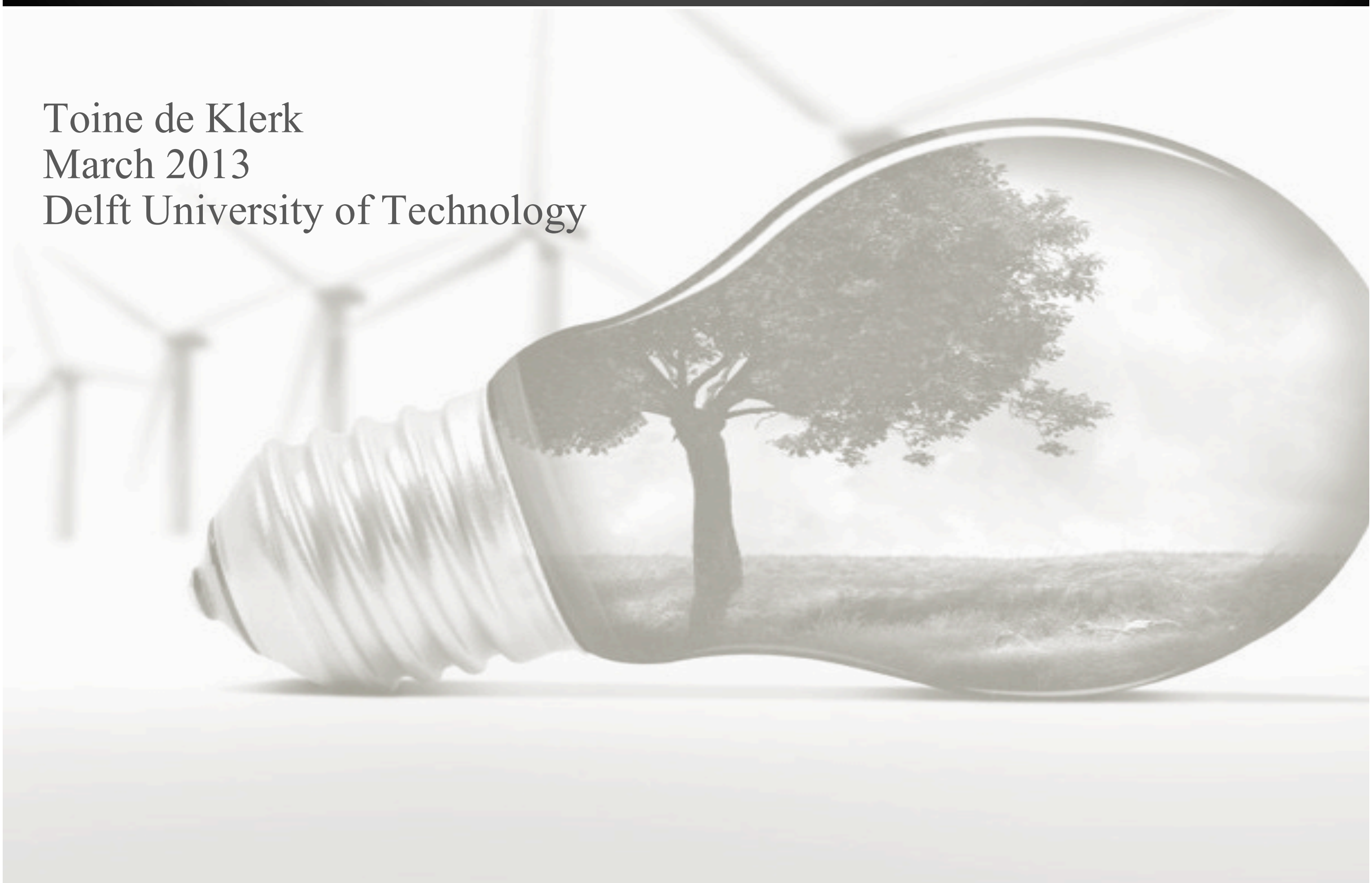
Wind Integration in Island Isolation

A mixed method research approach on facilitating the integration of additional wind energy on the Aruban electricity system through demand-side management

Toine de Klerk
March 2013
Delft University of Technology



Wind Integration in Island Isolation

A mixed method research approach on facilitating the integration of additional wind energy on the Aruban electricity system through demand-side management.

Master graduation thesis
System Engineering, Policy Analysis and Management
March 2013

Author: Toine de Klerk
Student number: 1264656

Committee:
Chair: Prof. dr. ir. M.P.C. Weijnen
Delft University of Technology, Faculty of Technology, Policy and Management
Section of Energy and Industry

1st supervisor: Dr. ir. L.J. de Vries
Delft University of Technology, Faculty of Technology, Policy and Management
Section of Energy and Industry

2nd supervisor: Dr. A.F. Correljé
Delft University of Technology, Faculty of Technology, Policy and Management
Section of Economics of Infrastructures

External supervisor: Ir. R. Westerga
TNO: Netherlands Organisation of Applied Scientific Research
Department of Service Enabling & Management, Groningen

Preface

This report is the end result of my Master Thesis project conducted at the Caribbean Branch Office of TNO (CBOT) located in Oranjestad, Aruba. This project was the final step in acquiring the MSc. Grade in System Engineering, Policy Analysis and Management from the faculty of Technology, Policy and Management at the Delft University of Technology.

My scientific interest and personal love for renewable energy technologies has been settled a long time ago and has grown ever since. So, when I first heard that TNO was spreading its wings to support the government of Aruba in achieving a sustainable energy system I was thrilled and took the opportunity to design my graduation project around this. Fortunately, it was possible to match my interest in wind energy with the interests of TNO in the potential of demand-side management (DSM).

Despite, the smooth sailing at first I was challenged in many fields; familiarizing myself with new methodologies and theories, my skills in conducting a scientific research project and my ability to fulfil such a project in a foreign environment. This project is beyond a doubt the most challenging and inspiring work I've ever done and required serious amounts of discipline and self-motivation. Looking back I'm very satisfied with the results. I'm convinced that the outcomes of this research are a valuable contribution towards the integration of all sorts of renewable energy technologies for the Aruban electricity system as well as other isolated systems.

This thesis would not have been possible without the support of many. I would like to thank my 1st supervisor Laurens de Vries for his dedication and continuous support throughout the project. Laurens was enthusiastic from the moment I called him and asked him to be my supervisor. Despite, that he missed all fun on the "happy island" he remained genuinely interested and supportive. I owe much gratitude to the entire CBOT team, and in particular Jan Ebbing and Ivan Flanegin who have given me the opportunity to work autonomously on such a cool project and at the same time supporting me whenever needed. I will never forget the team meetings, the philosophical talks over coffee and the dynamic working environment that contributed to this amazing experience. Furthermore I would like to thank Richard Westerga, my supervisor at TNO, who has been there from the start and introduced me to the world of DSM. I would also like to thank my 2nd supervisor, Aad Correljé and the chair of my committee, Margot Weijnen for their continuous support and straightforward feedback. Special thanks goes out to Pieter Bots, developer of the software-modelling package Linny-R. I really appreciate all the effort Pieter has put into adapting Linny-R specifically for my research considering that he was not even part of my graduating committee.

In general, I would like to thank TNO for giving me the opportunity the conduct this research at Aruba and write this thesis under their supervision in Delft. During my time in Aruba I've conducted interviews at 11 organisations. I appreciate all the time and effort these organisations have into answering my questions. Special thanks goes out to the employees of the Aruban utilities, Elton Lampe (ELMAR) and Carlos Raps (WEB) for providing me with all the necessary information.

Last but not least I would like to thank the people who supported me during the past years in Delft. In the first place, I am very grateful to my 'main sponsors' my parents. I feel privileged with both the freedom and support my parents and family have given me during my studies. Dad, if you are out there somewhere, I know you would be proud. Furthermore, I consider myself to be very fortunate to be surrounded by fantastic friends and to have found a soul mate in Floored during the past years. After seven amazing years, it's finally time to move on and I think this thesis reflects the broad range of skills I've gained throughout the years. It was a great pleasure to study and be student in Delft.

-Enjoy reading this thesis

Tine de Klerk

Delft, March 2013

Executive Summary

Introduction and research objectives

The exploitation of the abundant renewable energy potential in most Small Island Developing States (SIDS) will be crucial in the near future for safeguarding their access to affordable energy, and the preservation of their eco-system. However, these islands are dealing with the intermittent nature of renewable energy sources by only compensating the energy generation part of the electrical network. This limits the penetration level of RETs based on the flexibility of the supply side. Traditional solutions to prevent such situations require investments in expensive fast spinning reserves, interconnections or storage technologies. Another option to compensate the variable output of RETs is demand-side management (DSM). Although the theory behind this subject is well documented, little attention has been given to actual SIDS-cases where DSM is considered as a means to facilitate the integration of RETs. In addition there is not enough evidence to provide reliable estimates of the technical and economic potential and to account for the customer's willingness to participate. This research focuses on the island of Aruba. Aruba is currently one of the few SIDS with significant penetration of wind energy (14%). The build of a second wind park is high on the political agenda and could increase this share to 30% giving rise to the following uncertainties: 1) the technical capabilities of the electricity system to maintain the balance between supply and demand with additional wind energy and 2) the potential of DSM to facilitate this. Therefore, the following research question was formulated:

> *To what extent can DSM facilitate the integration of additional wind energy on the Aruban electricity system?*

Research methodology

In order to answer the research question a mixed method research approach is used. This research is divided into 4 distinct phases. In the *first* phase of this research, the characteristics of the Aruban electricity system are described by means of a system analysis. The analysis clarifies the delineation of this research and defines the solutions space. A thorough understanding of the electricity system and the implications of another wind park form the backbone of this research. This information is further used as input for a quantitative simulation model. The operational difficulties associated with extra wind energy are addresses by analysing and choosing a suitable DSM program. This choice is based on an extensive literature review on various incentive- and price-based DSM programs. In order to execute these programs different types of loads are controlled. This research places a particular focus on load-profiles that can offer large, available and constant loads. In order to find these loads, historical data of the demand of electricity is analysed.

The *second* phase covers the technical-physical complexity of the AES system. This part of the study is mainly based on a Unit Commitment (UC), formulated as a Linear Programming (LP) problem. For the development of the model a software-modelling package called Linny-R was used and enables us to model, implement and adapt simple and complex LP problems through an attractive and easy to use interface.

The *third* phase covers the quantitative analyses that are performed by applying the model designed in phase 2. The technical analysis is performed to identify technical requirement that must be met in order to increase system flexibility. The technical feasibility of the proposed DSM measure is determined by these requirements. Furthermore, a cost benefit analysis is performed to identify the economic feasibility of the proposed DSM measure compared to other suitable supply side measures.

The *fourth* phase covers the qualitative analysis that is performed by interviewing various General Managers and Directors of Engineering of large hotels. These interviews identify various barriers and opportunities that shape the willingness to accept the proposed DSM program. Socio-economic theories are used to structure the interview and to create assumptions on the behaviour of the hotels.

The Aruban electricity system

The system analysis shows that the net flexibility of a power system is based on the flexible resources (i.e. generation, storage, DSM and interconnection) and the flexibility required (i.e. variable demand, variable supply and contingencies). Therefore isolated power system operating inflexible generation with no capacity of DSM programs or storage will find it difficult to successfully integrate variable generation. This research shows that the flexible generation of Aruba is low because it is physically limited by the use of heavy fuel oil. Furthermore, no capacity of storage, interconnection(s) or DSM programs is operated in the system. The level of flexibility required is moderate to high due to a moderate variability in demand and a current moderate variability in wind output. Operational problems in compensating the variable output of wind energy occur during periods of sudden and severe wind decreases.

DSM programs and loads

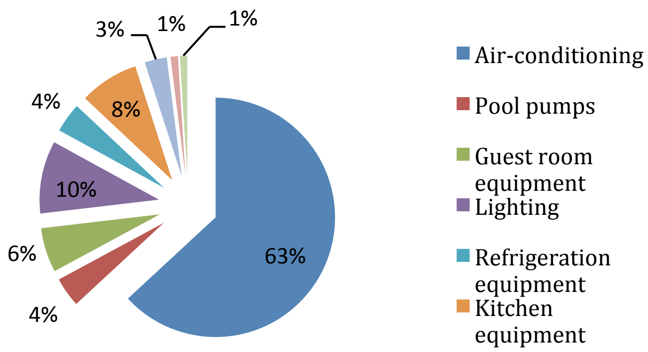
In generating power, the concept so far has been straightforward: if society demanded more power, the power companies would simply find a way to supply electricity to end-users by building more generation facilities. This concept of doing business has been labelled as supply-side management. Demand-side management describes the activities designed to influence customers' energy behaviour in such a way that the load shape curve of the utility company can be modified to produce power in an (technically and economic) optimal way. This research describes that the choice for a DSM program depends on what type of problem DSM intends to solve. This can be determined by two factors: the load shape objective and the time-scale. The load shape objective can include the following objectives: decrease load, increase load or shift load. The time-scale largely defines within what time (seconds, minutes, hours, weeks) the load has to be altered (see below table). Some DSM programs are characterized with short response times (seconds) other with response times of days and months. The classification of DSM programs is described as direct or indirect. In incentive based programs (IBP), the aim is to alter the electricity consumption of certain load profiles in response to a system event (i.e. variable output of wind energy). In a classical IBP a utility is able to control the customer's appliances, usually based on a contract, during critical system conditions. In addition the participating customers receive participation payments usually as a bill credit or discount rate for their electricity usage. In market based programs participants are rewarded for their performance depending on the amount of flexible load they offer during critical system conditions.

Table 1-1: Classification of DSM programs.

Incentive based programs (IBP)	*Price based programs (PBP) (indirect)*
• Classical (direct) ○ Direct load control ○ Interruptible/ curtailment programs • Market based ○ Demand bidding ○ Emergency DR ○ Capacity market ○ Ancillary services market	• Pricing programs ○ Time of use tariff ○ Real time pricing ○ Critical peak pricing ○ Extreme day pricing ○ Extreme day critical peak pricing • Rebates and subsidies • Education programs

Price based programs (PBPs) assumes that customers will alter their consumption of electricity in response to changes in its pricing. The pricing in these programs is dynamic, so the rates are following the real costs of electricity. In general, the customer's load is not interrupted and no (financial) penalties are amerced when loads are not altered. In this research, the integration for wind energy is the key driver for het interest in DSM. The research shows that the reliability of the Aruban electricity system is endangered during moments of sudden and severe wind decreases. This requires a DSM measure that is able to decrease loads within a short period of time. This excludes the option of price-based programs because it assumes the voluntary response of customer to an indirect incentive. On the other hand, direct load control programs provide a utility the opportunity to directly reduce the customer's appliances, e.g. water heater, air conditioning and public lighting on a short notice by sending signals. The capacity of the loads and the availability of the loads must be sufficient. The Aruban hotel sector represents 30% of the total electricity demand and 60-80% of this demand is related to air-conditioning load. Therefore this research focuses on the potential of shedding air-conditioning loads of the Aruban hotel industry in compensating sudden and severe wind power decreases.

Figure 1-1: Average electricity use of an Aruban hotel



Technical Analysis

Additional wind energy will affect the reliability of the electricity system, mainly caused by additional variation. To quantitatively assess the effects of additional wind energy the dispatch of generating units, and their characteristics are analysed under demand patterns and wind power output based on historical data. Unit Commitment has been used extensively for the last decades as a means to: simulate the integration of RETs, assess system flexibility and to assess the contribution of DSM to power system flexibility. The modelling approach used in this research is: optimization of supply sources according to a merit order, to supply demand within the technical constraints of the system (i.e. limits on generation capacity, ramp rates, start-up and shutdown times). For the development of the model a software-modelling package called Linny-R is used. The objective function was designed to minimize generation costs, including variable costs and start-up costs. And is expressed in the following formula:

MINIMIZE: $\alpha * P_{unit,1}(t) + \beta * P_{unit,2}(t) + \gamma * P_{unit,x}(t)$

With α being the variable costs per unit of production (measured in \$/kW) at time t related to the production level of $P_{unit,1}$ at time t and so on. Virtual costs were assigned to reflect the actual order in which the production capacity is used. By minimizing this function, the realistic unit commitment order is followed when solving the LP. The following five constraints were considered in the LP formulation. The generation of electricity must be equal to the demand with P_{total} being the total power production (measured in MW) at time t and D_{total} the total demand (measured in MW) at time t (eq.1). The total production level at a certain time is limited by the amount of units that can produce electricity with P_{fossil} being the total amount of electricity that is produced through fossil fuel based units (measured in MW) at time t and P_{wind} the total electricity that is produced by wind energy (measured in MW) at time t (eq.2). Another constraint is that wind energy has priority over fossil fuel based electricity and results in the residual demand that must be compensated by the fossil production (eq.3). The electrical output of a unit is limited by its minimum and maximum capacity with $P_{unit,x}$ being the electricity production of unit x (measured in MW) at time t and a,b being the lower- and upper bound of the units generating capacity (measured in MW). (eq.4). The limited amount of electrical output that can be decreased or increased per time unit is limited by the ramp rates. With $P_{unit,x}(t)$ being the electricity production of unit x at time t *and* $P_{unit,x}(t-1)$ being the electricity production of unit x at time $t-1$ (both measured in MW) and R_{up} and R_{down} being the ramp up and ramp down rate, that limits the increase or decrease of the production of unit x per time-step t (measured in MW/min) (eq. 5-6).

(1) $$P_{total}(t) = D_{total}(t)$$

(2) $$P_{total}(t) = P_{fossil}(t) + P_{wind}(t)$$

(3) $$D_{total}(t) - P_{wind}(t) = P_{fossil}(t)$$

(4) $a \leq P_{unit,x}(t) \leq b$

(5) $P_{unit,x}(t) - P_{unit,x}(t-1) \leq R_{up}$ *as generation increases*

(6) $P_{unit,x}(t) - P_{unit,x}(t-1) \leq R_{down}$ *as generation decreases*

The constraints have been specified according to the unit characteristics presented in the below table. DSM is also incorporated in the model as a virtual reserve that is only dispatched at times of imbalances. This enables us to identify the technical requirements necessary to compensate such imbalances in terms of frequency (#/yr), amount of power (MW) and the duration (min). These identify the technical potential of the shedding of air-conditioning load of the hotel industry.

Table 1-2: Unit characteristics. Source: WEB NV

Characteristics	*Recip[1] (I-II)*	*Recip III*	*VAASA*	*TG[2] 6,7*	*GT[3]*
Ramp up[4]	0,8	0,9	0,6	1,5	1,2
Ramp down	1,5	1,8	1,2	1,5	1,2
Max gen[5]	7	10	6	36	18
Min gen	5	7	5	15	3
Start-up failure	25%	25%	25%	0	0
Start-up time[6]	15	15	30	360	15
Shutdown time	2	2	2	240	15
Min up time	15	15	15	1440	15
Min down time	15	15	15	1440	15

Cost benefit analysis

The economic feasibility of load shedding as a reliability measure depends the on associated costs and benefits compared to other suitable supply side measure. In order to analyse this, the following costs are taken into account: i) capital costs ii) the net present value (NPV) iii) the total annualized costs including a capital recovery factor (CRF). The costs of load shedding are estimated literature study and complemented with current market price information[7]. We have evaluated various non-battery, battery and super capacitor storage technologies according to their applicability on the identified simulation requirements. For each storage technique, the costs of storage, conversion, balance of plant, capital costs, operations and maintenance have been estimated and calculated based on current prices and literature. The economic feasibility for any measure that aims to reduce system intermittency depends on the available capital. As a result, the costs per reliability technology may not exceed the benefits of the additional wind farm itself. Many studies use the notion of 'levelized costs' to analyse the economic feasibility of wind energy. This, as does not account for the additional investments in grid- or reliability measures associated with the integration of additional wind energy. However, this research does incorporate these costs in the analysis and provides a more accurate estimation. The following formula explains the relations between these costs and benefits. Each reliability technology defines an investment scenario. The scenario with the least investment costs results in the highest net system benefits.

(1) Net system benefits = system benefits – system costs
(2) System benefits = reduced fuel costs
(3) System costs = initial investments costs (wind) + grid investments costs + reliability investment costs

[1] Recip phase I&II included 6 generating units, phase III 4 units
[2] TG: Turbine Generators
[3] GT: Gasturbine
[4] Ramp rates in (MW/min)
[5] Generation capacity in (MW)
[6] Various time in (min)
[7] Contact with several private entities that offer the service of load shedding and demand response (see openadr.org)

Customer willingness to participate

The success of such a program depends for a great deal on the willingness of the hotel industry to participate. Therefore several interviews with General Managers and Directors of Engineering were conducted to identify possible barriers or opportunities related to the implementation of load shedding.

Although little is documented on such particular barriers, this research shows that there exist mutual barriers and relations with other forms of DSM. Extensive literature review on barriers to industrial energy efficiency was used to define and explain possible barriers and structure the interviews. The following barriers were used

i. Bounded rationality: suggests that actors are not able to always act fully rational, and that the inability to do so will results in a general state of satisficing, in which solutions that may or not be optimal are chosen if they meet minimum requirements
ii. Financial- and technical risk: risks associated with measures that require large investments may be hedged by short-term payback periods, which lead to less inefficient investments and innovative, non-familiar technologies may be subject to technical risks (unreliability, break-downs, disruptions), which may outweigh the potential benefits
iii. Imperfect information: the lack of information on energy efficiency opportunities may lead to cost-effective opportunities missed.
iv. Hidden costs: engineering-economic studies fail to account for either the reduction in service associated with energy efficient technologies, or the additional costs associated with their use i.e. general overhead costs of energy management, costs involved in individual technology decision and loss of service associated with energy efficient choices.
v. Access to capital: insufficient capital though external and internal resources lead to borrowing and taking loans and to low payback rates or non- investments.
vi. Split incentives: commonly used notion where landlords own property and tenants hire property. In such cases, there is little incentive for both parties to invest in energy efficiency. The landlord passes the electricity bill on through to the tenant thereby incurring no losses. While tenants may not invest to improve the energy efficiency of properties they do not own and pay a fixed electricity costs per month.

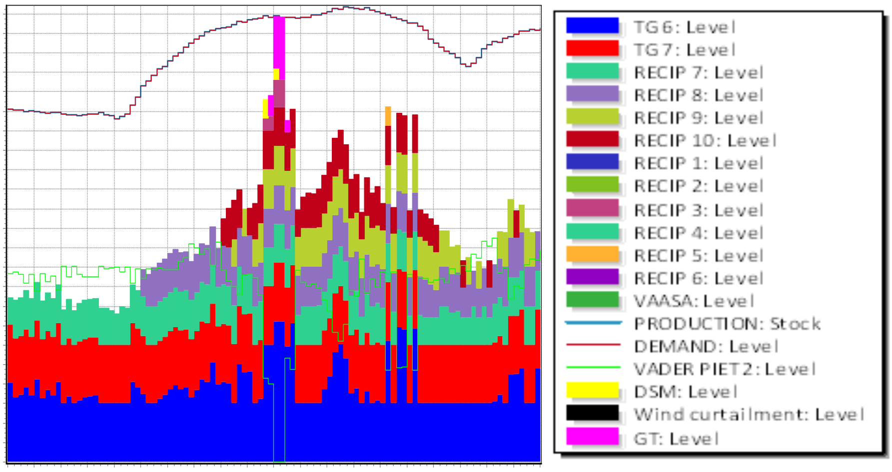
Results: technical analysis

The methodology was applied using a simulation time of a year and with time-step of 10 minutes time-step. The demand and the produced wind power are specified by time-series of historical data (2011) specified per 10 minutes. The additional wind park is modelled as lagging 10 minutes behind on the existing wind farm. The optimization problem was solved using the solver of the software package Linny-R. Three simulation scenarios were performed under various wind generation capacity scenarios, see below table. During the simulations no imbalances occurred for scenarios with 0 and 30MW of wind generation capacity. In total, seven imbalances occurred for the 60MW wind capacity generation. The most severe imbalance amounted to 8MW and lasted for 10 minutes. In addition it is found that the imbalances all occurred during periods of high utilization of reserves combined with a wind decrease between -21 to -25MW per 10 minutes. During such periods, standing reserves are not able to quickly provide sufficient capacity due to the unit constraints. Thus, any solution that aims to mitigate such imbalances must be able to provide at least 8MW of electricity, within 10 minutes for at least 7 times a year. The shedding of air-conditioning load of hotels can satisfy the above-mentioned requirements. Shedding AC load seven times a year does not pose any problems. Furthermore, the capacity of the AC load ranges between 12,7-17,8 MW and it is possible to gradually shut down or idle AC load within 10 minutes.

Table 1-3: Specification of simulation imbalances

Imbalances	*0MW wind*	*30MW wind*	*60MW wind*
Frequency	0	0	7 #/yr
Amount of power	0	0	8 MW
Duration	0	0	10 min

Figure 1-2: Specification of imbalance events during the simulation scenarios



Results: cost benefit analysis

The proposed methodology was applied to calculate the costs of load shedding for 18 of the largest hotels in Aruba and for various suitable storage technologies (flywheels, sodium-sulphur batteries, nickel-cadmium batteries and lead acid batteries according to the specified technical requirements. It is concluded that load shedding is the least-costs solution in providing reliability compared to other suitable storage technologies. As a result, the investment scenario proved to have the highest net benefits $ 6.998.953 (Figure 1-3). The investment is not capital intensive, does not require high upfront costs and is more based on contracts than technologies. The difference in the net system benefits of the load shedding and the scenario with the 2nd highest net benefits (flywheel) can be defined as the avoided system costs (Table 1-4). These costs are substantial and can (partly) be allocated as financial compensation or incentive payments for participating customers in the load shedding program. The utility is able to offer a substantial compensation for the low degree of load services required of hotels, resulting is a strong business proposition.

Figure 1-3: The annualized costs and net system benefit specified per reliability technology scenario

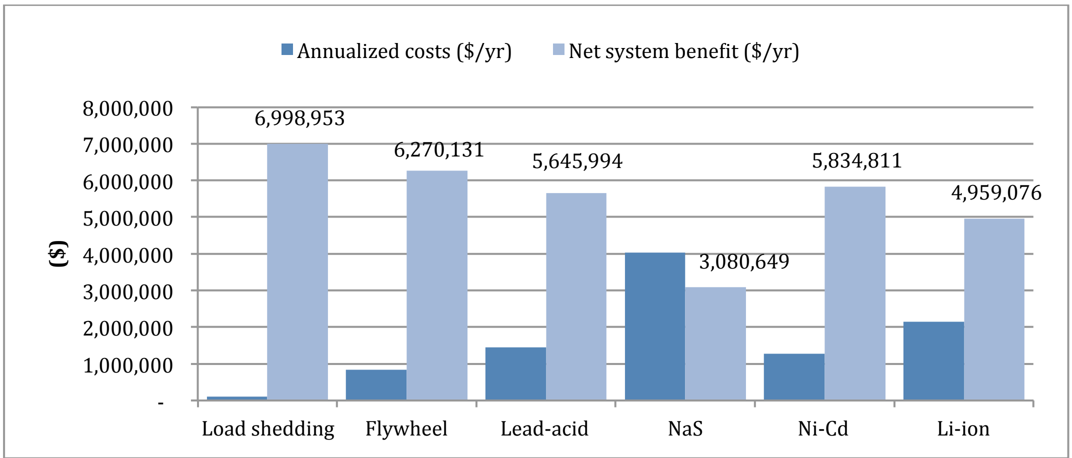


Table 1-4: Avoided annual system costs of load-shedding compared to other technologies

Scenario's	*Avoided annual system costs ($/yr)*
Flywheel	728.822
Lead-acid	1.352.959
NaS	3.918.304
Ni-Cd	1.164.142

Results: customer willingness to participate
Interviewees expressed concerns on the effects of shutting down or idling an AC system for various periods of time on the comfort temperature of the guests and the (in)direct effect on the guest satisfaction. Furthermore, according to the interviewees the guests are known to request rebates and financial compensation or even go to court if the level of service is not up to (their) standards. 70% of the clientele originates from Northern-America and if service is not 100% satisfactory they will require compensation. Another barrier is the technical integration of DSM equipment in the already existing electrical environment of the hotels. Most General Managers were uncertain if this integration is technically feasible and expressed concerns about the responsibility in case of breakdown or malfunctioning. Control of own- and chiller operations was issues mentioned by all the hotels. This is closely related to the issue of responsibility. Many hotels, may agree with load shedding if informed by prior notice. The idea of an utility intervening in their operations raised many technical and institutional concerns. Furthermore, there were concerns that the intervening entity would not have the same incentive and sense of urgency in keeping their guests satisfied. This led to believe that the intervention of 3rd party would be exercised more than strictly necessary. All three of these barriers are caused by a lack of information and institutional coordination.

Table 1-5: Barriers derived out of the interviews

Barriers	*Claim*
Bounded rationality	Issue of load shedding is subordinate to AC services related to guest satisfaction
Risk	Technical risk, risk of integrating load shedding equipment in existing hotel environment (unreliable, damages etc.) Issue of control of own operations
Imperfect information	Lack of information related to load shedding caused reservations and uncertainties
Hidden costs	Uncertainty on the effects of load shedding directly on the guest satisfaction and indirectly on guest compensation.
Access to capital	-
Split incentives	-

Generalisation
Although this research was performed for Aruba, the value of this research is not limited to this island. Similar to this case, most SIDS electricity systems are isolated and currently operate no storage, interconnections or DSM programs. In addition, much of the other RETs are similarly dependent on external factors i.e. temperatures, wind speeds, solar intensity, tides resulting in variable output. As a result, much of the outcomes can be generalized to other SIDS. Despite, the similarities, several results are too case-specific for generalization due to specific unit characteristics, local demand patterns, local wind fluctuations and specific load profiles. The methodology however is highly generalizable and can easily be adapted and conceptualized for other SIDS. This may prove valuable to anyone who wishes to assess the potential of DSM to facilitate other forms of RETs of SIDS. To further increase this value it is recommended to extent this methodology with additional case studies.

Conclusions
Through a mixed method research approach it is found that shedding air-conditioning load of the Aruban hotel industry is a technical and economical feasible DSM program in providing sufficient compensating capability for the variable output of an additional wind farm of 30MW. Despite, the potential, implementation may be hampered by customer related barriers and requires further research. It is recommended to overcome these knowledge-based barriers as well as the uncertainty related to the capacity and ramp rates of AC load by providing information through detailed metering studies, testing or pilot studies.

TABLE OF CONTENTS

1 Introduction

1.1 Background: Aruba's Energy Transition

There are approximately 52 of the about 140 developing countries in the world are islands that have a population of less than 5 million and a very small gross national product (GNP)[2] (see Appendix-A for an overview). These countries have a special set of economic, political, geographic and environmental characteristics that set them apart from the larger developing countries. Insular and remote regions present some specific problems related to energy supply and share similar characteristics related to energy supply including [3]:

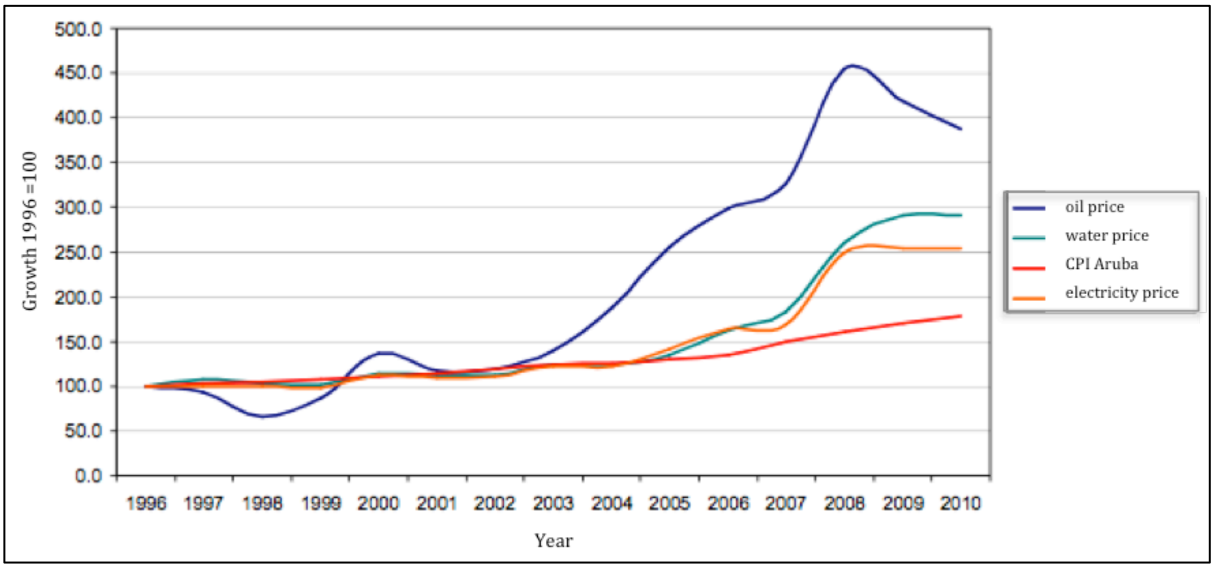
- Lack of conventional energy sources
- Abundance of renewable energy sources
- Small dimension of the electricity market
- High dependency on fossil fuels
- Diseconomies of scale

The combined effect of these characteristics makes power production for SIDS not only extremely expensive but also bears financial risks in the long term [4-7]. Interestingly, SIDS have the opportunity to harness energy out of their renewable sources which, as indigenous resources, do not require costly fuel imports [8-11]. The exploitation of such resources will be crucial in the near future to safeguard the access to affordable energy and the preservation of the islands eco-system.

However, they are dealing with the intermittent nature of these renewable energy sources by only compensating the energy generation part of the electrical network. This limits the penetration level of RETs based on the flexibility of the supply side. The other option for compensating the variable output of RETs is demand side management (DSM), and even though the theory behind this subject is well documented, little attention has been given to SIDS cases where DSM is considered as a means to facilitate the integration of RETs. In addition there is not enough evidence to provide reliable estimates of the technical and economic potential and to account for the customer's willingness to participate.

Aruba, part of the Kingdom of the Netherlands, is such an SIDS and faces a dependency of 76% on fossil fuels (heavy fuel oil) [12]. The high dependency on oil and the growing scarcity of oil are reflected by the rising electricity price in Aruba as presented in Figure 1-1. Within 15 years the electricity price has risen by almost 250%.

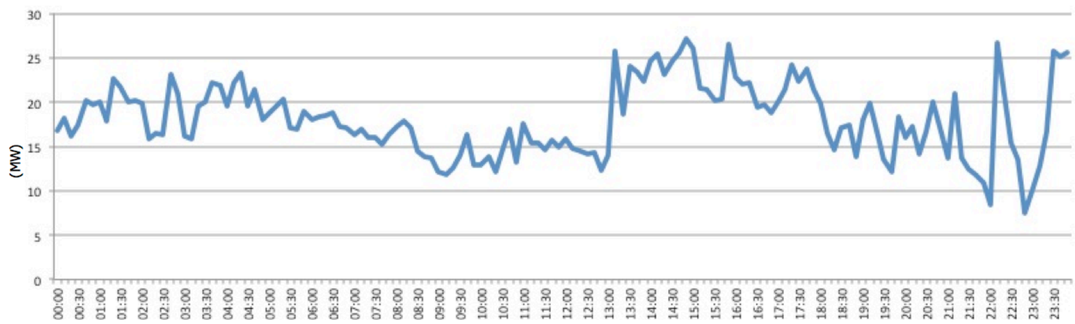
Figure 1-1: Increasing prices of utility services on Aruba. Source: [13]



More interesting is that the latter 14% of the electricity is generated by the 30MW 'Vader Piet 'wind farm [13]. This makes Aruba one of the few SIDS with significant penetration of renewable energy technology (RET). In addition the Aruban government has set ambitious standards in terms of the exploitation of renewable energy sources (RES) and has set targets for a renewable penetration between 70-100% by 2020. Wind energy is especially targeted on the short-term to increase this level to 30% and combat against high-energy prices and related price volatility.

Recent developments announce the build of another wind park 'Urirama' with the same capacity as the existing wind farm (30MW). A crucial element in this transition is often whether or to what extent the renewable energy technology is feasible in the envisioned context and if it can be implemented running into (technical) difficulties. There are many concerns about the flexibility, variability (see Figure 1-2), non-controllability of wind energy and the impact this has on the system ability to maintain the balance between demand and supply [14]. Utilities that operate electricity systems without variable RETs are only required to balance the variable demand, the Aruban utility however has to balance both the variable demand and the variable supply thereby requiring more flexibility of its system with an increase in variable RETs.
As illustrated in Figure 1-2, wind power output can fluctuate rapidly ranging from 26 MW to 8MW within the hour and power prediction forecasting is limited. Currently, only supply side solution such as fast spinning- and standing reserve units are considered as a means to balance the variable output of wind energy [15].
However, the technical ability of an electricity system to compensate this is restricted by the ability of its generating units to alter their power output accordingly, up to the point where imbalances may occur. In electricity system it is essential that power generation (supply) and the electrical load (demand) are close to equal every second to avoid overloading or blackouts of network components, which impose high costs and severe damages [16]. In Appendix-0 two newspaper articles are attached of both a blackout on Aruba and one of its neighbouring country Bonaire. Traditional solutions to prevent such situations require investments in expensive fast spinning reserves, interconnections or storage technologies .

Figure 1-2: Wind power production 'Vader Piet' per ten minutes on an average day (3 January 2011). Source: WEB N.V.



An alternative solution consists on the use of demand side management (DSM), which can have the double effect of reducing electricity consumption and allowing greater efficiency and flexibility in the grid management, namely be enabling a better match between supply and demand [17]. Instead of balancing the supply and demand by influencing the supply side within the value chain, DSM influences the demand of electricity. DSM involves the planning and implementation of utility activities designed to influence the time pattern and/ or amount of electricity demand in ways that will increase customer satisfaction, and coincidentally produce desired changes in the utility's system load shape [18, 19].
Many forms of DSM can be applied with a wide range of possible actions and may be aimed at addressing the following issues: reduce energy consumption, cost reduction, environmental and social improvement, reliability and network issues (thereby reducing the effects of wind power variability), improved markets [20].
In this research, the goal is to assess the potential of DSM in compensating the variable output of wind energy. However, the technical potential of the DSM programs of methods depends to a large degree on the characteristics of the electricity system, including factors as: the state of system reliability and flexibility, unit characteristics (ramp rates, start-up times etc.), the variability of the demand, the variability of wind power, etc. [21]. This highlights the need for a system analysis, where such aspects are identified. Besides, the technical potential the overall potential of a DSM method or program is determined by the economic feasibility and to what extent it can provide mutual benefits for the utility and the participating customer. According to Gellings et al. [19]: the success of such a program depends for a great deal on the willingness of customers to participate in the program. Due to the multidisciplinary nature of the assessment, this research proposed a mixed method research approach that relies amongst others on: linear programming (system analysis), a costs benefits analysis and a quantitative analysis on the willingness of customers to participate in the proposed DSM program.

1.2 Aruban Energy Policy and Research Demarcation

This research is written for TNO: Netherlands Organisation for Applied Scientific Research and in particular the Caribbean Branch Office of TNO (CBOT). TNO has opened its international office in Aruba in 2011 to support the country of Aruba in achieving the transition towards an island with a sustainable energy generation. This research is also consistent with the activities of the government of Aruba and in particular , the Aruban Ministry of Finance, Communication, Utilities and Energy and the executive agency Utilities N.V., which are responsible for overall functioning of the energy sector.
Ever since the increasingly high oil prices, electricity and energy have been an important subject in Aruban politics. De Vries et al. (2010) have distinguished three main policy objectives regarding energy supply industries [22] that also apply to the electricity system of Aruba: 1) reliability (short- and long term) 2) affordability and 3) environmental responsibility.
The high dependency on oil and the rising prices mainly affects the affordability of electricity. The current Cabinet led by Prime Minister Mike Eman has taken on an active attitude regarding the electricity sector and plans on developing Aruba into a sustainable country for the following reasons:

- Less dependency on HFO for its electricity production. The price of this fossil is high, subject to fluctuations and destined to increase over time.
- Lower energy costs for Aruban households. Energy cost represent 20% of the Consumer Price Index (CPI).
- Lower average energy consumption. Current consumption per household is high, ca. 9,000 kWh per year. In addition the cooling of private areas, water production, refining and transportation cost of consumer goods require large amounts of energy.
- The abundance of indigenous renewable energy sources is suitable for exploitation.
- Aruba's economic engine is driven by tourism. Sustainable energy offers opportunities for economic diversification.

Sustainability targets for Aruba in 2020 have been structured according to the Trias Energetica Model, see Figure 1-3. The model functions as a structured approach to prioritize and identify a coherent set of measures, including: 1) Energy efficiency: this step focuses on identifying measures that result in energy savings. Examples include: use of energy efficient appliances or increasing consumer awareness in energy use in order to influence behaviour 2) Increasing share of sustainable energy: the energy needs are met through a mix of fossil and sustainable energy. In this step the objective is to take measures that maximize the share of sustainably produced energy and 3) Optimizing use of fossil fuels: part of the energy needs will be met through fossil fuels (even if it is only reserve capacity). In this step the objective is to take measures that utilize this component in the most efficient manner in order to keep its use to an absolute minimum.

Figure 1-3: Strategy of trias energetica

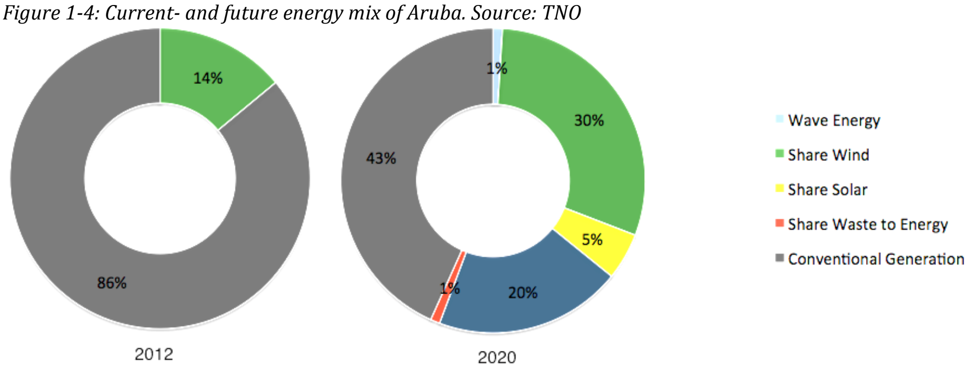
Aruba's long-term objective is to increase its renewable energy penetration to at least 70%, realize the potential for consumer energy efficiency of 35% and in general reduce dependency on fossil fuels as soon as possible without compromising grid stability and impairing existing investments. For a more specific approach, see the means-end diagram in Appendix-D. Below, the different energy targets specified per RETs for 2020 are presented.
As already stated in the introduction, this research limits itself to the target of increasing the share of wind energy to 30% and at the same time maintain the reliability of the system through DSM.

Table 1-1:Sustainable energy production targets for 2020.

Source	Share	Share Energy	Installed Capacity/ CF*
Share wind	30%	(± 210 GWh/annually)	(± 60 MW)/ 40%
Share solar	5%	(± 35 GWh/annually)	(±12 MW)/ 33%
Share waste to energy	1%	(± 7GWh/annually)	(±2 MW)/ 50%
Not yet included for 2020 but part of the ambition			
Wave energy	0,5%	(± 3,5 GWh/annually)	(± 400 kW)/ 100%
Sea Water Air Cooling	20%	(± 140 GWh/annually)	(± 16MW)/ 100%

* *Capacity factor. The factor with which the nominal production capacity will need to be multiplied in order to determine the actual production potential.*

Figure 1-4: Current- and future energy mix of Aruba. Source: TNO



Reliability of an electricity system relates to the *technical* aspects of providing electricity i.e. the availability and quality of the electricity. Affordability relates to the *economic* aspect of electricity i.e. the price of electricity ($/kWh). And environmental responsibility relates to the *social* aspect of electricity i.e. the acceptability of generation techniques, emissions and externalities. As argued by De Vries et al. (2010), in practice trade-offs between is inevitable. This is similar for the energy policy of Aruba, the implementation of additional wind energy may stabilize Aruban electricity prices, as the implementation of the Vader Piet wind farm has proved, yet the variability of additional wind energy causes operational difficulties in maintaining reliability. Consequently reliability, comes at a cost, which raises the question how much society is willing to pay for a given level of reliability [22]. This illustrates the importance of a multidisciplinary perspective when analysing measures that have influence on the electricity supply industry. In order for a government to maintain a reliable, affordable and environmental responsible energy supply system such measures should also be technically and economically feasible and socially acceptable. Therefor in this research, the technical, economic and social aspects that relate to DSM are analysed. The research methodology is presented in paragraph 1.7.

The geographical scope of this research is limited by the physical boundaries of the island, see Figure 1-5. Facilitating any form of electricity interrelates with the entire value chain of an electricity supply industry, from production to consumption. However, since the focus of this research is on facilitating wind energy through DSM the analyses performed will not take into account transmission and distribution aspects (Figure 1-6). Production and consumption (load) are strongly related in DSM measures. Technical, economic and social aspects related to this research are also limited by the value chain demarcation.

Figure 1-5: Geographical demarcation, map of Aruba

Figure 1-6: Value chain demarcation

1.3 Problem Statement & Research Objectives

The island of Aruba is currently one of the few SIDS with significant penetration of wind energy (14%).. Currently, Aruba deals with the intermittent nature of wind energy by only compensating the energy generation part of the electrical network, which limits the penetration level of based on the flexibility of the supply side. The build of a similar wind farm is high on the agenda, although the implications on the reliability of the system and the requirement for additional flexibility are unknown.
DSM is proposed as a means to compensate the variable output of wind energy. However due to the above-mentioned knowledge gap and the lack of knowledge related to the economic feasibility and the possible benefits it may generate for the utility and the customer the potential of DSM cannot be assessed. Taken this and the information presented in the preceding sections into account, the following problem statements is formulated:

It is unclear if the current configuration of the Aruban electricity system is able to facilitate the integration of another wind park and what the potential of DSM could be in this regard.

This problem is driven by two main uncertainties: uncertainty about the technical capabilities of the electricity system to continuously supply its consumers with electricity with additional wind energy and uncertainty about the potential of DSM as a technical, economic and social feasible solution to mitigate possible implications of additional wind energy.

Need for a simulation tool that handles system complexity
By modelling and simulating the electricity system it is possible comprehend the system complexity and understand the functioning of the system. In this research it is imperative to thoroughly understand the configuration of the system and the implications of additional wind energy on the system, because this defines requirements for DSM. The configuration of the system determines to a large degree the overall flexibility of the system. Flexibility of an electricity system is determined by the generation mix, the dispatch sequence and the variability of demand and supply. This highlights the need for a simulation tool where such complexities can be incorporated and assessed in a model. Furthermore by making use of a simulation tool it is possible to assess the effects on the system reliability in different scenarios of wind generation capacity.

Economic feasibility
The economic feasibility of DSM is analysed in order to clarify where DSM financially stands in comparison with (traditional) supply side options. Supply- or demand-side measures all require investments; some measures require more investments than others. In order to safeguard the affordability of an electricity system the most cost-effective measures should be implemented. To illustrate that DSM can be more cost efficient than traditional supply side options, the study of Strbac et al. (2009) indicates that only in cases of a system combining inflexible generation with significant amounts of unpredictable wind generation DSM techniques might become competitive in providing reserve over traditional supply side options [14].

Utility and customer's willingness to accept DSM
The 'success' of DSM depends for a great deal on the perception of the utilities towards DSM on the one hand and the perception of the customers (electricity consumers) towards DSM on the other hand. The objective is to analyse these perceptions and identify possible barriers or opportunities that may obstruct or lead to win-win situations. For demand-side management to be suitable it has to be able to cope with the social context in Aruba. Vashista et al state that: *"DSM implementation involves different actors with conflicting objectives and different implementation strategies, with varying implications in effectiveness, cost, feasibility, efficiency and stakeholder acceptance. This necessitates a critical analysis of the range of alternative strategies within the demand-side management program to determine preferred strategy or a combination of strategies from a specific stakeholder point of view ranging from generation, transmission to consumers."* [23].

1.4 Research Relevance

First of all, the main contribution of DSM can be found in reducing and stabilizing electricity prices for its end-users by enabling a higher penetration of renewable energy technologies (i.e. wind energy). Such additional penetration reduces the need for expensive HFO and lower the electricity price. Secondly, the implementation of DSM can avoid investments in expensive fast response reserves (i.e. storage technologies) thereby avoiding system costs, which can be allocated to benefit end-users. Thirdly, DSM may prevent brown- and blackouts of the electricity system thereby saving expensive network components and high costs.

Although, this research is performed using Aruba as the problem situation, the value of this research may not be limited to this island only. Similar like Aruba, there are ample SIDS that strive towards harnessing renewable energy out of their indigenous natural resources mainly due to rising oil prices. In some islands, fuel import bills now represent up to 20% of the Gross Domestic Product (GPD) catalysing the national ambition of high shares of renewable energy technologies (RETs) even more. Comparable to the Aruban electricity system, most island electricity system are isolated and operate no storage, interconnections or DSM programs. It this research, it is found that the combination of such system characteristics and the ambition of increasing the share of renewable energy technologies pose problem situations and requires additional investments in system reliability. DSM can prove a feasible solution in this respect. By contextualising the research findings in the general field can provide answers to what extent the outcomes of this research may be used in other SIDS to assess the potential of DSM to facilitate the integration of RETs.

The proposed DSM measure, in this research is the direct control shedding of air-conditioning load of the Aruban hotels industry. However, the method of load shedding is currently only applied in electricity system, which face capacity problems. In this research, load-shedding was found technical and economic feasible. Therefore, additional value can be found in a new application of an already existing DSM method.

1.5 Research Questions

Based on the problem situation and the research objectives formulated in the preceding sections, the main research question is formulated:

To what extent can demand-side management facilitate the integration of additional wind energy on the Aruban electricity system?

The main research question is answered by answering the following sub questions, which are divided in 5 distinct research phases.

phase 1: descriptive

1. What are the characteristics of the Aruban Electricity System?
2. How can demand-side management, in theory, facilitate the integration of wind energy in the Aruban electricity system?
3. Which load profile represents the highest amount of potential as to integrate wind energy?

phase 2: modelling

4. What are the requirements and objectives for the modelling approach?
5. What modelling technique can be used to reach these objectives?
6. How is this general modelling technique applied to the Aruban electricity system?

phase 3: quantitative analyses

7. To what extent is the identified DSM measure a technical feasible solution?
8. Is the identified DSM measure an economic feasible solution, taken into account the system costs and benefits of additional wind energy?

phase 4: qualitative analysis

9. Which barriers emerge when changing the energy demand of the corresponding load profiles?
10. What interventions would be needed to overcome implementation barriers?

phase 5: discussion and generalisation

11. To what extent can the outcome of this research also be used in other SIDS in order to assess the suitability of demand-side management as a measure for integrating renewable energy technologies?

1.6 TNO and its objectives

This research is executed under the supervision of TNO: Netherlands Organisation for Applied Scientific Research and in particular the Caribbean Branch Office of TNO (CBOT). TNO has opened its international office in Aruba in 2011 to support the country of Aruba in achieving the transition towards a sustainable energy supply together with (local) companies, government and universities. The transition to increased sustainable energy will require major investment in both (renewable) energy generation capability and modernization and upgrading of the distribution grid. Making sound investment decisions will require careful consideration of technical and economic factors and a proper policy framework.

TNO has noticed that different stakeholders could perhaps tend to different techniques to achieve such a transition. In order to sharpen the view on the development of the electricity system, TNO has been working on a systems level approach to help understand implications of different scenarios on the system and its impacts on the stakeholders operating within the system. Amongst others, it requires definition of a comprehensive set of energy mix scenario's to determine how supply will match demand. This analysis touches on the following issues: 1) Supply-side: assessment of existing renewable and non-renewable capacity, planned capacity, potential for Distributed Generation (DG), possible impact of renewable

energy sources other than wind/solar 2) Demand side: assessment of future demand, potential for demand side management and potential for energy efficiency.
This research contributes to a number of factors:

- Description of the Aruban electricity system
- Identification of the generation portfolio and the unit characteristics
- Simulations analysis on the technical ability of the Aruban electricity system to maintain the balance between supply and demand with the integration of an additional wind park
- Assessment of the technical potential of DSM to mitigate imbalances due to additional wind park
- Assessment of the economic potential of DSM compared to various suitable storage techniques by means of a cost benefit analysis

Furthermore, this research identifies a part of the potential for demand-side management by analysing the current demand. The results suggest that the current DSM potential for Aruba is a compensation capability between 13,5-23MW within 10 minutes, if only the largest consumer, i.e. the hotel sector, is involved. In addition the willingness of the hotel industry has to accept this DSM program has been thoroughly assessed through interviews.

1.7 Research Outline and Methodology

Throughout this research, a number of interviews have been conducted at 11 different organizations with 16 different persons. These interviews have been very helpful in understanding the overall functioning of the Aruban electricity system and the implications of renewable energy technologies in an isolated system. Furthermore it created a better understanding of the different roles and the different interests of the utilities and consumers in an electricity system. The list of organization that is interviewed is presented in Appendix-0.

In Figure 1-7, the structure of this thesis is presented. The sub questions are divided into 5 distinct research phases. In the *first* phase, the characteristics of the Aruban electricity system are described by means of a system analysis. The analysis clarifies the delineation of this research and defines the solutions space. A thorough understanding of the electricity system and the implications of another wind park form the backbone of this research. This information is further used as input for the quantitative model (phase 2). The results and conclusions of the system analysis are presented in chapter 2. In chapter 3, the operational difficulties associated with extra wind energy are addresses by analysing and choosing a suitable DSM measure. In chapter 4, the demand of electricity is analysed in order to identify a specific group of load-profiles that have sufficient available loads to offer. As a result, the combined air-conditioning load of the hotel industry is found suitable.
The *second* phase covers the technical-physical complexity of the AES system. This part of the study is mainly based on a Unit Commitment (UC), formulated as a Linear Programming (LP) problem. The modelling approach is defined as: *optimization of supply sources according to a merit order, to supply demand within the technical constraints of the system (i.e. limits on generation capacity, ramp rates, start-up and shutdown times).* For the development of the model a software-modelling package called Linny-R was used and enables us to model, implement and adapt simple and complex LP problems through an attractive and easy to use interface. In chapter 5, Linear Programming (LP) is introduced as a means to simulate electricity generation in general. In chapter 6, the constraints and main assumptions are specifically applied for the Aruban electricity system.
The *third* phase covers the quantitative analyses that are performed by applying the model designed in phase 2. In chapter 7 a technical analysis is performed to identify the effects of an additional wind farm on of electricity system. This analysis is performed to identify technical requirement that must be met in order to increase system flexibility. The technical feasibility of the proposed DSM measure is determined by these requirements. Chapter 8, presents a cost benefit analysis the proposed DSM measure and other suitable supply side measures to identify the economic feasibility.
The *fourth* phase covers the qualitative analysis that is performed by interviewing various General Managers and Directors of Engineering of large hotels. These interviews identify various barriers and opportunities that shape the willingness to accept the proposed DSM program. Chapter 9 presents a theory that is used to structure the interview and to create assumptions on the behaviour of the hotels.
Finally, in *fifth* phase (Chapter 10) the results are discussed and a generalisation of the results is presented. Chapter 11 reflects on the way of working, the methodology used and the choices made in this research. Finally, in chapter 12 conclusions and recommendations are stated.

Figure 1-7: Research approach and methodology

Phase 1: Descriptive

Input

1. What are the characteristics of the Aruban electricity system? (CH 2)

2. How can demand-side management, in theory, facilitate the integration of wind energy in the Aruban electricity system? (CH 3)

3. Which load profile represents the highest amount of potential as to integrate wind energy? (CH 4)

Method & output:

System Analysis
- Understanding of the Aruban electricity system
- Identification of challenges that correspond to additional wind energy implementation

Literature study
- Understanding of DSM
- Identification of possible DSM measure to mitigate previous identified challenges

Network/demand analysis
- Identification of suitable load profiles/ customers

Phase 2: Modelling

4. What are the requirements and objectives for the modelling approach? (CH 5)

5. What modelling technique can be used to reach these objectives? (CH 5)

6. How is this general modelling technique applied to the Aruban electricity system? (CH 6)

Literature study
- Suitable modeling tool

Data & Specification
- Main system constraints

Verification & Validation
- Model of the Aruban electricity system

Phase 3: Quantitative Analyses

7. To what extend is this identified DSM measure a technical feasible solution? (7)

8. Is the identified DSM measure an economic feasible solution, taken into account the system costs and benefits of additional wind energy? (CH 8)

Technical Analysis
- Identification of the effects of wind energy on the technical ability of the system to balance demand and supply
- Identification of technical requirements to mitigate the effects
- Technical feasibility of DSM as a suitable mitigation measure

Economical Analysis
- Identification of suitable supply side measures
- Identification of the costs of all suitable measures
- Economic feasibility of proposed DSM program

Phase 4: Qualitative Analysis

9. Which barriers emerge when changing the energy demand of the corresponding load profiles? (CH 9)

10. What interventions would be needed to overcome such barriers (CH 9)

Desktop research
- Theory on barriers in changing energy behaviour

Interview
- Barriers, perceptions, interests, opportunities
- Implementation strategies

Phase 5: Discussion and generalisation

11. To what extent can the outcome of this research also be used in other SIDS in order to assess the suitability of demand-side management as a measure for integrating renewable energy technologies? (CH10)

Synthesis
- Discussion of results
- Generalization of results
- Reflection of results (CH11)
- Conclusions & recommendations (CH12)

2 The Aruban Electricity System

An analysis of the electricity system (AES) requires a thorough understanding of the broader context, being the unique characteristics of the electricity supply industry and the environment in which it operates. This chapter aims to answer the following question:

What are the characteristics of the Aruban Electricity System?

In this case the unique character is an isolated system and refers to the fact that electrical supply systems of islands do not have interconnection possibilities and lack natural resources like the mainland. As a result this chapter touches lightly on implications of an isolated system and on the design of the electricity market. Section 1 presents a general overview of the electricity market of Aruba and its actors. Section 2 decomposes the system into generation, transmission and distribution where the characteristics and configuration of the conventional- and renewable generation are identified. Important subject in this section is the notion of flexibility. Section 4, presents a qualitatively assessment of the flexibility of the system and states challenges related to the integration of another wind farm. Finally, section 5 states conclusion.

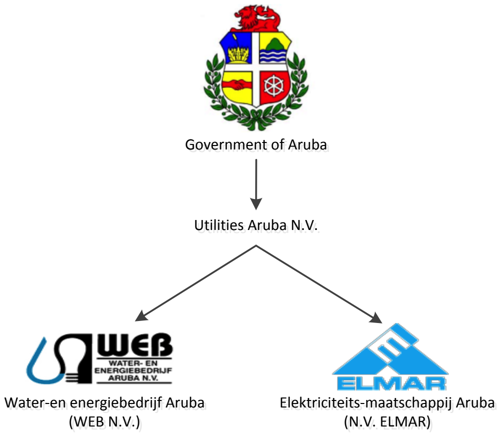
2.1 General Overview

A large number of possible options for electricity markets exist. Martina (2009) argues in his dissertation on 'Regulation in Splendid Isolation' that in practice however, four basic models emerge and although they may come in different variations, each power sector reform option can be classified as belonging to one of these four models [24]: 1) Monopoly – the traditional status quo, where a single entity generates all electricity and delivers it over a transmission network to distribution companies or customers.
2) Single buyer – where a single agency buys electricity from competing generators, has a monopoly on transmission and sells electricity to distribution and large power users without competition from other suppliers. 3) Wholesale competition – where multiple distributors buy electricity from competing generators, use the transmission network to deliver to their service areas under open access arrangements, and maintain monopolies on sales in their service areas and 4) Retail competition – where customers have access to competing generators, directly through a retailer of their choice, and transmission and distribution networks operate under open access arrangements. In Table 2-1 the options are summarized.
The monopoly model best describes the electricity market of Aruba. In Aruba the "Water- en Energiebedrijf Aruba N.V." (WEB) is the only company responsible for the generation of electricity on the island. Next to the production of electricity the main tasks of WEB involves the management of dispersed generators in the system to maintain suitable voltage and frequency and to prevent system breakdown. Although WEB is the Transmission System Operator (TSO), it does not operate or control the transmission grid. The "N.V. Elektriciteits Maatschappij Aruba" (ELMAR) is the only company responsible for the transportation and distribution of electricity on the island. ELMAR controls the transmission and distribution and does not interfere with the responsibilities of the TSO. ELMAR is the Distribution Network Operator (DNO). ELMAR buys its electricity from WEB and consequently sells it to its consumers. The tasks of the DNO involve metering and billing of electricity consumption, and the distribution of electricity from the high voltage network (transmission) to the low voltage network and finally to its consumers. Transmission and distribution are considered natural monopolies for competition in these sectors would result in duplication of existing network structures [24]. Both WEB N.V. as N.V. ELMAR are private separate entities and operate under the ownership of the holding Utilities Aruba N.V. with the Government of Aruba as its only shareholder, as depicted in the below figure.

Table 2-1:Taxonomy of electricity market model. Adapted from: [24]

Feature	**Monopoly**	**Single buyer**	**Wholesale competition**	**Retail competition**
Competing generators?	No	Yes	Yes	Yes
Choice for retailers?	No	No	Yes	Yes
Choice for customers?	No	No	No	Yes

Figure 2-1: Organisational chart



2.2 Functional Decomposition

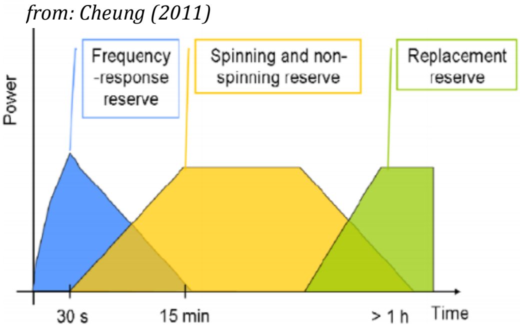
The electricity system is a stand-alone power system, which generates, transmits and distributes all of its demanded electricity to its end consumers. As seen in the previous section different actors control different parts of the electricity system. As proposed in [22] "*it is useful to distinguish, on the one hand, the physical, technical side of the system and the economical, institutional side on the other hand. The technical system consists of the physical chain through which electricity flows, from the power plants in which it is generated, through the transmission and the distribution networks (with all their supporting equipment) to the apparatus in which the electricity is consumed, the 'load'*." Figure 2-3 describes the electricity system according to this statement. The double pointed arrows indicate which actors control which parts of the physical system and also indicate the corresponding activities and/ or responsibilities. The arrows with the single point indicate the technical details of the physical system. This figure is based on the Aruban electricity system. The blue large value chain represents not only the elements within the system but also the flow of electricity.

2.2.1 Conventional Generation

This section, presents the configuration of the conventional generation. WEB produced in 2011 a total of 910GWh electrical power. Of this ca. 770GWh is distributed to end-users and ca. 710GWh is registered to the end users. The difference is (partly) attributable to transport losses (+/- 7%). The pairing of variable demand and continuous supply requires that WEB retains excess capacity to meet peak in demand. The demand for electricity is subject to random variation in both the short and the long term. At the same time, to satisfy customer's expectations, supply must be continuous, reliable and supplied with sustained frequency (60 Hz) and voltage (110 volts). Thus a system operator's responsibility entails the need to balance power fluctuations and ensure power quality at all times – including during scheduled or unforeseeable interruptions. The duration of power fluctuations can range between milliseconds to a few hours to a few days. To cope with all scenarios, the system operator must have a range of ancillary reserves in the generation portfolio to maintain system stability, regulation and in order to cope with worst-case scenarios. Ancillary services are generally divided into three categories according to how quickly they can ramp up or down its production to meet demand and/ or variable supply [25].

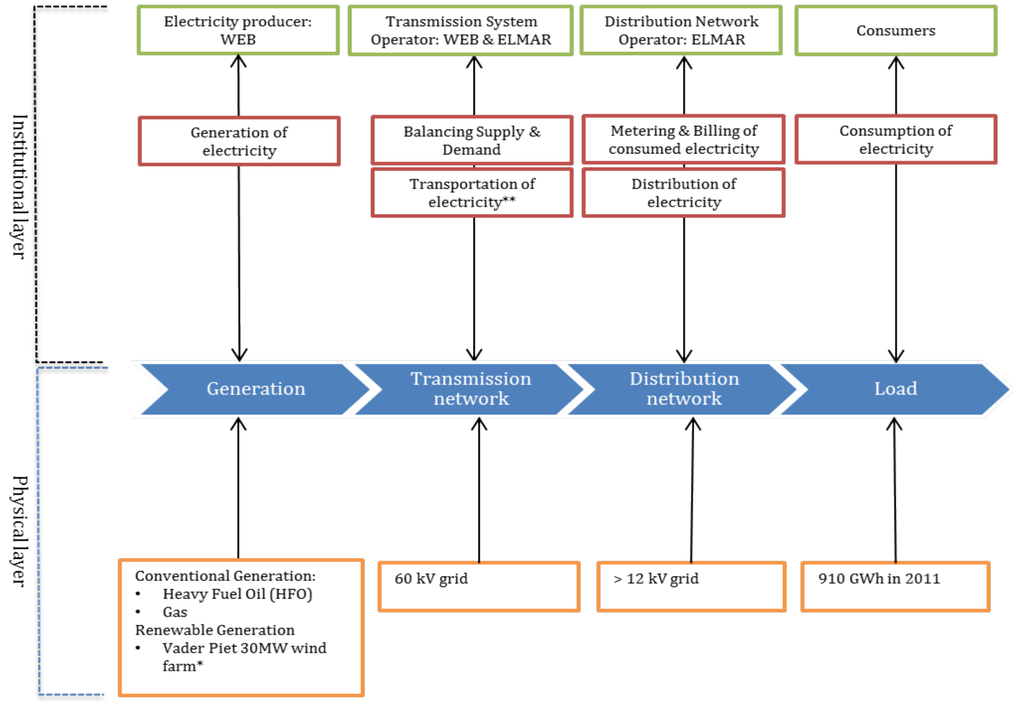
- Frequency response reserves: Primary generating units that are usually online and synchronised. They can ramp up or down production very quickly (within a few seconds to minutes) to respond to frequency disturbances.
- Spinning- and standing reserves: Secondary generating units may or may not be online but can ramp up or down within a relatively short timeframe (within 10minutes to a few hours).
- Replacement reserves: Tertiary generating units that are usually offline; they require more time (hours to a few days) to start up or shut down in response to load changes.

Figure 2-2: Overview of electricity reserves. Adapted from: Cheung (2011)



The total current installed generation capacity of WEB includes: 11 reciprocating engines, 2 turbine generators, one gas based generator and the Vader Piet wind farm. Combined this installed capacity accumulates to over 214 MW and is much higher than the peak demand of 130MW (see Table 2-2).

Figure 2-3: Diagram of the Aruban electricity system. Adapted from: de Vries et al. [22]



*An Independent Power Producer (IPP) produces the wind power and is sold to WEB N.V.
**WEB controls the 60 kV network to San Nicolaas and the Vader Piet wind farm.

All unit characteristics of the generation portfolio are shown in Table 2-2. The **frequency response reserve** of WEB is represented by one of the turbine generators (TGs). At times of stable demand and stable wind power production these turbine generators (TG 6 & 7) produce an output of 16 MW each. If wind power production should rapidly decrease (wind fall) i.e. by 10 MW or demand should the turbine generator would make up for the loss in production by ramping up their production of one of the TGs to 26 MW. The **spinning- and standing reserves** in isolated power systems, typically equates to power available from fast-start up generators. The spinning and standing reserves of WEB are represented by reciprocating engines (recips) and a gas turbine. At times that the demand exceeds the produced output of the TGs the recips can be brought online. The recips have a higher efficiency and should ideally be able to start-up (100% capacity) or shutdown within matter of minutes. This however, is not always the case due to the use of heavy fuel oil (HFO) as the predominant use of fuel (see Box 2-1). The **replacement reserves** of WEB are represented by Turbine Generator 3, which will only be brought online if one of the other turbine generators (TG6,7) needs replacing due to scheduled- or unscheduled maintenance.

.

Box 2-1: Heavy Fuel Oil

Heavy fuel oil is used as the main source of fossil fuel on Aruba. HFO is the less valuable fraction of crude oil and has complexities when utilizing it as a source for electricity generation. Due to its high viscosity and density, heavy fuel oil must be heated to reach the correct injection viscosity to ensure optimal combustion and engine performance [1]. The ignition quality of heavy fuel oil can vary. Low ignition quality may cause trouble at engine start-up and during low-load operation, particularly if the engine is not sufficiently preheated. In addition low ignition quality may also result in long ignition delay and may also cause a fast pressure rise and very high maximum pressures [1]. As goes for the utilization of HFO in the generation mix of Aruba, various problems are encountered ranging from:

- Adhered HFO on the fuel pumps results in start-up problems for reciprocating engines. According to WEB the start-up failure rate of the reciprocating engines is 25%
- Minimum stable generation of recips is 80% of capacity. Recip engines only run stable from 80% - 100% capacity, any lower than this rate and the engines perform substandard.
- Low ramp up ramp down rates, recips perform below factory standards. (A ramp rate is the amount of load you can add or decrease to a generator per unit of time. Power plant operators may want to increase or decrease load as fast as possible at times, the ramp rates limit the amount of megawatts of lad you can add or decrease.)
- Contamination of engines and waste heat boilers due to frequent start-up procedures poses negative impact on the efficiency and flexibility of the engines.

Table 2-2:Unit characteristics data. Obtained from: WEB N.V.

Units	Recip I&II*	Recip III**	VAASA	TG 3***	TG 6,7	GT	WtE
Start up ($/start)	42	54	33	381	381	977	Modelled as constant 5MW
VOM ($/MWh)	12	14	12	8	8	46	
Heat rate at 75% capacity (GJ/MWh)	8,6	8,5	9	13,9	12,6	12,5	
Heat rate curve	N/A	N/A	N/A	N/A	N/A	N/A	
Ramp up (MW/min)	0,8	0,9	0,6	1,5	1,5	1,2	
Ramp down (MW/min)	1,5	1,8	1,2	1,5	1,5	1,2	
Max generation (MW)	7	10	6	38	36****	18	
Min generation (MW)	5	7	5	20	15	3	
Start-up failure rate	25,0%	25,0%	25,0%	0,0%	0,0%	0,0%	
Maintenance rate	10,0%	10,0%	10,0%	0,0%	0,0%	3,0%	
Forced outage rate	7,5%	7,5%	15,0%	0,0%	0,0%	3,0%	
Start-up time (min)	15	15	30	360	360	15	
Shutdown time (min)	2	2	2	240	240	15	
Min up time (min)	15	15	15	1440	N/A	15	
Min down time (min)	15	15	15	1440	N/A	15	

*Reciprocating engines phase I&II consists of 6 units
** Reciprocating engines phase III consists of 4 units
***TG3 backup in case of maintenance
****TG7 max generation is 16MW, restricted constant base-load

2.2.2 Renewable Generation

Renewable energy generation on Aruba is supplied through the "Vader Piet" wind farm, which has been operational since December 31, 2009. The wind farm consists of ten 3.0 MW Vestas V-90 turbines placed on the southeast part of the island at the edge of the Arikok National Park near the sea. NuCapital and its principles are the majority owners and developers of the wind farm. They form a non-public entity and operates as an Independent Power Producer (IPP), in which WEB is the sole-off taker of their produced electricity. Vader Piet has a nominal capacity of 30MW. This number indicates the installed capacity, the total power that can be generated in theory. The power capacity factor should be added into this equation. In 2011 the wind farm produced a total of 112 GWh of electricity. The capacity factor for this wind in 2011 was: 0,43%[8]

$$\frac{112.000\ MWh}{(365\ days) * (24\ \ hours/day\ ) * (30\ MW)}\ =\ 0{,}43\ \%$$

This factor determines that effectively 12MW capacity remains of the nominal capacity of 30MW. The total distributed annual electricity is 746 GWh for the entire island. This brings the share of wind power to 15%. The more variation in the output of wind power the more WEB must balance this by ramping up/ down their TGs or dispatching/ shutting down their reciprocating engines. Figure 2-4 illustrates the wind power production of the Vader Piet wind farm for an average day (3rd of January 2011) specified per 10 minutes.

Figure 2-4: Wind power production Vader Piet per 10 minutes on an average day (3 January 2011). Source: WEB N.V.

To illustrate the difference in variability of wind and the difference in the implications this variability causes, two specific events are analysed that relate to the above figure. These events show that a sudden increase of wind energy poses less technical problems than a sudden decrease of wind energy. *First*, between 13.00 and 13.30 the wind production suddenly increases from 12 MW to 25,5 MW, requiring a decrease of 12,5 MW within a short amount of time, under the assumption that the demand is constant. *Secondly,* between 22.00 and 22.30 the wind production suddenly decreases from 26MW to 8MW, requiring an increase in production of 18MW within a short amount of time, under the assumption that the demand is constant. There are several reasons why a sudden and significant increase in wind production on Aruba poses less technical problems than a sudden and significant decrease of wind production. First of all, WEB is able to curtail an excess of wind production by setting certain set point so that an increase of wind energy is gradually integrated. Secondly, according to the unit characteristics of the generation portfolio WEB is able to decrease its production much faster than it is to increase its production. When confronted with a sudden increase in wind energy WEB can chose to completely shut down or partially ramp down a generator, both options taking less time than starting up or ramping up a generator (see Table 2-2). The higher the variability of wind energy, expressed in MW per minutes, the more difficulties this poses for operational control. This is in line with the opinion of Carlos Ras – Technical Support Engineer of WEB who states that:

"Balancing the supply and demand under variable output of Vader Piet causes operational problems. A large degree of the difficulties related to wind energy are caused during severe and sudden decreases of wind production. It is at those moments that the turbine generators are ramped up and the reciprocating generators must be dispatched quickly to avoid imbalance. Although a fast increase of wind energy can also cause problems, the setting of set points can control the increase of wind output."

8 For the Netherlands the correction factor is 21% due to the less favourable winds compared to Aruba.

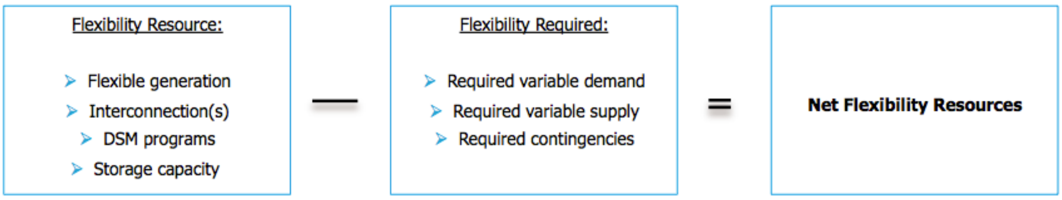
Next to the variations of wind power, it is important to identify how much of these sudden and severe decreases occur during a specific period of time. By analysing the change in wind power output of a year) it is possible to identify the frequency of power fluctuations over a specific time period. This is illustrated further in chapter 7.

2.3 Flexibility of the electricity system

Electricity systems are designed to constantly match supply and demand of electricity. In order to do so, an electricity system consists of various technical subsystems, including: units. Hence, the ability of an electricity system to constantly match supply and demand is inherently determined by the technical limitations of these system components. Within the system, different units exist to provide for the demand in electricity and differ in: fuel, capacity, ramp rates, minimum up- and downtime, failures rates during start-ups, start-up costs, variable costs and efficiency (see Table 2-2).
In order to compensate for the variable output of wind energy units are required to operate more flexibly or may limit the penetration level of wind energy. The flexibility of an electricity system can quantitatively assessed by the following formula:

$$\textit{Flexibility resources} - \textit{Flexiblity requirements} = \textit{Net flexibilty resources}$$

Figure 2-5: Net Flexibility overview



2.3.1 Flexibility Resources

Although net flexibility is a notion that is hard to quantify at this stage it may be possible to classify an electricity system in terms of low, moderate or high net flexibility. In chapter 7, the technical ability of the electricity system to cope with additional wind energy (flexibility required) is quantitatively assessed. The following aspects determine the level or availability of the flexible resources: 1) flexible generation, 2) interconnection, 3) DSM programs and 4) storage capacity. Flexible generation relates to the ability of the conventional generation portfolio to respond to fluctuations in demand or supply. Many factors restrict the physical ability of generating units including: minimum and maximum stable capacity, the start-up/start-down time, ramp rates, minimum up- and downtime and the general availability (maintenance, failures etc.). The flexibility of the current generation of the electricity system can be derived from Table 2-2 that quantifies all characteristics. Generally, the turbine generators provide the base-load and are under normal conditions always online. Their ramp rates are 1,5MW/min. That means their amount of power can be altered within a relative short amount of time. However, the characteristics of the recip engines show a high percentage of start-up failures (25%), low start-up times (15 – 30 min) and low ramping ability (0,6 – 0,9 MW/min). Despite, the large amount of generators the substantial failure rate determines a low to moderate flexibility of the generation.

Interconnection may allow for a greater geographical spread of variable wind production, so that the total variability between two systems will be less than the variability of each system by itself [26]. As a result, interconnections have been highlighted as potentially facilitating the integration of wind generation. Currently, the electricity system of Aruba is not interconnected with other electricity systems.
DSM programs allow for greater efficiency and flexibility by enabling a better match between supply and demand [17] as stated in the introduction. Needless to say, currently no DSM programs are operate by WEB. Storage capacity may allow for an increase in flexibility because dedicated storage plants (e.g. pumped hydro, compressed air energy storage, batteries, etc.) allow for more integration of variable energy sources by storing excess of renewable power during off-peak periods and supplying this power during peak periods [27]. No storage capacity is currently operated on Aruba.

2.3.2 Level of flexibility required

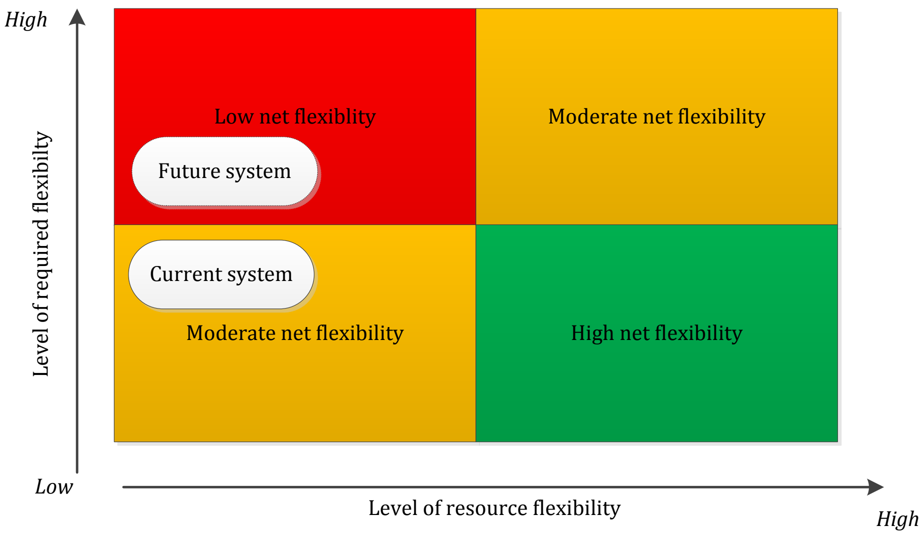
Electricity systems are designed to constantly match supply and demand, and are therefore constraints by 1) the required variable demand, 2) required variable supply and 3) required contingencies. Although the demand for electricity may be forecasted, actual demand varies posing a need for flexibility in an electricity system. The electricity demand of Aruba is analysed in chapter 4, and varies on an average day from 80MW to 110MW (Figure 4-5) requiring at least 30MW of extra capacity to be dispatched during that time. The level of variable demand can be characterized as moderate. In addition to variable demand, variable supply (i.e. wind energy, solar pv) also requires additional flexibility of an electricity system to cope with its non-dispatch able behaviour. The required flexibility depends for a great deal on the variability of the generation technology and the penetration share. Further in this research, the variability of wind energy is analysed (in chapter 7) and currently the share of wind integration is 14%. With the build of the additional wind park the penetration would increase to 30%. Required contingencies relate to utilities accounting for the probability of forced outages by carrying extra reserves. This is a reliability standard. The required contingency reserves equals to 6-8% of the total demand for most utilities. As a result, not all generation units are available. During this research, the issue of contingencies is not taken into account. For information, see paragraph 5.2.2-Constraints out of modelling scope.

2.3.3 Net Flexibility Resources

Isolated power system containing mostly generation units with long start up times and low ramp rates and without DSM programs or storage will find it more difficult to successfully integrate variable generation than in well interconnected power systems, that utilize DSM programs, storage capacity and contain many generation units which can start-up and ramp quickly.

For this case, the potential of the flexible generation is physically limited by the use of HFO and there is no availability of storage, interconnection(s) or DSM programs. Furthermore the level of flexibility required is moderate to high due to a current moderate variability in demand and a moderate share of wind energy The general low availability of flexible resources and the moderate to high level of flexibility required results in a low to moderate net flexibility of the electricity system.

Figure 2-6: Degree of net flexibility of the Aruban electricity system.



If in the future, the share of renewable energy increases under the same generation portfolio as the current system, the required flexibility will even further increase. This will result in an even lower net flexibility of the electricity system. As described in the previous sections the operational difficulties lie in those moments of sudden and severe wind power decreases. With the build of another wind park the frequency and intensity of those moments are bound to increase, posing even more operational difficulties. It is at those times that WEB needs to increase production with a significant amount of electricity within a short period of time. However, the flexible generation of WEB may not be adequate in achieving this operational objective. To further substantiate this, recent studies (KEMA, CRA) (undisclosed) indicate that the reliability cannot be safeguarded with the build of another wind park

2.4 Conclusions

What are the characteristics of the Aruban Electricity System?

The Aruban Electricity system can be defined as an isolated electricity system, with a low flexible generation portfolio that is constrained by the use of HFO fuel. Due to the absence of interconnections, DSM programs and storage capacity the overall level of flexible resources is low. Current level of flexibility required is moderate to high, mainly caused by the variable output of the Vader Piet wind farm and to a lesser degree the variable demand pattern.

It is found that due to the low flexibility of the system an already large degree of operational problems are caused during periods of sudden and severe wind energy decreases. With the build of another wind park the frequency and intensity of those moments are bound to increase, posing even more operational difficulties. It is at those times that WEB needs to increase production, by ramping up already online generators and starting up offline generators, with a significant amount of electricity within a short period of time. However, the current generation portfolio of WEB may not be adequate in achieving this operational objective. Recent studies (KEMA, CRA) (undisclosed) indicate that with the build of another wind park (Urirama) the supply and demand cannot be safeguarded with the current configuration of the generation mix resulting in stability issues and blackouts. In the next chapter DSM programs are introduced to address the operational problems.

3 Demand Side Management

The challenges indicated in the previous chapter are addressed by introducing various demand-side management objectives and methods. This chapter aims to answer the following research questions:

How can demand-side management, in theory, facilitate the integration of wind energy in the Aruban electricity system?

Section 1, presents background information on demand-side management. Section 2, specifies which load shape objectives, in theory, are suitable in facilitating the integration of wind energy in the Aruban electricity system. Section 3, goes more into detail on the incentive-based and price-based DSM programs and which of these programs are applicable in this case. In section 4, the choice for a DSM program is determined by the load-shape objective, the time-scale and the requirements of the utility. These requirements also determine which load profiles are suitable in the proposed DSM program. Finally, in section 5, the conclusions are stated.

3.1 Introduction to Demand Side Management

In generating power, the concept so far has been straightforward: if society demanded more power, the power companies would simply find a way to supply electricity to end-users by building more generation facilities. This concept of doing business has been labelled as supply-side management. Demand-side management however describes the planning and implementation of activities designed to influence customers in such a way that the load shape curve of the utility company can be modified to produce power in an (technically and economic) optimal way [28].
The implementation of DSM goes back to the 1970s when energy prices, consumption and the need for conservation responded to the beginning of the oil crisis [29]. The following drivers for demand-side management are identified by analysing: [14, 30, 31]:

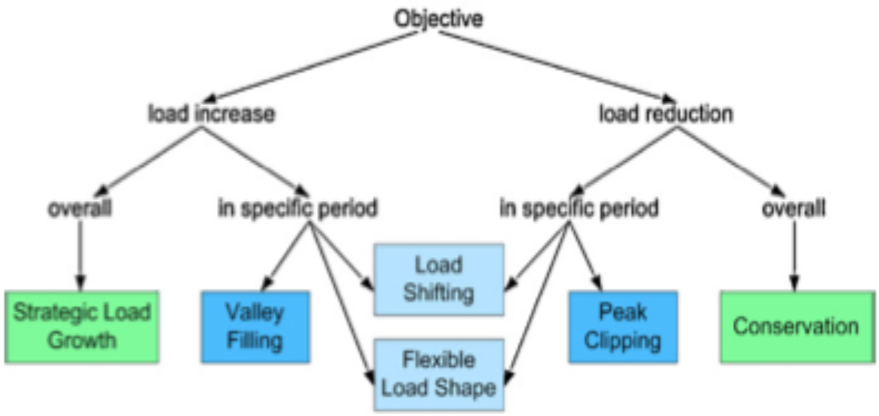
1. Increasing efficiency (technical and economic) of system operation and existing investment in the generation and transport of electricity.
2. Deregulation, paradigm shift towards a more active end-user who is in the centre of the decision making process regarding the operation and future development of the system.
3. Climate change development: given the interest in wind energy especially and the inherent variability of the output of this form of generation, there may be useful roles for DSM in the provision of system support services, such as different forms of operation reserve.
4. Development in information and communication technology (ICT), which in principle could enable the deployment of various DSM measures.
5. Ageing assets of the electricity infrastructure opens up the question of the strategy for infrastructure replacement, in particular the design and investment in future electricity networks and the role that enabling technologies, such as DSM, will have in designing future electricity systems.

Increasing DSM activity and further active involvement of active end-users can overcome two types of problems associated with the operations in an electricity supply system and planning of investments. Most of the end-users (also in Aruba) face flat tariffs and are not able to perceive the short-term time varying costs of electricity generation. This results to a situation where consumers tend to over-consumer in hours with high costs (i.e. peak hours with no wind) and to under consume in hours with low costs (i.e. during night time with large quantities of wind energy) compared to a system with time variation in prices (i.e. day, night tariffs). Generally, the goal of DSM is to encourage end-users to move the time of energy consumption to off-peak times. This does not necessarily lead to a decrease in total energy consumption, but is likely to reduce the need for investments in both networks and extra generation capacity (see §3.3.2). Furthermore DSM is able to increase the technical ability of a system to maintain balance and supply under various conditions. DSM can offer incentives so that end-consumers react to system events (see §3.3.1). As goes for this research, the integration of wind energy is the key-driver for the interest in demand-side management. As indicated in the previous chapter reliability becomes an issue at moments of sudden and severe wind decreases. This issue identifies two aspects of the challenge in integrating another wind farm. *First* a specific amount of wind power decreases and has to be compensated by either an increase in production (supply-side) or a decrease in demand (demand-side) to maintain balance. *Secondly*, the wind decrease is sudden, which indicates a certain relationship with time. During this chapter, it will become clear that the choice of a suitable DSM program is largely determined by the required load-shape objective and operational time-scale.

3.2 Load Shape Objectives

Methods of demand-side management aim to reshape the load curve [29]. The selection of the load shape objective depends on the operational objectives of the utilities. In other terms what one wishes to achieve by implementing DSM measures. The below figure illustrates the 6 different load shape objectives and how they relate to the interpretation of an operational objective. If the objective is to decrease the overall energy consumption on Aruba, the load shape objective *conservation* is suitable. If the objective is to increase the overall general energy consumption on Aruba, the load shape objective *strategic growth* is suitable. Figure 3-2 illustrates how the load shape is affected by the methods.

Figure 3-1: Overview of load shape objectives and related objectives. Source: [29]



Concerning this research, valley filling, load shifting, flexible load shape and peak clipping are at first impression suitable load shape objectives. By identifying the load shape objectives and their characteristics (properties and conditions) a more thorough understanding is achieved. As a result, it is possible to indicate more precise which objectives are suitable for the Aruban context. *Valley filling* is the practice of increasing load in specific periods when the overall load is low. The goal is to build up off-peak loads in order to smooth out the load curve. An example of valley filling is charging electric vehicles in car parks at night, so that the utility is not required to generate as much power during the day. This increases the load through the night and decreases the load during the day, flattening the overall demand curve.

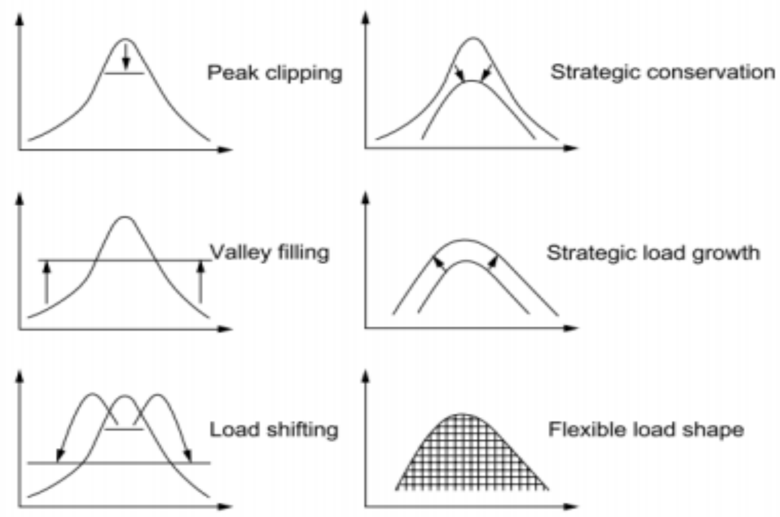
Peak clipping or load clipping is the practice of decreasing load during peak load periods, often achieved by direct control of customer's loads [32]. Direct load control and interruptible rates are used to reduce demand during peak load hours. This peak clipping effect can lower utilities cost of service by reducing the need to operate its most expensive unit and by postponing the needs for future capacity additions [28]. Typical examples of controllable loads are auxiliary generators and residential water and space heaters [32]. In addition there are peak-load management programs available to commercial and industrial classes of customers. Example: load-interruptible programs for the provision of reserve services and for enhancing system reliability.

Load shifting is the practice of combining valley filling and peak clipping both. Load shifting transfers load from on-peak to off-peak periods [21]. A pre-requisite is that the load is not bound to a specific time.
In the *flexible load* shape, programs such as demand subscription service and priority service pricing are used to tailor reliability of service to individual customer needs. It involves making the load shape responsive to reliability conditions. Utilities can realize both operating and future fixed costs by allowing dispatchers flexibility to reduce or postpone demand for selected customers [28].

DSM has technical value at times that the amount of integrated wind energy drops to such a level that the balance between supply and demand cannot be safeguarded by supply-side management. From this point of view peak clipping is the most suitable load shape objective, because it focuses only on those moments that load is required to decrease. However, peak clipping is the practice of decreasing load during peak periods, while the periods of sudden wind drops does not necessarily coincide with periods of peak demand. Therefore the objective of clipping load applied during system events seems suitable and is in literature referred to as: *load shedding.* Load shape objectives can be achieved by certain DSM programs, which may differ in operational time-scale. The next section identifies such programs and indicates which programs are suitable in this respect.

DSM could provide a load increase to prevent overproduction of electricity during times of sudden and severe wind increases. In this respect, valley filling and load shifting would be suitable load shape objectives. However, WEB already operates a technical "solution" and is able to gradually integrate produced wind energy by setting set points as discussed in the previous chapter (paragraph 0). Therefore, DSM has no current technical value at times of rapid wind increase and despite its possible economic value it is not considered in this report. The implications associated with this choice are reflected upon in chapter 11 (paragraph 11.1).

Figure 3-2: Load shape objectives. Source: [19]



3.3 Demand-side management programs

Load shedding has been selected as a suitable load shape objective, consequently an appropriate set of DSM programs needs to be identified. Important in this selection are the time scales associated with the duration and frequency of response. Some DSM programs are characterized with short response times (seconds) to response times of days and months. According to the literature review on load management techniques by Kostkova et al. (2012) on and according to the overview of demand response in electricity markets by Albadi et al. (2008) the classification of DSM programs can be classified as either incentive-based or price-based (see Table 3-1). Incentive based programs can generally be executed more directly than price-based program. Explanation are presented below the table.

Table 3-1: Classification of DSM programs. Adapted from: Kostkova et al. (2012) and Albadi et al. (2008) [29, 33]

Incentive based programs (IBP)	Price based programs (PBP) (indirect)
• Classical (direct) o Direct load control o Interruptible/ curtailment programs • Market based o Demand bidding o Emergency DR o Capacity market o Ancillary services market	• Pricing programs o Time of use tariff o Real time pricing o Critical peak pricing o Extreme day pricing o Extreme day critical peak pricing • Rebates and subsidies • Education programs

3.3.1 Incentive based programs

In incentive based programs, the aim is to alter the electricity consumption of certain load profiles in response to a system event. In classical IBP a utility is able to control the customer's appliances, usually based on a contract, during critical system conditions [29]. The participating customers receive participation payments usually as a bill credit or discount rate for their electricity usage. In market based programs participants are rewarded for their performance depending on the amount of flexible load they offer during critical system conditions. Direct load control programs (DLC) provide a utility the opportunity to directly control the customer's appliances, e.g. water heater, air conditioning and public lighting on a short notice by sending signals (frequency, radio, internet etc.). The signals can influence the load of the appliances, switch tariff relay in electricity meters or inform about the current price of electricity [33]. Similar to DLC programs, customers participating in interruptible/ curtailment programs will receive upfront discount rates or incentive payments and are usually offered to industrial customers and residential customers, who are asked to reduce their load to a given amount. The load interruption can help assure grid stability or handle emergency situations. Load reduction is achieved by a demand limiter or signals send form the utility [34]. If not followed contracted reduction they can face penalties [33, 35]. Demand bidding programs can be understood as an extension of interruptible/curtailment programs in which customers bid specific load reduction in electricity whole sale market. The bid is accepted if it is less than the market price. Customers are obliged to fulfil their offer or will face penalties. On the other hand, during emergency situations (i.e. service interruptions during times of supply scarcity) participating customers of emergency demand response are paid incentives for measured load reductions [36]. Capacity market programs are offered to customers who can commit to providing pre-specified load alternations when system contingencies arise [36]. Participants generally receive a day-ahead notice of events and will be penalized if they do not respond accordingly. Ancillary services market programs offer the possibilities to customers to bid interruptible load in the spot market as operating reserve. Whenever bids are accepted, participants are paid the spot market price for committing to act if load curtailment is required [36].

3.3.2 Price based programs (indirect)

The pricing program category assumes that customers will alter their consumption of electricity in response to changes in its pricing. The pricing in these programs is dynamic, so the rates are following the real costs of electricity. Time of use pricing (TOU) provides fixed but different prices per period i.e. during peak- and off-peak hours, workdays or week days and for different seasons (winter, summer). Other programs rates institute prices during periods of critical system operations, e.g. critical peak pricing (CPP), extreme day pricing (EDP), extreme day critical peak pricing (ED-CPP) or provide information about actual electricity price, e.g. real time pricing (RTP) [33, 35]. Generally, the customer's load is not interrupted and no (financial) penalties are amerced when loads are not altered. Another category includes programs where the utility rewards customers with a price rebate or subsidies for the purchase of energy efficient appliances or peak demand reduction. This program would be beneficial with the load-shape objective of strategic conservation (Figure 3-2). Another utility option is to educate its customers aiming to increase their electricity efficiency and electricity conservation awareness. Education programs are more suitable for residential sector customers who have bigger potential to shift electricity load to off-peak hours or weekends. Such programs may coincide with regional or national goals to reduce electricity consumption.

Table 3-2: Classification of DSM programs to time scale. Adapted from: Cappers et al. (2012) [37]

DSM program	**Time scale**		
	Advance notice of response	**Duration of response**	**Frequency of response**
Incentive based programs			
Direct load control	None	1-60 min	Sometimes limited in tariff
Interruptible/ curtailment	30-60min	Depends on contract	Sometimes limited in tariff
Emergency DR	2-24hr	2-4h minimum	Typically < 100hr/yr
Capacity market	2-24hr	2-4hr minimum	Typically < 100hr/yr
Ancillary service market	5s – 30min	10 min – 2hr	Depends on reliability level
Price based programs			
Pricing Programs			
- TUO	> 6 months	length of peak period (e.g. ~4-15 hr)	Daily, weekly, seasonal, etc.
- CCP, EDP, ED-CPP	2 - 24 hr	length of critical peak period (e.g. ~2-8 hr)	Typically < 100 hr/yr
- RTP	5 min - 1 hr	depends on price level (e.g. ~2-8hr)	Depends on price level
Rebates and subsidies	n.a.	n.a.	n.a.
Education programs	n.a.	n.a.	n.a.

3.3.3 Time scale of DSM

All forms of DSM programs have the basic anticipation that either the utility will directly control the electricity consumption of end-users or that the customer will voluntary (manually or automatically) alter their own electricity consumption based on (in)direct incentives. The applicability of a DSM program, depends to a large extent on the projected time scale in which the DSM program must be executed. Table 3-2 summarizes the time scale of advance notice of response, duration of response and frequency for each type of DSM program. The advance notice of response can provide customers the opportunity to prepare for the execution of a program objective (reduction or increase in load). This is particularly true for DSM programs that have a longer length of advance notice of response. For DSM programs where the length is very short (second to minutes), customers and utilities as a whole will need to rely on automation and control technologies, which may have the implication on the customer's ability to alter their consumption patterns and their willingness to participate in the program (see chapter 9).

In addition to this, the duration of response may also limit the willingness to participate in a DSM program as customers might not be able to curtail loads for a long period of time without affecting their personal comfort (in case of residential customers) or their operational obligations (in case of industries) Furthermore, the frequency of response pertains to how frequently signals to alter electricity consumption are received. It may occur that, the more frequently signals change, the more often the customer needs to respond to these changes. This may lead to fatigue of customers. On the other hand, the use of automation and control techniques can overcome such barriers.

3.4 Choice for a DSM program

When identifying suitable DSM programs it is important to understand the perspective of both the utility and its customer. A DSM program with the most value is characterized as maximizing value for both the utility and the customer. In this section, it is identified what programs are of greatest value to the utility, in chapter 9 the value of DSM to the customer is discussed. The strategy of WEB consists of several successive steps in order to balance supply and demand and to prevent network failures. Prior strategy focus of WEB N.V. is on the internal supply side management rather than on the external demand-side. When confronted with a sudden decrease in wind power, WEBs current strategy is presented below in this specific order:

1. Ramp up Turbine Generator 6 (frequency response reserve unit)
2. Ramp up *or* start up reciprocating units and gas turbine (spinning and standing reserve)
3. Reallocate steam (less water production, higher electricity production)
4. Disconnect low demand fields (San Nicolaas)
5. Disconnect high demand fields (North of the island)
6. Blackout

A DSM program should ideally be capable of providing sufficient capacity within a sufficient period of time to overcome sudden and severe drops in wind energy. By doing so, DSM may also provide a time window in which standing reserve generators can be brought online. According to this strategy, the DSM program should function as a fast spinning reserve that is able to maintain balance and prevent the disconnection of demand fields and eventually a total blackout. By incorporating such a measure, the following strategy emerges:

1. Ramp up Turbine Generator 6 (frequency response reserve unit)
2. Ramp up *or* start up reciprocating units and gas turbine (spinning and standing reserve)
3. DSM program
4. Reallocate steam (less water production, higher electricity production)
5. Blackout

During interviews and informal conversations with operators and employees of the technical staff of WEB the following requirements and prerequisites of utilizing demand-side management were identified, restructured and are categorized in the below

Table 3-3.

Table 3-3: Requirements for DSM utilization by WEB N.V.

Technical Requirements	**Social Requirements**	**Implementation requirements**
• Capacity of load: the amount of load must be enough to function as reserve (MW).	• Willingness for customers to accept and implement load shedding	• Direct control of load: control over customers appliance
• Availability of load: interruptible and preferably constant.		• Fast response: seconds to minutes

According to the chapter 2 and the perspective of the utility it is clear that the focus lies on finding a suitable DSM measure that is able to shed load within a short period of time. The quantification of this time is unknown and is quantified further in this research (chapter 7). However, it can be concluded that the advance notice of response and the duration of response should both be as low as possible. This excludes the option of price-based programs because they assume the voluntary response of a customer to an indirect incentive. In addition, it is found important that the utility is able to decrease loads directly by controlling customers' appliances. Taken this into account and the lack of a competitive market design of the Aruban electricity system (2.1 General Overview) excludes market based programs. As a result, direct DSM programs and in particular **direct load control** is as a suitable DSM program and able to provide these objectives.

3.5 Conclusion

How can demand-side management, in theory, facilitate the integration of wind energy in the Aruban electricity system?

First of all, it has been concluded that DSM can be applied for a variety of purposes that can be classified either as: improving the total efficiency of an electricity supply system or increasing the technical reliability of a system. In this case, the focus lies on increasing the technical ability of the Aruban electricity system by decreasing load accordingly at times whenever supply-side measures are not able to maintain balance due to negative wind fluctuations. This is called load shedding.
Secondly, a variety of incentive based- and price based DSM programs have been described and classified according to the time-scale of operations. According to the requirements of the utility and the nature of the objective that load shedding aims to fulfil it is important that whenever such a system event occurs the utility is able to directly control customers appliances within a short period of time. It is concluded that the direct load control program provides such options and traditionally customers receive incentive payments or reduced rates for their participation. Other market based- and price based programs may offers various possibilities for other objectives in other electricity systems, see §3.3.

In the next chapter an analysis of load profiles is performed to identify those customers (load-profiles) that operate appliances with sufficient:

- Capacity of load: the amount of load must sufficient in providing spinning reserve
- Availability of load: interruptible and preferably constant

4 Load profile Scan

The previous chapter indicated requirements for customers or load profiles. This chapter aims to answer the following research question:

Which load profile(s) represent(s) the highest amount of potential as to integrate wind energy?

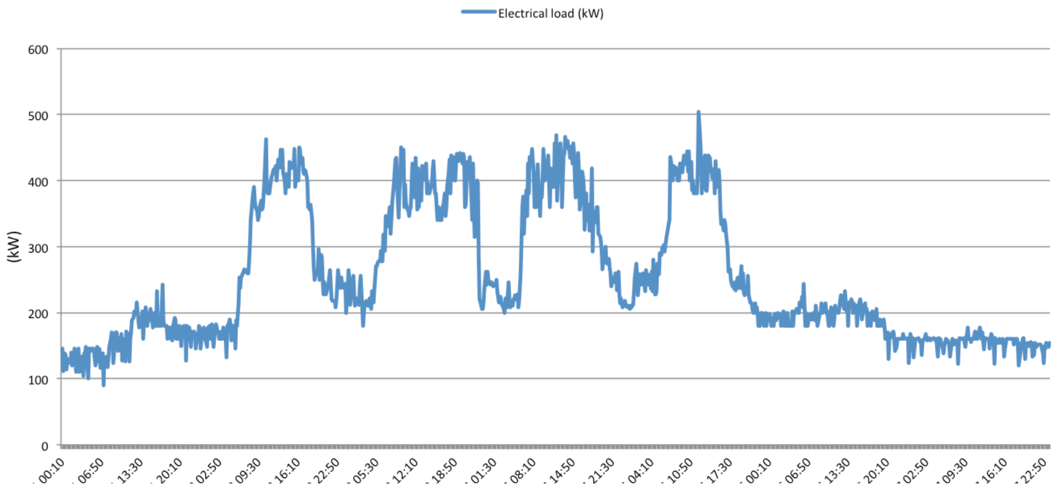
In order to identify suitable load profiles on Aruba information must be gathered concerning the large electricity consumption. In section 2, the energy demand on Aruba is assessed by identifying several industrial profiles. In addition the geographical distribution of electricity is analysed. Section 3, presents analyses of the demand of large hotels on Aruba and an evaluation according to the identified requirements in the previous chapter. Finally in the 4th section conclusions are presented.

4.1 Assessment of the Energy Demand

The section aims to clearly identify the assessment of potential load profiles. Loads in an electricity system can be very diverse. Electricity end-users are often classified in the following main groups: residential, commercial/ office and industry/ agriculture. Households mostly represent residential load profiles. The commercial sector on Aruba is mainly represented by hotels, resorts, restaurant, spa's and shopping malls. Industry is represented by a large water production factory and a beer factory. Furthermore, the island does not have a significant agriculture. During this research the focus has been on large loads represented by few profiles.

Prior to this research, the water production was considered as a potential load, as defined in [13]. However, that particular research was conducted in 2009. At that time, the water desalination plants was operated through an energy inefficient process and the load was estimated to be substantial (15-20MW). Investments in several high energy efficient Sea Water Reverse Osmosis Plants (SWRO) reduced this load to 5MW. This load is already utilized in the balance strategy of WEB.
The Balata beer factory (Brouwerij Nacional Balashi) is one of the few load profiles that represent the industrial sector. This load profile has been evaluated on its capacity (MW) and on its availability. The load profile of this factory is illustrated in Figure 4-1. As can be seen, the peak load of the beer factory is around 0,5MW, which is not substantial. Furthermore, the electrical load is not constant due to peak production during the day and low demand during the night. On a longer time perspective the electrical consumption during the weekend is also low. The process is a batch process rather than a continuous process. Based on the capacity and the availability of the load, it is concluded that the load profile of the Balashi factory did not satisfy the requirements.

Figure 4-1: Load profile of the Balashi beer factory (one week). Source: N.V. ELMAR



During this research, no clear and structured data was available concerning, energy intensive load profiles of the above-mentioned sectors and therefore no indication and specification of the largest electricity demand could be established. By analysing the geographical distribution of electricity with the cooperation of ELMAR it was possible to identify the geographical distribution of large loads. The layout of the electricity network, if analysed correctly, holds much information. Electricity is transported via high and low voltage electricity grids. The largest electricity flows are transported via more high voltage grids and more dense networks. This identifies a geographical estimation where the largest loads are situated on the island.

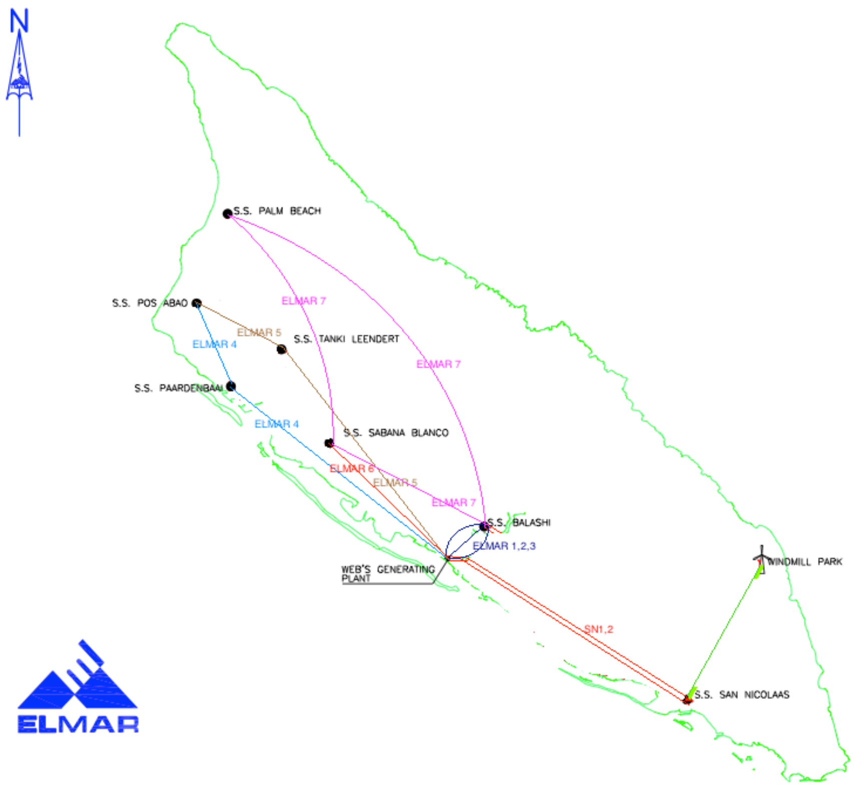
The electricity system has 7 substations where the electricity is further distributed at 12kV-level to end-users. The "high-voltage" electricity is transported around the island by nine 60kV cables that are all equipped with a distribution meter to monitor and meter the distributed electricity. The table below presents the distributed electricity per meter for 2011.

Table 4-1: Distribution figures of electricity per meter. Source: N.V. ELMAR

	EL 1	**EL 2**	**EL 3**	**EL 4**	**EL 5**	**EL 6**	**EL 7**	**SN 1**	**SN 2**	**Total**
Total (GWh)	66.6	40.4	148.5	63.5	106.0	103.2	137.8	49.7	30.5	**746.1**
Distributed electricity	8.93%	5.42%	19.90%	8.50%	14.20%	13.83%	18.46%	6.66%	4.09%	100%

In the above table the total distributed electricity per meter is displayed in numbers. The largest amount of distributed electricity in 2011 was measured through ELMAR 7 (18,5%). Most of the high and low voltage electricity grid connections are located in the North while the electricity is produced in the Balashi area (Figure 4-2). The density of the network in the North of the island is much higher compared to the South of the island. The below figure identifies which transportation lines are measured by the distribution meters. Palm Beach and Pos Abao are the locations where most of the tourist activities take place. The commercial activities in the North are mainly represented by the Low Rise (Pos Abao) and the High Rise area (Palm Beach), both names relating to the height of the commercial buildings including: hotels, casinos, resorts, restaurant, shopping malls and apartments. As seen in the below figure, the electricity demand in these locations is measured by ELMAR 4,5,7 and represents a combined electricity distribution of 41,2%.

Figure 4-2: Network map of Aruba. Adapted from: N.V. ELMAR



4.2 Hotel Loads

Being a small, service driven economy, the largest cluster of electricity consumption is represented by the commercial loads that are situated in the North. Together with the residential loads they are responsible for most of the electricity consumed on the island (>80%). In order to assess the potential of load shedding in hotels it is important to create a realistic representation of the hotel load. Benchmark data, obtained through R. Leonora (see Appendix-0) concerning the load of nineteen of the largest hotels has been used in order to identify the percentage of electricity used compared to the total distributed electricity. (The names of the hotels have been made anonymous for privacy reasons). According to this data (Table 4-2), 22,1% of all the electricity distributed on the island is consumed by these 19 hotels. Note: not all hotels did participate in this benchmark and through an extrapolation of statistical data and figures provided by ELMAR it is estimated that the electricity consumption of all hotels combined represent 30% of the total electricity demand on Aruba. This represent a significant share of electricity on the island and thereby satisfies the first criterion of "sufficient capacity".

Heating and cooling is one of the largest operating costs of total electricity expenditure in nearly all buildings. This is no exception for hotels in Aruba, where waste is considerably more prevalent and where guests are more than 50% of the time outside their rooms, frequently leaving the utilities running in their absence. Such air-conditioning load is interruptible and is a prime example of usable load in the DSM program. Temperatures are high in Aruba, ranging from a minimum of 22 °C at night to 38 °C during summer days (Figure 4-3). According to several General Managers of various High-Rise hotels, a Director of Engineering of the Radisson Hotel and a Senior Consultant in benchmarking Aruban hotels on their energy demand it was found that the average air conditioning load of hotels represents 50-70% of their total electricity consumption. Through obtained benchmark data and additional literature [38-40] on overall electricity use in the Caribbean hotel industry the following chart was generated.

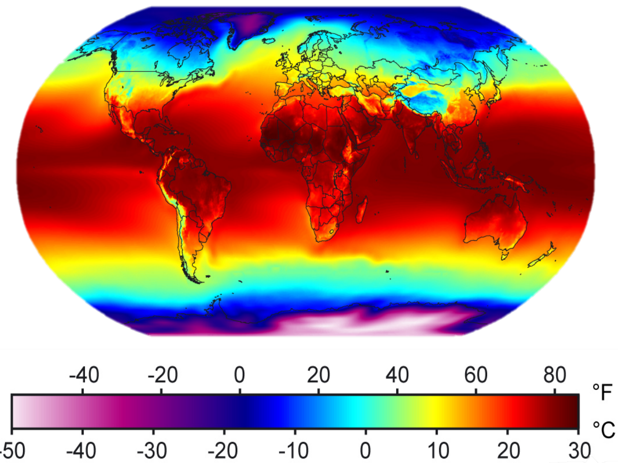
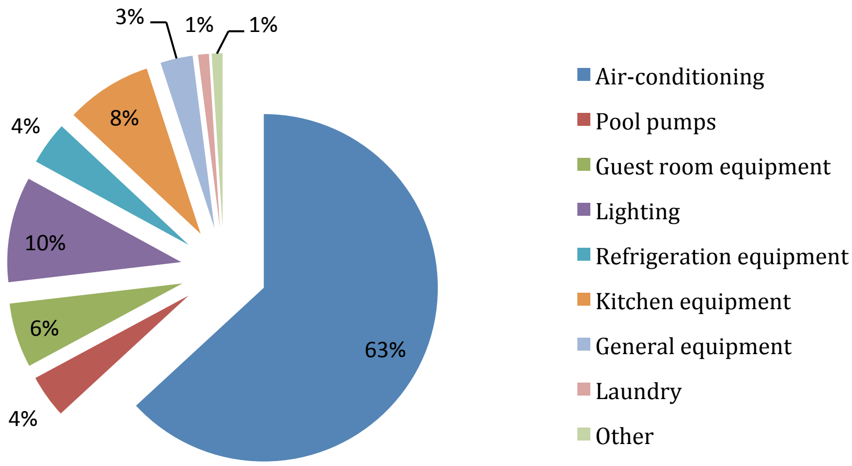


Figure 4-3: Annual mean temperature map

Figure 4-4: Average electricity use specification of an Aruban hotel. Calculations based on: [38-40].



The air-conditioning load represents the largest share of the electricity consumption in hotels. In most cases, such load is not constant throughout the year and strongly relates to fluctuations in temperature and tourist seasons. During this study no specific data concerning the AC load consumption in hotels was available since hotels do not measure this consumption and was also out of the scope of this research. Nevertheless, a thorough analysis is made of the total electricity demand of 10 representative hotels (similar hotels used in the benchmark 4.3.1), ranging from small to large hotels by using detailed consumption data of 2011 specified on a 10-minute interval. In Figure 4-5, the average total electricity demand on Aruba and that of the 10 hotels during low and high season is presented. The difference between the average total demand during high and low season is 20MW, while the difference in the hotel load is much lower (0,5MW) and more constant. The average overall electricity demand of the 10 hotels does not significantly fluctuate on a seasonal basis. In addition air-conditioning represents approximately 60% of this load. Therefore, it is estimated that the air-conditioning load is also constant throughout the year. The average electricity demand of the 10 hotels ranges from 9 MW during the day to 6,5 at night. The air-conditioning load correlates with temperate, therefore the AC load does also differ between day and night time. However, taken the above-mentioned into account the air-conditioning of large hotels in Aruba represents a significant, relatively predictable interruptible amount of load. The average distributed load in Aruba is 84,7 MW throughout the year. The electricity demand of the hotel industry contributes to 30% of this load (25,4MW). Furthermore, it is estimated that 50-70% of the hotel loads are represented by air-conditioning demand. These results suggest, that the current potential of AC load in the hotel sector is a compensating capability between 12,7-17,8MW.

Figure 4-5: Average electricity demand figures of 2011. Source: N.V. ELMAR

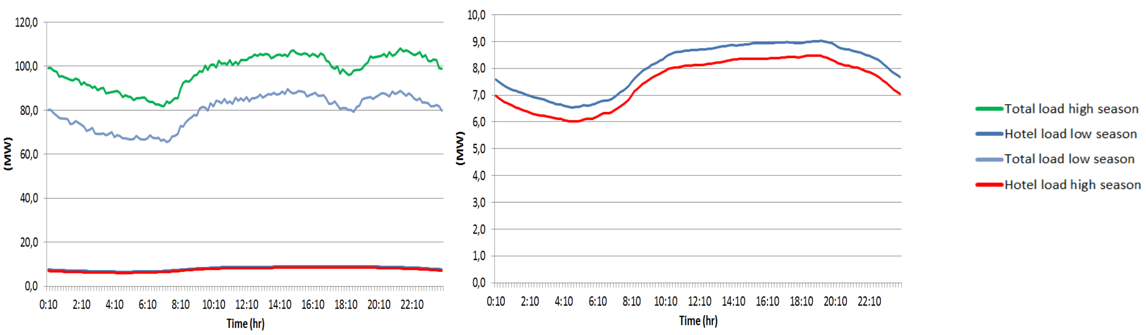


Table 4-2: Overview of hotel and total electricity consumption. Consumption specified further for AC consumption in hotel industry

	Scenario share of AC	Average electricity consumption (MWh)	Percentage of total	Average power (MW)	Share of AC	AC load (MW)
19 largest hotels	Minimum	163,99	22,1%	18,7**	50%	9,4
	Medium	163,99	22,1%		60%	11,2
	Maximum	163,99	22,1%		70%	13,1
All hotels	Minimum	222,6*	30%	25,4	50%	**12,7**
	Medium	222,6	30%		60%	**15,2**
	Maximum	222,6	30%		70%	**17,8**
Total consumption	-	742	100%	84,7	-	

* Based on extrapolation of statistical data, sources: R.Leonara, ELMAR N.V.

** Calculation: average electricity consumption (MWh) / 365 (days) * (24 hours)

4.3 Conclusions

Which load profile(s) represent(s) the highest amount of potential as to integrate wind energy?

The air conditioning load of the hotels industry on Aruba represents the highest amount of potential as to integrate wind energy through load shedding. Reasons for this conclusions are the following, *first* of all the electricity load of all hotels combined represents 30% of the total demand of electricity on Aruba, which is significant. *Secondly*, 50-70% of this demand is related to interruptible and relatively constant air-conditioning load. The results suggest, that the current potential is a compensating capability between (12,7-17,8MW), if only AC load of the largest consumer, i.e. the hotel sector, is involved.
Note, that due to the lack of specific AC load data this amount is based on extrapolation of statistical data estimations derived out of interviews and gives no exact numbers. It should also be noted, that in reality this amount could be much lower due to the fact that willingness to participate in load-shedding limits the technical potential. The role of the willingness of hotels is identified through a qualitative analysis in chapter 9.

The Aruban electricity system and its corresponding challenges to additional wind energy are explained. Load shedding, with direct control is found to be a suitable DSM program to (partly) mitigate these operational challenges. And with the identification of air conditioning loads of (large) hotels as suitable load profiles, this descriptive phase is finalized. In the second research phase, the technical and physical complexity of the electricity system is handled by creating a simulation model of the system. First the right modelling methodology is chosen in order to meet the model requirements set in the problem statement.

Figure 4-6: Research phase 1

Phase 1: Descriptive

Input	**Method & output:**
1. What are the characteristics of the Aruban electricity system? (CH 2) 2. How can demand-side management, in theory, facilitate the integration of wind energy in the Aruban electricity system? (CH 3) 3. Which load profile represents the highest amount of potential as to integrate wind energy? (CH 4)	System Analysis - Understanding of the Aruban electricity system - Identification of challenges that correspond to additional wind energy implementation Literature study - Understanding of DSM - Identification of possible DSM measure to mitigate previous identified challenges Network/demand analysis - Identification of suitable load profiles/ customers

5 Modelling the Aruban Electricity System with Linear Programming

The first research concluded on with a general understanding of the functioning of the Aruban electricity sector and its challenges related to (additional) wind energy. This second research phase begins on identifying a suitable modelling methodology to first clarify the technical-physical complexity of the Aruban electricity system and secondly to build a verified and valid model that is able to analyse the technical feasibility of the proposed DSM measure. This phase aims to answer the following research questions:

- *What are the objectives and requirements for the modelling approach?*
- *What modelling technique can be used to reach these objectives?*
- *How is this general modelling technique applied to the Aruban electricity system?*

In section 5.1, the modelling objectives are set, leading to the introduction of a Unit Commitment (UC) model and Linear Programming (LP) as a method to simulate the electricity system. Section 5.2 briefly introduces the general concepts of LP and its use to modelling electricity systems and in particular unit commitment models. The latter part of the section involves the conceptualisation of the main modelling assumptions (constraints, non-constraints, merit order and modelling setup) Finally, conclusions are stated in section 5.3.

5.1 Modelling objectives and approach

It is clear that additional wind energy will affect the reliability of the electricity system, mainly caused by additional variation. However, there is much uncertainty on what the exact effect is on the ability of the system to safeguard the balance between supply and demand, and about how to mitigate possible imbalances. In this section a modelling approach is introduced that quantitatively addresses these questions. The objective of the modelling step is to answer the following questions:

1) What is the effect of an additional wind park (30MW) on the technical ability of the electricity system to balance supply and demand? Will an imbalance occur, and if so, why and on what particular moments?
2) What are the technical requirements to mitigate such imbalances?
    a) Frequency of the imbalances (#/yr)?
    b) Amount of power imbalance (MW)?
    c) Duration of imbalance (min)?
3) To what extent is the shedding of air-conditioning load of large hotels a feasible solution in this aspect?

Electricity systems are designed to constantly match supply and demand of electricity. In order to do so, an electricity system consists of various technical subsystems, including: units. Hence, the ability of an electricity system to constantly match supply and demand is inherently determined by the technical limitations of these system components. Within the system, different units exist to provide for the demand in electricity. These units differ in capacity, fuel, ramp rates, minimum up- and downtime, failures rates during start-ups, start-up costs, variable costs, etc. Whether or not the system is able to compensate the variable output of additional wind energy thus depends on the limitations of these units.
As already mentioned in chapter 2, the net flexibility of an electricity system is constantly dependent on the (fluctuations in) demand of electricity and produced wind energy and on the characteristics of the generating units at that time. Example: a frequency response reserve that operates at 50% of its capacity can double its electrical output, if that would be necessary, in a short amount of time in order to cope with a sudden decrease in wind energy and/or sudden increase in demand. That same frequency response reserve, if operated at 100% of its capacity is not able to provide an increase in electrical production, should that be necessary, and therefore cannot cope with a sudden decrease in wind production and/or a sudden increase in demand. So, in order to adequately analyse the effect of additional wind it is essential

to analyse the dispatch of generating units and their characteristics under realistic demand patterns and wind fluctuations based on actual data. Therefore the following modelling approach is formulated:

Optimization of utilization of supply sources according to a merit order, to supply demand within the technical constraints of the system.

This type of optimization problem can be expressed by a unit commitment model and generally involves optimizing the least-cost dispatch of resources to meet the electrical demand. Unit commitment modelling has been extensively used in the last few decades as a means to; simulate the integration of RETs, assess the flexibility of power systems and to assess the contribution of DSM to power system flexibility [15, 32, 41, 42]. Generally, a unit commitment problem is formulated including the following unit constraints [43]:

- Minimum up-time and downtime;
- Unit generation capability limits; minimum- and maximum capacity
- Ramp rate limits;
- System reserve constraints;
- Crew constraint; and
- Deration of units.

The most important non-linear constraint is the unit's minimum up time and downtime. Units are required to be operational for a minimum amount of time to prevent unit failures. On the other hand, the minimum downtime is the amount of time a unit must be off-line before it can be brought online again. The unit generation capability limits are expressed by the maximum generation capacity: the maximum amount of electrical output a unit can produce and the minimum generation capacity: the minimum amount of electrical output a unit can produce while maintaining a stable process. The rate of increasing or decreasing electrical output is physically limited by the ramp rate limits. "System reserve constraints pertains to supply the load throughout the scheduling period with a certain degree of reliability. The number of units that can be started at the same time in a particular plant depends upon the limited personnel (crew) available. This is known as the crew constraints. The deration of a unit lowers the unit's upper capacity limit." [44]
In [44], Sen et al. explain that the unit commitment problem belongs to the class of complex combinational optimization problems. Due to recent mathematical developments and advances in computing technology, various methods are readily available to solve such time-dependent problems. These various methods include: 1) Extensive enumeration, 2) Priority list, 3) Dynamic programming and its variant 4) Lagrangian relaxation 5) Branch-and-bound method, 6) Linear Programming, 7) Expert systems/ artificial neural networks, 8) Simulated annealing 9) Genetic algorithms. For more information on these methods, see [44]: Although various methods exists to solve the unit commitment problem, this research requires a method which satisfies the following requirements:

- Workable: understandable for users without extensive mathematical programming knowledge, easy to implement changes , user-friendly interface.
- Suitable: suitable for the task at hand, optimal solutions, ability to model constraints
- Accessible: free, available, easy to understand for external parties
- Representable: ability of graphical representation for stakeholder and 3rd party communications
- Quick: low computing time

The far most important criterion in the choice for a suitable method to model a unit commitment problem is the workability. Most of all above-mentioned methods require extensive mathematical programming skills. It is important that user and clients can easily understand the method. Furthermore the mathematical programs in which these problems are modelled do not allow for easy changes and offer no user-friendly interfaces. Overall these methods pose a low degree of workability. **Linear Programming** (LP) on the other hand was found to be more comprehensible and adaptable. The tool, which is used for to formulate the Linear Program problem has the ability to easily implement changes and offers a user-friendly interface (see chapter 6). Although the overall method has a lower degree of suitability, due to its inability to model non-linear constraints it does remain a workable, accessible, representable and quick method. The choice for Linear Programming and its implications are reflected upon in chapter 11. In the next paragraph the method of linear programming and its function to unit commitment modelling will be further elaborated on.

5.2 Linear Programming and modelling assumptions

In Linear Programming, a linear objective function is optimized (maximized or minimized) over a convex polyhedron specified by linear and non-negativity constraints (source). In more general terms, linear programming is a mathematical method for determining a way to achieve the best outcome (such as maximum profit or minimal costs) in a given mathematical model for some list of requirements represented as linear relationships. The largest contributions to solving linear programming are accountable for the development of the simplex algorithm, developed by George B. Dantzig in 1947 gives the following example of an LP problem formulation and generally always consists of the following three parts:

Linear function to be optimized (max, min) Max: $c^T x$

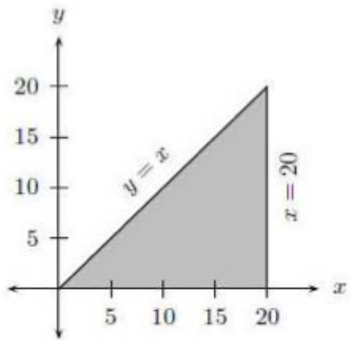
Problem constraints; Subject to: $Ax \geq b$

Non-negative variables: $x \geq 0$

The first function represents the objective linear function that has to be optimized while fulfilling the problem constraints and the non-negative variables represented by the second and third part of the formulation. In figure, a graphical representation of a simple LP problem is given with the following LP problem formulation. The arced area is the 'feasible area', the area that lies within the constraints. In this example, the area is constrained by the following:

Figure 5-1: Graphical representation of a simple Linear Programming problem.

$x \geq y$
$x \leq 20$
$x \geq 0$
$y \geq 0$



As the objective function is always linear, the optimal solution will always lie on the boundary of the feasible area. Depending on the objective function the optimal solution will either lie at one corner point or at the line between two corner points. Therefore, solving a LP problem can be done by systematically calculating the values at the objective function at corner points. There are different ways of doing this efficiently so that it isn't necessary to calculate the values for every point in the feasible area. The previous mentioned simplex algorithm is an example of such an effective method. In the preceding chapter, the modelling approach is defined as: *Optimization of utilization of supply sources according to a merit order, to supply demand within the technical constraints of the system.* This description covers the two main components in the modelling approach: *the system constraints* and the *merit order of supply sources*. Hereunder, the choice for the physical, technical constraints in the system and the merit order of sources is discussed, as are the underlying modelling assumptions and expressed in the LP formulation.

5.2.1 Incorporated constraints

In this section, a number of constraints are presented and described. The following 5 constraints are taken into account and described and conceptually expressed in LP formulation below:
The electricity system is designed to match supply and demand at all times. The production units of the electricity system must produce the exact electrical output the system requires. Imbalance in a system leads to blackouts, which are next to disrupting the need for electricity extremely expensive. Thus, the first type of constraint is the demand constraint. When expressed in mathematical terms, with $P_{\text{total}}(t)$ is the total production level at time *(t)* and $D_{total}(t)$ the total electrical demand level at time *(t)* (equation 1).
The second type of constraint is the production constraint. The total production level at a certain time is dependent on the amount and type of units that can that can provide electricity. When expressed in mathematical terms, $P_{total}(t)$ is the overall production level, $P_{fossil}(t)$ the production level of the fossil fuel units which consist of multiple fossil fuel units and $P_{wind}(t)$ *is* the renewable wind production at time *(t)*

(equation 2&3). The third type of constraint is the renewable production constraint. In this research, integration of renewable energy is key. The total renewable production at a certain time has priority over fossil fuel produced electricity. Generally, the electrical demand D_{total} at time *(t)* minus the renewable production P_{wind} at time *(t)* equals the residual demand for fossil fuel based electricity P_{fossil} at time *(t)* (equation 4).The fourth type of constraint is that of the unit generation capability limits. The minimum and maximum electrical output a unit can produce. This level of this constraint is constant throughout time (equation 5). The fifth type of constraint is that of the unit ramp rates. The rate of increasing or decreasing electrical output is physically limited by the ramp rate limits (equation 6).

(1) $$P_{total}(t) = D_{total}(t)$$

(2) $$P_{total}(t) = P_{fossil}(t) + P_{wind}(t)$$

(3) $$P_{fossil}(t) = P_{unit,1}(t) + P_{unit,2}(t) + P_{unit,x}(t)$$

(4) $$D_{total}(t) - P_{wind}(t) = P_{fossil}(t)$$

(5) $$a \leq P_{unit,x}(t) \leq b$$

(6) $$P_{unit,x}(t) - P_{unit,x}(t-1) \leq R_{up} \quad \textit{(as generation increases)}$$
$$P_{unit,x}(t) - P_{unit,x}(t-1) \leq R_{down} \quad \textit{(as generation decreases)}$$

5.2.2 Constraints out of modelling scope

Next to the five types of constraints incorporated in the LP problem, there are some constraints that do influence the functioning of the Aruban electricity system, but that are not taken into account in the modelling scope. Not all constraints can are linear and therefore cannot be expressed in linear form. However, this does not mean that these constraints cannot be manually incorporated in the model as will be explained in the next chapter (see paragraph 6.2). The following constraints are described in this section, as are the underlying assumptions for this choice:

- Minimum up- and minimum down time (manually incorporated)
- Start-up and shut down times (combined with ramp rates)
- Failure rates (manually incorporated)
- System reserve constraints
- Crew constraints
- Deration of units

The minimum up- and minimum down time constraint defines the minimum time of a unit to be online after dispatch or the minimum time of a unit to be offline after shutting the unit down. These constraints have influence on the availability of units and therefore indirectly the flexibility of the electricity system. However, this type of constraint is of a discrete nature which cannot be formulated unambiguously in the LP form. If modelled in the LP form, every node has to be checked with a previous time-step in order to pass the constraint. This would result, especially for longer time-steps, in an explosion of nodes contributing heavily to the complexity of the model. As a result, the suitability would slightly increase posing a decreasing workability and far longer computing times of the model. Therefore, this constraint is not incorporated in the modelling. However, it is possible to 'tweak' the model and manually incorporate this constraint at times where the constraint is of significant value, see chapter 7.
The start-up and shut down times defines the time it takes for a unit to be dispatched and operational or to be shutdown. Start-up times and shut down times are not to be mistaken with ramp rates. Ramp rates define the limited rate of increasing or decreasing electrical output ones a unit is already online. Start-up times and shut down times are very dissimilar to ramp rates in large generating units. i.e. large generation units, such as coal fired generation plants have a start-up time and shut down time of several hours, generally due to the slow process of firing up and cooling down. The capability of a coal fired plant to increase production from 50-90% however can be achieved in far less time. Interestingly, the start-up and shut down times in small generating units (engines) do not differ much from the ramp rates due to a very fast start-up and shut-down procedure and corresponding ramp rates. In addition, depending on the time step the two constraints can be combined. Rather than completely neglecting the start-up and shut down times, this constraints is incorporated by combining it with the ramp rates. For, specifications on

this topic, see section 6.2.5. The failure rates define the amount of failures whenever a unit is dispatched expressed in a percentage. Such a constraint limits the availability of units and indirectly influences the flexibility of the electricity system. This constraint is of a discrete nature, and like the minimum up and minimum down time would heavily contribute the complexity of the model. Therefore, this constraint is not incorporated in the LP formulation but may be manually incorporated in the model at times where the constraint is of significant value, see section 6.2.5. The **system reserve** constraint pertains to the amount of minimum backup capacity that has to be maintained in case of generator failure and blackouts. This system reserve is not taken into account. This analysis is in search to specify those moments where all system reserves have to be used in order to safeguard the balance between supply and demand.
The crew constraint is not taken into account, WEB has in total 2TGs and 11 reciprocating units, where all TGs and 1/3 of the recip units is basically always dispatched. During the research, it was found that WEB has enough personnel, during the day and night in order to dispatch all necessary units.
The deration of units is not taken into account, this constraint is useful during simulation with a very long time-span of multiple years. The time-span used in this analysis is much lower (see paragraph 5.2.5) and the deration has no effect. Furthermore the data used to specify these units is recent, as well as the units in operation.

5.2.3 Fictional reserve/ storage units

Linear Programming optimizes the objective function for every time step in finding the least-cost dispatch solutions for every time step over a defined time span. In this research, the objective is to identify and specify moments of imbalance, where the balance between and supply is not maintained. Basically, this means an analysis of moments within the LP when there is no solvable solution. A problem arises, because these moments are interesting yet the model cannot continue optimizing. In order to keep the LP problem solvable and be able to identify moments of imbalance, the following fictional units were incorporated in the model.
Demand-Side Management, in times of insufficient production this fictional reserve unit, which is typically last in the merit order has unlimited capacity and is not limited to any ramp rates or former identified constraints. The dispatching of this unit, equals an imbalance due to insufficient power production to meet demand and allows for the specification of technical details of this imbalance in terms of the difference in production and demand (MW) and the duration of the imbalance (min). This fictional reserve is called 'demand-side management' because in this research, one of the objectives is to analyse the effect of additional wind on the technical ability of the electricity system to prevent imbalances, during times of sudden and severe wind decreases and the role of DSM in mitigating these effects.
Wind Curtailment, in times of wind overproduction this reserve unit, which is typically last in the merit order has unlimited capacity and is not limited to any ramp rates or former identified constraints. The dispatching of this unit equals an imbalance due to an overproduction of power compared to the demand of power and would be able to specify the technical details of this imbalance in terms of the difference in production and demand (MW) and the duration of the imbalance (min). This fictional reserve is called 'wind curtailment' and in practical terms functions as storage unit.

5.2.4 Merit order

The modelling approach is defined as: *Optimization of utilization of supply sources according to a merit order, to supply demand within the technical constraints of the system.* The merit order of the supply sources form the objective function of the LP problem:

MINIMIZE $$\alpha * P_{unit,1}(t) + \beta * P_{unit,2}(t) + \gamma * P_{unit,x}(t)$$

With α being the variable costs per unit of production at time t for the production process related to the production level of $P_{unit,1}$ at time t and so on. Theoretically, in a competitive market the cheapest generator will be maximized first as to provide electricity for the lowest price before dispatching the second cheapest generator. This is called the merit order of supply. In the electricity system of Aruba however, the dispatch of generators is not ranked according to costs only. As a consequence of decommissioning the oldest turbine generators and transitioning towards a generation portfolio of more small and efficient (cheaper) capacity reciprocating engines the current portfolio exists of two turbine generators, eleven reciprocating engines and one gas-based turbine. HFO poses reliability issues for the recips. Therefore, the reliable and faster turbine generators provide for the base load. The generators are less efficient and therefore have higher variable costs than the reciprocating generators. Next in line, after the dispatch of the turbine generators, the cheapest reciprocating engines are dispatched. The following merit order of unit commitment is used:

1) Wind energy
2) Turbine generator: 6 (base-load, and frequency response reserve)
3) Turbine generator: 7 (base-load, fixed level)
4) Recip phase III: 7-10
5) VAASA
6) Recip phase I&II: 1-6
7) Gas turbine
8) Fictional unit (DSM and wind curtailment)

Assuming this, it is possible to specify a merit order that reflects the order in which the different generators are dispatched. For the costs α, β, γ etc. virtual costs have been assigned in this research. These virtual costs reflect the order in which the production capacity of these resources is used, while maintaining within the technical constraints of the system. By minimizing these virtual costs, the order is followed when solving the LP problem. In the next chapter, the specification of this merit order is presented.

5.2.5 Model setup

When assessing the flexibility of the Aruban electricity system, the model should be able to evaluate imbalance moment throughout a representative time span. It would not suffice to only analyse certain weeks or months where the fluctuations in wind energy are typically high. Therefore a time span of 1 year is used in this model. This covers, possible fluctuations in demand throughout the year as well as fluctuations in wind during different seasons etc. In this research the flexibility in power systems relates to short-term reliability. Therefore the most shortest time step the obtained data could allow for this model is used, namely 10 minutes. The optimization step and the look-ahead time used in this research is 1 step. As a result, the LP model will optimize the objective function for every 10 minutes without looking into the future. This has multiple reasons. *First* of all, all data used in realistic data. This in real life would mean that when using a higher optimization step the operators would be able to optimize their units commitment based on precise demand and wind production. This is not realistic because it does not account for forecasting errors and a degree of noise. Because it is not possible to incorporate noise or forecasting errors in LP a lower optimization step mitigates this effect. *Secondly,* optimizing over multiple steps and increasing look-ahead time drastically increase the number of constraints and therefore the solving speed. Reason for this is that in Linear Programming, the constraints can reflect not only limitations for the current time step but also for time steps in the future. This implies that all constraints and objective functions within the LP problem are not only set for time *t*, but for time *t, t+1,…t+x.*. By lowering the look-ahead time the workability of the model and the solving speed is maintained.

5.3 Conclusions

What are the objectives and requirements for the modelling approach?

First of all the objectives of the modelling approach is to make a model that is able to answer what the effect of an additional wind farm (30MW) is on the technical ability of the electricity system to balance supply and demand? If imbalances should occur the model should be able to indicate why and on what particular moments. Furthermore, the model should be able to quantify the frequency, amount of power and duration of such imbalances so that requirement may be formed. These requirement can than be used to evaluate the potential of the load shedding program.
Secondly, the modelling approach is defined as:

Optimization of utilization of supply sources according to a merit order, to supply demand within the technical constraints of the system.

The requirements of the modelling methodology can be summed as follow:
- Workable: understandable for users without extensive mathematical programming knowledge, easy to implement changes , user-friendly interface.
- Suitable: suitable for the task at hand, optimal solutions, ability to model constraints
- Accessible: free, available, easy to understand for external parties
- Representable: ability of graphical representation for stakeholder and 3rd party communications
- Quick: low computing time

What modelling technique can be used to reach these objectives?

Flexibility and therefore the technical ability to cope with wind power fluctuations are notions best assessed over a longer period of time. Flexibility for instance, depends on the commitment of units and the limitations of those units. The commitment of units in their turn depend on the merit order and the demand and wind energy production. In the preceding sections, it is proposed that linear programing is a suitable technique or method to model the unit commitment problem of the Aruban electricity system.
Linear Programming, solves such problems through mathematical optimization by determining a way to achieve the best outcome (such as maximum profit or minimal costs) in a given mathematical model for some list of requirements represented as linear relationships. In the preceding chapters the system constraints and the merit order have been conceptualized in the LP formulation. In the next chapter, these formulations are translated in a programming tool called "Linny-R" and further specified by making use of historical and realistic data.

6 Specifications & Design of the model using Linny-R

In the previous chapter, LP has been proposed to formulate a suitable and accessible unit commitment model of the Aruban electricity system. 5 key constraints have been identified as well as the merit order of sources that have to provide the electricity. The aim of this chapter is to answer the following research question:

How is this general modelling technique applied to the AES?

This chapter further specifies the conceptual LP problem formulations by using historical data and translates the LP problem by means of a software package called Linny-R. In section 6.1, data concerning the system constraints is presented and used to specify the constraints. Section 6.2 introduces the software-modelling package and describes how the important aspects of the LP problem are incorporated in this package. Section 6.3 discusses the verification and validation of the model. Finally, in section 6.54conclusions are presented.

6.1 Data and specification

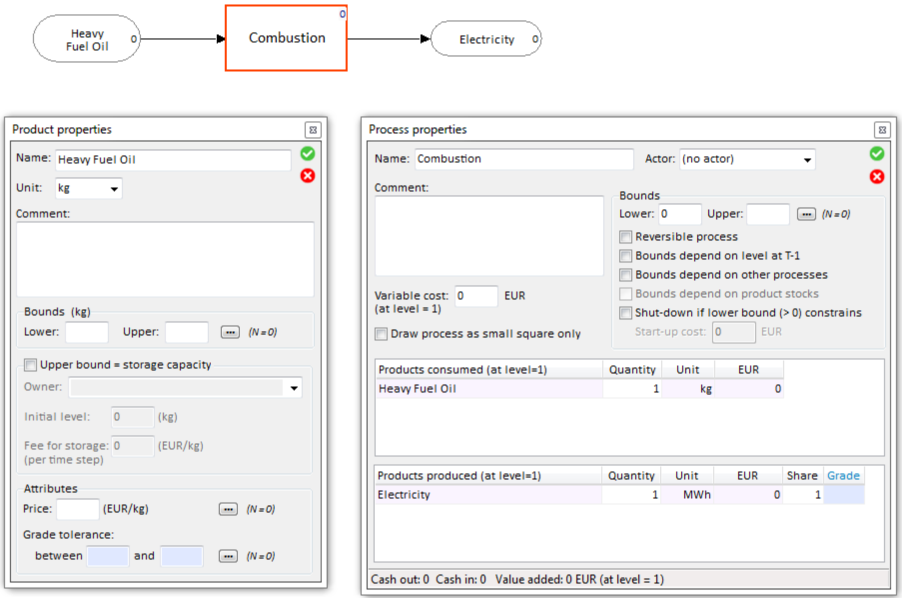
This chapter introduces the data which is used in the next chapter to specify and translate the LP problem in the Linny-R software-modelling package. The data used to represent the demand of electricity in Aruba is historical data of the total distributed electricity in 2011 specified on a ten-minute interval. This data has been obtained through the national distributor N.V. ELMAR. The demand constraints can be specified with this data-set. The data used to represent the renewable production of wind electricity in Aruba is historical data of the total distributed wind energy of the Vader Piet wind farm in 2011 specified on a ten minute interval and provided by WEB N.V. The data used to represent the wind energy production of the additional wind park (30MW) is the similar to the historical output of Vader Piet only lacking 10 minutes behind. Two main reason exist for the assumption 1) the another wind park, which is relatively close (5km) lacks 10 minutes behind on the wind production and 2) the developers of the new wind park announced that they will use a similar configuration of the new park (10x 3.0 MW Vestas V-90 turbines). The renewable production constraints can be specified with this data-set. By applying the unit characteristics of the generation portfolio shown in Table 2-2 the conventional production-, unit capability- and the unit ramp rates constraints can be specified.

6.2 Linear Programming tool Linny-R

The specified LP problem has been formulated in the previous section. With the use of a simulation tool, it is possible to design a computer simulation model that will solve this problem automatically. In this research the LP problem has been translated into a simulation model by using the software-modelling package "Linny-R". This section introduces and describes the function of Linny-R. Furthermore it elaborates on how the important aspects of the LP problem are translated into the simulation model.
The current LP problem with all its variables and constraints combined with its model set-up time of 1 year and its time-step of 10 minutes poses an enormous number of possible solutions. Manually calculating the objective function under such a number of possibilities clearly would require a long period of time as well as sufficient calculating capabilities. By making use of a software-modelling package could overcome such hurdles. In this research the software-modelling package used is Linny-R, developed at the Delft University of Technology by Dr. P.W.G. Bots, associate professor at the Faculty of Technology, Policy and Management. This software package is designed to model, implement and adapt simple and complex LP problems through an attractive and easy to use interface. One of the main advantages of using Linny-R is that the user does not have to work within the elaborate and sometimes complex (un)equality formulations but is able work within the interface translating and specifying objective functions, constraints and values.

In Linny-R there are two types of nodes: products and processes. A process is depicted as a square-shaped figure. A product is depicted as an ellipse-shaped figure. Products either represents the input or output of a process. Such relations are depicted by either an arrow going from a product into a process or from a process into a product. For every product or process, the user has to specify information (constraints, values). For a graphical representation of these products and processes, see Figure 6-1.

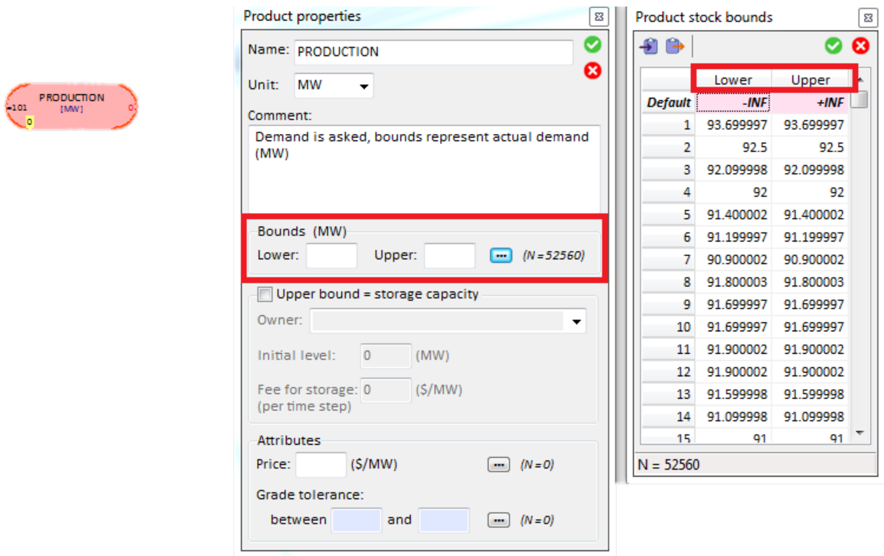
Figure 6-1: Products and processes in Linny-R



6.2.1 Specification of the constraints

The demand constraint varies every ten minutes and is therefore not constant. The time-span of the model is 1 year and the time step of the model is 10 minutes. Thus 52560 different values of demand have to be specified. The demand of electricity is not a process, it is a product and the production of electricity is a process. Within the 'bounds' area of the product specifications, a lower- and upper bound can be specified. The demand has no lower- or upper bound, it is one number. In order to translate that demand into Linny-R both lower- and upper bound are similar (Figure 6-2).

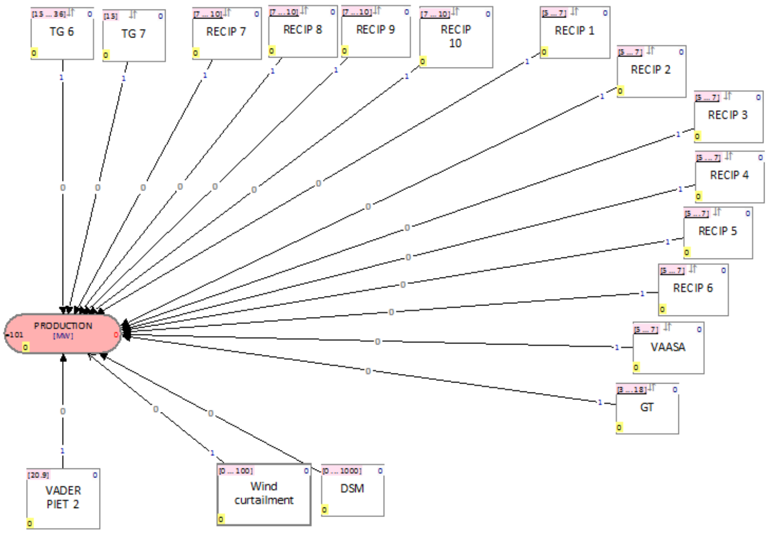
Figure 6-2: Product properties Linny-R



The production of electricity is facilitated by conventional and renewable energy technologies. The conventional production is facilitated by the TG's, 11 reciprocating engines (including the VAASA) and the gas turbine. Renewable energy is produced through the Vader Piet wind farm. Furthermore, the fictional units "DSM" and "Wind curtailment" are included in order to keep the objective function solvable (5.2.3-Fictional reserve/ storage units). All these production units can be seen as processes, see Figure 6-3.

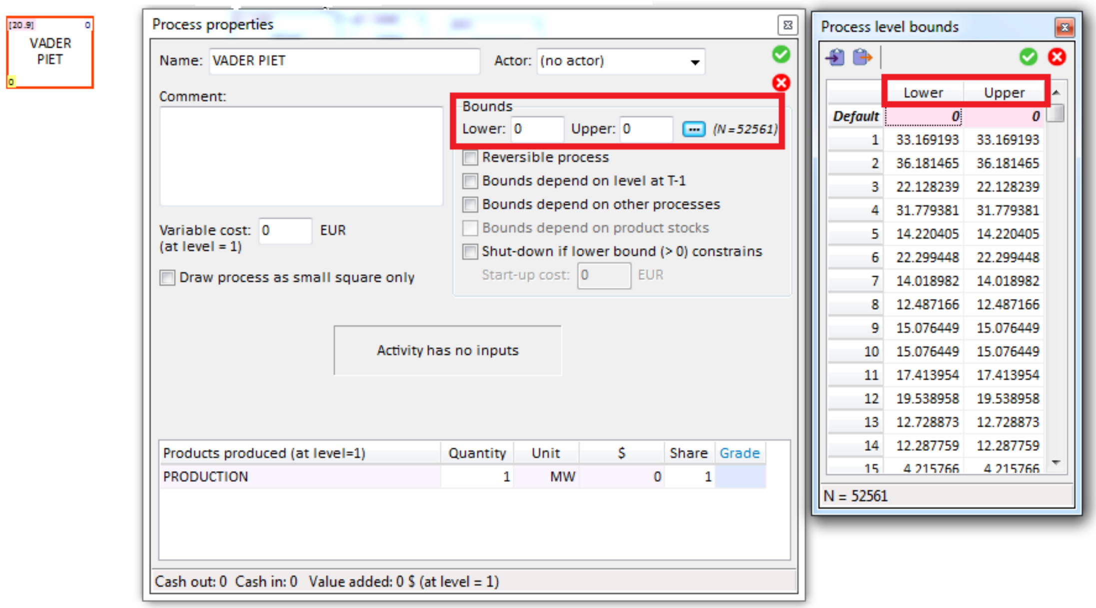
$$P_{total}(t) = P_{TG6}(t) + P_{TG7}(t) + P_{recip7}(t) + P_{recip8}(t) + P_{recip9}(t) + P_{recip10}(t) + P_{VAASA}(t) + P_{recip1}(t) + P_{recip2}(t) + P_{recip3}(t) + P_{recip4}(t) + P_{recip5}(t) + +P_{recip6}(t) + P_{GT}(t) + P_{DSM}(t) + P_{WindCurtailment}(t)$$

Figure 6-3: Overview of modelled generation portfolio in Linny-R



Where the electricity produced by the conventional generation can be manually influenced thus controlled, wind energy is not dispatchable. As this is an research on wind integration, produced wind energy is first in the merit order. As already formulated, the total demand minus the wind production is the residual demand, which has to be generated by the conventional generation units. Similar, like the specification of the demand also wind energy makes use of historical data and the production of wind energy doesn't have a lower- or upper bound (Figure 6-4).

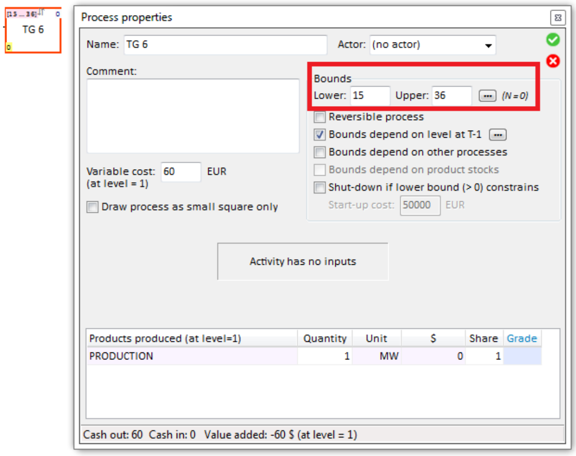
Figure 6-4: Product (Vader Piet) properties in Linny-R



The minimum- and maximum generation capabilities of the conventional units. As an example the generation capability of turbine generator 6 is presented. These values can be translated in Linny-R by defining the lower- and upper bound of a unit. By defining these bounds a unit is limited to produce electricity within these boundaries. Furthermore the bounds are constant throughout the simulation period (Figure 6-5).

$$15 \leq P_{TG6}(t) \leq 36 \quad \textit{(for turbine generator 6)}$$

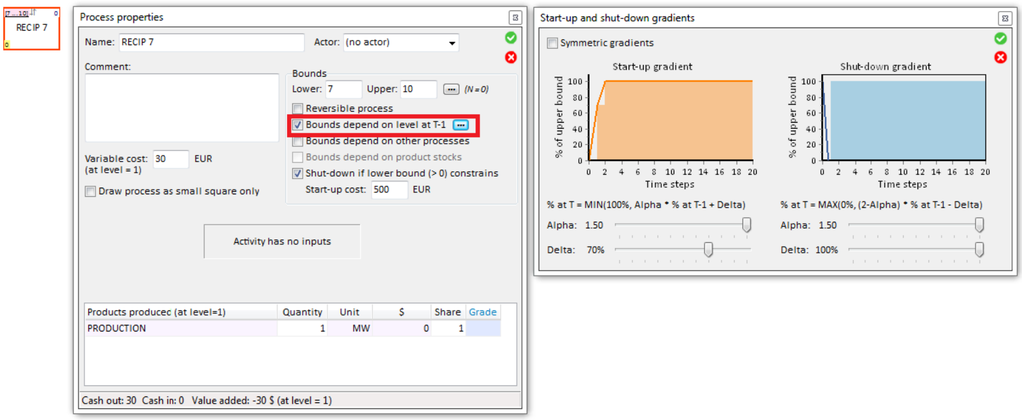
Figure 6-5: Process properties-bounds in Linny-R



The rate of increasing or decreasing electrical output is physically limited by the ramp rate constraints. As an example the ramp rates of the reciprocating unit 7 is presented. The values can be translated in Linny-R by defining the start-up and shutdown gradients. These gradients define how much of a unit capacity, expressed in percentages of the upper bound, increases after one time-step. According to the unit characteristics data a phase III reciprocating unit takes 15 minutes to start-up and 2 minutes to shut down. Furthermore the ramp up rate is 0,9 MW/min and the ramp down rate is 1,8 MW/min. This means that, a phase III reciprocating unit can be dispatched from an offline status to a 100% online status within two time-steps (20 minutes). It is assumed that after one time-step (10 minutes) the units' capacity is around 70%. Concerning the shut-down procedure, a similar unit can shut down from a 100% to 0% within one time-step, see Figure 6-6. This method incorporates both the start-up and shutdown times as well as the ramp rates, as was proposed in paragraph 5.4.2.

$$P_{recip7}(t) - P_{recip7}(t-1) \leq 0{,}9 \quad \textit{(as generation increases)}$$
$$P_{recip7}(t) - P_{recip7}(t-1) \leq 1{,}8 \quad \textit{(as generation decreases)}$$

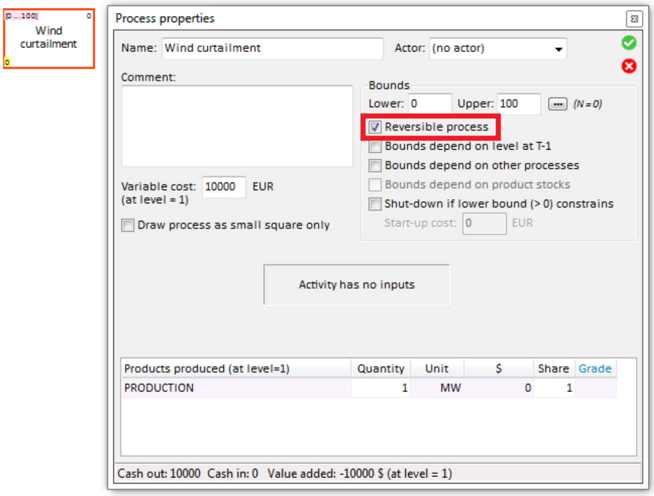
Figure 6-6: Process properties-ramp rates Linny-R



6.2.2 Specification of fictional reserve units

The fictional reserve units “DSM” and “Wind curtailment” have been specified as units without capacity boundaries of ramp rate limits. The use of these fictional units is to maintain the solvability of the objective function. The commitment of the DSM unit equals an imbalance due to insufficient power production to meet demand and allows for the specification of this imbalance in terms of the frequency, amount of power and duration (see modelling requirements paragraph 5.1). At such times, DSM is programmed to supply the difference in demand and supply by producing additional electricity.
The concept of the wind curtailment unit works slightly different. The commitment of this unit equals an imbalance due to an overproduction of power. During such imbalances, the difference in demand and supply is not solved by the production of additional electricity. Therefore, such a unit requires a different modelling approach for the unit and makes use of the option ‘reversible process’ (Figure 6-7). As a result, an overproduction of electricity is discarded or curtailed.

Figure 6-7: Process properties-wind curtailment Linny-R



6.2.3 Merit order

The merit order, introduced in the previous chapter can be manually modelled by assigning each process a virtual variable cost and/or a start-up cost (see paragraph 5.2.4). Assigning virtual variable costs influences the merit order of units and the utilization of those units. For example: turbine generator 6 provides base-load and at the same time functions as a frequency response reserve making TG6 the first conventional unit to be committed. Yet at the same time TG6 has to be operating at a minimum capacity to be able to provide the necessary frequency response capacity. Hence, the virtual variable costs are assigned in such a way that it is cheapest to run TG6 at the lowest capacity level except at moments when flexibility is required i.e. demand increase, wind decrease (Table 6-1). And in order to do so, higher variable costs have been assigned to TG6 compared to other the spinning reserve capacity (phase III reciprocating units) . The assignment of variable costs can influence the merit order of units and also the utilization factor of those units. In Table 6-1, the numbers of the variable- and start-up costs are presented. After the turbine generators, the virtual variable costs of the phase III reciprocating units are specified as the cheapest, resulting in these units to be committed next in line. This is the same for the VAASA, the phase I&II reciprocating units, the gas turbine at finally the fictional units.

Table 6-1: Assignment of virtual costs

	Wind power	TG6	TG7	Recip (III)*	VAASA	Recip** (I&II)	GT	DSM	Wind curtailment
Variable costs	-	60	9.000	30	60	60	90	5.000	10000
Start-up costs	-	50.000	50.000	500	350	400	800	-	-

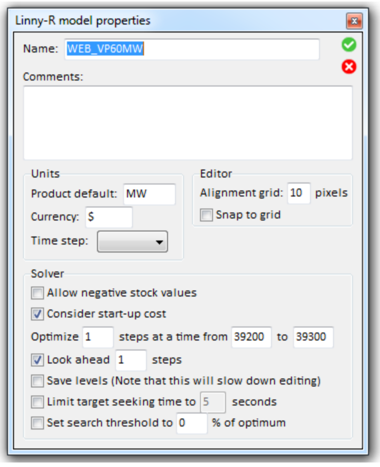
*Recip 7-10
**Recip 1-6

The assignment of virtual start-up costs influences the strategic commitment of units. It is not realistic that during an average day of producing electricity multiple units are brought online and offline within a small period of time. Generally speaking, each commitment of a unit requires capital and it has to be certain that this unit can stay online for a certain period of time. Linny-R may solve, if no start-up costs are used, its objective function by constantly committing and shutting down multiple units if the residual demand should increase or decrease marginally. Such behaviour is prevented and corrected by assigning start-up costs. As a result, Linny-R solves the objective function by finding the least-cost alternatives by increasing the utilization factor of an unit rather than committing a new unit.

6.2.4 Model properties

Model properties, such as time-span, time-step, optimization-step and look-ahead time can all be specified in the Linny-R model properties box. Time-span is 1 year and the time-step is 10 minutes, which makes the amount of steps Linny-R has to optimize and finds a solution for 52560. The optimization step is one, as is the look-ahead time.

Figure 6-8: Model properties Linny-R



6.2.5 Constraints out of modelling scope

Chapter 5 identified several constraints that are out of the modelling scope but could be manually incorporated by 'tweaking' the model. Such an option exists in the modelling tool of Linny-R.

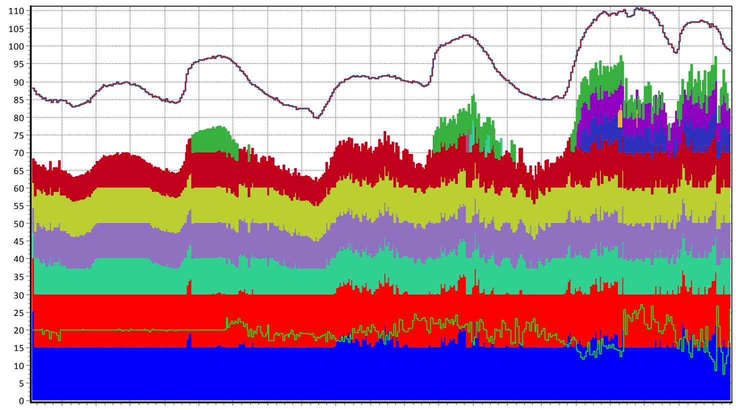
- Minimum up- and minimum down time (manually incorporated)
- Failure rates (manually incorporated)

Tweaks apply to processes where the lower- and/or upper bound and the variable costs can be modified during specified time period. Such tweaking gives possibilities to manually incorporate some of the above-mentioned constraints that could not be modelled as a constraint in the LP formulation. *First*, the minimum up- and minimum downtime can be manually incorporated by specifying how long a unit, after is has been committed, must be online. According to the unit characteristics presented in Table 2-2, the minimum up- and downtime of a phase III reciprocating unit is 15 minutes. Starting up such a unit to 100% capacity takes two time steps (20 minutes). According to the characteristics it is not possible to shut that unit down after these two time-steps. If this does happen, it is possible to fixate the lower- and upper bound within that 3rd time step as to 'prevent' that unit from going offline. The same is possible, with the downtime only then you'd fixate the lower- and upper bound zero to prevent that unit from going online. *Secondly,* the failure rates can be manually incorporated by manually preventing a unit that is committed in the simulation model to be committed. According to the unit characteristics, reciprocating units have a 25% failure rate. This means, that 25% of the times that a unit is committed ends as a failure and as a result that unit will be offline and, according to R. Cas unavailable for the next 18 time-steps (3 hours). This can be manually modelled by fixating a unit's lower- and upper bound as zero for a time period of 18 time-steps.
This quantitative model that now is developed is a tool to analyse the technical abilities of the electricity system to maintain the balance between supply and demand with additional wind energy. It is not possible to manually incorporate the constraints over the entire length of the simulation period, this however is not necessary. The analysis is more concerned with moments of imbalance and it is in these moments that the above-mentioned constraints are manually incorporated.

6.3 Verification & Validation

As described in the first chapter of the research (paragraph 1.7), interviews have been conducted at several organisation including the ELMAR and WEB. Some of these interviews mainly related to the verification of the modelling assumptions, the verification of the model data and validation of the outcomes of the model. During an interviews with C-Ras – Technical Support Engineering and R. Croes-Senior Operator (employees at the technical department of WEB) both reviewed, examined and compared the model with real-life dispatching of units under various demand scenarios and wind production output. This section presents a summary of the interview (full interview, see Appendix-E). First, the specification of the unit constraints were discussed. Both experts were in agreement that the specified lower- and upper bounds (unit capacity constraints) resembled the values of the units in real life. Logically, the configuration of the generation portfolio was also found realistic. Secondly, two simulation scenarios were presented 1) an average day with low variable wind output (Figure 6-9) and 2) a random day with high variable wind output (Figure 6-10).

Figure 6-9: Simulation scenario: average day with low variable wind output (left) legend (right)



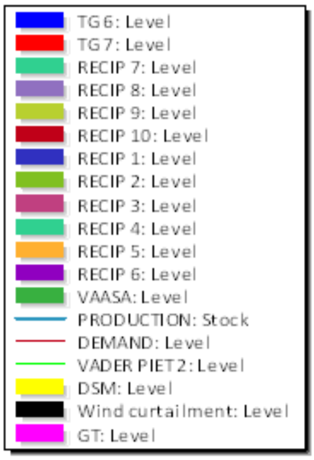
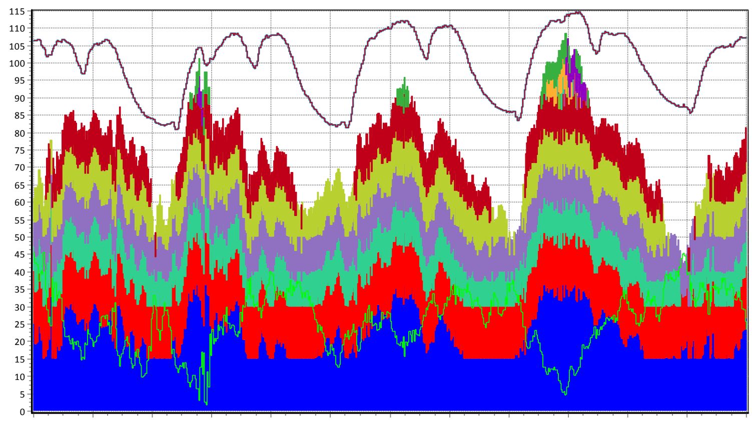


Figure 6-10: Simulation scenario: random day with high variable wind output



The interview has confirmed the theoretical merit order of units as introduced in this study as the order in which the different sources are used. TG6 and 7 are not the most cost effective generators they operate as base load. One of the TG6 operates at a constant level, TG7 operates as a spinning reserve. Although these are the least cost efficient production units they are operated because of their high reliability. According to both experts the model displayed this behaviour correctly. Recips phase III units[9] are the most cost efficient in the configuration and are next in line to be dispatched. It was found that the model simulated this dispatch also correctly. Recip phase (I&II)[10] are the last generators that are dispatched in the current configuration. At times of high demand and/or low wind penetration (sudden windfalls), these recips are dispatched. The models behaviour in this respect was also found to be correct. Vader Piet is modelled as the most cost effective generator in the configuration; its output will always be dispatched

[9] Recip phase III units include recip 7-10
[10] Recip phase I&II units include recip 1-6

in the model. The data-set used for specifying Vader Piet is derived from WEBs own production data and is verified and validated.
The demand however, was found to be lower than usual. This is related to the fact that the internal demand of WEB was not calculated in the modelled demand series of ELMAR. According to both experts, this consumption of WEB is approximately 10MW and is related to water production (2-5MW), internal use and electrical losses. The internal demand is fairly constant throughout the year, and may be modelled as such. This has been specified in the model accordingly. As stated earlier in this research (see paragraph 3.4 and 4.1) this load is already used in the balancing strategy of WEB.
During the meeting, information was presented on the constraints that could not be automatically incorporated in the model. This however, proved to have no effect on the validity of the model on an aggregate level, although could lead to unrealistic behaviour at times of high variability on a more minute-to-minute basis. It was recommended to manually incorporate these non-linear constraints, as already introduced in the previous chapter.

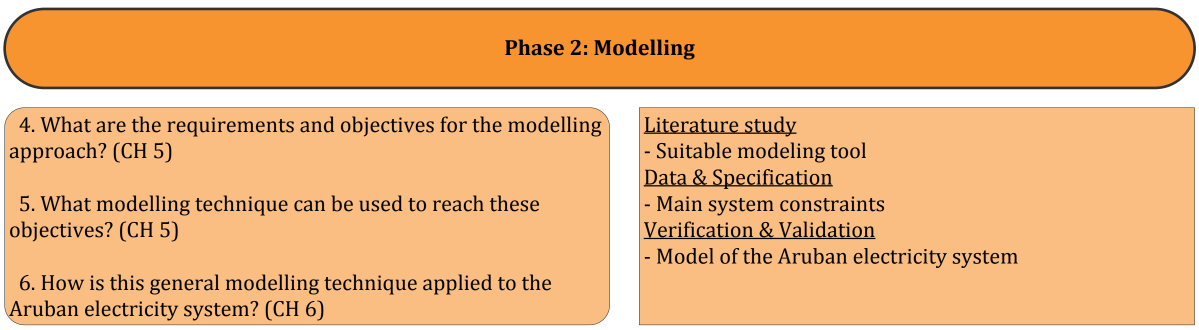
6.4 Conclusions

How is this general modelling technique applied to the AES?

First, the methodology of Linear Programming was proposed to formulate system constraints and the merit order of supply resources. After carefully specifying these constraints with the use of historical data (provide by the utilities ELMAR & WEB) the constraints and the merit order of supply resources were translated in the software-modelling package. Linny-R proved a workable, accessible, suitable (to a lesser degree) representable and quick model. The main assumption underlying in the simulation model is that Linny-R optimizes with complete and accurate information regarding the demand of electricity and the wind energy output for every time-step. In reality, operators work with forecasts and incomplete information. Operating low look-ahead times has mitigated this effect. The designed model has been verified found valid and will be used in the next chapter to design experiments to answer the modelling questions formulated in chapter 5.

In addition, some non-linear unit constraints could not be automatically incorporated in the simulation model. Although these do not affect the validity of the model on an aggregate level, it is recommended to incorporate them during more minute-to-minute analyses.
A model is always a simplified representation of reality. Assumptions made during the modelling phase have great influence on the behaviour of the model and its results. The choice for Linear Programming and Linny-R both have limitations and influence to some extent the results of the simulations. Being aware of such assumptions and limitation of is imperative in evaluating the value of the model and its outcomes. In Chapter 11 the reflection on the choice for LP and Linny-R its and the implications are presented in paragraph 11.2.

Figure 6-11: Research phase 2



7 Technical feasibility DSM

The second research phase ended with the design of a verified and valid unit commitment model of the Aruban electricity system. In this chapter, the model is used to answer modelling question presented in chapter 5 (see paragraph 5.1) and in general aims to answer the following research:

To what extent is the identified DSM measure a technical feasible solution?

In section 7.1, the first scenario simulations and results are presented. Section 7.2, goes into more detail on the general results and quantifies moments of imbalance. Section 7.3, evaluates the technical feasibility of load shedding according to the specifications of the imbalances and finally, in section 7.4 conclusions are stated.

7.1 Scenario simulations & Results

This section presents an answer to the modelling questions 1) What is the effect of an additional wind park (30MW) on the technical ability of the electricity system to balance supply and demand? 2) Will an imbalance occur, and if so, why and on what particular moments?
First, different scenarios are presented to illustrate the effects of additional wind power: 0 MW wind energy, 30 MW wind energy and 60 MW wind energy generation capacity. The scenarios are all runs of 52560 time- steps, which represents a year of simulation. If any imbalances should occur, the model dispatches a fictional flexible reserves (DSM or Wind curtailment) with unlimited flexibility and capacity. The amount of times this reserve is dispatched is an indicator of the amount of imbalances. Imbalances related to insufficient production are corrected through dispatching the process: DSM. Imbalances related to an overproduction of electricity are corrected through dispatching a process called: 'Wind curtailment'. The results of these scenarios are presented in the below table:

Table 7-1: Simulation results of various wind generation scenarios

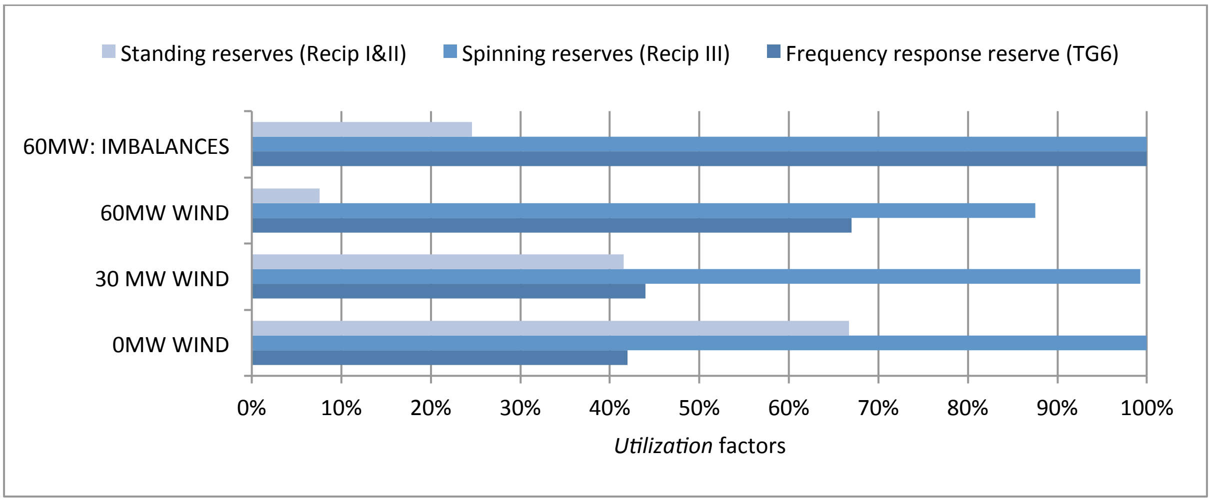
	0MW wind	30MW wind	60 MW wind
DSM (#/yr)	0	0	7
Wind curtailment (#/yr)	0	0	30
Total	0	0	37

No imbalances occurred during scenarios with 0MW and 30MW wind energy. However, with the addition of an extra 30MW wind energy (60MW), in total 37 imbalances occur during a year. Of these imbalances, 7 are related to overproduction due to sudden and significant increases in wind energy production. As already discussed in the previous chapters, operators can curtail wind energy up to a specific GWh cap per year (2,3 GWh/year). WEB curtails wind energy during sudden periods of significant wind increases. By applying set points WEB is already able to maintain reliability (see . Therefore, no further elaboration on imbalances related to overproduction is specified in this chapter. In chapter 11, the choices made regarding wind curtailment are reflected upon. More interesting are the imbalances related to insufficient power production, which currently require investments.

Figure 7-1 illustrates the average utilization factor per type of unit for the various wind scenarios and during periods of imbalance related to the decrease of wind energy. This figure identifies the characteristics of the generation portfolio during periods of imbalance compared to the characteristics of the portfolio for the specified scenarios. According to this table, during periods of imbalance the capacity of the frequency response- and the spinning reserves are fully utilized.
During the simulation scenario of 0MW wind energy generation capacity the system needs to balance supply and demand without compensating any variable output of wind energy resulting in a low utilization factor for TG6, a full utilisation of the spinning reserves and a utilization factor of 67% for the recip I&II units combined. During the simulation scenario of 30MW the system compensates the variable output by utilizing TG6 slightly more compared to the previous scenario. Due to the production of wind energy, the utilization factor of the spinning reserve is slightly lower (compared to the 0MW scenario) and that of the standing reserves is substantially lower (42%). During the simulation scenario of 60MW the system compensates the additional variable output by utilizing the TG6 substantially more (67%) compared to the previous scenarios. The additional amount of wind energy produced does results in lower utilisation factors for both the spinning- and standing reserves.

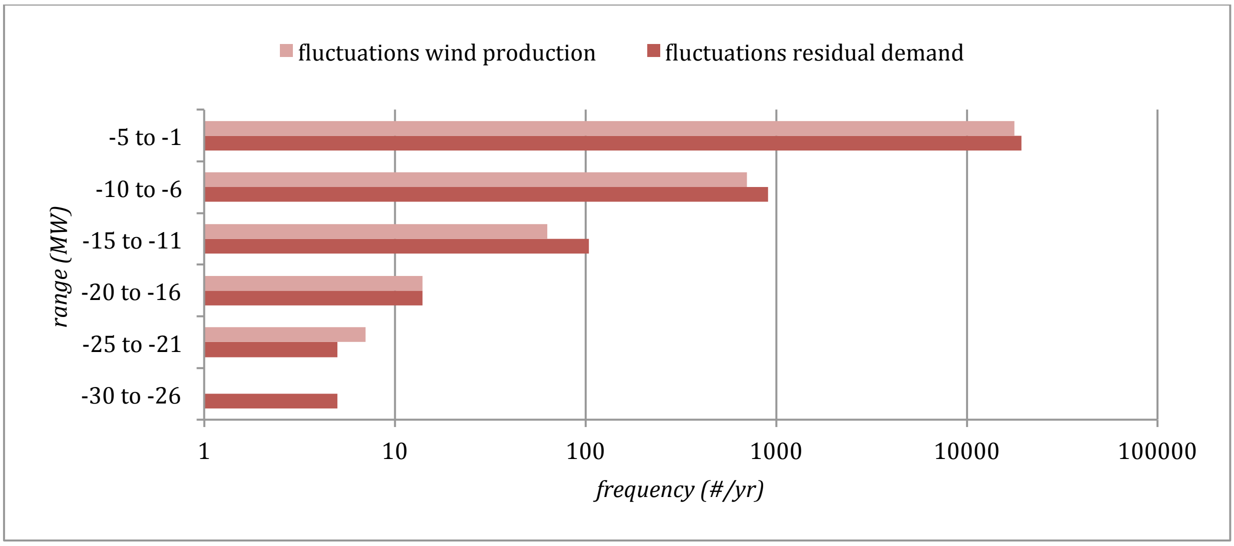
The results of the identified imbalance events, during the 60WM scenario suggest that despite the 100% utilisation of TG6 and the spinning reserves the variability in wind or demand cannot be compensated by the standing reserves. Logically, when the frequency response- and the spinning reserves are at full capacity the standing reserves need to be dispatched, however this process is subject to technical constraints; (i.e. start-up failures, start-up times, ramp rates) and as a results of that the system cannot maintain balance. Whether these imbalances are attributable to a decrease in wind energy or an increase in demand or a combination of both is explained below the figure.

Figure 7-1: Average utilization factors for units specified for various wind generation capacity scenarios and periods of imbalance related to the decrease of wind energy.



Results of the 0MW and 30MW simulation scenarios (Table 7-1) suggest that that the increase of demand did not lead to any imbalances. Furthermore, the calculated fluctuation of the residual demand (demand – wind production) for every time-step shows no substantial difference compared to the wind fluctuations for every time-step in the 60MW scenario (Figure 7-2). This graph illustrates the yearly distribution of the variation in residual demand and wind energy output within 10 minutes for the scenario of 60MW. According to this graph the residual demand fluctuations are mainly determined by the decrease in wind production and the fluctuation of an increasing demand cannot be regarded as an explanation for moments of imbalance. Therefore, it is found that the imbalance are the sole effect of rapid decreases in wind energy production. This section has illustrated that seven imbalances occur during times of high utilization factors of fast spinning reserves in combination with decrease of wind energy. To specify what amount of wind decrease lead to imbalances, a secondary analysis is presented in the next section.

Figure 7-2: Overview of distribution of residual- and wind fluctuations for 60MW wind scenario

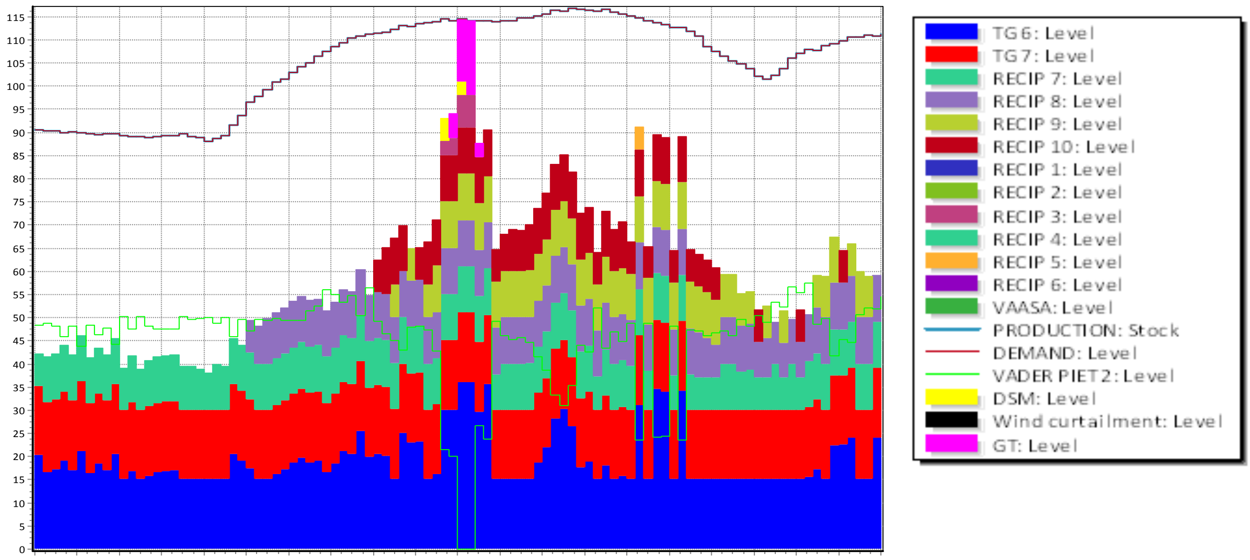


7.2 Quantification of the imbalances

This section, aims to quantify the technical details of the imbalances. The results of the former analysis show that wind decreases and utilization of fast spinning reserves play an important role during moments of imbalance. The role of these two factors are further analysed. In order to do so, the imbalance moments are analysed on a more minute-to-minute bases, which allows for the incorporation of non-linear constraints. The enables us to answer the following question: 1) When and why do imbalances occur and 2) What are specification of these imbalances in terms of (frequency, amount of power imbalance and duration)?

The simulation event in Figure 7-3, shows an imbalance during the 60MW scenario. In total the results show seven similar events. The sudden decrease of wind energy requires almost 40MW to be compensated within 40 minutes. The results, show that the capacity of the frequency response- and the spinning reserves at times of imbalance is fully utilized. The latter of the residual demand is compensated by recip 3, the gas turbine and the virtual DSM unit. The DSM unit delivers approximately 8MW and 3MW for a period of 10 minutes.

Figure 7-3:Simulation of an imbalance event during the 60MW scenario (right) legend (left).



In order to provide an answer on when such imbalances occur, the imbalances have been classified according to the amount of wind decrease and the utilization factor at the specific period. It is assumed that imbalances only occur during periods of wind decreases lower than -10 MW/10 min, therefore the wind decrease ranges used in this analysis are between:

- -11 and -15 MW/ 10 minutes
- -16 and -20 MW/ 10 minutes
- -21 and -25 MW/ 10 minutes

Furthermore, the average utilization of the fast spinning reserves during imbalance is 100%. In order to specify exactly, when the imbalances occurred the general utilization factor of fast spinning reserves is categorized according to the status of the units (online, offline) and their actual utilization. Three classifications are used in this analysis:

- Low utilization: during low utilization not all phase III reciprocating units are online and TG6 operates between 15-22 MW. Consequently, the total capacity of the fast spinning reserves lies between 14-15 MW.
- Medium utilization: during medium utilization all phase III reciprocating units are online and TG6 operates between 22-29 MW. Consequently, in this scenario the total capacity of fast spinning reserves lies between 7-14 MW.
- High utilization: during high utilization all phase III reciprocating units are online as are various phase I&II reciprocating units. TG6 operates between 29-36 MW, making the total capacity of fast spinning reserves between 0-7MW.

The results of this (second) analysis are illustrated by Figure 7-4. The green blocks represent sub-scenarios within the 60MW scenario where no imbalances occurred. The orange blocks represent periods where it was required to commit the gas turbine to maintain balance and illustrated the physical limit of the electricity system. The red block identifies at what particular moments an imbalance occurred. Table 7-2 shows the specifications of the sub-scenarios and quantifies the imbalances. The results show that during the 60MW scenario no imbalances occurred during periods of low to medium utilization in combination with wind decreases between -11 and -25 MW/10 minutes. Furthermore, the high utilization of reserves proved problematic for the ability of the electricity system to cope with wind decreases between all scenario ranges.
In total, seven imbalances occurred during periods of high utilization of reserves combined with a wind decrease between -21 to -25 MW per 10 minutes. The maximum power imbalance amounted 8MW and the maximum length of the imbalance amounted to 10 minutes. In addition, during all moments of high utilization (19 times per year) the commitment of the gas turbine unit was required to maintain balance. The required capacity of the gas turbine is between 8-16MW and was committed for at least 30 minutes.

Figure 7-4: Simulation results of the 60MW scenario per sub- scenario

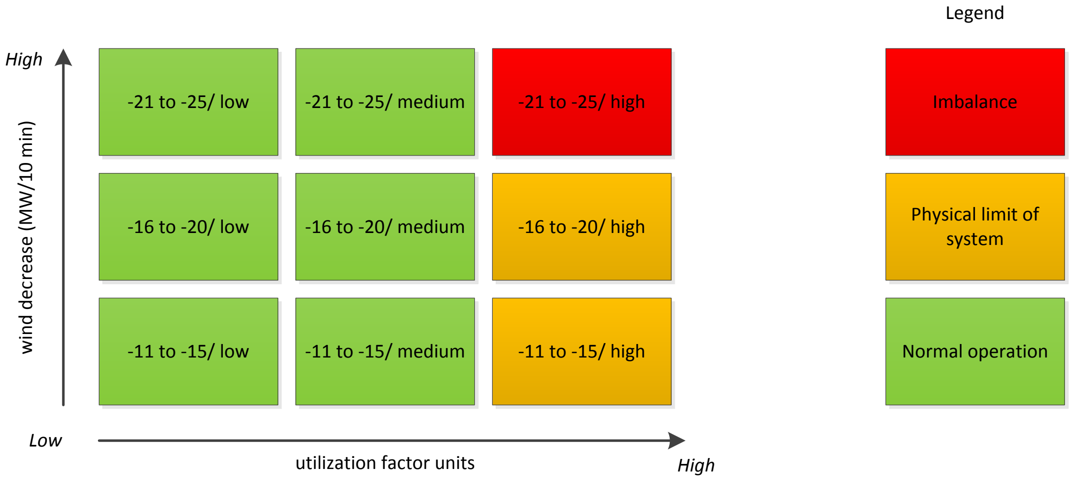


Table 7-2: Specification of simulation scenario of 60MW results per sub-scenario

Sub-scenario	**Imbalance**	**Compensating units**	**Frequency (#/yr)**	**Power amount imbalance**	**Duration**
-11 to -15/high	No	Frequency response-, spinning- and standing reserves including gas turbine	8x	8MW	30 min
-16 to -20/high	No	Frequency response-, spinning- and standing reserves including gas turbine	4x	8MW	40 min
-20 to -25/high	Yes	Frequency response-, spinning- and standing reserves including gas turbine and DSM	7x	8MW/ 16MW	10 min/ 40min

The simulations scenario of 60MW wind energy generating capacity shows that the current generation portfolio of WEB is unable to safeguard the balance between supply and demand during periods of sudden and severe wind decrease between -20 and -25 MW/ 10 minutes in combination with a high utilization of fast spinning reserves with the integration. If the aim is to mitigate all imbalances in this scenario it is necessary to minimally extend the fast spinning reserve capacity with a reserve that is able to provide 8MW of power, within 10 minutes for at least 7 times a year. These three criteria can be regarded as the technical requirements to mitigate imbalances caused by an additional wind farm of 30MW.

7.3 Technical feasibility of load-shedding

The technical feasibility of the proposed DSM program depends on whether or not the controllable appliances of the customer (AC load) and the characteristics of the direct load shedding program can satisfy the requirements defined in the previous section.
Regarding the frequency, it is technically possible to reduce the air-conditioning load for at least 7 times a year. Reducing the load may be done automatically by WEB or in concordance with the hotels. According to the simulation results, the required capacity (8MW) is lower than the potential capacity of air-conditioning load of hotels (12,7-17,8 MW) and therefore sufficient. However, this is a range of potential available load, which is based on historical data and interviews chapter 4. In order to exactly identify the potential load it is recommended to initiate a thorough metering study in combination with the analysis of an ample list of conditions and variables that influence the customers demand for air-conditioning. This is beyond the scope of this research and therefore not included (additional research on this topic is addressed in paragraph 10.2).
Regarding the duration, almost all air-conditioning systems in the medium and large hotels are centralized systems. Such systems mainly have multiple components that provide the cold (chillers) and can be centrally shut down or made idle (for more information in chillers see Appendix-F). During interviews with several General Managers and Directors of Engineering of several hotels it was concluded that it could be possible to completely shut down or idle an air-conditioning system within 2 to 3 minutes (see chapter 9). Therefore it would be technically possible to provide a decrease in demand of at least 8MW within ten minutes. However, to exactly identify the ramp rates of all air-conditioning systems additional research is needed (this is also addressed in section 10.2-Limitations, remaining questions and additional research). In paragraph 3.3 of this research, the choice of a DSM program was evaluated according to an estimation of the required time-scale of operations). This required time has been identified as less than 10 minutes. According to the characteristics (Table 7-3), the direct load control program meets the requirements.
One of the technical consequences of operating a DSM program with a very short- or none advance notice of response is that customers, in this case hotels, do not have the opportunity to prepare themselves for the direct reduction in load. This implies the need for automation and control systems. The controllable AC load may ideally be altered to follow the reduction in wind power rather than immediately shutting down. Conversely, the starting up of the combined air-conditioning systems of hotels would also require a gradually start-up process in order to prevent peaks in demand. This again implies the need for advanced metering and control equipment.

Table 7-3: Characteristics of direct- and required DSM program

DSM program	Time scale		
	Advance notice of response	Duration of response	Frequency of response
Direct load control	None	1-60 min	Sometimes limited in tariff
Required DSM program	None	1-10min	~7 times a year

Implications on technical architecture
System components of an architecture that aims to satisfy the above-mentioned requirements can be generally divided in the following categories: enabling technologies at the demand-side, communication infrastructure and a central control system (Figure 7-5).
Current load shedding, as well as demand-response schemes are implemented with commercial, industrial and residential customers, often facilitated through the use of dedicated control systems to shed load in response by a signal of the utility (request) or market (price). According to a recent news article on “How demand response can turn your hotel into a virtual power plant” (greenlodgingnews.com) some demand response providers use advanced technology to ensure that demand response capacity is available where and when it is needed. In this example, a company installs a small gateway device to the site’s electric meter, collecting electricity usage information in five-minute intervals, and sending that data back to its central control system. When dispatched by the local utility or grid operator, the DR provider sends a signal to the customers in its network indicating that it is time to reduce energy usage. When notified, hotel facility managers then enact their customized energy reduction plan for the duration of the demand response dispatch.

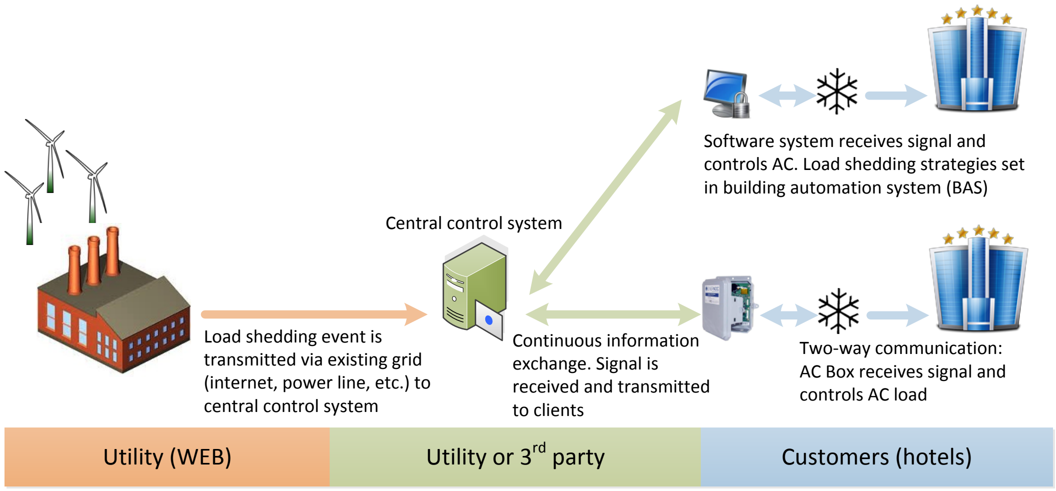
Box 7-1: Successful example of a DR in action at the Seaport Boston Hotel. Copied from: [(greenlodgingnews.com)]

> The Seaport Hotel is one of the leading hotels in the Boston area, a 330,000-square-foot mixed-use facility at the forefront of the green hotel movement. As part of its award-winning Seaport Saves program, the Seaport Hotel enrolled in a comprehensive demand response program in 2009. During DR dispatches, the hotel adjusts its air-conditioning, reduces its laundry activities, and shuts off or reduces non-essential lighting. These changes, controlled centrally via the hotel's building management system, temporarily reduce energy use by more than 300 kilowatts. In turn, this reduction earns the Seaport Hotel thousands of dollars in annual payments, which it uses to fund other sustainability efforts.
>
> "One of the great things about DR is that it lets us reduce electricity in ways that are virtually invisible to our guests—and that do not impact guest comfort in any way," said Matthew Moore, director of rooms and sustainability at the Seaport.

In this research, the above direct load shedding program can be facilitated in two ways. The first is through sending a signal from the utility to the hotels that interacts with a building automation system (BAS) (for more information on these systems, see Appendix-F) that can be programmed to take action based on that signal, enabling an event to be fully automated. The second option includes sending a signal to hotels that interacts with an apparatus and directly controls the AC load. In the first case, software would be needed to facilitate the request. In the latter case, where the AC is controlled manually dedicated control boxes (AC boxes) would be needed to (automatically) shutdown and start-up these systems whenever this may be necessary (Figure 7-5).
Various technologies are already commercially available to facilitate these operations. Variety exists in whether the technology detects the need for load shedding, communicates the available load to the utility or automates load shedding. In any case, the enabling technology at the demand side must include the following options:

- Continuous metering of shedable capacity (1-minute or less)
- Low resource response time (amount of time the AC load is shed after being notified)
- Ability to shut-down or lower AC capacity
- Ability to start-up or increase AC capacity
- Monitoring of capacity during shut-down and start-up
- Bypass options need to be limited or non-existent

Figure 7-5: Technical architecture of load shedding program



Communication can be either facilitated via existing infrastructures or through newly, undeveloped infrastructures. Possibilities for communication via existing infrastructures are: telecommunications systems (2G, 3G, 4G), radio communications, or power line based communications (PLC). The infrastructures on Aruba are capable of providing such services, i.e. via the up-to-date government-owned telecommunications company SETAR or via the existing power lines that are controlled by ELMAR. Either way it is not necessary to develop a new infrastructure particularly for these operations. Various categories and examples of load-shedding communications over existing infrastructure can be found in [29]. Other information on reliability services provided by private entities through demand side management, can be found in www.openadr.org. Finally, in order for a utility to actually shed loads a central control system (server) must be in place that is able to receive and send signals between the utility and the participating customers.

7.4 Conclusions

To what extent is the identified DSM measure a technical feasible solution?

The effect of additional wind energy resulted in some cases to a **technical inability** of the electricity system to balance supply and demand. To be more specific, during times of wind decreases between -21MW and -25MW combined with a high utilization of fast spinning reserves the electricity system is not able to maintain the balance between supply and demand. The frequency of the imbalances amounts to 7 times per year. The highest amount of power imbalance is 8MW and the duration of such imbalances is 10 minutes. Any solution that aims to mitigate such imbalances must thus be able to provide at least 8MW of electricity, within 10 minutes for at least 7 times a year immediately without prior notice.

The shedding of air-conditioning load of hotels through direct control can satisfy the above-mentioned requirements. Technically the shedding of load seven times a year does not pose any problems. The technical potential of AC load ranges between 12,7-17,8 MW and it is technically possible to shut down or idle AC load within 10 minutes. Operating such a DSM program with a short time-scale does require automation and control systems for both the customer and the utility. However, it is concluded that system components of such a technical architecture are widely available with sufficient functionality to facilitate such programs. In addition to these conclusions a critical note is mentioned. To precisely identify the capacity and the ramp rates of AC load additional research is necessary and not included in the scope of this research (more information on this additional research can be found in paragraph Limitations, remaining questions and additional research).

In this chapter, the technical feasibility of load-shedding is concluded. The next chapter aims, by introducing costs of other suitable supply side measures, to clarify the economic feasibility of load-shedding.

8 Economic Analysis

The technical requirements identified in the previous chapter dictates the range of suitable supply side measures. In this chapter analyses are performed between the costs of implementing load shedding compared to other suitable supply side management measures. This chapter aims to answer the following question:

Is the identified DSM measure an economic feasible solution, taken into account the system costs and benefits of additional wind energy?

Section 8.1, presents an introduction and evaluation of various storage techniques. In section 8.2, an overview of the general costs of both load shedding and other suitable measures is presented. In section 8.3, the notion of system costs is used to illustrate that the difference between the benefits of an additional wind park minus the marginal system costs associated with the addition of a wind park defines the maximum amount of capital that can be assigned to reliability measures. In section 8.4, the allocation of avoided system costs are discussed. Finally in section 8.5, conclusions are stated.

8.1 Storage techniques

In this analysis, no conventional generation technologies are analysed because in the previous chapter generation technologies such as: small reciprocating engines have been identified as inadequate measures to deliver such services. However, using energy storage systems can reduce such imbalances between generation and load, as the stored energy could be dispatched immediately to make up for a sudden reduction in supply.
More advanced storage technologies such as flywheels, batteries, (super)capacitors are suitable for this application because they respond instantaneously to frequent and unpredictable changes in wind [45]. Generally, commercial power storage techniques can be divided in the following categories:

- Flywheel storage
- Battery energy storage technologies
- Electrical (super)capacitor storage technologies
- (Hydrogen storage technologies)
- (Pneumatic storage technologies)
- (Pumped storage technologies)

This section aims to introduce several common and state-of-the-art storage technologies by presenting their general functioning and characteristics. Consequently, the costs of these storage techniques and information about their functioning, disadvantages and advantages is presented. Note, that hydrogen storage technology and pneumatic- and pumped storage technologies have not been evaluated. The use of hydrogen in frequency regulation is not suitable due to low response times, which results in the same problem as conventional generation techniques. Furthermore the scale of power applications suitable for the pneumatic- and pumped storage technologies far exceeds the scope of this analysis. Typical power applications for pneumatic- and pumped storage technologies are in the order of 100MW and above (see Figure 8-1). These techniques require both site availability and specific geographical surroundings i.e. pumped hydro storage: two reservoirs separated by elevation [46]. Below the storage techniques are explained and in Table 8-1 the advantages and disadvantages of the are presented.

In a recent research on evaluating various storage technologies for wind power integration it was stated that: *"**Flywheel** technology provides continuous power from a pulsating output by converting kinetic energy to electrical energy…The nature of cyclic rapid recharges and discharges as well as lower costs suggest that flywheel technology is well suited for frequency response."*[45] Flywheels, are commercially available and its use for frequency response regulation has been demonstrated. However, flywheels are not suitable in providing long term storage due to high standing losses and high self-discharge rates.
"**Storage batteries** are rechargeable electrochemical systems used to store energy. They deliver, in the form of electric energy chemical energy generated by electrochemical reactions."[46]. There exist multiple of types of conventional storage batteries, most familiar today are: the lead-acid battery, the nickel-based batteries and the lithium-based batteries. Important features of battery storage techniques can be found in [47]. **Lead acid batteries** are the most mature technology of storage batteries and require the least costs. The technology is based on chemical reactions involving lead dioxide, lead and sulphuric acid, which acts as the electrolyte. Because of its ability to discharge its stored power fast it is

able to provide frequency response power. However, the due to high standing losses and high self-discharge rates this technique is not suitable for long term storage.
Sodium sulphur (NaS) batteries are constructed from liquid sodium (Na) and sulphur (S). This type of battery offers a high energy density and efficiency. They are only suitable for large-scale (> 5MW) stationary applications due to high operating temperatures and highly corrosive nature of sodium. As a result, the operation costs are high and the batteries are currently only used in electrical grid related applications such as peak shaving and improving power quality.
Currently, **lithium-ion** based batteries are commonly used in small appliances such as: mobile or laptop systems. The technology offers high energy densities (80-150 W/kg) and power densities (500-2000 W/kg) and energy efficiencies. The high cycle life time is negatively affected by temperatures and can be severely shortened by deep discharges. This makes the batteries unsuitable for use in back-up applications where they may become completely discharged. Also, monitoring and temperature controls are required to prevent the battery from overheating and overcharging.
Nickel-cadmium (NiCd), Nickel-metal hybride (NiMH) and the nickel-zinc (NiZn) are the three most common nickel-based batteries. Generally, the NiCd battery is the only one of the nickel-based batteries that is commercially used for utility power system applications, such as in large energy storage for renewable energy systems. It has a high operational life- and cycle time and suffers from high self-discharges thereby lowering the energy efficiency of the battery. The functionality is comparable with a lead-acid battery.
Flow batteries are often called redox-flow batteries, based on the redox reaction between the electrolytes in the system. In contrast to traditional storage batteries, where the energy-storing materials and electrolyte are enclosed in a cell, a flow battery's electrolyte is stored in two tanks that are separate from the cell itself. The flow battery generates electricity when the liquid electrolytes, which are mixed with energy-storing material (iron, vanadium, zinc, bromine) flow through the two-half cells and react with the electrodes in each side of the cell. Characteristics are: high power, long duration and fast response (full discharge in 1ms). One of the main advantages is that the system does not suffer self-discharges and no degradation for deep discharges. Despite, the advantages flow batteries are still immature technologies, which face technical development issues and require high investment costs.

Although, similar to a battery, the double layer **capacitor** depends on electrostatic action. Since no chemical action is involved the effect is easily reversible with minimal degradation in deep discharge or overcharge and the typical life cycle is hundreds of thousands of cycles. Reported cycle time is more than 500.000 cycles at 100% depth of discharge. Limiting factors: operational lifetime of 12 years and a high self-discharge rate reaching a level of 14% of nominal energy per month. Investment in these capacitors requires significantly higher costs compared to well-established storage technologies such as lead-acid batteries. Currently, the high power storage ability of supercapacitors together with the fast discharge cycles, make them ideal for use in the temporary energy storage for short-term capturing and storing energy and for providing a response to sudden power demands.

Table 8-1: Advantages and disadvantages of storage technologies. Adapted from: [46-48]

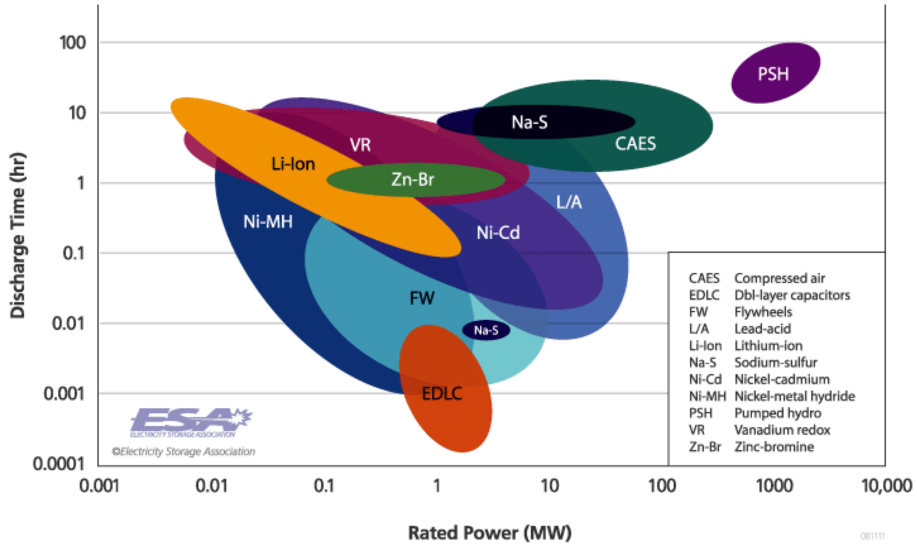
Storage category	Storage technology	Advantages	Disadvantages
Flywheel	Flywheel	• Able to provide frequency response power • Low investment costs	• High standing losses • High self-discharge rates • Not for long term storage
Battery storage technologies	Lead acid	• High energy efficiency (85-90%) • Easy to install • Low maintenance costs • Low investments costs	• Large, high levels of heavy metals • High self-discharge rates • Low cycle life (affected by depth of discharge) • Low operational lifetime
	Sodium sulphur (NaS)	• High energy efficiency (89-92%)	• Only suitable for large scale stationary applications • High operating temperatures • Very high operating costs

	Lithium-ion	• High energy efficiency (90-100%) • High energy and power density • Low self-discharge rate (5% per months) • High cycle life time (>1500)	• Life time affected by temperature and deep discharges. Unsuitable for backup • Requires monitoring and temperature control • High costs
	Nickel cadmium (NiCd)	• Higher operational life time compared to lead acid batteries • Operational lifetime (15-20 years) • Cycle life high (1300 – 1500)	• High self-discharge rates (higher than lead acid) • Low energy efficiency • High investment costs
	Flow batteries	• High power • Long duration • Fast response (1ms full discharge) • No self-discharge • No degradation for deep discharges	• Immature technology • Technical development issues • Very high investment costs
Super capacitor	Super capacitor	• Extremely high life cycle (> 500.000) • Limited operational lifetime (12 years) • No degradation for deep discharges	• Immature technology • Extremely high costs (20.000 $/kWh) • High self-discharge (14% per month)

In the preceding section, a variety of storage techniques have been identified according to their characteristics. Only the storage technologies that on the one hand satisfy the technical requirements and on the other hand prove economically feasible are considered in the costs benefit analysis. The technical requirement refer to the need for relatively high power (8MW) that is to be delivered over a relative small period of time (<10 minutes). Therefore, applicable storage technologies must be able to discharge enough required power within a short period. Immediate and deep discharges may be necessary to maintain balance at times. Therefore technologies that are severely affected by deep discharges are not suitable (lithium-ion) and may prove more valuable in storing and supplying energy over longer periods of time with less capacity. Figure 8-1 illustrates this, by displaying various storage techniques in terms of discharge time versus rated power. Regarding the economic requirement, immature storage technologies, such are also not considered because of the extreme high investment costs. Thus, according to the following storage techniques have been identified suitable and the associated costs are analysed in the next chapter.

- FW: Flywheel
- Na-S: Sodium-sulphur batteries
- Ni-Cd: Nickel-cadmium batteries
- L/A: Lead-Acid batteries

Figure 8-1: System rating of implemented storage techniques. Source: European Storage Association



8.2 Analysis of costs

This section identifies and analyses the capital costs, the net present value (NPV) over the expected lifetime of the storage technology and the total annualized costs, including the annualized capital costs with a capital recovery factor (CRF) of both the implementation of load shedding and storage systems.
The first subsection presents an identification and calculation of the costs associated with the implementation of load shedding. The second subsection, does this for the various storage techniques. All costs specified in this section are calculated according to the requirements shown in the below table.

Table 8-2: Power requirements for reliability applications.

Application	Power capacity (MW)	Duration needs	Energy-storage Capacity (kWh)
Frequency regulation	8 MW	10 min	1,333 kWh

8.2.1 Analysis of load shedding costs

It is important to distinguish several costs, such as participation costs, event specific costs (financial compensation for customers), initial system costs and operating costs. In this analysis, the total investments- and operational costs related to system costs are analysed. In order to classify costs and provide estimates of these costs the study of Bradley et al. (2012) is used [49]. This study provides a review of the costs and benefits of demand response for electricity in UK. The costs related to equipment and installation of demand response are similar to the equipment- and installation costs of load shedding. The f*irst* step in identifying the CAPEX and OPEX is indicating the costs of the required system components (for required components, see paragraph 7.3). *Secondly*, these costs are analysed and presented. Despite, the large scientific attention DSM and DR little is documented about investment costs and operational costs of load-shedding or demand-response equipment. Only aggregated information pertaining to costs and benefits was available. Load shedding and demand response has been actively utilized over the last years in California (openadr.org). Private entities that offer the service of load shedding and demand response programs (i.e. Enernoc and Honeywell) were contacted in order to specify the costs of investment in equipment and other related costs. According to these organizations, the general costs of installing all necessary equipment would range between $10.000- $15.000,- per site. This includes the necessary equipment, installation and maintenance and operational fees all together. These costs, without the revenue of the organizations are specified in the below table:

Table 8-3: Summary of cost component data load shedding

Technology	Investment costs ($/client) or ($/client*hr)	Installation costs ($/client*hr)	O&M costs ($/client*hr)	Lifetime (yr)
AC Box	3.000	150	150	15
Software	150	-	150	15
Central control system	200.000	150	150	15

The total costs of load shedding are calculated for 18 of the largest hotels in Aruba, which corresponds to the estimated capacity of the combined AC load (see chapter 4) and the required capacity of 8MW. The distinction in costs per hotel can be made whether or not a hotel operates a building automation system (BAS). Reason for this is that the costs for implementing load shedding in such a hotel are different compared to hotels that manually operate chillers. These hotels only require software installation instead of AC Boxes. as has been identified in the previous chapter. In Aruba, three hotels operate building automation systems (see 9.3.2). The other 15 large hotels manually operate their air-conditioning. They operate 4 chillers including the hotel, restaurant, casino and spa activities. The amount of hours required to install, test and verify an AC box is assumed to be 16 hours (2 days). The amount of hours required to program, test and verify a "load-shedding" protocol in an existing BAS is assumed to be 40 hours (one week). It is assumed that both an AC box and a software protocol do not require much yearly operational and maintenance work. The amount of O&M hours is set to 2 days (16 hours) per every client per every year. The central control system is a complex technical system that has to correspond with another technical system, namely the operation control of WEB. Taken this into account, the installation and the testing and verification of the control system is assumed to take 160 hours (4 weeks). The amount of O&M hours is similar as for the enabling technology at the demand-side. The overall costs are specified in the below table. For a complete AC load shedding system, focussed on large hotels, with an estimated technical potential between 13,5 – 23 MW a total capital costs of $ 560.000,- an NPV of $ 953.462,- and an operational cost of $ 104.685,- per year (including annualized capital costs) would occur.

Table 8-4: Summary of required load shedding costs

Technology	Investment costs ($)	Installation costs ($)	Capital costs ($)	O&M costs ($/yr)	NPV (-$)	Total annualized costs ($/yr)
AC Box	180.000	144.000	324.000	36.000	-	71.573
Software	12.000	-	12.000	4.800	-	6.118
Central control system	200.000	24.000	224.000	2.400	-	26.994
Total load shedding	392.000	168.000	560.000	43.200	953.462	104.685

8.2.2 Analysis of storage costs

Storage costs can be expressed in total capital costs of the storage system. In this research, the method, a majority of the figures and definitions proposed by Sundararagavan and Baker (2012) [45] are used in order to analyse total capital costs of storage technologies. The total capital costs of storage technology consists of three distinct costs [45]: 1) storage cost–associated with the storage reservoir power, 2) conversion system cost -associated with the interface connecting the storage to the utility and 3) balance of plant costs – associated with the housing needed to enclose the storage device. Storage costs are proportional to the energy storage capacity of the system, and are typically measured in $/kWh. The power conversion system acts as an interface between utilities and storage systems and consists of DC and AC switch gear, and programmable high speed controllers and converters. This cost is proportional to the power capacity of the storage unit, and is typically measured in $/kW. The balance of the plant costs can be measured either in terms of energy or power. Combined these three costs identify the initial capital costs of a storage system. The costs associated with operation & Maintenance (O&M) are on-going annual costs for maintaining the storage system in good condition. Efficiency (ŋ) of the storage technology, is the ratio of actual energy that is discharged compared to the capacity of the storage system. The actual discharged energy is less than the energy storage capacity. Lifetime of a storage technology corresponds to the number of years the storage technology is operational.

Table 8-6 below shows the calculated total storage cost for all the identified suitable storage technologies that correspond to the technical requirements of Table 8-2. The methodology used is based on the methodology developed in Poonpun and Jewell (2008) [48]. The detailed methodology of these calculations is presented in Appendix-G.

Table 8-5: Summary of cost component data for storage technologies. Data obtained from: [45].

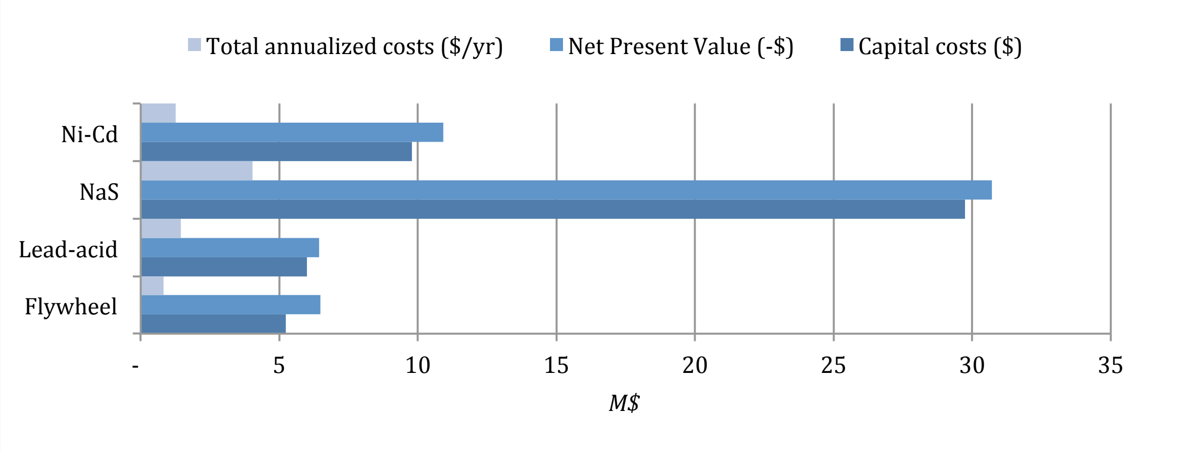
Technologies	Energy cost ($/kWh)	Power cost ($/kW)	Balance of plant cost ($/kW)	Operation & Maintenance cost ($/kW)	Efficiency (%)	Lifetime (years)
Flywheel	1000	350	100 $/kW	18	90	15
Lead-acid	300	450	100 $/kW	10	75	6
NaS	534	3000	100 $/kW	14	85	15
Ni-Cd	1197	600	100 $/kW	15	65	20

Table 8-6: Summary of required storage technologies costs

Technologies	Storage costs ($)	Conversion costs ($)	Balance of plant costs ($)	Capital costs ($)	Costs O&M ($/yr)	Net Present Value (-$)*		Total annualized costs ($/yr)
Flywheel	1.333.333	3.111.111	800.000	5.244.444	144000	6.483.720	€	833.507
Lead-acid	400.000	4.800.000	800.000	6.000.000	80000	6.428.421	€	1.457.644
NaS	712.000	28.235.294	800.000	29.747.294	112000	30.711.175	€	4.022.989
Ni-Cd	1.596.000	7.384.615	800.000	9.780.615	120000	10.922.243	€	1.268.827

*NPV calculated per storage technology on the basis of the specific lifetime (L), with an interest rates of 10%

Figure 8-2: Associated cost of implementing storage technologies according to technical requirement



For a least cost storage system, that satisfies the technical requirements a total capital cost of $5.244.444 a NPV of $6.483.720 and a total annualized cost of $ 833.507,- per year (including annualized capital costs) would occur. According to the above figure, the flywheel has the lowest capital costs for storage that satisfies the technical requirements. Next to the flywheel, the lead-acid battery has the lowest capital costs for storage and is the cheapest battery option. The lower costs of lead-acid are largely due to the low storage and conversion costs. Disadvantage of lead acid batteries is that the expected lifetime is much shorter (6 years) compared to other technology (15 years).
Ni-Cd is a more expensive options, due to high material costs and the need for monitoring and preventive measures. Most expensive storage option is that of the Sodium sulphur (NaS) battery. The associated costs are mostly driven by the high conversion costs that are related to the high operating temperatures the battery requires.

8.3 System Costs

The economic feasibility of any measures that aims to reduce system intermittency depends for a great deal on the available capital that can be allocated for such an investment. In this case, the costs associated with reliability investments may not exceed the net benefits of an additional wind farm itself. The aspect of **system costs** plays an important role in this and represents the collection of total costs associated with the operation of an electricity supply industry. In this section, several calculations are introduced that eventually will lead to an identification of the economic feasibility of load-shedding. *First*, the explanation and calculation of the incremental system costs of an additional wind park are presented. *Secondly,* these costs are complemented with costs related to different reliability investments. This defines different investment scenarios with different amounts of **avoided system costs.** In the case of load-shedding these costs can be allocated as an incentive to customers, this is addressed in the final section.
From a system level perspective the general idea of investing in a wind farm is that the produced wind power reduces the need for fossil fuels and that the corresponding reduction in fuel costs are (in the end) higher than the total costs associated with the implementation of the wind farm. Typically the costs of wind power generation is often compared on the basis of what is called "levelized costs" which represents the average costs per unit electricity generated during the lifetime of the plant encapsulating all these costs in a single number i.e. 0,05 $/kWh. As is discussed by Keay (2013) in a recent Oxford Energy Comment [50] this is not the ideal way of looking at generation costs, and in particular renewable generation costs. There are several reasons for this. A reason, that is clearly clarified in this research, is the issue of the variability and non-dispatchable nature of most renewable energy technologies, which require measures, such as load-shedding or storage techniques, to mitigate the problems related to intermittency (see previous chapter). Another reason, that may affect the system costs significantly is the need for extra transmission and installation cost. Wind energy, has to be sited in locations where the wind is most prevalent, these locations may not be close to existing or adequate transmission infrastructure. Incorporating those absolute costs in the overall costs of an electricity system may lead to more transparency concerning investments in renewable energy technologies. The following formulas explains the relations to these benefits and costs:

$$Net\ System\ Benefits = System\ Benefits - System\ Costs \quad (1)$$

$$System\ Benefits = reduced\ fuel\ costs \quad (2)$$

$$System\ Costs = initial\ investment\ costs + grid\ investments\ costs + reliability\ investment\ costs \quad (3)$$

This corresponds to the general purpose in this section, namely creating transparency in the incremental system costs- at how the system costs as a whole are affected by the addition of another wind park on Aruba. These incremental costs are classified in three categories: initial costs, grid investments and reliability investments (eq. 3). The total system benefits, expressed in reduced fuel costs (eq. 2), minus the initial costs, the grid investments costs the reliability investments costs define the net benefit of the additional wind park (eq. 1). In this case only the costs of reliability investments differs thus the scenario of the least-costs reliability measure results in the highest net system benefit. This 2nd wind farm has a similar configuration as the Vader Piet wind farm, in 2011 the total produced wind power amounted 112.482 MWh (§ 0). According to the yearly figures of WEB N.V. (see Appendix-H) the reduction in HFO consumption due to wind production amounted 320 barrels (bbl.) per day. It is accurate to assume that the new wind farm will have a similar effect, thereby reducing the annual amount of HFO barrels to (320*365) = 116.800 bbl./yr. Currently the price for heavy fuel oil is 107 $/bbl. This would mean that the expected production of an additional wind farm would reduce fuel costs by (116.800 bbl./yr *107 $/bbl.) $12.497.000 per year[11].

The initial costs of a wind farm represent the capital and operational expenditure required to construct, install, operate and maintain the wind farm for a period of twenty years. The investment- and operational costs of an additional wind park are illustrated in Table 8-7. These costs are based on the two following reports: "The Economics of Wind Energy" by the European Wind Energy Association (EWEA) (2009) [51] and "Cost and benefits of onshore wind" by Pondera Consult (2009) [52]. The calculation approach used is adapted from (de Klerk, 2012) [53]. The annualized initial investment costs of a second wind park amount to $4.677.793 per year.. For more detailed calculation and specification of the costs see Appendix-I. Recent research on required grid investments (source KEMA: undisclosed) estimated a necessary investment of 11M$ to facilitate the grid connection of the additional wind farm to the nearest high voltage grid of the Aruban electricity system. The annualized costs of such an investment are calculated to be $715.566 per year[12]. In section 3 of this chapter, the costs of investing in different reliability measures have been identified. In the below table the different total costs of reliability investments are illustrated.

The net system benefits are calculated for the different reliability investment scenarios and graphically represented by Figure 8-3. The total net benefit for every scenario is positive, this illustrates the importance of an additional wind park and the significance of the reduced fuel costs. Furthermore as can be seen clearly, the annualized costs dictate the net system benefits because the other costs are constant. The scenario of load shedding has the highest net system benefits due to the lowest annualized costs then followed by the flywheel scenario and the Nickel Cadmium batteries. In order to maintain a reliable and affordable electricity system the scenario with the highest net benefit should be chosen.

The cost difference between the scenario with the highest net system benefit and the 2nd highest net system benefit defines the annual avoided system costs for load shedding. By investing in load shedding instead of the flywheel technology avoids annual system costs of (6.998.953 – 6.270.131) = $728.822 per year. This illustrates that load shedding is an economic feasible measure. Furthermore the investment is not capital intensive, do not require high upfront costs compared to the below storage technologies and is more based on contracts rather than technology. The following avoided capital costs, NPV and annualized costs of load shedding compared to all scenarios are presented in the above table.

[11] calculated with constant HFO price
[12] annualized costs calculated with a life time of 30 years and an interest rate of 5%

Table 8-7: Initial costs of a second wind farm of 30 MW installed capacity.

Wind farm	Windturbine costs ($)	Installation costs ($)	Capital costs ($)	O&M costs ($/yr)	Net Present Value (-$)*	Annualized costs ($/yr)[13]	Lifetime (yr)
10 Vestas (V90)	21.510.297	6.521.739	28.032.037	1.600.026	60.032.551	**4.677.793**	15

*NPV calculated on the basis of an expected lifetime of 20 years and an interest rate of 7%.

Table 8-8: Annualized costs of the reliability investments

	Load shedding	Flywheel	Lead-acid	NaS	Ni-Cd
Annualized costs ($/yr)	104.685	833.507	1.457.644	4.022.989	1.268.827

Figure 8-3: The annualized costs and net system benefit of an additional wind farm specified per scenario of reliability measure

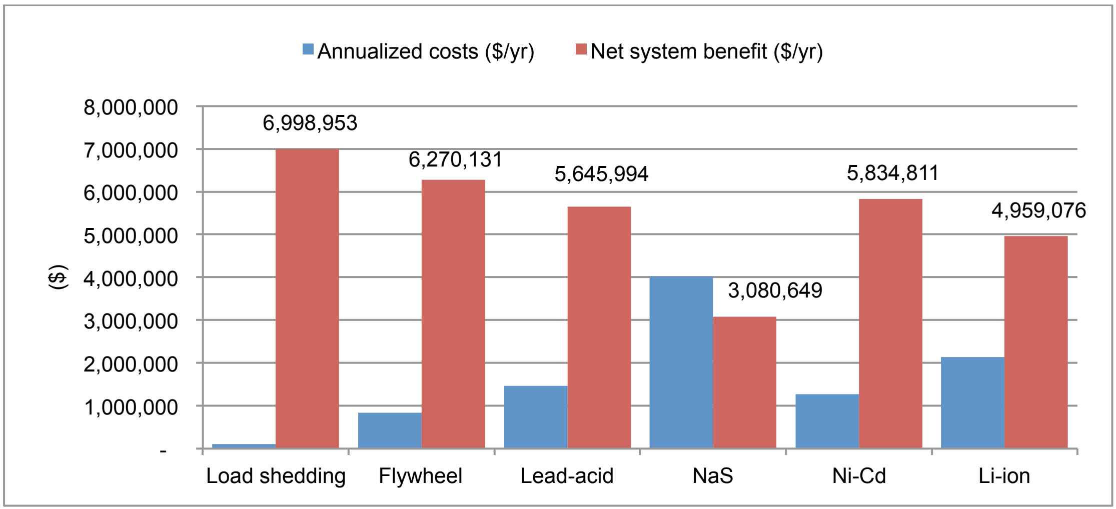


Table 8-9: Avoided costs per investment scenario compared to load shedding

Scenario's	Avoided capital costs ($)	Avoided NPV(-$)*	Avoided annual system costs ($/yr)
Flywheel	4.684.444	5.530.258	728.822
Lead-acid	5.440.000	5.474.959	1.352.959
NaS	29.187.294	29.757.713	3.918.304
Ni-Cd	9.220.615	9.968.781	1.164.142

*NPV calculated according to the specific lifetime of the technology with an interest rate of 10%

[13] annualized costs calculated with a life time of 20 years and an interest rate of 7%

8.4 Allocation of avoided system costs

The avoided costs are calculated on the system level of the overall electricity system. To be more specific these costs and benefits can be assigned to different parties (Table 8-10). The independent power producer (IPP) finances the initial investment costs for an additional wind farm and generates a certain Rate or Return (RoR) by selling produced wind energy to the utility (WEB). The utilities on the other hand benefit from the reduced fuel costs and invests in the grid and required equipment thereby avoiding costs. The hotels avoid the costs of purchasing load shedding equipment and the amount of reduced load.

Table 8-10: Specified costs per stakeholder

Stakeholder	Investments costs	Benefits	Avoided costs
IPP	Initial investment costs	Rate of Return (%)	-
Utilities	• Grid investments • Reliability measures (load shedding)	Reduction of fuel costs	Reliability measures (storage)
Hotels	-	Financial compensation	• Load shedding equipment • Amount of reduced load

However, the task of the customers is to offer their load for reliability purposes and as indicated in section 3.3.1(Incentive based programs) such programs require contracted participants that are offered a reduced rate or financial compensation per specific event. During the cost calculations no such costs have been taken into account (see 8.2.1). And despite the avoided costs of reduced load hotels would require a more substantial financial compensation especially if load shedding has impact on their energy services and in this case on guest satisfaction (Table 8-11). This loss of service is addressed by the notion of 'hidden costs' in paragraph 9.2.4.

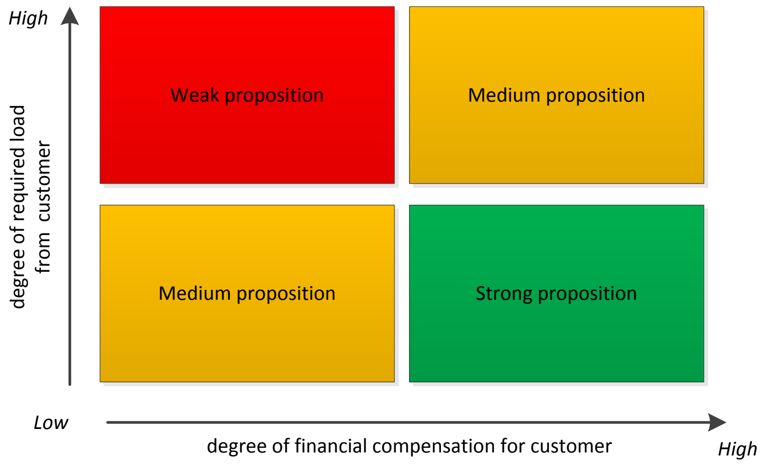
Table 8-11: Load shedding characteristics. Source: adapted from Motegi et al. 2007 [54] .

Attributes	Load shedding
Why participate (customer)	• Financial compensation, bill savings • Improve reliability • Potential environmental benefit
Equipment or infrastructure required	• Enabling technology demand side • Communication infrastructure • Central control centre
Who buys/ owns the equipment of infrastructure?	• Utility buys and owns central control system and enabling technology
Required customer actions (what must be done to participate)	• Shedding loads
Who controls?	• Utility or system operator
Impact on energy services (how does participation affect comfort, production level, etc.)	• Depends on duration: barely noticeable to substantial

The utilities benefit from the service provided by the hotels, thus from a market point of view it is only adequate that (a part of) the avoided costs are assigned to compensate the customers. In reality, such financial incentives have to be negotiated between the customer and the utility and preferable laid down in contracts and arrangements so that both parties can be held liable for their responsibilities.

Although is not the aim of this research to recommend what amount of compensation is appropriate in this case, it is possible to explore the boundaries of these costs. Taken into account the avoided system costs it is possible to define the maximum amount of capital ($728.822) that may be allocated to these costs annually. The extent to which such a financial compensation may prove substantial relates strongly with the electricity expenditure of the hotel. If this proves to be low, WEBs may not be able to sufficiently "convince" hotels on financial grounds to participate in the program. In addition, this economic potential can be integrated with the technical potential. Limited financial incentive in combination with a large degree of required load signifies a difficult proposition for load shedding. On the other hand, a significant financial incentive and a low degree of required load represents a more promising and strong proposition. This is illustrated in Figure 8-4.

Figure 8-4: Strength of load shedding proposition



To place the amount of financial incentive in perspective, the average annual electricity expenditure of hotels has been identified by using historical data (see chapter 4). The expenditure ranges between $ 3.000.000 - $4.000.000 per year per hotel. Compared to the annual electricity expenditure the avoided capital- and NPV costs are relatively high. Taken the frequency of seven imbalances per year and the combined load of 8MW into account, the degree of required load from the hotels is low. The maximum amount of financial compensation available for an event of imbalance would ($ 728.822/7) $ 104.100,-. This is ($ 104.100/1333,33 kWh) 78 $/kWh during times of imbalance. So if the utility would directly reduce the AC load of 1MW for 10 minutes (1000kW/6) during times of imbalance the maximum reimbursement for one hotel could be (166kWh* 78 $/kWh) $13.000,-. This illustrates a very high degree of financial compensation. The utility is thus able to offer a significant financial compensation for the services required of the hotels, resulting in a strong business proposition for load shedding.

8.5 Conclusions

Is the identified DSM measure an economic feasible solution, taken into account the system costs and benefits of additional wind energy?

It is concluded that load shedding is the least-cost solution in providing reliability as defined in the compared to other suitable storage technologies. As a result, the investment scenario of load shedding as a reliability measure proved to have the most net system benefits of an additional wind farm. Furthermore, the investment is not capital intensive, does not require high upfront costs compared to storage techniques and is more based on contracts than technology. The difference in net system benefits of the highest and 2nd highest scenario (flywheel technology) can be defined as the avoided system costs. These costs are substantial and amount to: for the capital costs ($ 4.690.000), the NPV ($ 5.530.000) and the annualized costs ($ 730.000). A share of these avoided annual costs can be allocated as financial compensation to customers for the participation and in the load-shedding program. To place all this in perspective, if WEB would decrease the AC load of an hotels with 1MW for 10 minutes the maximum amount of financial reimbursement could be $13.000 per hotel. Consequently, WEB is able to offer a substantial financial compensation for the low degree of load shedding services required of hotels, resulting in a strong business proposition. Even more, the investment in enabling technology was also taken into account in the cost analysis. This means, that if hotels themselves would invest in enabling technology, the avoided costs and indirectly the financial compensation would be even higher.

Note, that storage techniques can store i.e. wind energy during periods of low demand so that this may be used at a later time thereby reducing the need for fossil fuels. The reduction in these amount of fuel costs have not been taken into account for several reasons. The first is that information on the amount of curtailed wind energy was not available in this research. Therefore no indication of how much wind energy can be stored per year is available. Secondly, the configuration of storage techniques (frequency control), proposed in this chapter, may not be appropriate to supply electricity on a longer time scale and this also effects the use of the stored electricity.

With the conclusion of the technical and economic feasibility of load shedding, research phase 3 has ended. The next research phase aims to identify the willingness of the customers (hotels) towards load shedding through qualitative analysis.

Figure 8-5: Research phase 3

Phase 3: Quantitative Analyses

7. To what extend is this identified DSM measure a technical feasible solution? (7)

8. Is the identified DSM measure an economic feasible solution, taken into account the system costs and benefits of additional wind energy? (CH 8)

Technical Analysis
- Identification of the effects of wind energy on the technical ability of the system to balance demand and supply
- Identification of technical requirements to mitigate the effects
- Technical feasibility of DSM as a suitable mitigation measure

Economical Analysis
- Identification of suitable supply side measures
- Identification of the costs of all suitable measures
- Economic feasibility of proposed DSM program

9 Willingness to accept load shedding

The previous research phase focused on the technical and economic potential of load shedding as a means to mitigate reliability issues during periods of sudden and severe wind energy decreases. This chapter aims to answer the following questions:

- *Which barriers emerge when changing the energy demand of the corresponding load profiles?*
- *What interventions would be needed to overcome implementation barriers?*

It is imperative to identify the willingness of customers to accept and implement load shedding for it limits the technical potential of load shedding. This chapter presents the interests and perspectives of the Aruban hotel industry towards load shedding by making use of interviews. Section 9.1, identifies common barriers towards changing energy behaviour. In section 9.2, these barriers are used to assume certain relations between energy behaviour of hotels and the acceptability towards load shedding. These assumptions are an input for the design of a semi-structured interview. In section 9.3, the design and results of the interviews are presented and. In section 9.4, these results are compared to the barriers mentioned in section 9.2 and possible interventions are described . Finally in section 9.6, conclusions are presented.

9.1 Barriers in changing energy behaviour

The practice of DSM describes the planning and implementation of activities designed to influence customers in such a way that the load shape curve of the utility company can be modified to produce power in an optimal way [28]. An important notion in this definition is the practice of *behavioural change* of energy end-users. It is proposed to reduce the air-conditioning load of Aruban hotels during moments of sudden and severe wind decreases. Although not much is written on particular barriers related to load shedding it is reasonable to suggest that there exist mutual barriers and relations with other forms of DSM. The first section introduces and explains general barriers related to DSM.

9.1.1 Barriers related to DSM

There is substantial literature on barriers related to energy-efficiency, and on the appropriate responses to overcome these. However, most of the literature is written from an aggregate point of view i.e. efficiency related to national or global goals. In this research, the focus lies on identifying barriers related to acceptance and willingness of hotels and in particular to participate and implement load shedding. Due to a lack of available literature on this topic, various other sources are used. Especially notable is the extensive literature review report of the United Nations Industrial Development Organization (UNIDO) (2011) on barriers (Table 9-1) to industrial energy efficiency. Reason to use this literature is that the energy-intensive hotel industry has a high similarity to general energy-intensive industries and some of the reviewed studies also include the commercial sector.

Table 9-1: Taxonomy of barriers related to industrial energy efficiency. Directly quoted from: United Nations Industrial Development Organization (UNIDO) (2011) [55].

Barrier	**Claim**
Bounded rationality	Owing to constraints on time, attention, and the ability to process information, individuals do not make decisions in the manner assumed in economic models. As a consequence, they may neglect opportunities for improving energy efficiency, even when given good information and appropriate incentives.
Risk	The short payback required for energy efficiency investments may represent a rational response to risk. This could be because energy efficiency investments represent a higher technical or financial risk than other types of investment, or that business and market uncertainty encourages short time horizons.
Imperfect information	Lack of information on energy efficiency opportunities may lead to cost-effective opportunities being missed. In some cases, imperfect information may lead to inefficient products driving efficient products out of the market.

Hidden costs	Engineering-economic analyses may fail to account for either the reduction in utility associated with energy efficient technologies, or the additional costs associated with them. As a consequence, the studies may overestimate energy efficiency potential. Examples of hidden costs include overhead costs for management, disruptions to production, staff replacement and training, and the costs associated with gathering, analysing and applying information.
Access to capital	If an organization has insufficient capital through internal funds, and has difficulty raising additional funds through borrowing or share issues, energy efficient investments may be prevented from going ahead. Investment could also be inhibited by internal capital budgeting procedures, investment appraisal rules and the short-term incentives of energy management staff.
Split incentives	Energy efficiency opportunities are likely to be foregone if actors cannot appropriate the benefits of the investment. For example, if individual departments within an organization are not accountable for their energy use they will have no incentive to improve energy efficiency.

9.2 Possible barriers for hotels

It this section the previous mentioned barriers to industrial efficiency are assumed to have some relation to possible barriers that emerge when facing Aruban hotels with the decision of implementing load shedding. This section aims to identify possible factors that are important for the hotels and propose how these factors may shape the attitude towards load shedding. This step is a first step in laying out the design of the interview. Different economic theories are used to explain the various barriers.

9.2.1 Bounded rationality

The logic of action of energy-consumers in a neo-classic approach is typically characterized as *full rational behaviour*. Factors such as lack of information, and cognitive capacity have led to believe that the notion of fully rational consumers is lacking realistic views concerning the amount of information we can possible deal with and the result this has on the behaviour of consumers. In this light, the notion of *bounded rationality* is preferred. Bounded rationality was first coined by Herbert A. Simon and suggested that actors are not able to always act fully rational, and that the inability will result in a general state of satisficing, in which solutions that may or not be optimal are chosen if they meet minimum requirements [56]. Bounded rationality is due to at least three factors:

1. Cognitive capacity of individual decision maker is limited and requires complete knowledge, not all information is available.
2. Often impossible to know *all* the possible alternatives and consequences
3. Clear and complete understanding of one's own preference structure is often lacking

This emphasizes that individuals do not make decisions in the manner assumed by conventional economic models, due to above-mentioned reasons. In organisation, this could mean focussing on core-activities, such as the primary production process, rather than peripheral issues such as energy use. This raises the question to what extent, the targeted end-consumers of energy in this research, the hotels display such bounded rationality when confronted with the decision of implementing and accepting load shedding. They may have never heard of load shedding and may hardly understand its consequences. Even more, the hotels might not even have information on their energy usage and energy expenditure and find it simply easier to pay the bill.

Such behaviour is explained by bounded rationality i.e. the core activity of hotels does not concern the efficient use of energy or electricity. Hotels are part of the hospitality industry where generally, the objective is to maximize the number of customers. Where conventional hotels are establishments that provides basic accommodations, the hotels in Aruba can be defined as Resort Hotels where the aim is to create more revenue by providing more in-house or in-resort facilities including: casino's, spa's, shopping malls, etc. and services that satisfy the customer's needs such as: public and private air-conditioned areas. It is suggested that the hotels find the issue of energy use and efficiency subordinate to satisfying their customers' needs and requirements. As a consequence, they may even neglect opportunities, such as load-shedding to improve energy efficiency and gain financial benefit through appropriate incentives.

9.2.2 Financial- and technical risk

Risks can either be characterized as financial investment risk or risks of technical nature. *First,* financial risks of energy efficient measures might require large investments. Examples of energy efficient measures that require relative large investments include: refurbishments related to isolation, new air-conditioning systems, efficient lighting systems, motion sensors etc. Such risks may be hedged by short payback periods, which may lead to investing in less efficient and less costly measures. However, in the case of load-shedding the required investments are not large compared to the above-mentioned examples of energy efficient measures. In addition, the equipment may also be financed by the utilities. Therefore it is suggested, that direct financial risks plays a trivial role in the acceptance of hotels towards load-shedding and might pose opportunities for the implementation of load shedding. *Secondly,* energy efficient technologies may be subject to technical risks. Unreliability, the risk of breakdown and disruptions may outweigh any potential benefit from reduced energy costs. Such risks are particularly associated with new and unfamiliar technologies [55].

In this case, the technical risks perceived by hotels relating to the implementation and operation of load shedding may cause barriers. Load shedding intervenes either manually or automatically in the AC operations of hotels. In addition, the investment costs of central air-conditioning systems are relatively high ($150.000 – $400.000) per hotel. Therefore, it is suggested that the technical feasibility of load shedding may pose a barrier.

9.2.3 Imperfect information

According to Valentova (2012) one of the main barriers to energy efficiency is the lack of information on either individual energy efficiency opportunities or on the energy performance of different technologies [57]. Also, the non-availability of billing information is experienced as a barrier. The general availability of information, defined in [55] "depends on the information content of utility bills, the level of sub-metering, the availability of relevant benchmarks, the use of computerised information systems, the time devoted to analysing consumption information etc. Most of these will be associated with investment, operational and staff costs which may be best be understood as a particular category of transaction costs."

In addition, not only the lack of information may pose barriers also information asymmetry pose barriers. However, even if such a hotel would be able to obtain all relevant information the lack of knowledge or capacity that is explained by bounded rationality would still limit the capability to optimally conclude on i.e. investments and efficient options.

In this case of load shedding, it is imperative that detailed billing and metering information of energy usage within hotels is available in order to (exactly) specify the technical potential of air-conditioning load. Whether imperfect information or lack of information of hotels might pose a barrier towards load shedding is unclear. Because of the lack of information the hotels might be more sceptic towards the implementation. This has a strong relation with technical risks.

9.2.4 Hidden costs

The notion of hidden costs refers to the claim that engineering-economic studies fail to account for either the reduction in service associated with energy efficient technologies, or the additional costs associated with their use. Three different types of hidden costs can be classified [55]: general overhead costs of energy management, costs involved in individual technology decision and loss of service associated with energy efficient choices. For a detailed explanation on hidden costs, see [55]. It appears likely; that the salary overhead costs associated with energy management will be a major obstacle for many organizations, and especially those with relatively small energy bills.

In the case of load shedding however, the first and second costs are costs that are not for the hotels to bear. Such costs are directly allocated to the utilities for they operate and control the load-shedding system. The third type of hidden costs may present some barriers for the hotels. The load shedding of air-conditioning in hotels has influence on the temperature in the hotels. Shedding AC load may have effect on the level of guest satisfaction if the temperature reaches a certain level outside the guests' comfort zone. It is unclear whether or not financial compensation is granted to guest due to insufficient service levels or what the amount of such financial compensation is. This is an example of a hidden cost and relates to a loss of service. It is suggested that this particular type of cost may pose barriers for the implementation of hotels.

9.2.5 Access to capital

The access to capital problem has two components: insufficient capital through external sources of capital and internal sources of capital. External sources of capital can be raised or gained through borrowing

money and taking loans. Barriers of external sources of capital relate to for example firms borrowing less money needed in order to finance a low risk energy efficiency project or measure with high rates of return (see financial risk). Another example relates to an organisations inability to obtain external capital due to bad credit. Accessing internal sources of capital in order to invest in energy efficient measures can be given a lower priority than essential more expensive projects. Secondly, such investments tend to be evaluated using very low payback rates, which as a results will lead to either no investments or investments in less efficient measures.
In this case of load shedding, no prior information is obtained on the financial status of hotels, which makes it difficult to suggest barriers. Thus, whether or not the access to capital may pose barriers towards the implementation of load shedding is uncertain. As already stated in the preceding section, the investment costs of load shedding per hotel are relatively low compared to investment costs related to energy efficient measures and projects in hotels. Therefore, it is not expected that access to capital should pose barriers. On the contrary, the low investment costs might prove opportunities.

9.2.6 Split incentives

The notion of split incentives is commonly used in relation to the residential sector but is also applicable in the commercial sector, where landlords own property and tenants hire property. In such cases, there is little incentive for both parties to invest in energy efficiency. The landlord passes the electricity bill on through to the tenant thereby incurring no losses. While tenants may not invest to improve the energy efficiency of properties they do not own and pay a fixed electricity costs per month.
Within organizations, investments in project with short-term payback can also be explained from split incentives. It is often the case that managers remain in their post for relatively short periods of time [58]. In large companies, there may even be a policy of job rotation. A manager who is in a post for two- three years does not have the incentive to initiate investments that have a longer payback period.
In the case of load shedding, it is suggested that the first example does not pose any barriers. The second example, however may pose a barrier if the position of general manager or the director of engineering changes every few years. This could result in the decision-making of longer-term projects.

Table 9-2: Overview of possible barriers related to the implementation of load shedding in the hotel industry

Barrier	Claim
Bounded rationality	Core activity of the hotel industry is to satisfy guests in order to maximize the number of customers. Energy use is not a primary focus. As a consequence, they may neglect opportunities, such as load shedding to improve energy expenditure and gain financial benefit through appropriate incentives.
Risk	Technical risk of breakdown and feasibility of load-shedding equipment might prove unreliable and may cause damage to expensive AC equipment
Lack of information	Hotels might be more sceptic towards the implementation. This has a strong relation with technical risks.
Hidden costs	Unclear whether loss of AC service associated with load shedding might increase financial compensation for insufficient guest satisfaction.
Access to capital	The notions of internal or external access to capital are not expected to pose any barriers. They however might pose opportunities.
Split incentives	Job rotation, may lead to barriers in implementing long-term projects.

9.3 Results of the interviews

In the preceding section, possible barriers of hotels towards the acceptance of load shedding were identified. These barriers are used in this section to structure the interview and were used during the interview to steer the direction of the interview. Furthermore in this section, the results of the interviews are presented and analysed.

9.3.1 Structure of the hotel interviews

The following General Managers and Director of Engineering have been interviewed: Richard Roy (GM) – Westin Resort Aruba, Ewald Biemans (Owner & GM) – the Bucuti & Tara Beach Resorts, Fred Hoffmann (GM) – Hyatt Regency Aruba Resort & Casino, Paul Gielen (GM) – Renaissance Aruba Resort & Casino and Gerard Puts (Director of Engineering) – Radisson Aruba Resort, Casino & Spa. Prior to all interviews, information relating to the objective of the interviews and background information on load shedding was presented. In addition at the start of every interview the same information was again presented, as to fully inform the interviewee about the subject. The structure of the interview is presented in Appendix-I. Note that the actual interviews were always performed in a semi-structured fashion to create room for unforeseen opinions, comments, standpoints etc. After every interview, the structure of the interview was revised and certain questions were added and some questions were given less attention.

The *first* part of the interview relates to the general awareness of the hotels energy consumption and to what extent the hotels have already taken energy efficient measures. By asking for example who is responsible for certain energy conservation measures the internal decision making processes in these hotels can be identified. The general aim of this part is to create an understanding of the energy awareness in the hotel operations, to identify the characteristics of the AC system and to identify if specific energy related data is available. The *second* part of the interview poses various open questions (trade-offs, most important factors) to identify the perspective towards accepting load shedding and the specific barriers that shape this behaviour. The *third* part of the interview, aims by posing several thesis-structured question to identify implementation options and to what extent certain trade-offs could be made. *Finally*, semi-structure questions and opinions concerning the general energy policy in Aruba were asked. This identifies the hotels perspective on not only load-shedding but sometimes revealed the hotels concerns about the energy policy and its implications on the hotel industry in general.

9.3.2 Results of the hotel interviews

An overview of the results is presented in the below table , for minutes of the interviews see Appendix-I.

Table 9-3: Results of energy efficiency and load shedding barriers related hotels

Program	Barriers	Claim
Energy efficiency energy	Bounded rationality	Issue of energy efficiency subordinate to energy services related to guest satisfaction
	Risk	Hotel brands and owners typically change over periods of 4 to 6 years and therefore have no incentive in investing in longer-term projects. Business uncertainty.
	Imperfect information	Lack of information. Monthly electricity bills, no in-house metering of electricity, unaware of consumption specification.
	Hidden Costs	-
	Access to capital	Investments in the hospitality industry require very short payback periods (< 3 years). This is interrelated with barriers of risk and internal decision-making hierarchy.
	Split incentives	Hotel brands, owners and managers typically change over periods of 4 to 6 years and therefore have no incentive in investing in longer-term projects. Business uncertainty.
	Internal decision making hierarchy	Most hotels are part of a franchise. Investment decisions taken by board of directors and property owners. Both parties do not evaluate investment on same criteria, results in non-decisions or sluggish process.

Load shedding	Bounded rationality	Issue of load shedding is subordinate to air-conditioning services related to guest satisfaction.
	Risk	Technical feasibility, risk of integration of load shedding equipment in existing hotel environment. Issue of responsibility.
	Imperfect information	Lack of information related to load shedding, functioning causes reservations and uncertainties.
	Hidden costs	Loss of services: guest satisfaction and customer rebates. Uncertainty on the effect of shedding of AC load directly on guest satisfaction and indirectly on guest compensation
	Access to capital	-
	Split incentives	-

9.3.2.1 General awareness energy consumption

Hotels implementation of energy conservation measures and their general awareness were qualitatively assessed on the basis of implemented energy conservation measures (lighting, building renovations, solar boilers etc.), the applications of motion sensors, the metering of electricity consumption, smart computer systems and the type of air-conditioning systems. In terms of energy general measures taken by the hotels, there is much diversity among the hotels.

Low awareness

Large and somewhat older hotels in the High Rise area, such as the Westin, the Radisson Resort have invested in only *low hanging fruit* energy conservation measures only, such as: LED and CF lighting. In general these hotels operate low chillers in their air-conditioning system and have not invested in motion sensors that can control the guest rooms lighting or AC temperature when a room is inactive. A major implications of the absence of such control mechanisms is that a large proportion of the guests leave their AC and other energy intensive equipment running 24 hours a day. Furthermore these hotels do not operate any metering any in-house metering systems and therefore lack information about their energy consumption. For these hotels the total annual energy expenditure ranges between 3 M$ - 4 M$. Interestingly, is the investment decisions for energy consuming measures of larger hotels, that are part of a franchise, have to be reported *first* to the General Manager, *secondly* to the Vice President of Engineering and also to the Property Owners. Such decisions are generally taken by the board of directors and the property owners.
According to the Director of Engineering, investments in the hospitality industry require very short-term payback periods of generally lower than 3 years. Such requirements explain why the majority of the large, corporate hotels may lack major energy reduction measures or programs. This can be defined as a barrier related to internal access to capital. In addition hotel brands and owners typically change over periods to 4 to 6 years and therefore have no incentive to invest in longer-term projects.

Low-Medium awareness

Other hotels of similar size, for instance the Renaissance have taken both the above-mentioned conservation measures and invested in solar boilers. The Renaissance used to operate a sensor system, where in case of room inactivity the AC would decrease to 74 degrees Fahrenheit to prevent mould growth and retain a certain level of humidity. Malfunctioning of the system impacted guest satisfaction enormously, resulting in high financial compensation. Despite, the energy expenditure of $403.000 a month (4M$-5M$ annually), these hotels do not operate any metering system and are therefore unaware of their consumption specifications and **lack information.**

Medium-High awareness

Newer and more energy aware hotels, (i.e. Hyatt and the Marriott) have invested heavily in energy conservation measures including: solar boilers, motion sensors (in public spaces). Furthermore, the Hyatt reduced their energy consumption by 40% over the last year compared to the previous years. This substantial reduction was due to adopting a very efficient computerized AC, which is centrally operated in Canada. Investment decisions on the AC system were taken by top management and the general property owners. A opportunity of internal access to capital can be found here: the investment in the efficient AC system was in line with the formulated strategy of top management where carbon footprint was a priority. Also the Hyatt Aruba is the flagship resort of the Hyatt Hotels chain.

High awareness
An example of a hotel with high-energy awareness is that of the smaller Bucuti Resort. Mr. Biemans, both owner and general manager of the Bucuti Resort has invested in both the *low hanging fruit* conservation measures and also in advanced computer software packages that enables to control every rooms temperature and lighting. The Bucuti Resort, is labelled as a *sustainable* or *green* resort and attracts more environmentally aware customers. In terms of metering and consumption awareness, the Bucuti operates metering systems and has information how much electricity is consumed by the guesthouses, the pools, the restaurants etc. The total energy expenditure of the Bucuti Resort amounted to 5-6% of their total annual costs. One of the reasons why such investments can be taken and are justified is that this particular resort is privately owned. According to the preceding, the gap in energy efficiency can mainly be explained by the barrier of internal access to capital and internal decision-making hierarchy.

Mostly all hotels use central chiller plants to provide air-conditioning for public and private areas in their resorts. Below is a technical description of the working of such a chiller plant.

Box 9-1: Working of a centralized chiller plant

A central chiller plant consists of one or multiple chillers and their ancillary systems. These provide chilled water for air-conditioning. Refrigerant flows through the coil thereby cooling the water. This chilled water is pumped through a piping loop to air handles in the space to be cooled (public and private areas), where it absorbs heat from the air that flows over the air handling coil. In the private guestrooms the customers decide whether or not to turn the air conditioning on. The air-conditioning in the guestrooms is connected to the centralized system.These are not separate, individual air conditioning systems (split controller ACs). These systems are centrally operated.

The “warmed up” water then returns through the piping loop back to the chillers, where the heat is absorbed and is released to the refrigerant flowing through the chiller’s evaporator coil. Such an air conditioning system requires several additional components (often called auxiliary or ancillary systems) to move chilled water between the plant and the air handlers and reject heat from the chillers to the outside world. These auxiliary systems include several chilled water pumps, condenser water pumps and one cooling tower.

9.3.2.2 Perspective towards load-shedding

The following three issues were found to be the most significant:

- Hidden costs: Guest satisfaction (short- and long-term)
- Risk and imperfect information: Technical risk (responsibility)
- Risk and imperfect information: Control of own operations (prior notice)

One exception was made on behalf of Bucuti & Tara Beach Resort, which would not mind the direct intervention of an utility in their energy consumption several times a year for a period of 10 to 20 minutes. Main reason is that the resort has enough backup capacity to fully sustain their energy demand, the reaction of Mr Biemans: “I’d be happy to implement, either way it would be a great test to see if my equipment works.” All others hotels do operate back-up power although this is insufficient in providing the necessary load for air-conditioning.

Guest satisfaction
Although the general opinion was that shutting down a part of the AC-system for a period of 10 minutes probably would not cause any impact on the guest satisfaction still many concerns were mentioned:

“Air-conditioning is the basic need for any tourist visiting Aruba” and *“Aruba offers sun and sea, we sell shade and air-conditioning”*.

The Westin illustrated their concern by introducing the notion of limited control and limited area. Limited control pertains to which crucial (lighting, elevators) and non-crucial loads (AC, pool pumps) could be controlled. Limited area control refers to an acceptable shedding of load in specific air-conditioned areas

that typically do not impact guest satisfaction. For example in the Westin the AC in the upper- and lower lobby may be shed. The AC in the ballroom is always off, unless there is activity and in case of an activity load shedding is not desirable. AC in private rooms may be shed although this would depend heavily on the effects of shedding AC load on the comfort temperature of the guest and indirectly the guest satisfaction.
More research is needed on the effects of shutting down, or to idle an AC system for various periods of time on the comfort temperature of the guests and the (in)direct effect on the guest satisfaction. Furthermore, according to the interviewees the guests are known to request rebates and financial compensation or even go to court if the level of service is not up to (their) standards. 70% of the clientele originates from Northern-America and if service is not 100% satisfactory they will require compensation. To give an example: the AC-system of the Westin hotel in 2012 was partly offline due to a defect on one of the chillers. That week alone the Westin compensated over $80.000,- in terms of customer reimbursement and illustrates the amount of **hidden costs**. However, not only the short-term dissatisfaction but also the long-term effect of guest dissatisfaction is considered a major barrier by hotels.

Technical risk
The technical integration in the already existing electrical environment of the hotels posed various barriers. Different opinions were mentioned. According to two Directors of Engineering, idling an AC system can be remotely or manually. This takes takes several minutes and prior notice. It poses no technical problems. Note, that in the past engineers were asked to reduce some of the AC load during periods when ELMAR faced difficulties related to grid operations. Such requests could be met easily.
However, the General Managers expressed concerns about the responsibility in case of malfunctioning or breakdown.

Control of own operations
Control of own chiller operations were mentioned as a requirement by all the hotels. This is also closely related to the issue of responsibility. Many hotels, may agree with load shedding if informed by prior notice. The idea of an utility intervening in their operations raised many technical and institutional concerns. Whether direct control was technically possible, the Director of Engineering – Radisson stated the following: "Direct control executed by another entity is possible through already existing grid network controllers and via signals. To hedge against technical thorough testing of equipment and mode of operation is advised." Furthermore, there were concerns that the intervening entity would not have the same incentive and sense of urgency the hotels have in keeping their guests satisfied. This led to believe that the intervention of 3rd party would be exercised more than strictly necessary.

9.3.2.3 Implementation options
The following answers were given in response the proposed theses:

"If a full control load shedding is offered with a reduced rate for electricity, I will accept it."
During the interviews most interviewees reacted positive towards this thesis, which stresses the importance of the financial benefit hotels may receive. Also preconditions were mentioned, in the form of safeguarding the safety of equipment through testing, and providing clarity on responsibility when implementing such programs. In only one case, the response was negative and caused by the belief that the shedding of AC load would affect guest satisfaction and that a reduced rate would only soften the blow in the reimbursement for customers.

"It is best that customers/ guest do not know that load shedding is applied in this hotel."
Two basic scenarios evolved after reviewing and analysing the answers given in this respects, some of these scenarios were even proposed by the hotels themselves: the seamless implementation of load-shedding, or the value case of load-shedding. Seamless implementation pertains to the scenario that would be implemented without posing impact on the guests and indirectly guest satisfaction. Guests would not know that their AC load is reduced and control would be limited to a fixed number of chillers. If this is the case, it is probable that a large quantity of hotels would agree with load shedding.
Value case implementation pertains to the scenario that may pose an impact on the guest satisfaction. The control would be direct and unlimited. Concept of this scenario is that the customers are informed about the implementation of load shedding. The participation of these hotels could be seen as a means to substantially contribute to the integration of renewable energy on Aruba. Although all hotels acknowledged that the "Green Aruba Island" marketing campaign already attracts significant more

tourist, some hotels could not imagine the additional value of load-shedding if that meant a negative impact on the comfort of its customers. In this light, the necessity of informing and educating guests was raised.

9.3.2.4 Energy policy in general

There are multiple indications that the hotel industry experiences problems with the height and volatility of the current energy prices. Not only do hotels, with the introduction of a new energy price regulation system, pay a relatively higher price for their electricity compared to smaller consumers, they also feel helpless in the social dialogue with the utilities. One of the reasons that were mentioned, is that the lobby from the Aruba Hotel and Tourism Association (AHATA) does not seem to influence any decisions made by the utilities concerning energy policy. Related concerns are also raised about cost of electricity due to the retrofitting of the grid and the implementation of another wind park. The position of the hotels, from an economic point of view, has to be maintained because they are the primary sources of income on the island. It is in this respect, that high-energy prices endanger the competitive position of hotels. It is not possible for the hotel industry to directly calculate a higher rate of electricity in their room rates i.e. if the Ritz-Carlton in Jamaica lowers its rates by 10% then this directly affects the hotel industry in Aruba and vice versa. Also, energy price volatility makes it difficult for the hotel industry to correctly budget projections for upcoming years. Interestingly enough, hotels do strive towards making energy saving but this process is hampered by barriers such as: bounded rationality, lack of information and barriers related to access of capital and internal decision-making.

9.3.3 Evaluation of results

This section compared the barriers identified in the interview with the barriers mentioned in section 2 and to describes their differences. The below table shows which of the barriers mentioned in the literature (see section 2) were relevant in revealing barriers related to energy efficiency and load shedding in the hotel industry. Also differences in these barriers are presented and explained below this table.

Table 9-4: Relevance of barriers found in literature in identifying barriers in load shedding

Program	Barriers	Relevant	Different compared to literature
Energy Efficiency	Bounded rationality	Yes	Yes
	Risk	Yes	No
	Imperfect information	Yes	No
	Hidden costs	No	-
	Access to capital	Yes	No
	Split incentives	Yes	Yes
	Decision-making hierarchy	Yes	Yes
Load shedding	Bounded rationality	Yes	Yes
	Risk	Yes	No
	Imperfect information	Yes	Yes
	Hidden costs	Yes	No
	Access to capital	No	-
	Split incentives	No	-

It was found that bounded rationality concerning energy efficiency and load shedding in the hotel industry could not solely be explained by cognitive capacity or limited information processing capabilities as H. Simon may suggest. Although this plays a role, the majority of the bounded rationality found within the hotel industry lies in the fact that energy related subjects are for most hotels subordinate to their core business. This organizational behaviour, where trade-offs are made on time and attention may result in making less energy- and economic efficient optimal decisions. The notion of imperfect information was relevant for both the DSM programs. Interestingly, the lack of information related to load shedding caused uncertainty and increased perceived technical risks. This illustrates that although the hotel industry may be characterized with a bounded rationality the provision of comprehensive and transparent information may overcome these barriers. The issue of hidden costs is not a substantial barrier in the objective towards energy efficiency. For load shedding, this barrier was far more evident. Especially the hidden costs of loss of AC service were found very important. The notion of access to capital did prove relevant in identifying the required rate of returns or payback periods in the hotel industry related to energy efficiency programs. No, relevance of this notion was found in identifying barriers related to load shedding because it is suggested that no investments of the hotels are necessary.
Split incentives have been relevant in understanding and identifying the issue hotels changing their brands, locations and managers every couple of years. As a result, there is no incentive in investing in longer-term projects. However, split incentives did not prove useful in identifying barriers for load shedding. This could be explained by the fact that load shedding is not capital intensive compared to energy efficiency measures, is more based on contracts than technology (see paragraph 0) and therefore does not require large investments.
The notion of decision-making hierarchy is not specifically mentioned in the used literature, however it did pose a large barrier for energy efficiency measures. The board of directors and the property owners make decisions in the hotel industry. Both are different parties with different perspectives and motives. This makes the could results in sluggish- or non-decision making.

9.4 Interventions

9.4.1 Load shedding barriers

The most substantial barriers are: 1) guest satisfaction, 2) technical risk and 3) control of own operations (Table 9-5). Both the first and the second can be characterized as knowledge based barriers. *First* of all, it is uncertain to what extent the shedding of AC load influences the temperature in private and public areas of hotels and how this relates directly to the guest satisfaction and indirectly to the amount of financial compensation. This lack of information is an important factor that shapes the perspective towards implementation and acceptation *Secondly* the issue of technical risk is caused by a supposed risk in integrating load shedding equipment. This also strongly relates to the issue of responsibility. Interesting is that this risk is not perceived by several general managers and directors of engineering. In order to overcome knowledge based barriers information is required, some of this information may not be available and would involve additional research, such as detailed metering studies. During the interviews, the testing of load shedding has been proposed to ensure safety and gain information on the effects of load shedding, see paragraph 10.2 for additional research.

Table 9-5: Possible interventions for load shedding barriers

Barriers	Issue	Intervention
Knowledge based barriers	• Lack of information	• Information o Already existing business cases (i.e. California) o Metering o Testing o Additional research
Institutional based barrier	• Lack of coordination	• Communication • Institutional coordination o Contracts o Arrangements

The third barrier, control of own operations can partly be explained by a lack of information about the effects of load shedding but moreover by the lack institutional coordination between the intervening utility and the customers. Proper communication and institutional coordination may resolve such barriers. First of all, communication between the utilities and the customers mutual understanding of perspectives can be achieved. Secondly, issues such as responsibility and i.e. the amount of times load shedding can be applied per year, months, etc. can be overcome by setting up contracts and arrangements. Such contract and arrangements are business as usual in many parts of the world i.e. in California where load shedding during summers is performed on a daily basis and utilities and 3rd parties intervene in operations of shopping malls, hotels, and industries, without problems.

9.4.2 Opportunities

Financial incentives

Although further information may be a key aspect in overcoming barriers, opportunities such as financial incentives could also significantly lower some of the barriers for they pose high opportunities for hotels. As illustrated in chapter 8, financial compensation may be available. This would require some communication via negotiations or institutional coordination through contracts and arrangements between the utilities and the customers. Financial incentives could lower the already high energy expenditure and may be used to stabilize the energy price fluctuations for participating hotels. Some hotels may be willing to participate without knowing the impacts of load shedding on the guest satisfaction in advance.

Advanced metering and control equipment

The installation of advanced metering and control equipment might reduce or overcome the barrier of lack of information. This equipment could eventually be compatible with a smart-grid and enable more bilateral alignment between demand and supply creating even more mutual gains.

9.5 Conclusions

Which barriers emerge when changing the energy demand of the corresponding load profiles?

The following barriers emerged after interviewing General Managers and Directors of Engineering of various small and large Aruban hotels: 1) hidden costs related to guest satisfaction, 2) technical risk relating to implementing load shedding equipment without damaging already existing equipment, and 3) the issue of control of own operations where hotels may not accept intervention of a third party and require prior notice before a load shedding event. During the interviews it was found that most of these barriers are caused by the lack of information about the general effects of load shedding.

Whether or not the shedding of AC load has any impact on the comfort of guests directly affect the guest satisfaction and indirectly the amount of financial compensation. More than 70% of the guest in Aruban hotels originate from Northern-America and will require financial compensation if service is not up to standards. As a results, a clear distinction was made between a seamless implementation, where the implementation of load-shedding is only acceptable if it does not impact guest satisfaction and a value case implementation, where the implementation of load-shedding may pose a negative impact on the guest satisfaction. In the latter scenario, hotels found it necessary to compensate this negative impact by marketing the participation of hotels in the load shedding program as a “green” and “sustainable” contribution furthermore the issue of education and informing the guests was raised. To what extent these barriers limit the technical potential of AC load is yet unclear, it is recommended that additional research is needed on temperature fluctuations in private and public areas of hotels when AC load is shed (this additional research is addressed in the discussion chapter, see paragraph

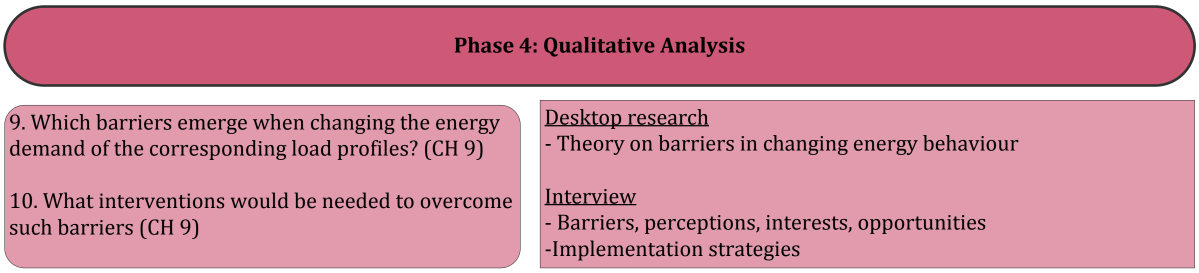
A lot of concerns were raised whether or not the load shedding equipment would damage the existing hotel infrastructure (AC system and BAS). Also, the issue of responsibility in the case of malfunctioning must be clarified. According to two Directors of Engineering, the shutting down or idling the AC systems with prior notice could be technically possible within minutes. However, hotels reacted risk adverse towards the proposition of another entity interfering in their operations and automatically lowering or shutting down their AC load. Remarkably, hotels have had experience in the past with lowering their AC load at ELMARs demand during periods of grid instability.

What interventions would be needed to overcome such barriers?

The two first identified barriers are related to knowledge gaps on the effects of implementing load shedding. It is recommended that to overcome these barriers more information is required which may involve metering, testing, and other additional research (see section 10.3) The third barrier, control of own operations can partly be explained by a lack of information about but moreover by the lack institutional coordination between the intervening utility and the customers. Communication through negotiation or coordination by means of contracts and arrangements between those parties is advised in this respect. Although further information may be a key aspect in overcoming barriers, financial incentives could also significantly lower some of the barriers for they pose high opportunities for hotels. Furthermore, the installation of advanced metering and control equipment may provide extra information and on a longer-term be compatible with more smart grid solutions thereby creating even more mutual gains.

With the answers presented in this chapter, research phase 4 has ended. In the next chapter, the results of the previous research phases are discussed.

Figure 9-1: Research phase 4



10 Discussion

The discussion chapter starts with the interpretation of the results and the methodology used, then moves outwards to contextualize these findings in a general field. Section 10.1 of this chapter addresses what the results 'mean' and describes causes and relations that lead to these results. Also a comparison between the results with what was expected from existing theory is presented. In section 10.2, the limitation and remaining questions of this research are addressed and additional research is discussed. In section 10.3, the implications of this research on the current and future activities of TNO are discussed. Finally, section 10.4 discusses to what extent the outcomes of this research can be used in other small island developing states (SIDS) in order to assess the suitability of DSM as a measure for integrating renewable energy technologies?

10.1 Discussion of Results

This section begins with a restatement of the research question, followed by a statement about whether or not and how much, the research findings 'answer' the question:
RQ: To what extent can demand-side management facilitate the integration of wind energy into the Aruban electricity system?

This research question is driven by two main uncertainties: uncertainty about the technical capabilities of the electricity system to continuously supply its consumers with electricity with an additional wind park and the uncertainty about the role of DSM as a technical, economic and social feasible solution to mitigate possible implications of additional wind energy. To specify this answer in more detail, first the findings related to the functioning of the electricity system are presented. Secondly, the findings related to the feasibility of DSM are presented.

Results on the electricity system
Unit commitment modelling through linear programming enabled to quantify the technical ability of the Aruban electricity system to maintain balance between supply and demand. Because the isolated electricity system operates an inflexible generation and no interconnections, DSM programs and storage capacity, one might expect that the integration of an additional wind park would lead to imbalances. The results in this research support and augment these expectations and revealed that imbalances occur at times of sudden and severe wind decreases (between -20 and -25 MW per 10 minutes) in combinations with a high utilization of fast spinning reserve capacity.
If the aim is to mitigate all imbalances it is necessary to minimally extend the generation portfolio with a fast reserve that is able to provide 8MW of power, within 10 minutes for at least 7 times a year. These three criteria can be regarded as the technical requirements to mitigate imbalances caused by additional wind energy.

Results on demand-side management
Despite these requirements, a cost-effective and technical feasible demand-side management program does exist to maintain balance under such circumstances. By means of a literature study, the direct load shedding of flexible loads was identified as a suitable DSM solution in this regard. The highest potential of loads, in terms of capacity and flexibility were found in the air-conditioning loads of the hotel industry.
Furthermore, analysing costs and benefits of an additional wind park in combination with incremental system costs related to grid- and reliability investment allowed to compare the economic feasibility of the load shedding program with various suitable storage technologies. Despite all the reliability investment utilities are faced with, the costs for load shedding are lowest, resulting in an investment scenario with the highest net benefits.
The avoided system costs can be allocated as a financial incentive for participants and could be a necessary intervention to overcome associated barriers, such as impact of shedding AC load on guest satisfaction, technical risk of DSM equipment with already existing equipment and the involvement of 3rd party on the control of hotel operations. Regardless of the financial compensation, the hotel industry tended to be uncertain and reserved about the proposition, mainly due to a lack of information and coordination.

Results related to previous studies and literature
As introduced in the beginning of this research the study of Strbac et al. (2009) indicates that only in cases of a system combining inflexible generation with significant amounts of unpredictable wind generation DSM techniques might become competitive in providing reserve over traditional supply side options [14]. The results of this research support and expand these findings by showing that DSM techniques (in particular load shedding) are competitive in providing extra reserve over various storage technologies. To specify, the incremental reliability costs associated with additional wind energy are lowest for load shedding in comparison with various storage techniques. These avoided annual costs range from $700k – $2.000k.

Furthermore, it was stated by Strbac (2008) that DSM, if managed correctly can safeguard reliability, increase efficiency and lower overall costs of the electricity system [14]. The results of this research partly support this claim. It shows that the proposed DSM program can increase reliability and compared to other storage techniques generate the most net benefits of an additional wind park. However, the way in which the avoided system costs are allocated may affect the overall costs level of the electricity system. To illustrate, the proposed DSM program, does require a financial compensation for participating customers. This raises the question of: how much of the avoided costs may be allocated as compensation? This is not taken into account in this research and it is suggested that this requires alignment between the two parties that can be achieved through i.e. negotiations or institutional coordination (contracts & arrangements).

Also stated in the introduction, is that the 'success' of a DSM measure depends for a great deal on both the perception of the utility and the customers. This notion clearly emerged in during the research. Specifically, the choice of a direct control program (load shedding) was made according to the problem situation and the perception of the utility. However, to ensure the successfulness of this program, the associated barriers of the hotel industry should be overcome. The theories and notions used to identify and describe barriers to energy efficiency have been party relevant in identifying the most substantial barriers associated with load shedding (see 9.3.3). It was found that that the bounded rationality concerning energy related issues in the hotel industry could not solely be explained by cognitive capacity or limited information processing capabilities as Herbert A. Simon may suggest. Although this plays a role, the majority of the bounded rationality found within the hotel industry lies in the part that energy related subjects are subordinate to their core business and trade-offs between time and attention may lead to energy- and economic inefficient decision. Additional research on this is presented in the next section.

10.2 Limitations, remaining questions and additional research

Limitations of the simulation tool
The simulation tool as designed has been able to answer the proposed modelling questions (chapter 5) satisfactorily to a large degree. However, it is important to realize the limitations of this modelling approach and how these affect the results. Not all unit characteristics constraints could be modelled correctly in the simulation tool. Although this did not affect the overall validity of the model on an aggregate level, it has had implications on the suitability of the model to quantify imbalance specifications on a more detailed level. These shortcomings resulted in tweaking the model manually to incorporate certain non-linear relations (see chapter 6). Consequently, the model has been sufficient in indicating why and on what particular moments these imbalances may occur although some uncertainty exists about the precise quantification of these imbalances. It is important to understand and realize that this model does not per se predict with what specifications power imbalances occur, it rather explores the maximum boundaries of an electricity system. Reflection on the suitability of this methodology and simulation tool is presented in the next chapter.

Additional research
Throughout this research, many limitations and recommendations for additional research have been mentioned. In this section the additional research is discussed. The technical potential of the load shedding program depends on 1) the available capacity and 2) the amount of capacity that may be decreased per unit of time (ramp rates). Although estimates about the capacity were calculated (see chapter 3) and interviewees mentioned the possibilities of immediate shutting down or idling the AC load (see chapter 9) there may still be uncertainty about these issues. During this research no information on

the electricity usage associated with AC per hotel and the related ramp-rates were available. Note, that the AC load varies over time and cannot be expressed as a fixed number. This does not mean that the findings are unreliable, but rather exemplifies the importance of additional information. Additional research through the use of advanced metering equipment could enable a minute-to-minute communication of the amount of shedable load per unit to the utility. Furthermore, it is suggested that the hotel industry may run tests to identify how much time it takes to shut-down or idle AC load (see pilot study, below).

The success of the DSM program depends for a large degree on the willingness of hotels to participate. The knowledge based barriers: 1) the effect of AC shedding on the temperature and indirectly on the guest satisfaction and 2) the technical implications of load shedding equipment on already existing hotel systems may be overcome by the provision of adequate information. However, it is found that bounded rationality may hamper energy efficiency and the implementation of load shedding. This begs the question:

> *If an actor (general manager/ director of engineering) lacks the time, attention, capacity or skill to use existing information, is there use in providing more information?*

On the other hand, considering the results of the interviews that not all hotels are evenly energy unaware and display the same level of bounded rationality:

> W*hat information is then needed to overcome these knowledge-based barriers and how would this information be obtained?*

In this regard, two different forms of additional research are proposed and discussed:
1) Through an extensive simulation study the effects of AC load shedding on the comfort zone temperature of the clients could be analysed. Thermal comfort modelling calculations could be able to identify the temperature increase per minute in public and private areas of hotels under specific conditions (outside temperature, inside temperature, humidity, etc.). Information related to the specific conditions of public and private areas, such as: heat capacity could be assumed or measured during a field research. The aim of this study would be to identify the boundaries of temperature increase due to shedding AC load. These boundaries determine the technical potential of AC load in hotels in order to retain the comfort of the end-user.
2) Pilot studies are used as feasibility studies, to ensure that the ideas or methods behind a research are sound, as well as to "work out the kinks" before launching a larger study or implementation. During such a pilot study, a single or set of representative hotels could participate in the shedding of AC load with the purpose of gaining information and experience. In contrast to the simulation study, actual results on e.g. room temperatures can be measured and technical implications of load shedding equipment on already existing hotel infrastructure can be identified through actual implementation and testing. To what extent TNO and in particular the Caribbean Branch Office of TNO (CBOT) can facilitate such a pilot study as addressed in the next section 10.4.

As mentioned more elaborately in, section (11.1 Reflection on chosen DSM measure) during the analysing of a suitable DSM measure the issue of wind curtailment has not been taken into account. The results of the simulation analysis did show imbalances related to an overproduction of wind energy during periods of low load (night). During this analysis, these results were not analysed in depth but it was found that the minimum stable generation of both the turbine generators limited the integration of wind energy. In contrary to periods of decreases of wind, the load should be increased instead of to cope with these fluctuations. The use of air-conditioning systems in this regard has been underexposed because it is not only possible to provide a decrease in load, but also an increase in demand. It is advised to further analyse such imbalances and in turn assess the role of demand-side management in these imbalances.

10.3 Implications for TNO-Aruba

The activities of the Caribbean Branch Office of TNO (CBOT) involve two major projects for the upcoming years: the Smart Energy System Aruba (SESA) and the Smart Community. The aim of this section is to address the results of this research in light of these current activities and discuss limitations and additional research.

Smart Energy System Aruba
SESA is a project continuation of the energy goals for 2020 that were established in combination with the Aruban government and TNO in 2012. The objective of this project is to define and structure the transition path towards the identified goals for 2020. This research has a short-term and long-term focus. In the **short-term**, the focus is on the micro-effects of an additional wind farm as well as solar p.v. projects on the electricity system. Amongst others, the findings of this research illustrate that additional reliability is required if more integration of variable renewable energy technologies is intended. And that DSM (load shedding) is a technical and economic feasible solution in providing that reliability. Furthermore, a large portion of the total Aruban electricity load is represented by flexible loads of the commercial sector that may be utilized in other ways that are beneficial for the electricity system (energy efficiency, peak shaving etc.) Therefore it is strongly advised to take the results and conclusions of this research into account and further research other purposes of DSM in this regard. In the **long-term,** the focus of the SESA project is more related to mapping the transition to an electricity system that is able to satisfy the goals set for 2020. This approach is of a more strategic and conceptual nature. Various scenario developments are taken into account that may be driven by the following issues:

- Demand/ supply
- Generation: centralized / decentralized
- Focus DSM: residential/ commercial/ industrial
- Grid investment: increased capacity / smarter grid

One of the recommendations that fit in the long-term perspective of the SESA is that TNO has the opportunity, as a facilitating research organization to help the country of Aruba that demand-side management is a feasible solution. The current perspective on Aruba and especially that of the utilities is that that the balance of electricity can only be influenced by the supply side. However the demand-side of the value chain holds large potential, as (energy inefficient) hotels already represent 30% of the total electricity demand of Aruba. Utilizing this potential through proper coordination and communication between utility and client could substantially contribute to the affordability and reliability of the Aruban electricity system as can be (partly) concluded out of this research. TNO could play a substantial role in unlocking this potential of demand-side management by acting as the facilitating party between the utilities and the demand-side by initiating and safeguarding (institutional) coordination and communication between these parties.
During this research it has been suggested that WEB N.V. would be the controlling party. However, the implications of WEB offering such services on their traditional business model are not addressed in this research and may hinder investments in DSM. Traditionally, utilities revenue has been directly tied to the sale of electricity. That is, the more electricity a utility's customer use, the more revenue that utility earns. Under this paradigm, a utility favours supply-side resources over DSM resources. This raises the discussion of:

> H*ow does the provision of DSM services such as: load shedding and demand-response affect the traditional business case of WEB and how could this be managed?*

In this regard, TNO may take on the role as external advisor or facilitator to support WEB in gradually changing their business model by learning, testing and developing all aspects that are related to an utility that also provides DSM programs.

Smart Community
In short, the Smart Community is a secured, confined and experimental environment where the scalability of: renewable energy technologies (RETs), smart grids, sustainable building, behavioural change, electrical vehicles and water and waste technologies can be researched and consequently studied to island-wide application (see Presentation-Smart Community). TNO has the opportunity to create a synergy between the experiments in the Smart Community and proposed additional research in this research (pilot study). The largest estimated potential of demand-side management is represented by 20-

25 organisation (the hotel industry). Thus, in terms of transaction costs, this group represents more potential than ten thousands of house-holds. Therefore it is recommended that a part of the experimental- and test studies are developed in such a way that the gained information out of these studies can be used to overcome the identified barriers related to the hotels in this research. Barriers such as: the impact of load-shedding of AC on room temperature and the technical implications of load-shedding (in general DSM) equipment on already existing infrastructures can be researched in this confined environment (see pilot study).
Further recommendations include:

- Learning to operate DSM (load-shedding) equipment
- Testing of DSM (load-shedding) equipment
- Certification of DSM (load-shedding) equipment
- Developing new business model for DSM in combination with utilities and clients
- Transferring knowledge of TNO-the Netherlands concerning DSM (Power matcher)

10.4 Generalisation

Although this research was performed using Aruba as the problem situation, the value of this research may not be limited to this island only. Similar like Aruba, there are ample SIDS that strive towards harnessing renewable energy out of their indigenous natural resources mainly due to rising oil prices. In some islands, fuel import bills now represent up to 20% of the Gross Domestic Product (GPD) catalysing the national ambition of high shares of renewable energy technologies (RETs) even more.
Similarly, most island electricity systems are isolated and operate no storage, interconnections or DSM programs. It is found that the combination of such system characteristics and the ambition of increasing the share of renewable energy technologies poses problem situations and requires additional investments in system reliability. DSM proved to be a feasible solution in this respect. By contextualising the research findings in the general field of other SIDS the following question is answered:

To what extent can the outcome of this research also be used in other SIDS in order to assess the suitability of DSM as a measure for integrating renewable energy technologies?

To generalize the outcome of only one case study to other island is challenging to say the least. Besides that there are no other cases to compare with, the results of this study are to a large extent defined by the case-specific circumstances and characteristics. Also methodologies and steps taken in this study may have been defined by case-specificity. So, in order to answer the above question the outcomes and steps taken in this research are evaluated on case-specificity and consequently to what extent this impacts the ability to generalize these outcomes and steps to other islands.

Focus on the integration of wind energy
The fact that the implementation of an additional wind farm is high on the political agenda of Aruba determined to a large extent the research scope of this research. However, this does not mean that the steps taken in this research are not applicable for a research that has a focus on other renewable energy technologies (RETs).
On the contrary, much of the RETs output is dependent on external factors, including: temperatures, wind speeds, solar intensity, tides, etc). Thus the concerns about the flexibility, variability, non-controllability of wind energy are also true for most the RETs. Especially when taken into account that most SIDS do not have the opportunity to realize less fluctuating forms of RETs such as: hydropower and biomass incineration plants due to diseconomies of scale and the lack of specific geographical conditions and natural resources.

System flexibility, modelling and simulation results
The net system flexibility of a power system, as explained in chapter 2 is defined by resource flexibility and required flexibility. Most electricity systems of SIDS are similar isolated systems, which currently do not operate any storage, interconnection or DSM capacity. Therefore, it is safe to state the general resource flexibility is low in most SIDS. The flexibility required however, is dependent on the variable demand and the variable output of already or future-planned RETs. These are to a large degree case-specific which makes a general statement about the net flexibility of SIDS systems problematic. Therefore, the results of the specific, which in chapter 2 may not be applicable for other SIDS although it is suggested that SIDS in general have a low net flexibility.

This is would be even more prominent in the simulation results of different cases where the case-specific unit characteristics, demand patterns and variable RET output dictate the results. Consequently, the simulation results of this research are not applicable to other SIDS.
The modelling approach however, can be applied for other cases because it allows for easy adaptation of the objective function, constraints and characteristics within the model. This makes the methodology used in this research highly applicable to other cases for a variety of purposes.
Note, that the availability of historical (demand, wind power output) and statistical data (unit characteristics) contributed to the validity of the simulation model. Without, such data these methods may not be suitable.

DSM programs and corresponding load profiles
The choice for a DSM program as explained in chapter 3, is defined by the load-shape objective and the time-scale in which the program should be executed. Because the output of most RETs varies quickly over time (wind power, solar pv), it is suggested that the direct control program would be most suitable. On the other hand if a RET with a less variable and more predictable output (i.e. tidal energy) would be used a DSM program with a higher time-scale could be more appropriate. However, the majority of the renewable energy sources on SIDS are presented by wind and solar. Furthermore, curtailment of RETs output may not always be available or desirable, therefore it is proposed that a DSM program in should be able to compensate both positive- and negative variations of RET output. Therefore, the load-shape objective of load-shedding may not be applicable to other SIDS although the direct-load control program may prove very applicable.
Such DSM programs require a special set of non-crucial controllable appliances that have a buffer capacity. An appliance has buffer capacity if it is able to shift its production or consumption of energy in time within the boundaries of the end-users requirements, i.e. refrigerators, cool-cells, heating, water production, ventilation and air-conditioning (HVAC) etc. Most SIDS are situated near the equator (Appendix-A). Tourism contributes between 20-60%[14] to the GDP of SIDS. This suggests some availability of air-conditioning loads. Although, these loads been found very suitable in this research it is uncertain that they would show similar potential in other SIDS. In addition, industrial activities may also be utilized in the DSM program (see interruptible- and curtailment programs, paragraph 3.3).
Note, that the availability of historical-, benchmark- and statistical data was necessary in order to establish a technical potential on load profiles.

Economic potential
This research has shown that in the case of electricity systems combining inflexible generation with significant amounts of unpredictable wind generation DSM is "cheaper" in providing fast spinning reserve than storage techniques. It is however, questionable and uncertain that the same economic potential exists for other cases. As identified in chapter 8, all the factors that contribute to the net benefits of additional RETs have to be taken into account. Despite, that the storage cost estimates are relatively independent of the location, the other costs and benefits are dependent on the local context (i.e. initial RETs costs, grid investments, reduced fuel benefits, etc.).

Willingness of customers
The methodology of the interviews itself can be applicable in any other SIDS . The barriers related and opportunities related to the implementation of load shedding in hotels are suggested to be generic as well for other hotels in SIDS. However, these barriers and opportunities may be different for other sectors (i.e. residential, industrial)

Conclusion
To what extent can the outcome of this research also be used in other SIDS in order to assess the suitability of DSM as a measure for integrating renewable energy technologies?

SIDS share specific problems and similar characteristics related to the energy supply. Due to these similarities a substantial part of the outcomes and approaches presented in this research are applicable for other SIDS who would wish to assess the potential of DSM in integrating RETs. Nevertheless, the case-specific nature of this research also limits the applicability of some results. An overview of the conclusions is shown in Table 10-1.

[14] Share of tourism on total GDP on SIDS obtained from: UN-Data, The World Bank and online statistical databases.

Table 10-1: The generalizability of results and outcomes

Approach	Important factors	Generalizability of results	Generalizability of approaches
System Flexibility	• Net flexibility ○ Flexibility resources ○ Flexibility required	• Medium ○ flexible resources SIDS high ○ flexibility required: case-specific (low)	High
Modelling (LP, Linny-R)	• Unit characteristics • Time-series demand • Time-series RETs output	-	Low- High, depends on data also see paragraph 11.2
Simulation results (scenario analysis)	• (same as above)	• Low	Low-High (same as above)
Identification of suitable DMS program	• load-shape objective • time-scale	• Medium ○ load shedding: low ○ direct control: high	High
Identification of potential load profiles	• Flexibility (very case-specific)	• Low/ Medium	Medium/ high, depends on available data
Economic potential (cost benefit)	• Net benefits (see CH8)	• Low	High
Willingness of customers (interview)	• Sector (residential, commercial, industrial)	• Low for other sectors • High for hotel industry	High

Phase 5: Discussion and generalisation

11.To what extent can the outcome of this research also be used in other SIDS in order to assess the suitability of demand-side management as a measure for integrating renewable energy technologies? (CH10)

<u>Synthesis</u>
-Discussion of results
-Generalization of results
-Reflection of results (CH11)
-Conclusions & recommendations (CH12)

11 Reflection

The aim of this chapter is to reflect on the way of working, the methodology used and the choices made in this research. Section 11.1, reflects on the choice for load shedding as a suitable DSM measure. Section 11.2 reflects on the choice of Linear Programming and Linny-R as a suitable methodology in this research.

11.1 Reflection on chosen DSM measure

Prior to this research a research proposal was written that had an initial broader scope of the effects of additional wind energy. The focus was that both a sudden increase and decrease in wind energy could be problematic for the integration of wind energy and that a DSM measure should be able to deal with both negative and positive fluctuations. During the empirical research on Aruba, it was found that although sudden wind increases do pose some technical limitations they could easily be managed by curtailing the excess of wind energy. Through interviews the perspective of WEB was adopted in that wind curtailment was executed within the boundaries of the contracts that was established between the IPP of the Vader Piet wind farm and the purchaser WEB. WEB already had a 'feasible solution' for the possible negative impact increasing wind energy could have on the electricity system. Therefor the focus shifted towards finding a DSM measure that would be able to deal with wind decreases only. This in retrospect defined the choice for load shedding as a suitable DSM measure in facilitating additional wind energy.
The choice for a suitable DSM measure is particularly dependent on the load shape objective (increase, decrease, shift) and the time-scale in which this difference in shape must occur (second, minutes, hours). By rather focussing on DSM measure that decrease load within minutes various DSM measures were not taken into account. It is important to understand this limitation and realize that there are DSM measures capable of providing "completer" solutions. This has been addressed in by proposing additional research related to coping with wind curtailment, see chapter 10.2. Also this has led indirectly to the choice of the air-conditioning loads of hotels as the most potential loads for the purpose of load shedding. The analysis of various industrial loads did not prove useful in this DSM program. Residential loads were not taken into account in this research because in terms of transaction costs, it was suggested that this group represents more potential than ten thousands of house-holds. Again, it is important to understand the reasoning behind this (chapter 3 & 4) and realize that different loads may offer potential for different DSM measures.
In retrospect, the choice of load shedding determined to a large extent the focus and outcome of this research early in the process. As a results (see above-mentioned) some issues may have been overlooked or underexposed. This could be avoided by changing the chronological order of the methodologies used. Performing the modelling phase earlier in the process (after the system analysis) may identify additional information before DSM programs and load-profiles are chosen. As a result, decision about appropriate programs and load-profiles are taken not only on the basis of existing information and hypotheses but complemented by additional simulation results.
This could prove more valuable in cases, where no information on the effects of the integration of a RET is available in advance. In this research, information was already on wind integration due to the existing Vader Piet wind park.

11.2 Reflection on Linear Programming

In chapter 6 the modelling questions and objectives for the modelling research phase were formulated. Based on these requirements, Linear Programming was chosen as a suitable methodology in order to answer these questions and fulfil these objectives. The discussion on the applicability of Linear Programming and the simulation model has been presented in chapter 10.2. This section reflects on the choice of linear programming as a modelling methodology in electricity systems in general.
The modelling requirements as introduced in chapter 5:

- Workable: understandable for users without extensive mathematical programming knowledge, easy to implement changes, user-friendly interface.
- Accessible: free, available, easy to understand for external parties
- Suitable: suitable for the task at hand, optimal solutions, ability to model constraints
- Representable: ability of graphical representation for stakeholder and 3rd party communications
- Quick: low computing time

To reflect on the choice for LP as a modelling methodology these above-mentioned requirements are addressed. Modelling realistic unit commitment models generally requires an extensive mathematical background. The main advantages of LP and the software package Linny-R were the high degree of workability and accessibility. All the elements of the LP formulation could easily be specified and modified in the simulation tool due to the attractive user-interface. The Linny-R software package proved an essential tool in specifying and consequently analysing the functioning of the electricity system. In general, without the software package the degree of workability and accessibility of the LP methodology would not be sufficient.
The suitability of the model was satisfied to a lesser degree. Unit commitment models are complex problems that are characterized by a set of various mathematical relations that pose physical limitations to the abilities of an electricity system. Not all of these physical limitations (constraints) in an electricity system are linear (continuous, discrete, non-linear). Therefore, not all constraints could be incorporated (see chapter 5-6). In this respect, the methodology of linear programming is less suitable in simulating unit commitment models. Despite, the possibility to manually enter limitations into the existing simulation model, this proved complex and very time-consuming thereby lowering the workability and accessibility of the model. During this research this has clearly identified the trade-off between the workability, accessibility and suitability of a methodology. When reflecting on the suitability it is found that LP and Linny-R are not optimal methodologies for the purpose of this and similar studies. During this research, the model was eventually used rather to explore the boundaries of the electricity system, than to quantitatively predict at what time and with what specifications power imbalances would occur.
If the choice of a model requirement would solely be based on the suitability it is recommended to choose other methodologies. This would also impact the choice for a simulation tool, such as mathematical tools (Mathlab-Simulink, Plexos) and Electrical Engineering software e.g. ETAP. These methods and tools, however would require more data, user licences and an extensive mathematical or programming background thus lowering the workability and accessibility. The graphical representation of the simulation scenarios provided a clear and easy to interpret overview. Especially during communication with external parties this was noticeable i.e. during the verification and validation with WEB operators, presentation of results with the graduation committee and various laymen. The solving time of the simulations is low and no significant problems were encountered. A small time-step was used, because this was necessary to cover for the 10-minute fluctuation. Furthermore, a small look-ahead time of 1 step was used to account for optimizing with perfect information and not being able to incorporate forecasting errors and a degree of noise in LP. Note, that the simulation model has been tested with an increased look-ahead time. This drastically increased the number of constraints and thereby the solving speed. Reason for this is that in Linear Programming, the constraints can reflect not only limitations for the current time step but also for time steps in the future. In this study, a higher look-ahead time was not required. Note that, in a study where a large look-ahead time is required in combination with an extensive list of constraints the slower solving speed may limit the workability of LP to this type of problem.

To conclude, all model requirements were met satisfactorily, except for the requirement of a suitable model that is able to model all constraints. Non-linear constraints could not be incorporated in the model. This did not affect the validity of the model, but limited the ability of the model to quantitatively assess the power system on a more detailed level. During this research the trade-off between suitability, workability, accessibility of a model became clear. The choice of the LP methodology, considering the objectives and alternatives is explained by identifying these trade-offs.

12 Conclusions & Recommendations

In chapter 10 and 11 the results of this research have been discussed and reflected upon. With this insights and the insights gained from the preceding chapters conclusions and drawn recommendations are stated in this final chapter. After the conclusion in section 12.1, recommendations are stated in section 12.2.

12.1 Conclusions

In the introduction it was stated that of the build of another wind park on Aruba is high on the political agenda and that it is uncertain what the corresponding implications are on the short-term reliability of the Aruban electricity system and how these relate to the configuration of the system.
This has led to an interest in DSM, which may be able, if managed correctly, to safeguard reliability, increase efficiency and lower overall costs of the electricity system. This uncertainty has been addressed by the initial problem statement and led to the following research question:

> *To what extent can demand-side management facilitate the integration of additional wind energy into the Aruban electricity system?*

To answer the research question, several sub-research question have been formulated. These and their answers are presented below, followed by the answer to the research question.

1. What are the characteristics of the Aruban electricity system?
The Aruban Electricity system can be defined as an isolated electricity system, with a low flexible generation portfolio that is constrained by the use of heavy fuel oil. Due to the absence of interconnections, DSM programs and storage capacity the overall level of flexible resources is low. It is found that due to the low flexibility of the system an already large degree of operational problems are caused during periods of sudden and severe wind energy decreases. With the build of another wind park the frequency and intensity of those moments are bound to increase, posing even more operational difficulties. As a result, there exists serious doubt that the electricity system is able to maintain the balance under such circumstances.

2. How can demand-side management, in theory, facilitate the integration of wind energy in the Aruban electricity system?
First of all in chapter 3, it is concluded that DSM can be applied for a variety of purposes. In this case, the focus lies on increasing the technical ability of the Aruban electricity system by decreasing electricity demand (loads) at times whenever supply-side measures are not able to maintain balance due to negative wind fluctuations. This is called load shedding. According to interviews with the utilities and the nature of the objective load shedding aims to fulfil it is important that whenever a DSM event occurs the utility is able to directly control customers appliances within a short period of time. By extensively comparing literature on DSM programs with these requirements it is concluded that the direct load control program provides such options. Here customers receive incentive payments or reduced rates for their participation. Other market based- and price based programs may offers various possibilities for other objectives in other electricity systems, see §3.3.

3. Which load profile(s) represent(s) the highest amount of potential as to integrate wind energy?
In chapter 4, it is found that the air conditioning load of the hotels industry on Aruba represents the highest amount of potential as to integrate wind energy through load shedding. Reasons for this conclusion are the following 1) the electricity load of all hotels combined represents 30% of the total demand of electricity on Aruba and 2) 50-70% of this demand is related to interruptible and relatively constant air-conditioning load.

4. What are the objectives and requirements for the modelling approach?

The modelling approach, as defined in chapter 5 is defined as: optimization of utilization of supply sources according to a merit order, to supply demand within the technical constraints of the system. First of all the objectives of the modelling approach is to make a model that is able to answer what the effects of an additional wind farm (30MW) are on the technical ability of the electricity system to balance supply and demand. If imbalances do occur the model must be able to indicate why and on what particular moments. Furthermore the model must be able to quantitatively assess 1) the frequency of the imbalances, 2) the amount of power imbalance and 3) the duration of imbalance.

Secondly, the requirements of the modelling approach can be summed as follows:

- Workable: understandable for users without extensive mathematical programming knowledge, easy to implement changes , user-friendly interface.
- Suitable: suitable for the task at hand, optimal solutions, ability to model constraints
- Accessible: free, available, easy to understand for external parties
- Representable: ability of graphical representation for stakeholder and 3rd party communications
- Quick: low computing time

5. What modelling technique can be used to reach these objectives?

Linear Programming is chosen in chapter 5 on the basis of the above-mentioned objectives and requirements as an appropriate modelling technique.

6. How is this general modelling technique applied to the Aruban electricity system?

First, the methodology of Linear Programming was used to formulate system constraints and the merit order of supply resources. After carefully specifying these constraints with the use of reliable historic data, the constraints and the merit order of supply resources were translated in the software package Linny-R. Linny-R provided a workable and accessible model. The model was verified and validated.

7. To what extent is the identified DSM measure a technical feasible solution?

The simulation model, showed that at times of wind decreases between -21MW and -25MW combined with a high utilization of fast spinning reserves the electricity system is not able to maintain the balance between supply and demand. Any solution that aims to mitigate such imbalances must be able to provide at least 8MW of electricity, within 10 minutes for at least 7 times a year immediately without prior notice. The shedding of air-conditioning load of large hotels can satisfy these above-mentioned requirements. The required automation and control systems for such purposes are commercially available. In addition to these conclusions a critical note is mentioned, to precisely identify the available capacity and ramp rates (amount of load that can be altered per time unit) additional research is necessary.

8. Is the identified DSM measure an economic feasible solution, taken into account the system costs and benefits of additional wind energy?

By performing an elaborate cost benefit analysis the DSM program is found economically feasible because: (1) load shedding is the least-cost solution in providing reliability compared to other suitable storage technologies (2) the investment scenario of load shedding as a reliability measure proved to generate the most net system benefits of an additional wind farm and (3) the annual avoided system costs (0.7M$ - 2.0M$) may be (partly)allocated as financial compensation for participating customers resulting in a strong business proposition.

9. Which barriers emerge when changing the energy demand of the corresponding load profiles?

The following barriers emerged after interviewing General Managers and Directors of Engineering of various small and large Aruban hotels: 1) hidden costs related to guest satisfaction, 2) technical risk relating to implementing load shedding equipment without damaging already existing equipment, and 3) the issue of control of own operations where hotels may not accept intervention of a third party and require prior notice before a load shedding event. During the interviews it was found that most of these barriers are caused by the lack of information about the general effects of load shedding.

10. What interventions would be needed to overcome implementation barriers?

The two first identified barriers are related to knowledge gaps on the effects of implementing load shedding. It is recommended that to overcome these barriers more information is required which may involve metering, testing, and other additional research . The third barrier, control of own operations can partly be explained by a lack of information but moreover by the lack institutional coordination between the intervening utility and the customers. Communication through negotiation or coordination by means of contracts and arrangements between those parties is advised in this respect. Although further information may be a key aspect in overcoming barriers, financial incentives could also significantly lower some of the barriers for they pose high opportunities for hotels.

11. *To what extent can the outcome of this research also be used in other SIDS in order to assess the suitability of demand-side management as a measure for integrating renewable energy technologies?*

Although this research was performed for Aruba, the value of this research is not limited to this island. Similar to this case, most SIDS electricity systems are isolated and currently operate no storage, interconnections or DSM programs. In addition, much of the other RETs are similarly dependent on external factors i.e. temperatures, wind speeds, solar intensity, tides resulting in variable output. As a result, much of the outcomes can be generalized to other SIDS. Despite, the similarities, several results are too case-specific for generalization due to specific unit characteristics, local demand patterns, local wind fluctuations and specific load profiles. The methodology however is highly generalizable and can easily be adapted and conceptualized for other SIDS. This may prove valuable to anyone who wishes to assess the potential of DSM to facilitate other forms of RETs of SIDS. To further increase this value it is recommended to extent this methodology with additional case studies.

To what extent can demand-side management facilitate the integration of additional wind energy into the Aruban electricity system?

It is found through a mixed method research approach that the demand-side management program of shedding air-conditioning load of the Aruban hotel industry is a technical and economical feasible solution in mitigating the negative effects an additional wind farm of 30MW would have on the technical ability of the Aruban electricity system to maintain the balance between supply and demand. Although the proposed DSM program was found technical and economically feasible, implementation may be hampered by customer related barriers and requires further research.

12.2 Recommendations

In the first subsection, general recommendations related to demand-side management are mentioned. In the second subsection, recommendations for further research are stated. In the final subsection, the recommendations for TNO are stated.

12.2.1 General recommendations

The main recommendation in this research is to seriously consider the option of load shedding as a means to facilitate the integration of another wind park. The proposed program proved to be technically and economically feasible. However, it is also recommended that more research is needed to identify the realistic potential of the combined air-conditioning load and to overcome the barriers related to the hotel industry (see next section). The current perspective on Aruba is that that the balance of electricity can only be influenced by the supply side. This research shows that the demand-side of the value chain holds large potential, as (energy inefficient) hotels already represent 30% of the total electricity demand of Aruba. Utilizing this potential through proper coordination and communication between utility and customer could substantially contribute to the affordability and reliability of the Aruban electricity system as can be (partly) concluded out of this research. The current government of Aruba has the ambition to increase the share of renewable energy sources even more. This further demonstrates the importance to tap into demand-side resources. Therefore it is recommended to also broaden the scope of DSM solutions and put more effort in finding other areas of applicability (energy efficiency, peak shaving) and identify other suitable load profiles in this respect. This could lead to new business models where the utilities would not only produce electricity but would also offer services to their customers. In this respect, it is advised that TNO may play a valuable role (see 12.2.3).

12.2.2 Recommendations for further research

Throughout this research, limitations and recommendations for additional research have been mentioned. It is advised that further research should focus on the following knowledge gaps: 1) specific potential of hotel AC loads and 2) identified barriers of hotels.

The technical potential of the load shedding program depends on 1) the available capacity and 2) the amount of capacity that may be decreased per unit of time (ramp rates). Although estimates about the capacity were calculated (see chapter 3) and interviewees mentioned the possibilities of immediate shutting down or idling the AC load (see chapter 9) there may still be uncertainty about these issues. In this regard it is recommended to perform additional research. The discussion (see section 10.2) proposed making use of advanced metering equipment that would enable a minute-to-minute communication of the amount of shedable load per unit to the utility and to run tests in hotels in order to identify how much time it takes to shut-down or idle AC load (see pilot study, below).

The success of the DSM program depends for a large degree on the willingness of hotels to participate. The knowledge based barriers: 1) the effect of AC shedding on the temperature and indirectly on the guest satisfaction and 2) the technical implications of load shedding equipment on already existing hotel systems may be overcome by the provision of adequate information. In this regard, two different forms of additional research are recommended:

- Simulation study: the aim of this study would be to identify the boundaries of temperature increase due to shedding AC load in different scenarios and how these relate to comfort zone temperatures.
- Pilot study: a single or set of representative hotels could participate in the shedding of AC load with the purpose of gaining information and experience. In contrast to the simulation study, actual results on i.e. room temperatures can be measured. And technical implications of load shedding equipment on already existing hotel infrastructure can be identified through actual implementation and testing.

Recommendations for the role of TNO

TNO in combination with other local parties are developing a secured, confined and experimental environment “the Smart Community” where the scalability of: renewable energy technologies, smart grids, sustainable building, behavioural change, electrical vehicles and water and waste technologies can be research to island-wide application. Through this community it is recommended to create synergy between the experiments in the Smart Community and the proposed additional research (previous section). A part of the experimental- and test studies should be developed in such a way that the gained information out of these studies can be used to overcome the identified barriers in this confined environment.

Furthermore TNO has the opportunity, as a facilitating research organization to help the country of Aruba recognize that demand-side management holds feasible solutions to a variety of problems. It is strongly advised to take the results of this research into account and include loads shedding as a possible reliability solution. However, implementation is, as could be seen in this research hampered by above-mentioned barriers. On more than one occasion communication and (institutional) coordination is required to overcome such barriers and facilitate processes between utilities and participating customers. This leads to the final recommendation, in which TNO should acts as a neutral in this respect and may also act as an external advisor to support WEB in gradually shifting their business model from a traditional power supplier to a more service based utility.

Bibliography

1. Juoperi, K., *Heavy fuel oi - still the dominant fuel quality for diesel engines*, in *Royal Belgian Institute of Marine Engineers*2004, Marine news Wartsila.
2. Monteiro Alves, L.M., A. Lopes Costa, and M. da Grava Carvalho, *Analysis of potential for market penetration of renewable energy technologies in peripheral islands.* Renewable Energy, 2000. **19**(1,2): p. 311-317.
3. Kristoferson, L., P. O'Keefe, and J. Soussan, *Energy in small island economies.* Ambio, 1985. **14**(4/5): p. 242-244.
4. Hoyle, B., *Islands, transport and development. In: Biagini, E., Hoyle, B. (Eds.),.* Insularity and Development: International Perspectives on Islands. Pinter, London., 1999.
5. United Nations Economic and Social Council, *Sustainable Development of Energy Resources in Small Island Developing States.* E/CN.17/1996/20/Add.2. United Nations, New York, 1996: p. 1-18.
6. Kakazu, *Sustainable Development of Small Island Economies.* Westview Press, Oxford, 1994.
7. Mayer, P.C., *Reliability economies of scale for tropical island electric power.* Energy Economics, 2000. **22**(3): p. 319-330.
8. Farinelli, U., *Energy as a Tool for Sustainable Development.* European Commission and UNDP, New York, 1999.
9. Headley, O., *Renewable energy technologies in the Caribbean.* Solar Energy, 1997. **59**(1-3): p. 1-9.
10. Jensen, T.L., *Renewable Energy on Small Islands.* Forum for Energy and Development, Denmark., 2000.
11. Weisser, D., *On the economics of electricity consumption in small island developing states: a role for renewable energy technologies?* Energy Policy, 2004. **32**(1): p. 127-140.
12. Aruba, G.o. *Caribbean Branch Office TNO, for sustainable energy*. 2011 14-03-2012]; Available from: http://www.greenaruba.org/images/Folder Ebbing 11HB Aruba.pdf.
13. FESCA, *Economische Ontwikkeling van Aruba: Deelstudie Energie.* 2009.
14. Strbac, G., *Demand side management: Benefits and challenges.* Energy Policy, 2008. **36**(12): p. 4419-4426.
15. Kabouris, J., et al., *Computational environment to investigate wind integration into small autonomous systems.* Renewable Energy, 1999. **18**(1): p. 61-75.
16. Sovacool, B.K., *The intermittency of wind, solar, and renewable electricity generators: Technical barrier or rhetorical excuse?* Utilities Policy, 2009. **17**(3,Äì4): p. 288-296.
17. Pina, A., C. Silva, and P. Ferrao, *The impact of demand side management strategies in the penetration of renewable electricity.* Energy, 2012. **41**(1): p. 128-137.

18. Faruqui, A., Gellings, C.W., *Should demand-side management be a top-down or a bottom-up process?*, in *Strategic Planning and Marketing for Demand-Side Management: Selected Seminar Papers*1985, Electric Power Research Institute: Palo Alto, CA.
19. Gellings, C.W., *The concept of demand-side management for electric utilities* Proceedings of the IEEE, 1985. **73**(10): p. 1468-1470.
20. Fitzgerald, N., A.M. Foley, and E. McKeogh, *Integrating wind power using intelligent electric water heating.* Energy, (0).
21. Gellings, C.W., *Integrating demand-side management into utility planning.* IEEE Transactions on Power Systems, 1986. **1**(3): p. 81-87.
22. Vries, d.L.J., Correlje, A., Knops, H.P.A.,, *Electricity: Market design and policy choices*2010.
23. Vashishtha, S. and M. Ramachandran, *Multicriteria evaluation of demand side management (DSM) implementation strategies in the Indian power sector.* Energy, 2006. **31**(12): p. 2210-2225.
24. Martina, I.S., *Regulation in Splendid Isolation - A Framework to Promote Effective and Efficient Performance of the Electricity Industry in Small Isolated Monopoly Systems*, in *Next Generation Infrastructures Foundation*2009, Delft University of Technology: Delft. p. 336.
25. Porter, K., Mudd, C., Fink, J., DeCesaro, Wiser, R., *A Review of Large-scale wind grid integration in the United States.* The Energy Foundation: China Sustainable Energy Program,, 2009.
26. Denny, E., et al., *The impact of increased interconnection on electricity systems with large penetrations of wind generation: A case study of Ireland and Great Britain.* Energy Policy, 2010. **38**(11): p. 6946-6954.
27. Bove, R., M. Bucher, and F. Ferretti, *Integrating large shares of wind energy in macro-economical cost-effective way.* Energy, 2012. **43**(1): p. 438-447.
28. Bellarmine, G.T., *Load management techniques.* Proceedings of the IEEE, 2000. **10**(1109): p. 139-145.
29. Kostkova, K., et al., *An introduction to load management.* Electric Power Systems Research, 2013. **95**(0): p. 184-191.
30. Breukers, S.C., et al., *Connecting research to practice to improve energy demand-side management (DSM).* Energy, 2011. **36**(4): p. 2176-2185.
31. Moura, P.S. and A.b.T. de Almeida, *The role of demand-side management in the grid integration of wind power.* Applied Energy, 2010. **87**(8): p. 2581-2588.
32. Aho, I., et al., *Optimal load clipping with time of use rates.* International Journal of Electrical Power & Energy Systems, 1998. **20**(4): p. 269-280.
33. Albadi, M.H. and E.F. El-Saadany, *A summary of demand response in electricity markets.* Electric Power Systems Research, 2008. **78**(11): p. 1989-1996.
34. Majumdar, S., Chattopadhyay, D., Parikh, J., *Interruptible load management using optimal power flow analysis* IEEE Transactions on Power Systems, 1996. **11**(2): p. 715-720.

35. Associates, C.R., *Primer on demand-side management with an emphasis on price-responsive programs*, R.P.f.t.W. Bank, Editor 2005: Washington, DC.
36. US Department of Energy, *Benefits of Demand Response in Electricity Markets and Recommendations for Achieving them*, in *Report to the United States Congess*2006.
37. Cappers, P., et al., *An assessment of the role mass market demand response could play in contributing to the management of variable generation integration issues.* Energy Policy, 2012. **48**(0): p. 420-429.
38. Bohdanowicz, P., Churie-Kallhauge, A., Martinac, I. *Energy-efficiency and Conservation in Hotels - Towards Suistanable Tourism*. 2001.
39. Escalante, A. *Energy Conservation in the Caribbean - A profitable industry for regional and foreign entrepreneurs*. 2006.
40. Henry, G. *Energizing the Caribbean Hotel Industry*. World Tourism Day, 27th september, 2012 2012 [cited 2013 20 february 2013]; Presentation]. Available from: http://www.onecaribbean.org/content/files/WTD2012GHENRYEnergizingCaribbeanTourismIndustry.pdf.
41. Keane, A., et al., *Demand side resource operation on the Irish power system with high wind power penetration.* Energy Policy, 2011. **39**(5): p. 2925-2934.
42. Rosso, A., Ma, J., Kirschen, D.S., Ochoa, L.F.,, *Assessing the contribution of demand side management to power system flexibility*, in *Proceedings of IEEE Conference on Decision and Control and European Control Conferenec 2011*2011: Schotland.
43. Sheble, G.B. and G.N. Fahd, *Unit commitment literature synopsis.* Power Systems, IEEE Transactions on, 1994. **9**(1): p. 128-135.
44. Sen, S. and D.P. Kothari, *Optimal thermal generating unit commitment: a review.* International Journal of Electrical Power & Energy Systems, 1998. **20**(7): p. 443-451.
45. Sundararagavan, S. and E. Baker, *Evaluating energy storage technologies for wind power integration.* Solar Energy, 2012. **86**(9): p. 2707-2717.
46. Hadjipaschalis, I., A. Poullikkas, and V. Efthimiou, *Overview of current and future energy storage technologies for electric power applications.* Renewable and Sustainable Energy Reviews, 2009. **13**(6,Äì7): p. 1513-1522.
47. Divya, K.C. and J. Ostergaard, *Battery energy storage technology for power systems - An overview.* Electric Power Systems Research, 2009. **79**(4): p. 511-520.
48. Poonpun, P. and W. Jewell. *Analysis of the cost per kWh to store electricity*. in *Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, 2008 IEEE*. 2008.
49. Bradley, P., M. Leach, and J. Torriti, *A review of the costs and benefits of demand response for electricity in the UK.* Energy Policy, 2013. **52**(0): p. 312-327.
50. Keay, M., *Renewable energy targets: the importance of system and resource costs.* The Oxford Institute for Energy Studies, 2013.
51. EWEA, *The Economics of Wind Energy - A report by the European Wind Energy Association*, S. Krohn, Morthorst P.E., Awerbuch, S., Editor 2009.

52. Pondera, *Kosten en baten windpark op land.* Definitieve rapportage | 12 oktober 2009, 2009. **Geldstromen duurzame energie in opdracht voor Senternovem**(709003): p. 22.
53. de Klerk, A.C.H., *Amsterdam Windportfolio - Een kosten-baten analyse naar het meest economisch rendable windportfolio voor een extra 100MW geinstalleerd windvermorgen voor de gemeente Amsterdam*, in *Energy & Industry*2012, Delft University of Technology: Delft.
54. Motegi, N., Piette, M.A., Watson, D.S., Kiliccote, S., Xu, P., *Introduction of Commercial Building Control Strategies and Techniques for Demand Response*, 2007, Berkely National Laboratory
55. UNIDO, *Barriers to industrial energy efficiency: a literature review*, U.N.I.D.O. (UNIDO), Editor 2011. p. 83.
56. Simon, H.A., *The Sciences of the Artificial*. Vol. 3rd ed. 1996, Cambrigde: MA: MIT Press.
57. Valentova, M., *Barriers to Energy Efficiency - Focus on Transaction Costs.* Acta Polytechnical, 2010. **50**(4): p. 87-93.
58. DeCanio, S., *Barriers within firms to energy-efficient investments.* Energy Policy 1993. **21**(906-914).

Appendix

A. Small Island Developing States

Figure 0-1: Map of all SIDS

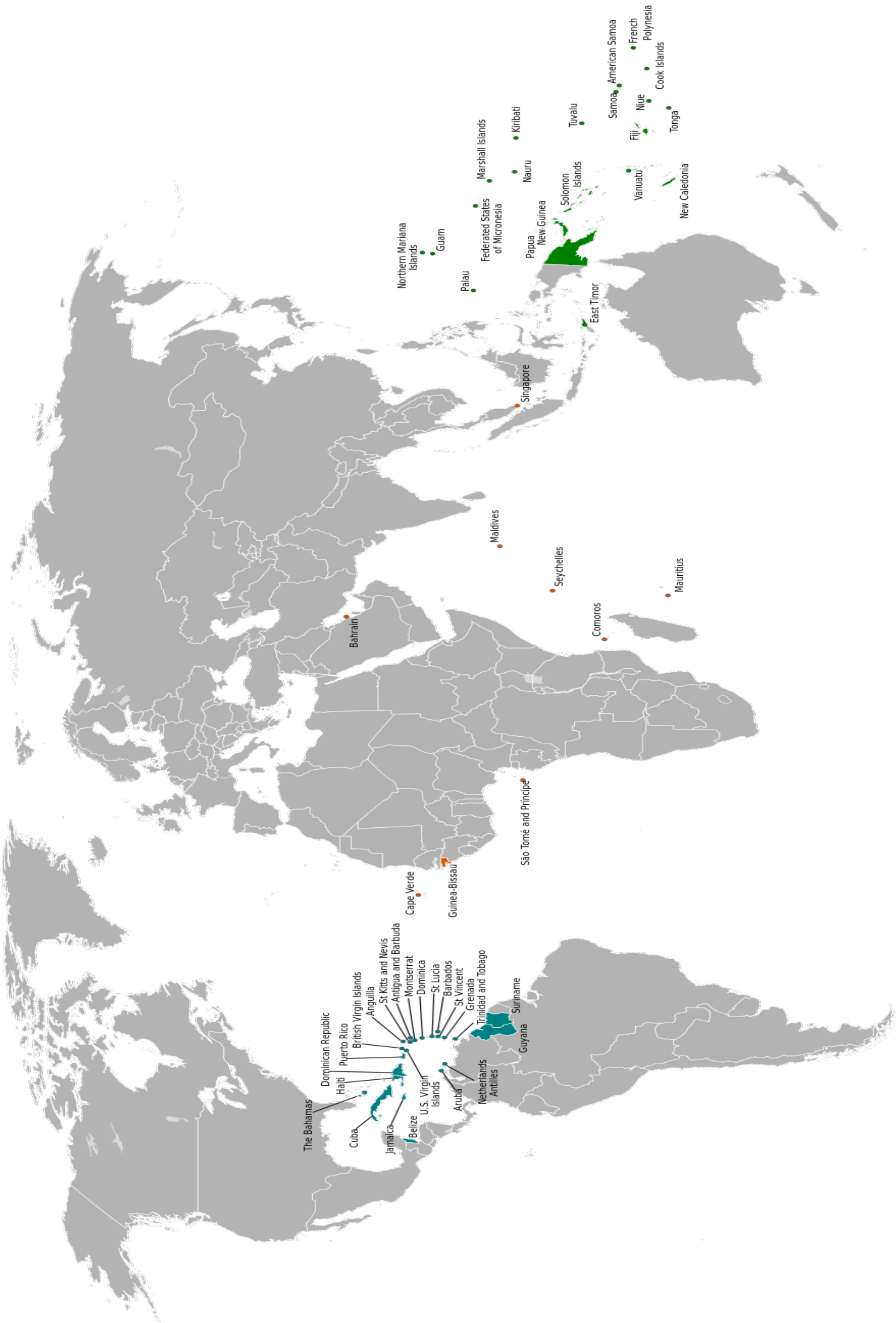


Table 0-1: Categorization of SIDS in different regions. Copied from: SIDS

Caribbean	Pacific	Africa, Indian Ocean, Mediterranean and South China Sea (AIMS)
Anguilla [3, 4, 7]	American Samoa [2, 6, 7]	Bahrain [3, 6]
Antigua and Barbuda	Cook Islands [7]	Cape Verde [6]
Aruba [3, 5, 7]	Federated States of Micronesia	Comoros [1]
Bahamas	Fiji	Guinea-Bissau [1, 6]
Barbados	French Polynesia [3, 4, 7]	Maldives [5]
Belize	Guam [2, 6, 7]	Mauritius
British Virgin Islands [3, 4, 7]	Kiribati [1]	São Tomé and Príncipe [1, 6]
Cuba [6]	Marshall Islands	Seychelles
Dominica	Nauru	Singapore [6]
Dominican Republic [5]	New Caledonia [3, 4, 7]	
Grenada	Niue [7]	
Guyana	Northern Mariana Islands [3, 6, 7]	
Haiti [1]	Palau	
Jamaica	Papua New Guinea	
Montserrat [3, 7]	Samoa [1]	
Netherlands Antilles [2, 5, 7]	Solomon Islands [1]	
Puerto Rico [3, 5, 7]	Timor-Leste [1, 3, 5]	
Saint Kitts and Nevis	Tonga	
Saint Lucia	Tuvalu [1]	
Saint Vincent and the Grenadines	Vanuatu [1]	
Suriname		
Trinidad and Tobago		
United States Virgin Islands [2, 6, 7]		

1. Also a Least developed country
2. Observer of the Alliance of Small Island States
3. Not a member or observer of the Alliance of Small Island States
4. Associate member of regional cooperation body
5. Observer of regional cooperation body
6. Not a member or observer of regional cooperation body
7. Not a member of the United Nations

B. Newspaper articles: blackouts Aruba & Bonaire

Figure 0-2:Newspaper article on a blackout in Aruba caused by a defect in the fuel supply. Source: Amigo

Stroomuitval legt Aruba plat
zaterdag, 05 januari 2013 09:20

ORANJESTAD — De energiecentrale van het Water- en Elektriciteitsbedrijf (WEB) is vanochtend omstreeks kwart over tien volledig uitgevallen. Overal op het eiland viel daardoor de stroom uit en in sommige gebieden ook het water.

De oorzaak lijkt een probleem in de brandstofvoorziening naar de generatoren die de elektriciteit opwekken. "Een technisch defect in de toevoer van brandstof naar boiler zes", aldus WEB-woordvoerder Asja Dongen tegen de *Amigoe*.

Rond kwart voor elf werd bekendgemaakt dat WEB bezig was met het probleem, maar dat het tussen de vier en zes uur zal duren voordat het hele eiland weer van stroom wordt voorzien. Dongen laat weten dat de stroom vermoedelijk rond twee uur vanmiddag weer terug is. Zoals gebruikelijk zullen de verschillende wijken geleidelijk weer van stroom worden voorzien, waarbij het ziekenhuis en het hotelgebied voorrang krijgen. Hoe het kan dat de brandstoftoevoer naar een boiler uitvalt, is nog niet bekend.

Naar verluidt leverde de stroomuitval een probleem op voor het Horiacio Oduber Hospitaal (HOH). De noodgeneratoren sloegen niet aan, waardoor het hele ziekenhuis zonder stroom zat. De brandweer heeft er snel voor gezorgd dat in ieder geval één generator weer werkte, waardoor de meest kritieke afdelingen weer elektriciteit hadden.

Ten tijde van de stroomuitval was de redactie van de *Amigoe* nog volop bezig met het maken van de krant van vandaag. Door het uitvallen van de stroom is het helaas niet mogelijk om vandaag op Aruba een krant uit te brengen. Op Curaçao wordt een aangepaste Aruba-pagina uitgebracht. Onze excuses daarvoor.

Figure 0-3:Newspaper article on a blackout in Bonaire caused by sudden wind decreases. Source: Amigo

Totale black-out op Bonaire

KRALENDIJK — Bonaire heeft gistermiddag weer enkele uren zonder stroom gezeten. Als gevolg van een instabiliteit bij de centrale van Ecopower ontstond er rond het middaguur een totale black-out.

Volgens een communiqué van WEB NV ontstond de instabiliteit doordat vrij onverwacht de stroomproductie door de windmolens inzakte. Daardoor moesten de dieselgeneratoren alle productie overnemen, om aan de vraag te voldoen. Die situatie heeft gezorgd voor de instabiliteit die vervolgens leidde tot de volledige stroomstoring. Rond kwart voor twee was het gelukt om de dieselcentrale van Ecopower weer op te starten en werd begonnen met het aansluiten van de verschillende wijken op het distributienet.
Als gevolg van tegenspoed gedurende dat proces, heeft het langer dan normaal geduurd voordat alle wijken weer aangesloten werden. Dat kwam doordat een van de elektriciteitskabels die Ecopower met het substation bij Amboina verbinden, voor problemen zorgde. Daarop besloten WEB en Ecopower gezamenlijk om de wijken via een enkele kabel van stroom te blijven voorzien, zodat alle wijken aangesloten konden worden op het distributienet. Dat heeft voor enig oponthoud gezorgd.

Later kreeg ook WEB te maken met problemen in het substation bij Hato. Dit heeft voor vertraging gezorgd bij het opnieuw aansluiten van de wijken Hato, Republiek en Sabadeco. Ook die wijken konden rond half vijf weer worden aangesloten.

WEB zegt dat het distributiesysteem tussen WEB en Ecopower zodanig is ontworpen, dat het zonder problemen op een enkele leiding kan opereren.

Controverse over

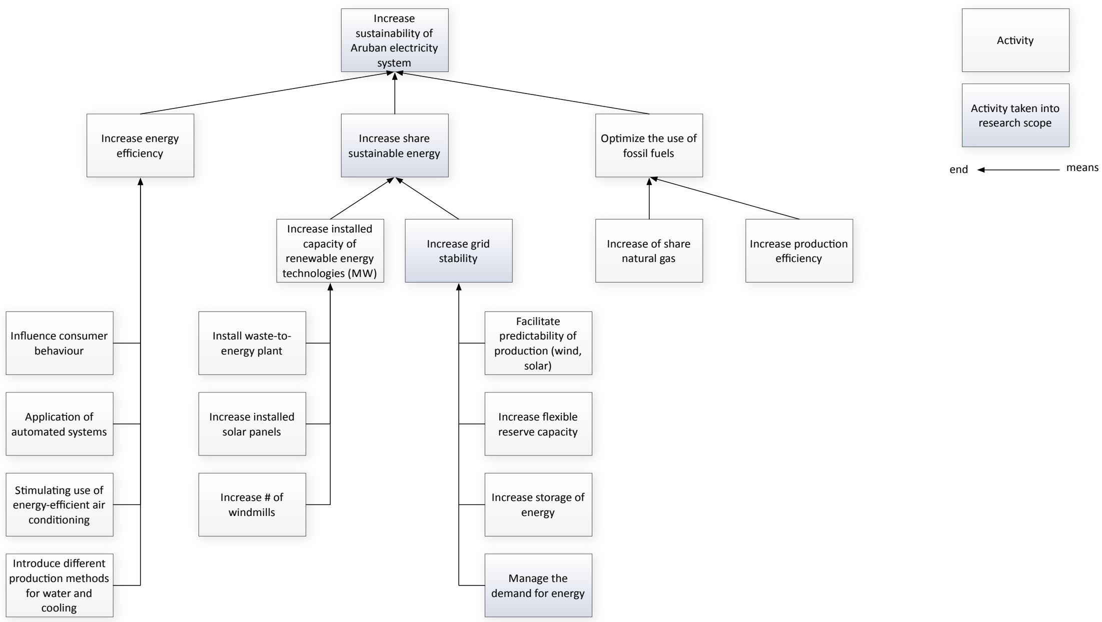
C. List of interviewees

Table 0-2:

Organization	Name of interviewee	Function
TNO	R. Westerga	-Senior Consultant
Caribbean Branch Office TNO (CBOT)	J.H.J. Ebbing I. Flanegin R.J. Moons	-Managing Director -Senior Consultant -Senior Consultant
WEB	C. Ras R. Croes	-Technical Support Engineer -Senior Engineer
ELMAR	E. Lampe T. Koolman	-Business Development Officer -Operations Manager
AHATA	J. Hepple	-President & CEO
Bucuti & Tara	E. Biemans	-Owner & Managing Director
Hyatt Regency Aruba	F. Hoffmann C. Terzano	-General Manager -Assistant F&B Director
The Westin Resort & Casino, Aruba	R. Roy	-General Manager
Renaissance Aruba Resort & Casino	P. Gielen	-General Manager
Radisson Aruba Resort, Casino & Spa	G. Puts	-Director of Engineering
Sustainable Solutions Aruba	R. Leonora	-Director

D. Means-end diagram

Figure 0-4:



E. Minutes Carlos Ras – WEB

Tuesday, 11 December 12

Concerning the expert validation

The unit commitment model that was created in the software-modelling tool Linny-R was verified and validated by Carlos Ras – Technical Support Engineer and Rocky Croes – Senior Operator (both employees at the technical department of WEB). When checking the lower and upper bounds specified in the model (unit capacity constraints), both experts were in agreement that these values resembled the unit characteristics in real life. The dispatch of the generators throughout an average load day under normal VP output was found similar to the real dispatch. Note that this could also be checked with capacity data of 2012.

Concerning the strategic dispatch of the generators:

TG6,7 although not cost effective these TGs operate as base load. One of the TGs operates at a constant level, the other one is utilized as spinning reserve. Although the TGs are the least cost efficient production units, these units are operated because of their high reliability. According to both Mr Ras and Mr Croes the model displayed this behaviour correctly. RECIPS III are the most cost efficient generators in the configuration. Therefor they are next in line to be dispatched. The model showed this dispatch also correctly. RECIPS I&II are the last generators that are dispatched in the current configuration. At times of high demand and/or low wind penetration (sudden windfalls), these recips are dispatched. The models behaviour was found to be correct. All RECIPS were characterized as standing reserve units.

Vader Piet:

Vader Piet is modelled as the most cost effective generator in the configuration, its output will always be dispatched in the model. The data-set used for specifying Vader Piet is derived from WEBs own production data and was verified and found valid.

The **demand** however, was found to be lower than usual. This is related to the fact that the internal demand of WEB was not calculated in the modelled demand series. According to both expert, the internal consumption of WEB is 10MW and is related to the water production (5MW) and other internal loads. The internal demand is fairly constant throughout the year, and may be modelled as such.

Regarding the second scenario, both experts also agreed that the dispatch was modelled accordingly to real life situations.

Lacking specifications

During the validation, information was presented on what aspects of the units operational characteristics were not incorporated. Aspects missing:

-25% start-up failure

-Minimum up- and downtime

Regarding the 25% start-up failure, the following specifications were added. Whenever a RECIPS has to start up, the fuel supply needs to be manually connected to the generator. In case of a start-up failure there is a delay of 2 minutes to connect the fuel pump and get permission to access another recip generator.

Other specifications:

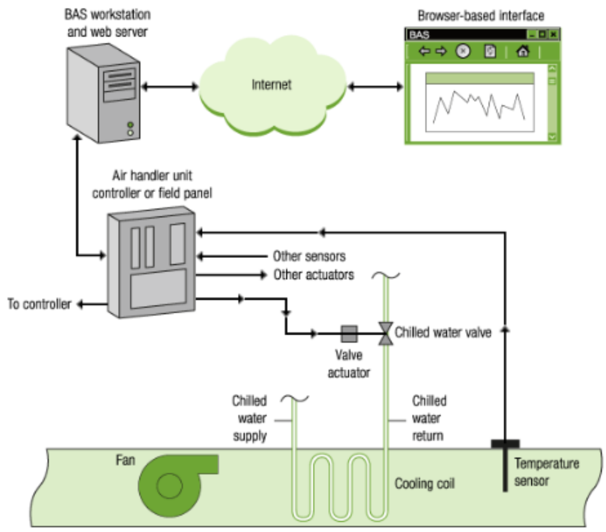
Full load time, recips III 5min if every parameter is correct (water, temperature, etc).

Full load time, recips I&II 12 min if every parameter is correct.

F. Building Automation System

The building automation system (BAS) has become the accepted technology used in controlling HVAC and other systems in most new commercial and institutional buildings. Existing buildings can be retrofitted with BASs, a change that has been shown to provide economically beneficial improvements in energy efficiency and occupant comfort. Although most BASs are designed primarily for HVAC control, many incorporate additional functions, such as lighting control, computerized maintenance scheduling, life-safety functions (such as smoke control), and access (security) control.

Figure 0-5: A BAS consists of sensors, controllers, actuators and software. An operator interfaces with the system vai a central workstation of web browser. Adapted from: esource.com



Box 0-1: Explanation of a chiller plant. Directly copied from: Building Automation

Chilled water is often used to cool a building's air and equipment. The chilled water system will have chiller(s) and pumps. Analog temperature sensors measure the chilled water supply and return lines. The chiller(s) are sequenced on and off to chill the chilled water supply.
A chiller is a refrigeration unit designed to produce cool (chilled) water for space cooling purposes. The chilled water is then circulated to one or more cooling coils located in air handling units, fan-coils, or induction units. Chilled water water-based cooling systems are typically used in larger buildings. Capacity control in a chilled water system is usually achieved through modulation of water flow through the coils; thus, multiple coils may be served from a single chiller without compromising control of any individual unit.

G. Storage cost calculations

This method of cost calculation (chapter 8) to calculated the costs of storage technologies specified for the introduced technical requirements (chapter 7) is based on the proposed method by: Poonpun & Jewell (2008) and Sundararagavan and Baker (2012) [45, 48] This method is explained below:

The total (non-annualized) capital cost of each storage technology ($Cost_{CC}$) are calculated by summing up the storage costs ($Cost_{storage}$) , the conversion cost ($Cost_{conv}$)and the balance of plant cost ($Cost_{balance}$):

(1) $Cost_{CC}(\$) = Cost_{storage}(\$) + Cost_{conv}(\$) + Cost_{balance}(\$)$

Storage cost, measured in \$, is proportional to the energy cost (C_E) and the amount of energy stored (E). As discussed in the section 8.2, energy cost is the per unit cost of the storage system measured in \$/kWh. Inefficiency associated with storage systems is accounted for in the calculations as shown below. Where, C_E is the energy cost, measured in \$/kWh, $_E$ is energy storage capacity, measured in kWh, ŋ is efficiency of the storage system, measured in%:

(2) $Cost_{storage}(\$) = (C_E * E)/ ŋ$

Power conversion system cost, measured in \$, is proportional to the power cost (Cp) and the power capacity (P) of the storage unit. Where, Cp is the power cost, measured in \$/kW, P is power capacity, measured in kW:

(3) $Cost_{conv}(\$) = Cp * P$

The balance of plant cost, measured in \$, is proportional to the per unit balance of plant cost (\$/kW) and power capacity (P) The calculation is expressed as follows:

(4) $Cost_{balance}(\$) = C_{balance}(\$/kW) * P$

Annualized cost (AC) allocates the initial capital cost of storage across the lifetime of the technology. It is determined by multiplying the capital cost of storage $Cost_{cc}$ with the capital recovery factor (CRF) as shown below:

(5) $AC= Cost_{cc} *CRF$

Calculation of capital recovery factor is given below, where i is the annual interest rate (%) , L is the lifetime of energy storage (years):

(6) $CRF = i(1+i)^L / [(1+i)^L-1]$

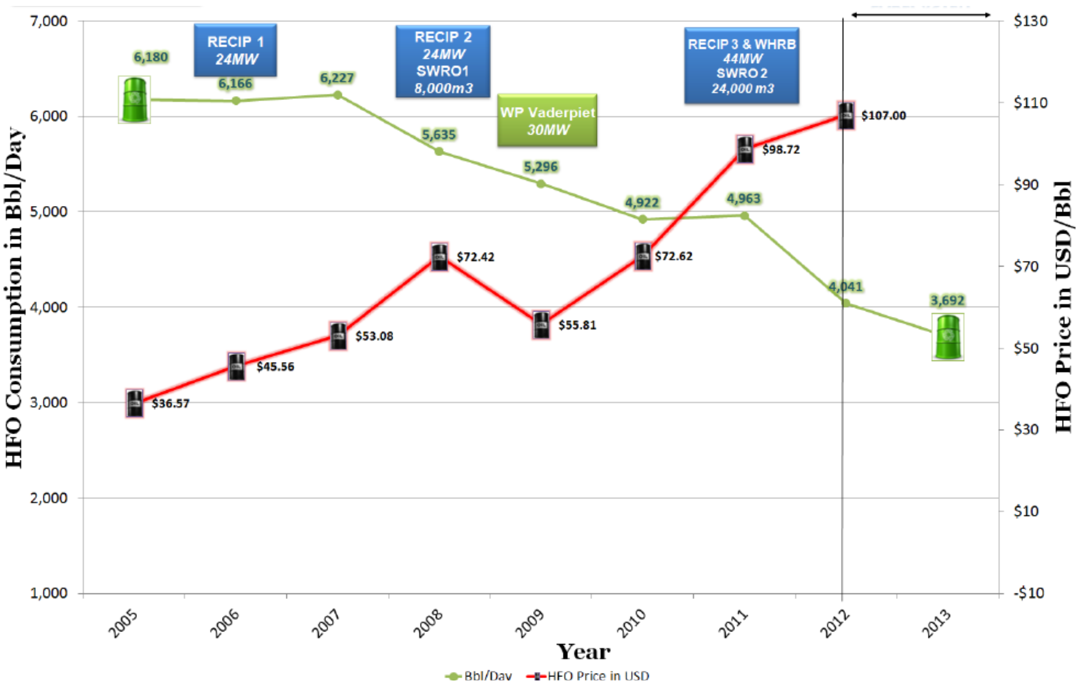
The Operational and Maintenance costs are calculated by multiplying the $C_{O\&M}$ with the power capacity (P) of the storage system as shown below, where $C_{O\&M}$ is the operation and maintenance cost, measured in \$/kW-year and P is the power capacity, measured in kW.

(7) $Cost_{O\&M}(\$) = C_{O\&M} * P$

Finally, the total annualized costs of the storage system ($Cost_{TOTAL,AC}$), measured in \$/yr, is the sum of the annualized costs (AC) and operation and maintenance costs ($Cost_{O\&M}$) as shown below:

(8) $Cost_{TOTAL,AC =} AC + Cost_{O\&M}$

H. WEB Power and water production time-line



Taken into account the increase of demand in 2009 and 2010, the decrease of HFO consumption (bbl/day) due to the produced wind energy consumption between 2009 and 2010 amounts to ~320 bbl/ day.

I. Calculation of initial wind power costs

The here-under calculations show an overview of the initial costs of a wind farm consisting of costs ten 3MW Vestas V90 wind turbines, based on cost estimates derived from EWEA (2009) and Pondera (2009). This method is adapted from de Klerk (2012).

Turbines					
	Type of turbine			V90	
	Park efficiency			80%	
	Number of turbines			10	#
	Capacity			3	MW
	Total capacity			30	MW
	Park Estimated Average Production			112.482	MWh*
	Park Estimated Average Production			112.482.337	kWh

Investment costs		standard		discounted	
	wind turbines	717		21.510.297	$ / kW
	foundation	61		1.830.664	$ / kW
	electrical infrastructure in the wind park	14		411.899	$ / kW
	net grid connection	83		2.494.279	$ / kW
	land rent	37		1.098.398	$ / kW
	financial costs	11		343.249	$ / kW
	road construction	8		251.716	$ / kW
	control systems	3		91.533	$ / kW
		934		934,4012204	$ / kW
	total investment costs			**28.032.037**	$

Maintenance and operational costs					
	Maintenance, service, insurance	0,008	$ / kWh	943.788	$ / year
	Grid connection	11	$ / kWh / year	330.000	$ / year
	Land costs	10	$ / kWh / year	300.000	$ / year
	Property taxes	0,0936%	%	26.238	$ / year
	Total			1.600.026	$ / year

Economic factors			
	Return on investment	10	year
	Depreciation time	15	year
	Cost price electricity	0,039	$ / kWh
		39,14596286	$ / MWh

Total Annualized Costs			
interest rate	7%	**4.677.793**	$ / year

* Similar to park average production of Vader Piet

J. Structure of the interview

Part I General Awareness
Please circle appropriate responses.

1. The investment decisions for major energy consuming appliances are taken by (i) top management (ii) middle management (iii) concerned manager

2. Energy conservation measures are taken by the hotel. (i) Yes (ii) No

If yes:

   a. What measures were taken?
   b. Who is responsible for that?
   c. Are the energy conservation measures reviewed by the top management? Yes/ No.

If yes, frequency of review; (i) yearly (ii) half yearly (iii) quarterly (iv) monthly (v) weekly

3. Energy consumption monitoring is done on regular basis? Yes / No.

If yes , who is responsible for energy monitoring and management?
(i) Energy manager (ii) No one in particular (iii) Others (Please specify).

4. Does the hotel by any chance have an overview of the total yearly consumption and the distribution according to electrical appliances, such as share of air conditioning, pool pumps, lighting etc.?

Part II Perspective on load shedding

5. Would you implement or agree on implementing load shedding in your hotel?

6. Why? Name five reasons and prioritize them in descending order.

7. What are the main concerns ?

8. How could these be overcome?

9. Trade-offs?

Part III: Thesis

Thesis 1:
If a load-shedding contract is offered with a reduced rate for electricity, I will accept it.

Thesis 2:
It is best that customers do not know that load shedding is applied in this hotel.

Thesis 3:
Customers may see load shedding as an environmental measure and will understand its necessity

K. Minutes interview: the Bucuti & Tara Beach Resorts

Interviewee: Ewald Bieman, Owner and General Manager of the Bucuti & Tara Beach Resorts
Interviewer(s): Toine de Klerk (TNO- CBOT & TUDelft) and Jan Ebbing (TNO- CBOT)
Date: 7th December 2012
Location: The Bucuti & Tara Beach Resorts

This document is an elaboration of the interview taken by Toine de Klerk & Jan Ebbing with Ewald Biemans, the Owner and General Manager of the Bucuti & Tara Beach Resorts. This interview is part a MSc Thesis Research relating to demand-side management, and in particular load shedding in the hospitality sector and the integration of wind energy into the Aruban Electricity System.

Concerning General Energy Awareness
In terms of energy conservation measures taken by the hotel, the Bucuti Resort incorporated by far the most profound and allround measures:

- All lighting is gradually replaced by LED lighting
- Sealed chiller airconditioning system converting to inverter system
- Motion sensors in public areas, also office rooms that control lighting, and airconditioning
- 0,5 M$ invested in computer software, the Bucuti can control every rooms temperature and lights
- Motion sensors in guestrooms, after several minutes of inactivity the airconditioining and lighting is switched off.
- Moisture and humidity sensors to prevent the mould growth in rooms or areas
- Various public spaces are non-air conditioned i.e. entrée lobby, restaurant
- Solar boilers for hot water
- Certified Green Globe hotel
- Certified Travel Life Gold
- Certified ISO ….

The bucuti operates a software package that allows them to monitor and control the rooms temperature and lighting. Furthermore the Bucuti makes use of sensors inside the guestrooms. If a room is inactive for a period of time the AC and the lighting will be turned off. As a result, it prevents the unnecessary use of electricity when customers are not present in their rooms. Problems could arise in rooms where the AC is not on. Mould growth is a common problem in the event rooms are too humid and moist. The Bucuti operates humidifiers that actively react to moist and humidity sensors to prevent mould growth. In terms of metering and consumption awareness, the Bucuti operates metering systems and knows how much electricity is consumed by the guesthouses, the pools, the restaurant etc. Bucuti has taken such a number of profound energy conservation measures that their energy expenditure amount to 5-6% of their total costs annually.

Concerning Load Shedding
Concerning load shedding no issues emerged from the perspective of Bucuti, in fact Bucuti would not mind the direct intervention of WEB in their energy consumption several times a year for a period of 10-20 minutes.The main reason is that Bucuti has enough own generator capacity to fully backup their energy demand for a period of time. The generators run on diesel. According to Mr. Biemens, "I'd be happy to implement it, either way it would be a good test to see of my equipment works."The air conditioning system of the Westin is characterized as a centralized closed-loop chilling water system.

Proposition – Carrot and Stick Approach
The general attitude of Mr Biemans on behalf of the Bucuti & Tara Resort was positive and open. Taken into account the above-mentioned perspective towards the implementation no issues emerged. Yet there was mention of a concern regarding the energy use of the High Rise hotels. Mr Biemens, who is been on the island for over 4 decades and has been on the board of AHATA identified an carrot and stick approach relating to the implementation of load shedding and the High Rise hotels

Carrot and Stick Approach (also "carrot or stick approach") is an idiom that refers to a policy of offering a combination of rewards and punishment to induce behavior. It is named in reference to a cart driver dangling a carrot in front of a mule and holding a stick behind it. The mule would move towards the carrot because it wants the reward of food, while also moving away from the stick behind it, since it does not want the punishment of pain, thus drawing the cart.

1. The utility companies should offer a financial incentive to the High Rise hotels, figuratively he called this the carrot.
2. On the other hand if the hotels do not cooperate, they eventually have to deal with the implications being higher energy prices or lower reliability of the network. Mr. Biemans calls this the stick.

Concerning the proposed theses
Thesis 1:
If a full control load shedding is offered with a reduced rate for electricity, I will accept it.
Yes, even without a financial compensation.

Thesis 2:
It is best that customers do not know that load shedding is applied in this hotel.
No, customers may know yet in practice this has no impact on the guest due to the back-up capacity.

Concerning opportunities for contracts and arrangements
Regarding opportunities for contracts and arrangement between the utilities and the hotels, the following issues emerged:

Willingness the Bucuti is open for implementation of load shedding, yet the amount of load which can be shed by Bucuti may not be relevant to WEB due to Bucuti's relatively small size and high efficiency.

L. Minutes interview: Hyatt Regency Aruba Resort & Casino

Interviewee: Fred Hoffmann, General Manager of the Hyatt Regency Aruba Interviewer(s): Toine de Klerk (TNO- CBOT & TUDelft) and Jan Ebbing (TNO- CBOT) Date: 10th December 2012 Location: Hyatt Regency Aruba

This document is an elaboration of the interview taken by Toine de Klerk & Jan Ebbing with Fred Hoffmann, General Manager of the Hyatt Regency Aruba Resort & Casino. This interview is part a MSc Thesis Research relating to demand-side management, and in particular load shedding in the hospitality sector and the integration of wind energy into the Aruban Electricity System.

Concerning General Energy Awareness
In terms of energy conservation measures, the Hyatt Recency Aruba has taken the following:

- 100% computerized air conditioning system, which is centrally operated from Canada.
- Building renovations: isolations, double glassing, air curtains
- LED lighting
- Sensors in public spaces that control the AC and lighting
- Electrical heating element in dishwashers is bypassed by using already pre-heated water
- Solar boiler system for hot water

The Hyatt has reduced their energy consumption by 40% over the last year compared to previous years. The most substantial reduction was made by switching to a new air conditioning system. All conservation measures were taken by the top management and the general owners of the building(s). This is in line with the formulated strategy of top management where point of attention being the reduction of the carbon foot print. Regarding the ownership they must commit to the fact that there is enough money available to make such investments. The AC system of the Hyatt Regency Aruba is operated centrally in Canada. The whole AC system can be controlled via a software package.The specification of their systems are unknown (see Edwin Nguero). Compared to the previous water cooled chiller system (same as Westin) the AC system is more efficient yet it is also much more complex and sensitive to starting up and shutting down procedures. During the interview the technical implementation and feasibility of load shedding formed an significant barrier. In comparison with the previous AC system , which could be switched of immediately by a local engineering staff the new system if more complex and in order to intervene operationally it would require communication with Canada. However, the possibility exists to manually override operations. Most of the maintenance concerning the AC is done during 4 am (closing time casino) and 7.30 am as to not impact customer service level. All rooms and areas are air conditioned at a minimum of 74 degrees Fahrenheit to control humidity and prevent mould growth. The Hyatt does not have sensors or a room card system for the guest rooms. This means that all the electrical equipment in the rooms can be on for 24 hours a day. According to Mr. Hoffmann 80% of our customers originate from North-America where such systems a considered 'cheap' and imply a low level of service. The Hyatt, being a high class resort sells a high level of service towards their customers. "The customers travel to Aruba for the sun and the beach, we sell them shade and AC". In terms of metering and consumption awareness, the Hyatt does not operate a metering systems and therefor does not know how much electricity is consumed per group of electrical equipment. The Hyatt is connected to grid by 3 distribution meters. Those meters are the only source of information available. One separate meter is devoted to the demand for air conditioning, the % of air-conditioning compared to the total amount of electricity used is...?

Concerning load shedding some issues emerged during the interview:

- Technical feasibility
- Prior notice
- Guest satisfaction It was mentioned that such decision go directly to board of directors in Chicago.

Technical feasibility

As already mentioned, the AC system is complex and is controlled via a central entity situated in Canada. Shutting off the air-conditioning would impose severe technical problems especially when starting up. Pressure of chilled water in the system has to always be maintained, during start-up procedures it has happened that the pressure would rise to such an amount the water piping could break. Starting-up could take several hours posing severe impact on guests.

During the interview the "shutting down of air-conditioning" invoked significant commotion relating the technical feasibility of load shedding. Instead of shutting down the AC system, the same result, as goes for electrical consumption, could be achieved by idling the system. Technically going to an idle state of 0% air conditioning is possible, it takes several minutes and prior notification. The change of words significantly changed the reaction of the General Manager for idling the system is a feasible possibility. Mr Hoffmann also proposed to run test to overcome technical barriers relating to load shedding.

In the past the Hyatt was asked several times to reduce some of the (AC) load during periods of time when ELMAR faced difficulties concerning grid operations. Such interferences did not pose any problems. Despite the fact that the Hyatt operates backup capacity for emergency appliances this is not adequate enough to supply the level of demand needed for air conditioning.

Prior notice

A direct control with prior notice invoked a barrier concerning technical issues. Idling the air-conditioning would, at best, take several minutes according Mr Hoffmann. Due to the systems vulnerability the operators or engineers related to the AC would have to be informed in advance to comply with the requirements of WEB on these specific crucial moments.

Guest satisfaction

The Hyatt is one of the most high-class resorts on Aruba with rooms ranging from $400 to over $1000 per night. Room rates are the main source of income and their guest demand a certain level of service in correspondence with these rates. Providing those customers with a high level service of air conditioning is a vital overall service. Guest are known to request rebates or go to court if the level of service is not up to (their) standards. This poses a possible barrier. Yet an interruption for 10-15 minutes would be agreeable according to the general manager of the Hyatt if properly communicated and managed correctly.

In relation to this last point, Mr. Hoffmann also mentioned to educate his customers on the use of load shedding so they would understand the sudden non-availability of some services in the hotel and this could result in a higher acceptation level.

To conclude the most significant barrier mentioned was the technical feasibility of load shedding in combination with the Hyatt's 'complex' AC system. The feasibility of the technical implantation is direct connection with the impact on the guest satisfaction. In the interview we tried to avoid going into too much technical details concerning the AC system, yet it still remained a prominent issue.

Concerning the proposed theses

Thesis 1: If a full control load shedding is offered with a reduced rate for electricity, I will accept it.

Yes, although the decision lies with the board of directors in Chicago. Barriers are of technical nature and relate directly to the guest satisfaction.

Thesis 2: It is best that customers do not know that load shedding is applied in this hotel.
No, customers should know and should be educated. Market this load shedding correctly and turn the negative into something positive.

General concerns about electricity
According to Mr. Hoffmann a lot is expected from the hotels on Aruba concerning their energy behaviour. Hotels on the other hand are not in agreement with the energy policy and the way the electricity rates are structured.
There is a social dialogue between the hotels and the utilities although this has not led to any change of thoughts on the electricity rates for the hotels.The large consumers, which are mostly hotels pay more per electricity used compared to residential and small consumers. Industrial consumers and distribution companies, which also resemble a significant part of the energy consumption calculate a raise in electricity prices directly through in their product pricing. Hotels are not able to do this, which imposes a competitive disadvantage on and off the island for the hotel industry. The Hyatt competes more off the island. Example: Let's say the Ritz Carlton in Jamaica lowers its rates by 20% then this affects the Hyatt in Aruba. So in the event of higher electricity rates in Aruba the hotels have a competitive disadvantage because they are not able to directly calculate this raise into their product without losing customers.

Concerning opportunities for contracts and arrangements

Energy expenditure is a main component in the hotel, the Hyatt has taken on several measures to decrease its energy consumption and is still looking for further options. In light of this **measurement** of energy expenditure could prove useful. **Lower rates**, financial incentive would lower energy expenditure. **Installed measuring equipment**, could provide insights in energy consumption per area of the hotel and per group of electrical appliances. Monitoring and measuring is an important aspect of maintaining energy efficiency. Instead of lower rates utility companies could (co-)invest and install such equipment. In view of long term strategy: this equipment could be compatible with a smart grid.

M. Minutes interview: Radisson Aruba Resort, Casino & Spa

Interviewee: Gerard Puts, Director of Engineering Radisson Aruba
Interviewer(s): Toine de Klerk (TNO- CBOT & TUDelft) and Ivan Flanegin (TNO- CBOT)
Date: 13th December 2012
Location: Radisson Aruba Resorts, Casino & Spa

This document is an elaboration of the interview taken by Toine de Klerk & Ivan Flanegin with Gerard Puts, Director of Engineering with the Radisson Aruba Resort, Casino and Spa. This interview is part a MSc Thesis Research relating to demand-side management, and in particular load shedding in the hospitality sector and the integration of wind energy into the Aruban Electricity System.

Concerning General Energy Awareness
In terms of energy conservation measures, the Radisson has taken the following:

- Already installed CFL lighting gradually replaced by LED lighting
- Some of the rooms are equipped with a temperature control system, that automatically increases the temperature, thereby lowering the air conditioning demand, to a certain 'safe' level. Safe in terms of mould growth and humidity.
- Airconditioning system, air cooled chiller system.

In general the Radisson has not taken thorough steps in energy reduction. Currenlty they are preparing the installement of a Building Automation System, which can control all electrical equipment that have a controller installed. Focus is on first controlling the large engines of the chiller plant, these represent a high share of energy demand. The BAS is able to control temperature by controlling the apparatus, which control the AC. Through complex algorithms it is able to optimally control temperature or other electrical equipment throughout the entire resort. Mr Puts mentioned that the Hyatt, Marriott and the Renaissance already operate such a system. The costs of such a system represent 1,5 M$. The Radisson has installed 4 chillers, currently they operate 3 chillers due to a malfunctioning chiller. This implies that all 3 chillers work at 100% capacity posing huge electricity demand. Mr Puts stated that 80-85% of the electricity consumption is represented by the air conditioning system. In financial terms the energy expenditure amounts to nearly 500.000 afl = 285.000 $ per month
Mr Puts's former employer, the Marriott hotels has an average energy expenditure of 750.000 – 800.000 afl = 430.000 – 460.000 $ per month. The (major) **investment decisions** for energy consuming measures have to be reported to the General Manager, the Vice President of Engineering and to the property owners. According to Mr Puts in the hospitality business such actors require a 'very' short term Return on Investment generally lower than 3 years. This is one of the reasons why the majority of the hotels may lack major energy reduction measures or

programs. "In the end it's all about the money". In addition hotel brands and owners change typically over periods to 4-6 years. To give an example: in the past the Radisson was in need of new chillers for their air conditioning system. They could chose between the cheaper and energy inefficient air-cooled chillers or the more expensive energy efficient water cooled chillers. Their decision was based on short-term payback periods consequently they chose the inefficient chillers

The Radisson currently does not operate a metering or monitoring system of its electricity consumption. The metering and measurement equipment and related system do require high investment costs and as said before pose trade-offs and the decision lies with the board of directors and the property owners.

Concerning Load Shedding

Concerning load shedding some issues emerged during the interview: Note: the interviews previously taken were all with the General Manager. This interviewee is the Director of Engineer and results also in other conclusions and issues:

- Technical feasibility
- Required equipment and investment

Technical feasibility

According to Mr Puts, in the case a AC chiller system is controlled via the Building Automation System intervention and shutting down the whole AC system could be seamlessly implemented without significant technical complications. *Most hotels do not operate a BAS system, it is not certain how the implementation and central control of air-conditioning systems would be technically feasible. More research on this matter is required. In addition some hotels do not have a centralized system at all, and use separate split controller ACs for their air conditioning. These separate units are only manually controlled and a compared to a centralized chiller system highly inefficient. How to exert control over such units in a centralized manner is not yet clear.*

Direct control executed by another entity is possible through already existing grid network via controllers and signals. To hedge against technical problems thorough testing of equipment and mode of operation is advised.

Equipment and Investment

Mr Puts raised several interesting questions, which will be addressed in the economic analysis:

- What equipment needs to be installed?
- What are the costs of this equipment?
- Who will invest in this equipment?

Proposition

Mr Puts sketched a rough scenario where WEB would implement, invest, install and program the required load shedding equipment in order to work seamlessly in combination with already installed hotel systems. In addition Mr Puts mentioned the use of backup generators to foresee in the air-conditioning demand. The current back up capacity is consists of 2 generators (250 kW & 400 kW). Combined these generators are not able to supply enough capacity for the air conditioning demand. The backup generators are in place for basic emergency demand (lighting, elevators, etc).

General concerns about electricity

High electricity prices lead to competitive disadvantages, financial incentive could prove useful. The green focus of the Aruban government is interesting for the hospitality business. The general interest of the American guest is more towards sustainability and guests show a general concern relating to sustainability issues.

Concerning opportunities for contracts and arrangements

Energy expenditure is a main component in the hotel, the Radisson has not taken significant measures in decreasing their electricity consumption and is still looking for further options. In light of this **measurement** of energy expenditure could prove useful. A BAS would prove useful in this. In view of long term strategy: this equipment could be compatible with a smart grid.

Lower rates, financial incentive would lower energy expenditure

N. Minutes interview: Renaissance Aruba Resort & Casino

Interviewee: Paul Gielen, General Manager of the Renaissance Aruba Resort & Casino
Interviewer(s): Toine de Klerk (TNO- CBOT & TUDelft) and Robert-Jan Moons (TNO- CBOT)
Date: 10th December 2012
Location: Renaissance Aruba

This document is an elaboration of the interview taken by Toine de Klerk & Robert-Jan Moons with Paul Gielen, General Manager of the Renaissance Aruba Resort & Casino. This interview is part a MSc Thesis Research relating to demand-side management, and in particular load shedding in the hospitality sector and the integration of wind energy into the Aruban Electricity System.

Concerning General Energy Awareness
In terms of energy conservation measures, the Renaissance has taken the following:

- Solar heaters on the roof for hot water provision
- Current AC chiller system is 9 years old, and they are continuously looking for improved chiller technology. According to Mr. Gielen, to date no feasible business case could be made by installing new chiller technology.
- Lighting in public area is for 90% LED
- Come april 2013 all rooms will be retrofitted with LED lighting.

Renaissance used to operate a sensor system, where in case of inactivity in the rooms the air-conditioning would decrease to 74 degrees Fahrenheit to prevent mould growth and retain a certain level of humidity. The system did not work properly and this impacted guest satisfaction enormously. The Renaissance switched back to the old system. Currently the air conditioning is set manually to 74 degrees Fahrenheit during guest room cleaning. The Renaissance is composed of the following buildings, next to each building the amount of AC chillers is presented

- Renaissance Marina Resort (2 chillers) & Casino (1 chiller)

- Renaissance Ocean View Resort (2 chillers)
- Renaissance Convention Center & Casino (1 chiller)

In total the Renaissance operates 6 chillers for the air conditioning demand. According to the figures Mr. Gielen presented us around 40% of the total energy consumption is directly related to the demand for these chillers. Financially speaking, the Renaissance's energy expenditure amounts to $ 403.000,- per month, representing 8% of the total overall costs. In terms of metering and consumption awareness, the Renaissance did know how much energy consumption was related to air conditioning. No further information was presented on how much electricity is consumed per group of electrical equipment over time.

Concerning Load Shedding

Concerning load shedding some issues emerged during the interview:

- Technical feasibility & safety
- Control of operations
- Guest satisfaction (1 or 2 chillers)

The Renaissance had previous experience with lowering their energy demand in case ELMAR or WEB asked them too. This involved shutting down 1 chiller. Three years ago this happened on a regular basis.

Technical feasibility & safety

A concern mentioned was technical feasibility. During the meeting Mr. Gielen called the Chief of Heat Vaporization and Air Conditioning (HVAC) and informed if it was possible to instantly shut down chillers. The response was positive it is possible to completely shut down chillers without imposing technical difficulties. Even shutting down via remote operations was a possibility. The capacity of one chiller amounted to 250 Ampere. If for example one chiller in a two chiller system is shut down, the 2nd chiller will increase load to 100% thereby still resulting in a 200 Ampere reduction. To start-up chiller the chiller would operate at 100% thus reachting 300 amp. Preconditions to shutting down the chillers automatically:

- Safety
- Testing
- Issue of responsibility in case of malfunctioning or damage to equipment. Financial implications of damaging chiller $ 250.000,-
- Control of own operation

Own control over operation and chiller operation was a concern mentioned by Mr. Gielen. This also corresponds to the notion of responsibility. One of the relating concerns was that if Web would exercise direct control over the chillers, they could use it more than once and in times they would not strictly need it. The issue of sense of urgency was mentioned as to define the difference in WEBs own operation and WEBs control over hotel operation. The Renaissance does operate back-up capacity, yet these are only capable in supplying enough load for the casino, lighting and elevators.

Guest satisfaction

According to Mr. Gielen the shutting down of one chiller for a period of 15 minutes would probably not pose any impacts on guest satisfaction because another chiller would still operate. In the case of completely shutting down the two chillers, concerns about guest satisfaction were mentioned. As stated by Mr. Gielen 'Airconditioning is a basic need for the tourist visiting Aruba. Clientele is king. 70% of the customers originate from North-America and if service is not 100% satisfactory they will require a compensation." To give an example: general guest satisfaction in the Renaissance is 80%. In the past it happened that there were some problems related to hot water or air conditioning this would directly result in a decrease of 3-4% guest satisfaction over the next month. What this example illustrates is that the level of service is in direct contact with the satisfaction level of the customer. Mr. Gielen acknowledged the fact that more research could be done as to what impact a 15min idle air-conditioning has on the temperature level in public and private guest areas and how this relates to customer satisfaction. Mr. Gielen also proposed to test this in his own hotel for a period of 15 minutes. He also mentioned, that a financial incentive would be very important in discussing such matters.

Concerning the proposed theses

Thesis 1: If a full control load shedding is offered with a reduced rate for electricity, I will accept it.
Yet, but preconditions:

- Safeguard the safety of equipment through i.e. testing
- Clarity on responsibility when implementing such programs

Thesis 2: It is best that customers do not know that load shedding is applied in this hotel.
Yes, do not let them know. Air conditioning is a basic need for the tourist visiting Aruba. The clientele will not appreciate such programs. Suggestion of a seamless implementation: 1chiller would pose no problem, 2 might. Although Mr. Gielen acknowledged the fact that the whole 'Aruba green island' marketing campaign would attract a lot more tourists, he could not imagine that the open participation in a load-shedding program could be a value case towards its customers.

General concerns about electricity

As said before, the monthly energy expenditure is $ 403.000, which amounts to 8% of the total overall costs of the Renaissance. Energy expenditure and in particular the energy prices were stressed with regard to concerns about electricity on the island. Mr. Gielen mentioned that if going greener means a higher price, than the hotels would strongly oppose. Further expressions were made with regard to price stability.

Concerning opportunities for contracts and arrangements

Energy expenditure is a main component in the hotel, the Renaissance has taken on several measures to decrease its energy consumption and according to Mr Gielen they've done almost everything they can yet they are still looking for further options. In light of this **measurement** of energy expenditure could prove useful. **Lower rates**, financial incentive would lower energy expenditure. **Price stability,** stability of prices would result in better risk management and budgeting. **Installed measuring equipment** could provide insights in energy consumption per area of the hotel and per group of electrical appliances. Monitoring and measuring is an important aspect of maintaining energy efficiency. Instead of lower rates utility companies could (co-)invest and install such equipment. In view of long term strategy: this equipment could be compatible with a smart grid.

Other matters mentioned

The Renaissance in Curacao operates a SWAC unit, but this has not been confirmed.

O. Minutes interview: the Westin Resort Aruba

Interviewee: Richard Roy, General Manager of the Westin Resort Aruba
Interviewer(s): Toine de Klerk (TNO- CBOT & TUDelft) and Robert-Jan Moon (TNO- CBOT)
Date: 6th December 2012
Location: The Westin Resort Aruba

This document is an elaboration of the interview taken by Toine de Klerk & Robert-Jan Moons with Richard Roy, the General Manager of the Westin Resort Aruba. This interview is part a MSc Thesis Research relating to demand-side management, and in particular load shedding in the hospitality sector and the integration of wind energy into the Aruban Electricity System.

Concerning General Energy Awareness
In terms of energy conservation measures taken by the hotel, the Westin incorporated the following:

- LED lighting
- CFs lighting
- Motion sensors in public areas that control lighting, and other appliances
- Retrofitting of the air conditioning chillers, installation of more efficient chillers
- Green Initiative for customers: a $5,- per day incentive is granted if customers do not make use of the every day service of the cleaning of towels and rooms

No sensors are placed in the **guest rooms**. As a result, the electricity consumption per room cannot be controlled by the Westin. A major implication of the absence such control mechanisms is that a large proportion of the customers leave their air-conditioning and other non-crucial equipment running 24 hours a day. The Westin has addressed this issue in their Property Implementation Plan (PIP). In terms of metering and consumption awareness, the Westin does not operate a metering system. Only two installed meters (by ELMAR) give an overview of the total consumed electricity, yet no metering equipment is installed on those meters. No information is available on what share of equipment represents the total energy consumption in the Westin. The only information regarding their energy expenditure is provided by ELMAR in terms of a monthly and annual electricity bill.
The Westin would be interested in implementing measurement systems, so energy efficient measures could be taken accordingly. In 2012 the total energy expenditure amounted 3.3 M$. For the month November 2012 this amounted $350.000. For 2013 the energy expenditure is budgeted at 3.4 M$.

Concerning Load Shedding
Concerning load shedding four issues emerged during the interview:
- Guest satisfaction (during the day no problem, 90% of the customers are not in the guestroom or in the hotel)
- Limited control
- Limited area
- Technical integration

Limited control meaning that if load shedding is implemented not all electricity should be shut, off only those electrical appliances that provide non-crucial services. In this regard, air conditioning was mentioned as a non-crucial service as well as pool pumps. Crucial services included: lighting, elevators and air-conditioning at certain times **Limited area** meaning that if load shedding is implemented by shedding air conditioning, only those areas where the shedding does not affect customer **satisfaction** load shedding might be implemented depending on other incentives. The air conditioning system of the Westin is characterized as a centralized closed-loop chilling water system.

The central chiller plant consisting of two chillers and their ancillary systems provides chilled water for air-conditioning. In the chiller refrigerant flows through the coil that cools the chilled water. This chilled water is pumped through a piping loop to air handles in the space to be cooled (public and private areas), where it absorbs heat from the air that flows over the air handling coil. In the private guestrooms the customers decide whether or not to turn the air conditioning on. The air-conditioning in the guestrooms are connected to the centralized system and are not individual air conditioning systems.

The “warmed up” water then returns through the piping loop back to the chillers, where the heat is absorbed and is released to the refrigerant flowing through the chiller’s evaporator coil.

Such an air conditioning system requires several additional components (often called auxiliary or ancillary systems) to move chilled water between the plant and the air handlers and reject heat from the chillers to the outside world. These auxiliary systems include several chilled water pumps, condenser water pumps and one cooling tower.

The Westin makes use of two chillers, one for the public areas being the lower- and upper lobby and the ballroom and one chiller for the private guestrooms. The shedding of air conditioning load could be implemented in the lower and upper lobby, never in the ballroom. The ballrooms air conditioning is always off unless there is activity (i.e. conference, weddings) in the ballroom and in case of such activity load shedding is not desirable. Depending on what type of load shedding contracts and arrangements also the shedding of air conditioning in guestrooms could be implemented (see two different cases).

Technical integration
Regarding the technical integration of load shedding **technical feasibility** and the issue of **implementation without posing technical problems** were two notions mentioned. Technical feasibility meaning if it is technically possible to implement load shedding in this hotel. Technical problems emphasizing that load shedding should not cause damage or any related problems concerning the already installed physical equipment such as the above-mentioned air conditioning systems equipment.

2 Cases
The general attitude of Mr Richard Roy on behalf of the Westin Aruba Resort was positive and open. Taken into account the above-mentioned issues related to the implementation of load shedding he indicated two possible scenarios:
1. Seamless implementation
2. Value case implementation

In both cases incentives should be proposed by utility companies.

Seamless implementation
In this scenario load shedding would be implemented to pose no impact on the guests and indirectly the guest satisfaction. The control would only be limited to public spaces thus excluding the ballroom and the guestrooms.

Value case implementation
In this scenario load shedding would be implemented and could pose an impact on the guest satisfaction. The control would not be limited solely to public spaces. Concept of this scenario is that the customers are informed about the implementation of load shedding. The participation of the hotels should be correctly marketed towards the customers. Example the Westin participates in the load shedding program as a means to substantially contribute to the integration of renewable energy on Aruba.