DETERMINING AN APPROPRIATE ELECTRICITY SUPPLY MIX FOR LOCAL GOVERNMENTS: A SYSTEM DYNAMICS APPROACH TO A SOUTH AFRICAN CASE STUDY

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ABSTRACT

South Africa has a highly centralised, monopolistic and regulated electricity sector. Eskom is the country's national electricity utility and a state-owned enterprise. Steep electricity tariff hikes have caused many consumers to invest in embedded generation technologies such as rooftop solar photovoltaic (PV) systems to reduce their dependence on grid-based electricity. Most of the defecting electricity consumers have purchased electricity from a local government entity, which in turn purchased electricity directly from Eskom. The profits from electricity sales are often used to subsidise other local government functions. A shrinking customer base at local government level can threaten the financial viability of a municipality. To maintain their revenue streams, local governments react by increasing the price of electricity again. This cycle leads to more consumers investing in embedded generation, which causes the electricity customer base to shirk further. This complex system and its interactions are commonly referred to as the municipal dilemma, or the utility death spiral. The purpose of this paper is to investigate the various impacts of renewable electricity generation at a local government level, to determine an appropriate renewable electricity supply mix and to determine its possible implications regarding the municipal dilemma. A case study research approach, focusing on the Hessequa Local Municipality was employed for this research. The municipality is located in the Eden district of the Western Cape Province, South Africa. System dynamics was selected to model the local electricity sector and the factors that have an impact on it. Both biomass (in the form of invasive alien plants) and solar resources were found to be available in sufficient supply for electricity generation to meet a preliminary renewable energy target for Hessequa. Simulation results indicated that solar PV and biomass power can be attractive in terms of their capital cost and the cost of generated electricity. Through implementation of these technologies, simulation results indicated that CO_2 reductions up to 37% can be expected by 2040 relative to the business-as-usual case. Financing and investment requirements are currently major obstacles to the realisation of this scenario. An estimated investment of approximately US$ 47.3 million or more will be required by 2040. Furthermore, if the municipality is allowed to purchase electricity directly from an independent power producer (IPP) at prices below Eskom's grid price and then resell it to local customers, the challenges surrounding the municipal dilemma can be largely avoided, or at least mitigated.

Key words: Renewable Energy; Municipal Dilemma; System Dynamics; Hessequa

INTRODUCTION

The South African electricity sector

South Africa is a developing country. The energy intensive economy is mainly supplied of electricity generated by Eskom, a state-owned enterprise that also has a monopoly on the country's electricity sector. Eskom is responsible for approximately 95% of South Africa's electricity generation using mainly coal-fired (35.7 GW) and nuclear (1.8 GW) power generation capacity (Eskom, 2015).

Due to a convergence of a number of factors including mass electrification of households, inadequate maximum load planning (Holm, 2009), and the strong economic growth in various industrial sectors in South Africa, the demand for electricity was greater than the supply until the 2008 global economic crisis. Coal could not be produced and delivered fast enough to keep up with demand. As a result, load shedding was implemented in 2008 (Fell, 2009). Other reasons for the lack of generating capacity was the lack of maintenance of many of the South African power plants, a lack of investment in new generation capacity since 1998, delayed decisions regarding the construction of the Medupi and Kusile power stations as well as inadequate geological surveys, skills shortages, boiler welding issues, labour unrest and strikes delayed construction of these two projects even further (Ismail, 2014; Kenny, 2015). NERSA estimated the national cost of the 2008 electric energy shortage at US$ 3.48 billion (Mail & Guardian, 2008). Prior to the energy crisis, the availability of comparatively cheap and abundant supplies of electricity has led to the available electricity being used inefficiently (Winkler, 2007). This may also have contributed to the energy shortage.

Due to an inadequate supply of electricity and the resulting constraints placed on the economy, South Africa's Department of Energy has attempted to apply various strategies to expand current generating capacity, including the following: building the Medupi and Kusile coal-fired power stations (which are still under construction), plans for new nuclear power plants, IPP programmes, and additional oil and gas production programs (offshore and fracking) (Hedden, 2015).

For a short period load shedding events were avoided through the commissioning and operation of expensive diesel generation capacity: open cycle gas turbine (OCGT) power plants. Koeberg's (South Africa's only nuclear power plant) average electricity price at the time was approximately 5 US¢/kWh[i], but the new gas turbine electricity generation cost exceeds 0.22 US¢/kWh (Kenny, 2015). The idea was to only run OCGT plants for short periods during peak times when the load on the national grid was high. Unfortunately, they were used very frequently and for long time periods. The associated fuel cost alone was approximately US$ 348 million in 2013 and US$ 759 million in 2014 (Kenny, 2015). To cover the additional costs, Eskom applied to NERSA (National Energy Regulator of South Africa) for electricity tariff increases (Hedden, 2015). In 2014, Eskom suffered a furnace explosion, the collapse of a coal silo and the failure of an ash removal system at three different power stations (Kenny, 2015). Load shedding was again implemented that year and the lack of energy security had many negative effects on the country and the economy (Van der Nest, 2015).

Renewable energy options were also considered by Eskom and the national government in an attempt to close the electricity supply-demand gap, but these prospects are no longer as promising as they once were. Various parties voiced their concern over Eskom's recent refusals to sign new

[i] An exchange rate of 14.37 ZAR = 1 US$ as on 14 November 2017 was used for all currency conversion.

Power Purchase Agreements (PPAs) with Independent Power Producers (IPPs) after the latest Renewable Energy Independent Power Producer Procurement Programme (REIPPP) bidding rounds. In a news article, le Cordeur (2016a) stated that such actions by Eskom is not only against government policy, but also anti-competitive.

Eskom has managed to avoid load shedding for a couple of years now due to improved performance by state owned enterprise's power plants and the stagnated growth in electricity demand (le Cordeur, 2016b). As a result, the need for new renewable generation capacity is not as apparent as it was a few years ago.

Eskom's electricity prices have increased dramatically over the last decade and the cost of renewable energy technologies have decreased significantly. The net effect of Eskom's rising electricity price and the recent fall in renewable energy generation costs, is that stand-alone renewable energy generation capacity now competes with grid-supplied electricity. Hence, many South Africans have started to switch to off-grid renewable energy technologies to meet their energy demands.

Some more background information is required to see why this is not a problem for Eskom only. A significant share of Eskom's electricity (41.8%) is sold to the local governments or municipalities (Eskom, 2016). The local governments act as retailers and resells electricity to consumers in their distribution grids. In many cases, electricity sales account for a major share of municipal revenue. The profits from electricity sales are also often used to subsidise other municipal functions like service delivery. Thus, a shrinking electricity customer base can threaten a local government's ability to maintain service delivery levels. To maintain their revenue streams, local governments increase the price of electricity again. This leads to more consumers investing in embedded generation, which causes the electricity customer base to shrink even further. This nexus of challenges is commonly referred to as the municipal dilemma and is illustrated in the causal loop diagram in Figure 1.

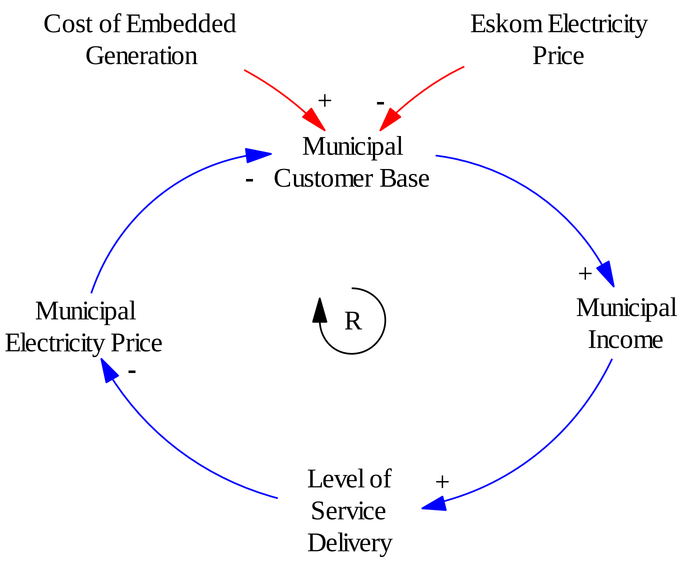

Figure 1: Causal loop diagram of the municipal dilemma

This paper presents the highlights of research conducted for a master's thesis. Within the above context the aim is to develop a modelling tool for local governments that wish to take a proactive approach to dealing with the challenges surrounding the municipal dilemma by investing in renewable energy technology (RET). The model can be used to estimate electricity demand and to investigate the impacts of different RET mixes on a local government's electricity sales profits (and by implication also the challenges surrounding the municipal dilemma as it was just discussed), the capital cost of technologies, electricity costs as well as the socio-economic and environmental impacts of these investments. The model results can then be used to make basic recommendations regarding electricity policies, the appropriate RET mix and general challenges regarding the municipal dilemma.

RESEARCH METHODOLOGY

Renewable energy technology evaluation

The technology selection criteria used for this study included capital cost, levelised cost of electricity, renewable resource availability, technology maturity and other technically limiting factors. At this stage, concentrating solar power (CSP) is considered to be too expensive (approximately 6.19 US$/W based on the 3rd Renewable Energy Independent Power Producer Procurement Programme (REIPPPP)[ii] bidding round (Eberhard, Leigland & Kolker, 2014) and not mature enough due to the relatively low global installed capacity (4.4 GW (REN21, 2015)). Winter rainfall and relatively low ambient temperatures in the Western Cape limit CSP as a renewable energy technology for Hessequa.

Internationally geothermal power capital costs range from 1900 – 5500 US$/kW, depending on the technology used (REN21, 2015). Although geothermal power is not new, the global generation capacity is only 12.8 GW (REN21, 2015), making the technology appear less mature. There are also no known viable sites in Hessequa for geothermal electricity generation.

Ocean power is still in its infancy with a global generation capacity of 0.5 GW. Capital costs for these projects range from 5290 – 5870 US$/kW (REN21, 2015). The technology is still new and there are many issues with logistics as well as maintenance because of the harsh environment that equipment is exposed to.

Landfill power was considered to be unviable due to Hessequa's relatively low waste generation and the lack of a central landfill site. Most of the towns in Hessequa have their own landfill site. Couth, Trois, Parkin, Strachan, Gilder and Wright (2011) state that electricity generation is usually not viable for small to medium sized landfills (receiving 500 – 1000 tonnes of waste a day). Landfill power generation was thus ruled out for this study.

Based on the evaluation criteria only solar PV, wind power, biomass power and pumped storage (hydropower) are considered as potentially viable RETs in the Hessequa area. All of these technologies are mature and have relatively affordable capital cost and levelised costs of electricity. Initial analyses also indicate that these technologies should be viable from a resource availability

[ii] The Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) was launched by the South African Government to increase the country's renewable energy capacity. The process utilised a number of competitive bidding rounds and successful bidders were allowed to build renewable electricity power plants and electricity into the national grid.

perspective. It should be noted that although Hessequa has dams that might be viable for pumped storage, no studies have been conducted regarding generation potential. Therefore, great uncertainty surrounds resource availability for pumped storage in the area.

System dynamics and complexity

The aim of system dynamics modelling (SDM) is to understand the main drivers of behavioural change in a system. To accomplish this, properties of the real system such as feedback loops, delays, and non-linear interactions are identified and analysed using causal relationships (Sterman, 2000). Unlike many other modelling methods, system dynamics modelling follows a top-down approach. Therefore, extensive knowledge is required regarding the interactions between system elements.

Benefits of system dynamics modelling include the fact that it can provide a means to express the feedbacks and complex relationships in a system of interrelated activities and processes. Its usefulness is also demonstrated in facilitating policy intervention in complex systems by offering insight into potential outcomes of these interventions (Kaggwa, 2013). System dynamics can be used over any spatial or time scale (Sterman, 2000). Bassi (2014) indicates that correct system boundary definitions and identifying the correct causal relationships are some of the challenges associated with simulation type models.

The qualities of SDM make it a suitable modelling tool for addressing the complexities involved in the municipal dilemma and for testing policies that relate to RET implementation. The methodology of this modelling method is described in Maani and Cavana (2012). The five-phased process of systems thinking and modelling is described in Figure 2. The various phases tend to overlap to some degree due to the iterative nature of the modelling process.

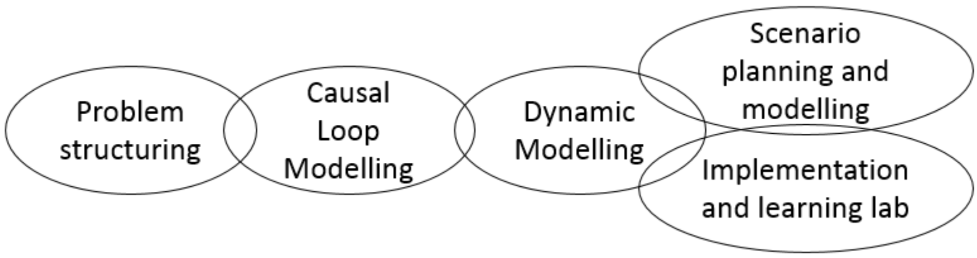

Figure 2: System Dynamics Modelling methodology. Source: Maani and Cavana (2012)

THE HESSEQUA LOCAL MUNICIPALITY CASE STUDY

Introduction to Hessequa

Hessequa Local Municipality is located within the borders of the Eden District Municipality in the Western Cape Province (see Figure 3). Hessequa covers an area of approximately 5 730 km^2 and is inhabited by a population of approximately 58 000. Formal housing is available to 94.2% of the population, of which 78% is urbanised. Major economic sectors include trade (20.3%), community services (18.5%), construction (15.6%), finance (15.0%), agriculture (14.3%) and transport (12.2%) (StatsSA, 2011). Figure 4 depicts Hessequa's historic electricity demand profile, which peaked in 2009 and has remained relatively stagnant since then.

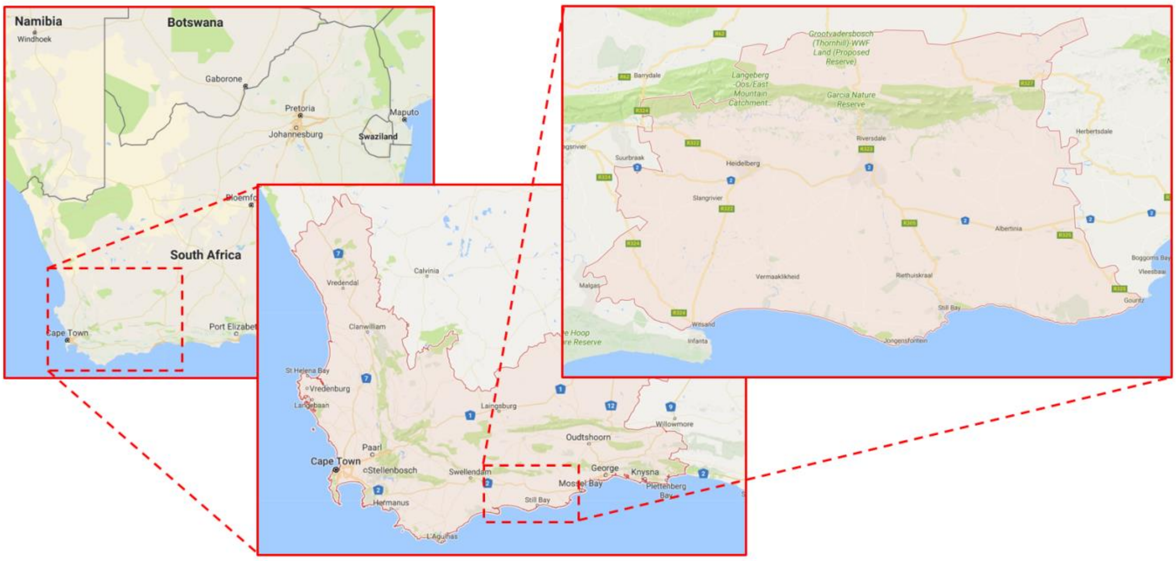

Figure 3: Location of Hessequa

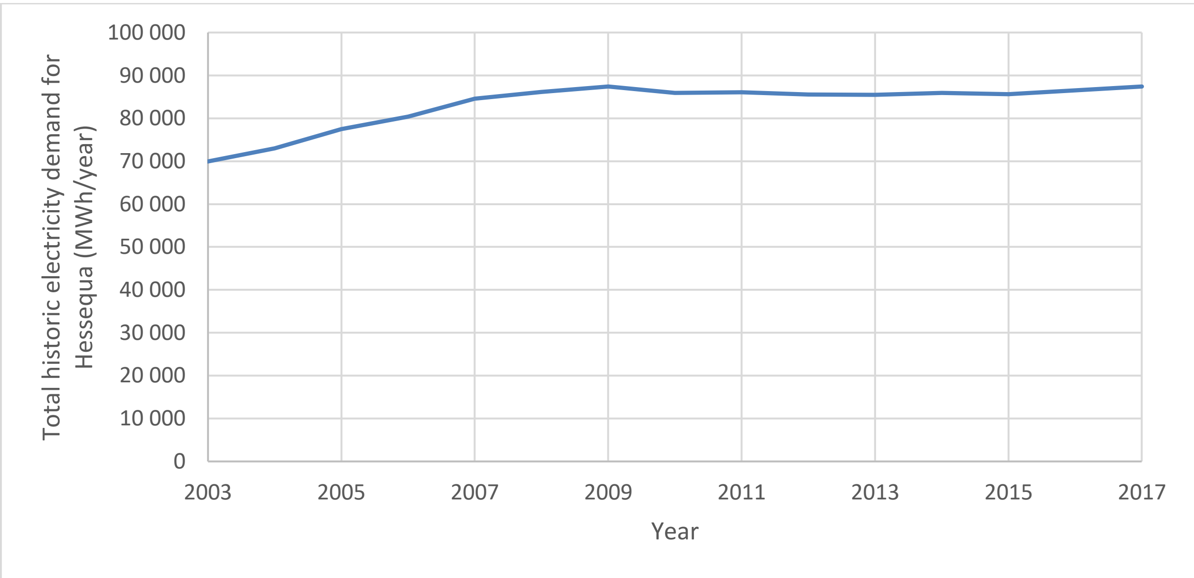

Figure 4: Historic electricity demand in Hessequa. Source: Lesch (2017b)

Conceptual formulation of the Hessequa renewable energy model

One of the first steps involved in system dynamics modelling is creating a qualitative model of the system called a causal loop diagram. This section briefly discusses this conceptual, qualitative model that was later used to formulate the quantitative stock-and-flow model. The complete causal loop diagram is presented in Figure 5.

Population growth and electricity demand loops (R1, B1 and B2)

There is a strong correlation between population growth and electricity demand in the Hessequa Municipality according to a technical official (Justin Lesch) working for Hessequa Municipality (Lesch, 2017b). The reinforcing loop (R1) and balancing loop (B1) respectively indicate the population increase through births and decreasing through deaths (see Figure 5). Balancing loop B2 in Figure 5 describes the effects that GDP per capita has on fertility rates. Recent studies prefer to use the Human Development Index (HDI) as a far more encompassing indicator of human well-being and development than GDP per capita.

A report prepared by Frontier Economics (2007) briefly reviews models that investigated the relationship between energy consumption and wealth. The report found that energy consumption increases as wealth increases. This effect is illustrated in Figure 5 were an increase in HDI causes an increase in electricity demand.

As electricity prices increase, various efforts will focus on increasing energy efficient and reducing wasteful energy consumption. This will in turn reduce electricity demand, as indicated by the causal relationship between electricity price and electricity demand in Figure 5.

Renewable electricity capacity loops (B3, B4, B5 and B6)

Modelling the Hessequa Municipality's electricity system requires it to be considered as a system defined independent from the national electricity grid, to some extent at least. This is technically incorrect since South Africa's grid allows for electricity generated in almost any part of the country to be used in any other part of the country. For the purpose of this model it will be assumed that the electricity demand in Hessequa that is not supplied by local generators of renewable electricity, will be supplied by Eskom through the national electricity grid.

To measure progress towards greener, renewable energy futures, the Hessequa Municipality will require a properly defined renewable energy goal. The renewable electricity goal is to supply one third of the total electricity demand by means of RET. The 'goal gap' will be used to gauge the remaining need for investment into RET generating capacity over time in order to realise this goal. The 'goal gap' is defined here as the difference between the renewable electricity target of 33.3% of actual total local electricity demand, and the actual RET generation. The investment capital will then be used to expand the RET generating capacity.

The process of establishing a new RE facility requires a couple of years' lead time due to the long planning process, environmental impact assessments, construction and commissioning time. This time delay between the decision to invest and the actual commissioning and operation of RE generating capacity is incorporated into the balancing loop B3 in Figure 5 (the parallel lines in the link between RE investment and RE generating capacity denotes a time delay). Increased RE generation capacity would enable Hessequa to generate more renewable electricity and in doing so, reduce the goal gap indicated in Feedback loop B3. Most technologies have a limited life span. Over time facilities depreciate, become more expensive to maintain or the technology becomes outdated. Eventually these facilities are decommissioned or retired at the end of their lifespan. This process is demonstrated in the balancing loop B4 in Figure 5 and the delay sign is once again used to indicate the time between commissioning of new RET generation capacity and retirement of that capacity. The actual time delay will be dependent on the average lifespan of the different technologies.

Aside from utility scale renewable energy installations, small scale embedded generation capacity like rooftop solar PV panels can also contribute towards renewable energy generation in Hessequa. Among the major factors driving households towards small scale renewable energy solutions are

Eskom's rising electricity prices and the falling costs of small scale electricity generation systems (see Figure 5).

The towns in the Hessequa municipal area are serviced by medium voltage feeders with a peak line capacity. Eskom has connection criteria stating that embedded generation may not exceed 15% of the peak line capacity. However, this applies to generation capacity that is connected to the grid, but not to off-grid capacity. Therefore, should grid-connected embedded generation like rooftop PV installations approach this limiting criteria, policies or bylaws will have to be put in place to limit further installations. This balancing feedback (B5) loop is presented in Figure 5. It is expected that only higher income households will consider installing small scale generation to take their homes off-grid. As more and more of these high income households install embedded generation, the market of those who can afford it will become more and more saturated leading to a decline in new small scale RE installations, as demonstrated in the balancing loop B6 in Figure 5.

Figure 5 also illustrates how an increase in RET generation capacity will lead to reduced GHG emissions and job creation.

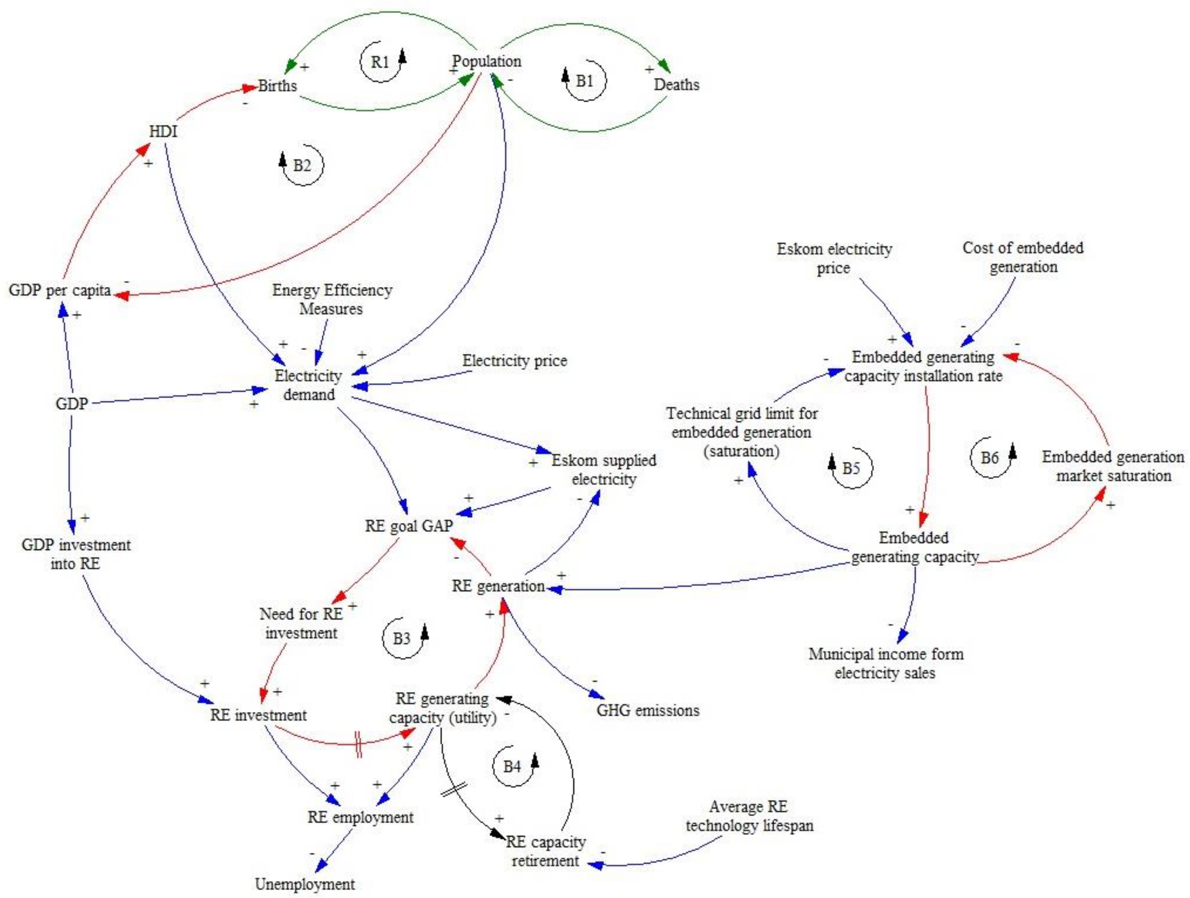

Figure 5: Causal loop diagram of Hessequa's electricity system

Data collection

Data was collected from various sources ranging from published academic papers, Hessequa Municipality's integrated development plans and reports as well as interviews with field experts and Hessequa Municipality officials. Due to the relatively detailed focus of the project, data specific to the municipal area was not always available. In these cases, district, province or national level data was used or assumptions were made.

Model verification and validation

Forrester and Senge (1980) describe 17 tests for model verification. They also highlight what is considered to be "core" tests for a system dynamics model. These included structure tests (structure verification, parameter verification, extreme condition tests, boundary adequacy tests and dimensional consistency), behaviour tests (behaviour reproduction tests, behaviour anomaly tests and behaviour sensitivity test) and policy implementation tests (changed-behaviour prediction and policy sensitivity tests). Only the structure tests and behaviour tests were performed on the SDM that was developed for this study, called the Hessequa renewable energy model or "HessREM".

Structure tests

Structure verification was done by comparing the qualitative and quantitative models and their causal relationships to related work that focused on energy transitions (Oosthuizen, Brent, Musango & de Kock, 2016), green economy modelling (UNEP, 2013) and the municipal dilemma (Tshehla, 2014). Parameter verification was done by using values from the literature whenever possible. Alternatively, expert opinion or plausible estimates were used. Various extreme conditions tests were performed by investigating the impacts of step changes pulse increases in crude birth rate on population and GDPR growth rates and the cost of Eskom electricity for total end user electricity demand. Other extreme conditions tests include initial value increases in initial electricity demand, the capital cost of RETs and GDPR investment fractions to investigate the impacts on the model's predicted RET generation capacity over time.

The expected effects were observed in all extreme test cases. Boundary adequacy will depend on the model's purpose. Municipal officials as well as study supervisors were consulted to ensure and to confirm the model's boundary adequacy. Vensim's (modelling software by VENTANA Systems Inc.) built-in dimensional consistency tools were used to ensure dimensional consistency in the model.

Behaviour tests

Two behaviour anomaly tests were performed in the model. First the construction time for utility scale RET was set to 10 years to investigate the impact on the rate of Hessequa's RET implementation. The additional construction time caused significant delays in the implementation of RETs and consequently delayed the municipal renewable energy goal being achieved. The second behaviour anomaly test increased the expected RET plant life spans to 100 years for all technologies. The result indicated a significantly slower degradation rate of Hessequa's total RET generation capacity, as expected. Various sensitivity analysis tests were also performed to determine the impacts of uncertainty associated with various model parameters.

Scenario description

The main variables that are changed in the scenario simulations include the fraction of GDPR that will be invested in RET and the policy decisions for each technology's contribution to achieving Hessequa's renewable energy goal. Compensation for rooftop PV electricity fed back into the grid is also considered. The following five main scenarios are discussed in this paper:

i. Business-as-Usual Scenario - BAU
ii. Low Investment Scenario (Biomass and Solar Power) – LIS (BS)
iii. Low Investment Scenario (Solar and Wind Power) – LIS (SW)
iv. High Investment Scenario (Biomass and Solar Power) – HIS (BS)
v. High Investment Scenario (Solar and Wind Power) – HIS (SW)

Business-as-usual scenario

Under business-as-usual conditions, the only RET that is considered for investment is rooftop solar PV systems. This investment is assumed to emanate from private entities such as home owners who receive no compensation for the electricity fed back into the grid. In this scenario, utility scale electricity generation plays no role in Hessequa's renewable energy future.

Active investment scenarios

In both the low and high investment scenarios Hessequa actively takes steps to reduce its dependence on Eskom electricity supplies, to reduce its carbon footprint and to promote an overall greener future. It is assumed that all electricity generated by RETs in Hessequa would be consumed within the Hessequa municipal area. The assumption is also made that local government would be allowed to purchase electricity directly from independent power producers (IPPs). There are many legal and regulatory obstacles to such a scenario, but that might change in future. The City of Cape Town wants to take the South African Department of Energy and the National Energy Regulator, NERSA, to court to challenge Eskom's exclusive right to procure electricity from power producers (Yellend, 2017). Should they be successful and granted the right to purchase electricity directly from IPPs, it will create a precedent and many other municipalities will probably want to do the same.

Low investment scenarios

In the low investment scenarios 1.5% of annual real regional gross domestic product (GDPR) of the Hessequa municipal district is invested in RET (as long as RET electricity generation does not meet Hessequa's renewable energy goal). Policy decisions in the low investment scenario that employ only biomass and solar PV technology require the renewable energy goal gap to be filled with approximately 70% of solar PV and 30% for biomass power. For the other low investment scenario approximately 60% of solar PV and 40% of wind power are used to fill the renewable energy goal gap. In both of these scenarios local government pays a feed-in tariff set at 50% of the real cost of rooftop PV electricity. It is estimated that 30% of all electricity generated by embedded generation systems would be fed into the local electricity grid.

High investment scenarios

In the high investment scenarios investment is doubled to 3% of annual GDPR. This allows Hessequa to achieve its renewable energy goal sooner, but presumably at a higher total investment cost. In these scenarios the owners of embedded generation are paid a feed-in tariff equal to 100% of the real cost of rooftop PV electricity. All other assumptions used for the low investment scenarios apply to the high investment scenarios as well, including the shares of biomass- , solar- and wind power. A summary of the five scenarios are presented in Table 1.

Table 1: Main simulation scenarios

Model Variable	Business-as-Usual	RET Investment Scenarios			
		LIS (BS)	LIS (SW)	HIS (BS)	HIS (SW)
GDPR investment fraction	0.0%	1.5%	1.5%	3.0%	3.0%
Embedded generation compensation	No	Yes (50%)	Yes (50%)	Yes (100%)	Yes (100%)
REGGG Filled Fraction Solar PV	0.0%	70%	60%	70%	60%
REGGG Filled Fraction Wind Power	0.0%	0%	40%	0%	40%
REGGG Filled Fraction Biomass Power	0.0%	30%	0%	30%	0%

SIMULATION RESULTS AND DISCUSSION

A quantitative stock-and-flow model was developed (using Vensim software) to capture the dynamics presented in the causal loop diagram in Figure 5. Simulations were then run to determine the impacts of RET investment policies and incentivising the installation of embedded generation capacity. These scenarios were then compared to a business as usual scenario as well. The simulation results of various system aspects are discussed in this section, namely the electricity demand drivers, local RET capacity and the subsequent electricity generation as well as the impacts on local government, the environment and socio-economic conditions.

Electricity demand drivers and end user electricity demand

The Hessequa Renewable Energy Model (HessREM) predicts that the population in the municipal area will increase by approximately 41% from the current 58 642 people to 82 709 by the year 2040. Real GDPR is predicted to grow from US$ 211.5 million in 2017 to US$ 371 million in 2040 and real GDPR per capita is predicted to grow from US$ 3 620 per person to US$ 4 484 per person for the same time period. All of these factors are expected to have an impact on total end user electricity demand in the Hessequa area. Growth in the total end user electricity demand is presented in Figure 6. The electricity generation required from RET to meet Hessequa’s renewable energy goal is also presented in Figure 6.

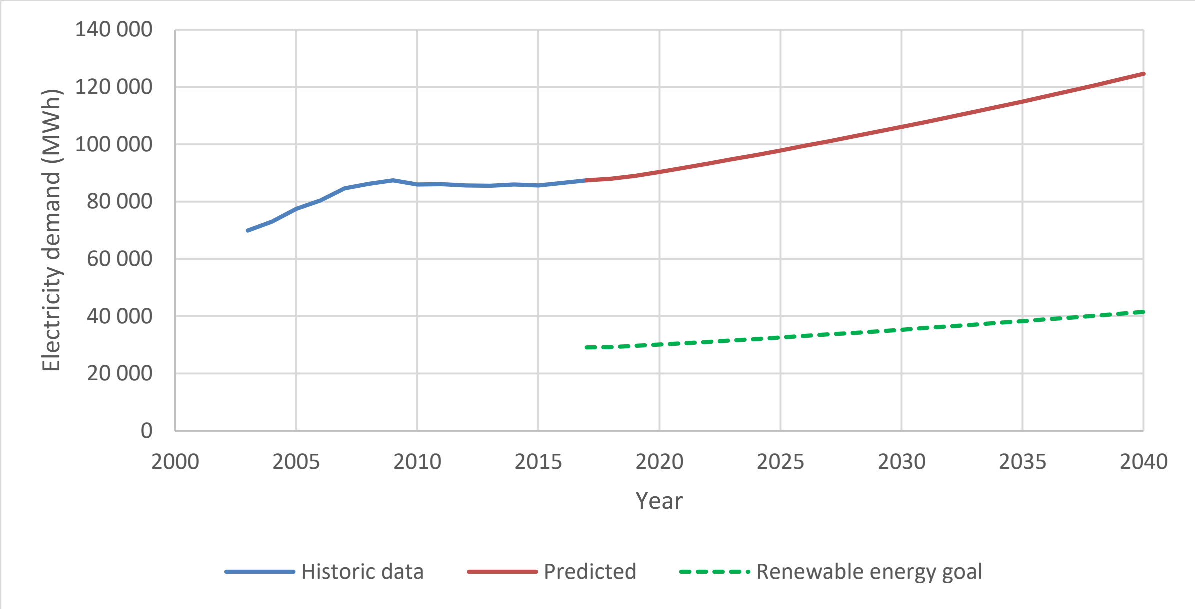

Figure 6: Hessequa's total end user electricity demand between 2003 and 2040. Source: Lesch (2017b)

Renewable energy technology expansion and the required investment

Initially, it was assumed that Hessequa has a current installed RE generation capacity of 200 kW embedded generation (solar PV), as well as a 33 kW solar PV capacity that is used at a water treatment plant. Under BAU conditions, the model predicted renewable electricity generation capacity to increase to 779 kW in 2040. In this scenario Hessequa's RE goal will not be reached. In all the active investment scenarios utility scale RET is implemented in a significantly larger capacity, as indicated in Table 2.

Table 2: Simulation results for Hessequa's total renewable energy power capacity and electricity generation

Scenario	**2017**	**2020**	**2025**	**2030**	**2035**	**2040**
Hessequa total RE generation capacity (MW)						
BAU	0.23	0.28	0.39	0.52	0.65	0.78
LIS (BS)	0.23	2.09	11.14	18.77	16.48	20.95
LIS (SW)	0.23	2.34	12.32	23.56	21.78	27.38
HIS (BS)	0.23	3.90	20.35	18.50	19.23	24.16
HIS (SW)	0.23	4.40	24.23	23.99	26.57	28.60

Figure 7 presents the predicted net renewable electricity generation that results from the RET capacity presented in Table 2. Figure 7 also presents the RE electricity generation that would be required to meet Hessequa's RE goal as the area's total electricity demand increases. The goal seeking behaviour observed in Figure 6 is the result of system delays. This is a common occurrence in non-first order systems.

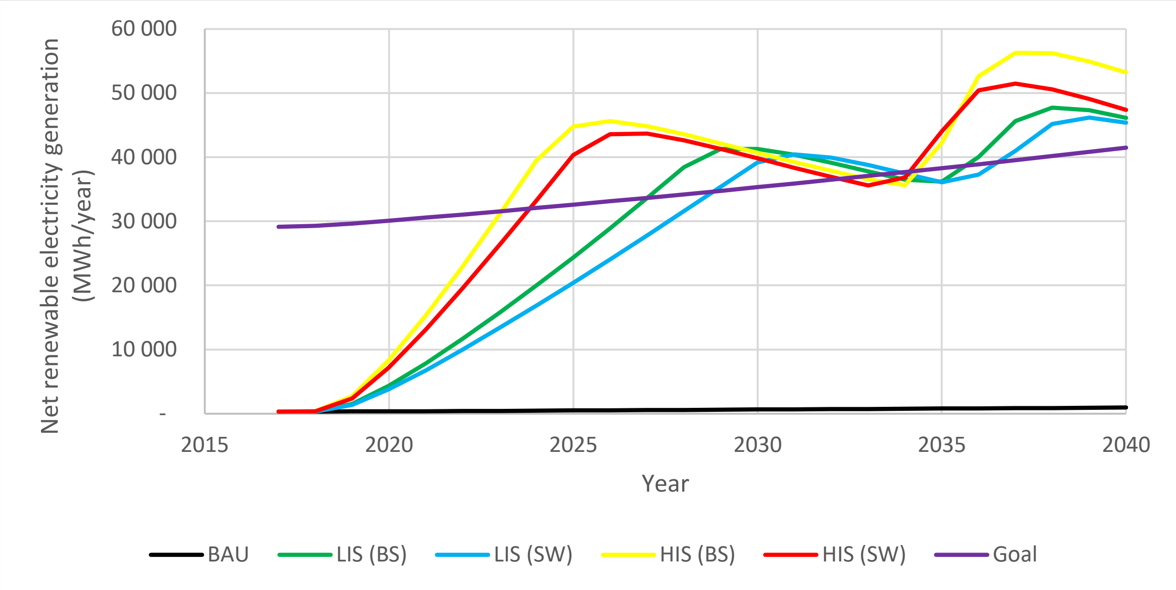

Figure 7: Simulation results for Hessequa's net renewable energy electricity generation

In the high investment scenarios, Hessequa's renewable energy goal can be achieved around the year 2023, and in the low investment scenarios around 2027. As already stated, the goal and progress towards achieving it will change as electricity demand and the RET electricity supply change over time.

Implementing the required RET will require significant capital investment. In the high investment scenarios, larger investments are made at an early stage. In both of these scenarios the effects of learning curves and capital cost reductions over time cannot be utilised to the same extent as in the low investment scenarios. Goal overshoot is also significantly reduced in the low investment scenarios. As indicated in Table 3, the result is that similar technology mixes will require over a US$ 8.77 – 11.06 million more in investment for the high investment scenarios than for the low investment scenarios.

Table 3: Simulation results for accumulated RET investment

Scenario	**2017**	**2020**	**2025**	**2030**	**2035**	**2040**
Cumulative RET Investment (US$ million)						
BAU	0	0	0	0	0	0
LIS (BS)	0	9.67	27.84	35.98	43.56	47.25
LIS (SW)	0	9.67	27.84	43.22	48.43	56.58
HIS (BS)	0	19.35	41.06	41.06	58.32	58.32
HIS (SW)	0	19.35	47.11	47.11	65.34	65.34

Impacts on local government

Table 4 contains the model predictions for the real price of electricity when local government purchases it from Eskom only. Table 4 also indicates the average real cost of electricity when local government is allowed to purchase electricity directly from an IPP (at the model predicted electricity prices of each RET). All scenarios result in an electricity cost that is lower than Eskom's electricity cost.

Table 4: Simulation results regarding the real price of electricity when purchased by local government

Scenario	2017	2020	2025	2030	2035	2040
Real Eskom Electricity Cost (US¢/kWh)						
All	5.64	5.98	6.54	7.17	7.86	8.70
Real Hessequa electricity Cost (US¢/kWh)						
BAU	5.64	5.98	6.54	7.17	7.86	8.63
LIS (BS)	5.64	5.98	6.26	6.47	7.03	7.24
LIS (SW)	5.64	5.92	5.98	5.92	6.54	6.75
HIS (BS)	5.64	5.98	6.05	6.47	6.89	7.03
HIS (SW)	5.64	5.85	5.50	5.92	6.26	6.68

The predicted gross profits from electricity sales are presented in Table 5. The increased gross profit is due to a predicted increase in electricity demand as well as a rising electricity sales price. The increased profits could potentially be used for socio-economic development, improved service delivery, infrastructure improvements or additional RET investment.

Table 5: Simulation results regarding local government's electricity sales gross profit

Scenario	2017	2020	2025	2030	2035	2040
Electricity sales gross profit (US$ million)						
BAU	2.20	2.41	2.86	3.40	4.05	4.82
LIS (BS)	2.20	2.38	3.10	4.15	5.01	6.48
LIS (SW)	2.20	2.44	3.35	4.67	5.51	7.06
HIS (BS)	2.19	2.36	3.28	4.12	5.16	6.72
HIS (SW)	2.19	2.48	3.83	4.68	5.82	7.14

Assumptions had to be made regarding Hessequa's initial rooftop PV capacity, as well as the rate at which new capacity will be added. In both the low and high investment scenarios, policies that incentivise the installation of embedded generation have a marked impact on the total embedded generation capacity by the end of the modelling period (see Table 6). Table 7 presents the financial impacts on the local government's income that results from a shrinking municipal electricity customer base. As expected, gross profit losses (due to electricity demand being met with embedded generation instead of the local electricity grid) will impact negatively upon local government from a financial point of view. The expected feed-in tariff impacts are expected to be relatively small. The model predicts that the feed-in tariff policies involved in the low and high investment scenarios will respectively result in expenses for local government of only US$ 2 545 and US$ 11 796 per year by 2040. These impacts are relatively small when one considers the significant increase in electricity sales gross profit that can be expected between 2017 and 2040 due to a bigger sales margin for the municipality based on the difference in purchase price for the municipality between Eskom power and RET power and the increased electricity demand (Table 7).

Table 6: Simulation results regarding rooftop PV capacity in Hessequa

Scenario	2017	2020	2025	2030	2035	2040
Rooftop PV capacity (kW)						
BAU	200	255	370	500	634	766
LIS (BS & SW)	200	287	451	623	790	940
HIS (BS & SW)	200	319	531	742	929	1 089

Table 7: Financial impacts of rooftop PV on local government

Scenario	2017	2020	2025	2030	2035	2040
Rooftop PV Compensation (US$)						
BAU	0	0	0	0	0	0
LIS	1 182	1 386	1 676	1 986	2 329	2 545
HIS	4 729	6 166	7 900	9 458	10 965	11 796
Municipal electricity sales gross profit lost due to private PV generation (US$)						
BAU	4 855	6 541	10 457	15 527	21 607	28 675
LIS (BS)	4 850	7 304	13 789	23 591	33 331	47 349
LIS (SW)	4 850	7 485	14 941	26 551	36 688	51 609
HIS (BS)	4 845	8 050	17 260	27 934	40 424	56 914
HIS (SW)	4 845	8 451	20 098	31 721	45 625	60 544

Environmental impacts

Water demand

The two main environmental impacts considered in the model are water requirements and carbon dioxide emissions of RETs. Both of these factors are important from a sustainability point of view, especially in a carbon intensive and water scarce country like South Africa. RETs like solar PV and wind power require no water during operation (aside from occasional cleaning to maintain their efficiency, in the case of PV panels). The simulation results regarding RET water consumption are presented in Table 8. Even though biomass electricity accounts for only about 30% of total RET electricity generation (in the scenarios where biomass electricity is considered), it would be responsible for over 60% of water consumption for most of the simulation period. This is due to cooling requirements involved in almost all thermal electricity generation processes. For the scenarios where only solar and wind power are considered water consumption is expected to be very low and marginal.

Table 8: RET water requirements

Scenario	2017	2020	2025	2030	2035	2040
Total RE water consumption (m3/year)						
BAU	102	122	166	216	269	321
LIS (BS)	102	2 583	14 993	25 620	22 579	28 861
LIS (SW)	102	830	4 274	8 155	7 550	9 488
HIS (BS)	102	5 045	27 705	25 308	26 375	33 337
HIS (SW)	102	1 538	8 376	8 307	9 207	9 916

Hessequa's water balance for 2009 indicated "revenue-water" of 2 315 741 m^3 and "non-revenue water" of 414 259 m^3(Hessequa Municipality, 2017). Non-revenue water is defined here as water that is processed, but is lost before it reaches the end user. In the HIS (BS) case presented in Table 8, RETs will require 33 337 $m^3/year$. This is equal to only 8.05% of 2009's non-revenue water losses. If local government can improve or maintain water infrastructure, RET water requirements should not be considered a major obstacle to their implementation.

Since biomass electricity generation is expected to be fuelled by invasive alien plants (IAPs), the argument could be made that relatively high water requirements for a biomass plant can be justified. IAPs would have consumed a significant amount of water if they had not been harvested. A biomass power plant may therefore offset a portion of its water requirements due to IAPs being used for fuel. The model estimated that 16 898 t/year and 19 543 t/year of biofuels would respectively be required to meet Hessequa's biomass electricity generation in the low and high investment scenarios that included biomass power.

CO_2 emissions

One of the main environmental benefits of most non-biofuel RETs is the fact that they produce no direct carbon dioxide emissions during operation. However, the model does account for life cycle CO_2 emissions of RET. The model results as well as historic emission estimates are presented in Figure 8. Under BAU conditions, emissions were predicted to increase by 37% between 2017 and 2040. It should be noted that these emissions are the result of electricity consumed in the Hessequa area and produced by the Eskom fleet of coal-fired power stations in the northern provinces. Therefore, the direct environmental impacts of Hessequa's increased emissions alone (under BAU conditions) will not be experienced in the area. In all of the active investment scenarios emissions are predicted to be lower than BAU, but also lower than 2017 emission levels.

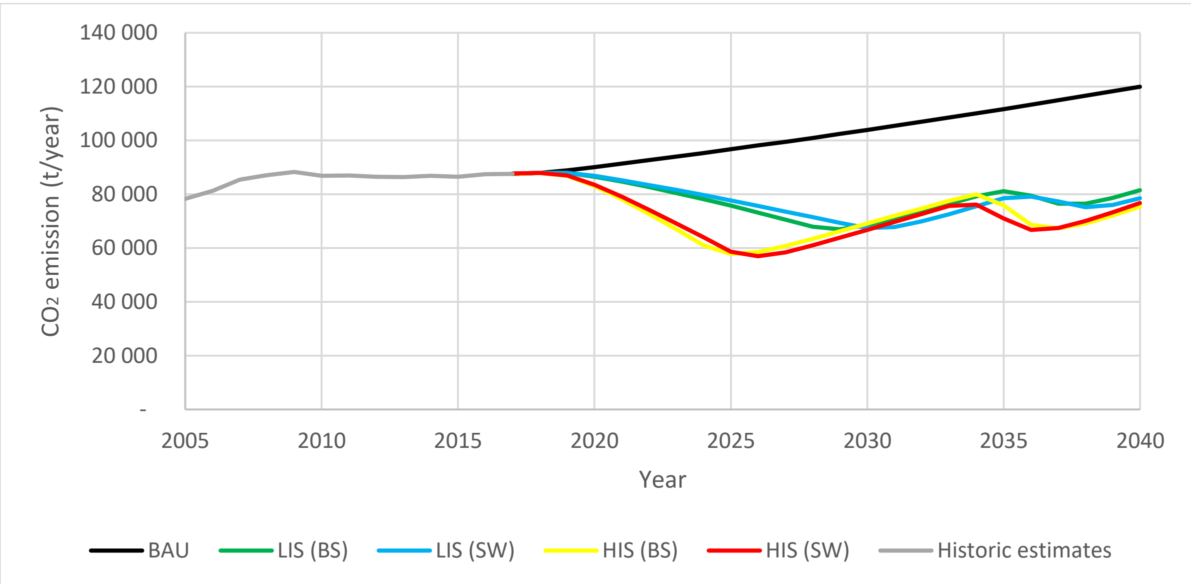

Figure 8: Hessequa's annual CO2 emissions

According to the World Bank (2013b), South Africa's 2013 total man-made CO_2 emissions were 471 238 836 t. Emissions associated with Hessequa's total electricity consumption for the same year were estimated around 86 341 t, less than 0.02% of South Africa's total CO_2 emissions. Never the less, it is important to consider reduced emissions in the South African context, rather than a local context. When RET is implemented anywhere in South Africa, it contributes towards the entire country's efforts in the fight against global warming, climate change and pollution. Since South Africa's electricity sector is extremely carbon intensive, implementation of RET on a grand scale offers a great opportunity for reducing the country's carbon footprint. If Hessequa can serve as testing ground for the implementation of RETs that serve the immediate area, it could potentially lead other municipalities to do the same. Only then will a meaningful impact be made on a national level.

Socio-economic impacts

RET investments are expected to create job opportunities in the Hessequa area. Some of these jobs would be created during the construction phase of the projects and others during the operational phase. It was assumed that there is very little opportunity for localisation regarding construction, manufacturing and installation jobs. However, it is probable that local people can be trained to perform operation and maintenance jobs on RET projects. Simulation results regarding the number of operation and maintenance jobs are captured in Table 9. Because of the relatively small generation capacity predicted in the model, the possible number of new job opportunities is also expected to be relatively low.

Table 9: Local job opportunities created by RET investment

Scenario	2017	2020	2025	2030	2035	2040
Local job creation (Jobs)						
LIS (BS)	0	2	10	17	15	19
LIS (SW)	0	1	5	9	8	11
HIS (BS)	0	3	19	17	18	22
HIS (SW)	0	2	9	9	10	11

Biomass fuel harvesting jobs could however be greatly underestimated in the model. In most cases, fuel harvesting is likely to have a high degree of mechanisation. If the local government for instance requires an IPP to limit mechanisation in biomass harvesting, it could increase the number of jobs created. However, doing so will most likely also have a negative impact on the operating cost of an IPP producing biomass electricity. The result will be a higher electricity cost. The trade-off will have to be investigated in detail before a decision is made.

CONCULSIONS AND RECOMMENDATIONS

Conclusion

Steep electricity tariff hikes have motivated many electricity consumers to invest in embedded generation technologies, and are becoming less dependent on the national grid. The impacts of increased embedded generation have a direct negative impact on the financial income statements of many local governments, particularly in South Africa, who depend on profits from electricity sales to subsidise other municipal services. If Hessequa's local government is allowed to purchase electricity from an IPP at a lower cost than from Eskom, it might significantly increase the municipal profits from electricity sales.

Based on simulation results, it is recommended that Hessequa Municipality should encourage investment in an electricity supply mix with a large share of solar PV and biomass power. This technology mix will achieve Hessequa Municipality's renewable energy goal at a relatively low cost. In addition it should result in a reduction in the total cost of electricity purchased from Eskom and IPPs combined; it offers the greatest job creation potential as well as the additional environmental benefit of IAP clearing.

Based on model assumptions and the simulation results, embedded generation capacity does not pose a significant threat to municipal electricity profits in the Hessequa municipal area, even under BAU conditions. In all investment scenarios investigated, local government can be encouraged to incentivise the installation of embedded generation in order to diversify the Hessequa electricity supply mix and to reduce the weighted average cost of purchased electricity.

Complete independence from Eskom will be extremely difficult and risky to achieve at this stage, but based on the Hessequa case study it can be concluded that RET does offer an alternative to Eskom supplied electricity, even if it is only in a supplementary capacity for the foreseeable future.

Currently, strict electricity regulations and politics are considered to be the biggest obstacles to RET implementation in Hessequa.

Recommendations

Although there is a level of uncertainty regarding the price of electricity purchased from an IPP, the electricity prices were based on real trends that are currently visible in the sector. If local government can indeed negotiate with NERSA, national government and Eskom for the right to purchase electricity directly from an IPP, it is recommended that local government resell the electricity as if it was purchased from Eskom. In other words, when electricity is sold to end user customers, it should not be offered at a lower rate than BAU. The added profits can be used for infrastructure improvements, economic development initiatives like tourism and local skills development.

Although solar PV technology is predicted to be significantly cheaper than both biomass and wind power in terms of capital cost and the cost of generation, biomass power should not be discarded. The environmental considerations and job creation potential involved in biomass power generation make a compelling argument for its share in the local electricity supply. If invasive alien plants are used as fuel in biomass power plants, areas with high IAP concentrations can be cleared. Biomass harvesting is a low skill job. Very little, if any, training is needed before harvesting positions can be filled. Although the impact on local unemployment will be limited, it will not be negligible.

It is extremely unlikely that renewable electricity production anywhere in Hessequa will exceed demand at any given moment. That means there will be no electricity produced locally that is not immediately consumed locally. Although there is great uncertainty regarding pumped storage potential in the area, this storage could potentially be used for peak load shaving. However, more research regarding pumped storage potential is required at this stage. Due to the low capacity factors predicted for wind power in the area, it is also not recommended to invest in wind power generation capacity.

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