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Insights into the Thermal Generation Futures of Isolated Island Electricity Systems Using System Dynamics

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Abstract

In future, long-term thermal generation investments will be greatly influenced by the best available mixes of legacy fossil fuels and renewable sources. Intuitively, a detailed first look at the dynamics which surrounds thermal investments will assist policy makers in shaping optimally required generation mixes. To achieve this, a system dynamics model of an isolated island electricity system was developed. This model gauges the long-term investment decisions that can exist within such systems. It addresses the thermal capacity additions and the extent to which financially influenced and demand growth influenced additions affects the long-term stability of the system. Reflecting a reality typical of island systems, this model does not have a supply and demand driven pricing mechanism and thus adopts exogenous electricity tariffs. It however accounts endogenously for changes in the thermal capacity margins and capacity costing. The case study used considers the Azorean island of Sao Miguel; which provides a background for the model and is used for testing its ability to capture various aspects of historical behaviours and real-world influences on the long-term thermal generation decisions. The paper concludes with a discussion of the investment decision insights gained and the possible future extensions, uses and modifications of the model.

Keywords: capacity margin, policy analysis, energy, isolated islands energy systems, thermal generation, capacity expansions, investments

1. Introduction

There is an inherent need for energy consumption as a means of economic growth, an assumption which relies heavily on the intuition that human development and quality of life is dependent on continuous, abundant and economic energy supply (Gómez-Expósito et al, 2009). Access to electricity is agreed to be a necessary, but not a sufficient, condition for economic development (Barnes, 2007). The need for electricity is embedded in today's modern societal structure with consequential overreliance on its consumption. This fact paves the way for most developed and developing countries to improve and expand their electricity power generation systems. In so doing, emphasis is placed on the most economical and systematically efficient generation mixes of both thermal and renewable sources. An even more urgent call can be given to the decision makers in remote/isolated island systems where there is a lack of financial and innovative economical drivers within their economies. Isolated island systems may be left behind in this global technological race and will have to adopt strategies from bigger interconnected systems. As shown in (Cross-Call, 2013 & MIT-Portugal, 2013) the economic and technical viability of such systems can best be understood within their own context, due to unique factors such as their non-liberalised markets and single electric utilities with power purchase agreements (contracted sole electricity provider).

This work will capture the detailed outlooks of the key dynamics surrounding the long-term thermal generation capacity expansion of isolated island electricity systems. It gauges the long-term investment decisions that can exist within such systems. The Azores islands (described further in Section 3) will be used as a case study for this model. The model is an initial system dynamics work that will later on form part of a full model as consideration is given to a more complete portfolio of generation mixes. The relevant follow on models will incorporate renewable energy resources penetrations, energy efficiency mechanisms and other smart grid enabling technologies. The key findings highlighted within this initial model are the investment decisions policy analysis of the "business as usual" scenarios for capacity expansion of the thermal generation dominated system. Important variables such as the financially influenced investment drivers, the demand forecasted influenced drivers, the 'derated' capacity margin (RAE, 2013) drivers, and the thermal generation capacity, are all endogenously accounted for within the model. This gives an in-depth understanding of the strategies that normally exist, and can exist in the absence of renewables and other smart grid enabling technologies. Ford (1997), provides valuable insights into the legacy electric power industry with a focus on forecasting capacity needs with stocks of capacity under construction, and the time delays inherent to such systems. These insights are all key inputs into this work. The resulting main goal of this research study is to understand the dynamics surrounding the long-term thermal investment decisions affecting this system and to provide useful policy insights into the future of these evolving complex systems.

This rest of this paper is organised as follows: Section 2 presents a review of existing modelling approaches as a means of understanding the complexity surrounding the capacity expansion problem. Additionally, the relevant context and characteristics of the case study island of Sao Miguel is also discussed in Section 2. The developed thermal capacity expansion model is detailed in Section 3. Subsequently, Section 4 discusses the initial findings, analysis and insights gained. And finally, Section 5 concludes the paper with an outlook of the next steps and future uses and revised modifications of the model.

2. Review of relevant literature

The underlying and widely used solution for the development and expansion of electrical power networks hinges on the concept of long-term power planning also known as capacity expansion planning. Long-term power planning attempts to establish and pursue the least-cost options needed for capacity expansion that meets anticipated growing demand, over a 10 to 30 years long-term horizon (Jordan, 2013). According to (Jordan, 2013), these costs are typically the sum of the capital investments of newly constructed capacity and the ongoing operational system costs within the given horizon of the model. The associated electricity demand and total costing are usually assumed to be deterministically-based within these planning models. However, to fully understand and make the best investment decisions for the development and utilization of optimally efficient generation mixes, a more holistic view of the dynamics surrounding the electricity demand, capacity needs forecasting and the total costing is required (Jordan, 2013). The system dynamics modelling tool provides an excellent avenue for achieving this, as shown in the works of (Ford, 1997; Steel, 2008; Jordan, 2013). The methodology of system dynamics is long used to address many different aspects of energy policy applied to past and present electric power grid systems. Aspects such as capacity planning, operating investments and balancing of fuel/technology mixes for grid system performances are all keenly highlighted in the literature (Sánchez et al, 2007; Jordan, 2013; Arango et al, 2008; Carvajal et al, 2011). These works show the usefulness of system dynamics for investment decision analysis and for gaining insights into emerging characteristics, even those that are not yet apparent or fully understood within their respective systems.

Specific to this research study and as highlighted in (Ford, 1997), system dynamics is particularly useful for the capacity expansion problem since it has the advantage of capturing the effect of time delays and endogenous feedbacks within the system. This leads to a better understanding of the total dynamics within the whole system as described in (Collins et al, 2013). The authors, Collins et al, made use of exogenous energy demand and supply within their model in order to analyse the long-term technology-specific capacity expansion to meet projected growth of demand load in Saudi Arabia. The paper makes use of a high-granularity approach of the demand load instead of the conventional way of aggregated demand load. Key insights into the capacity investments needed and the informed policy development for such capacity investments were observed. However, an endogenous view of the energy demand and supply and the relevant capacity costing will prove to be more beneficial for fully understanding the system. In a separate paper by (Arango et al, 2008) a system dynamics model was developed for the estimation of cash flows and other financial indicators needed for capacity expansions within the Columbian energy market. The main area of focus with this work was the capacity costing needed for the endogenous market prices of the system. Conversely, here, no attention was given to the relative installed capacity of the electricity system. Separately, deregulated electricity markets as a catalyst for capacity expansion have been explored by others (Jaeger et al., 2009; Vogstad, 2004). These previous studies were all based on very large systems, and with less focus on key system specific self-evolving variables. Properly, characterising these appropriate key endogenous variables and dynamics within the system will prove fruitful for the analysis. Our interest in island systems and their inherent ‘closed loop’ uniqueness motivates our concern for such endogeneity.

Acknowledging the differentiated dynamics and also the higher levels of complexity in larger systems, there exist considerable advantages in considering smaller, but nevertheless complete, autonomous electricity systems. And with such a desire for contextual simplicity, we employ the system dynamics methodology for our isolated island case study to reflect the self-evolving and autonomous complexities (feedbacks) that exist within such systems. The Azores islands are chosen as the case study for this research work. The Azores are an archipelago of nine Portuguese islands about 1,500 km west of mainland Portugal within the Atlantic Ocean. The islands are clustered in three major groups; the eastern, central and western group with a total population of 245,000. The full archipelago stretches 600 km along a southeast-to-northwest axis (Azores, 2015). Importantly to this research work, the Azorean islands have been extensively studied over the last 7-8 years as “a living laboratory” for sustainable energy solutions (MIT-Portugal, 2013). This provided a rich collection of suitable data that is harnessed for this work. Additionally, the electricity systems on these islands are all stand-alone without any grid interconnections (preventing the selling and buying of electricity in peak load and supply situations) and without electricity market pricing structures (EDA, 2014). These conditions exemplifies our definition of an isolated island needed for this modelling work and will likely set the stage for what challenges and opportunities such autonomous electrical power grid system will likely face in the future.

The literature details some attempts of energy policy studies that has been conducted on islands and the Azores islands in particular. One such example is by (Pina, Silva, & Ferrão, 2012) which focused on the island of Flores and made use of this "green" island characterized by high renewables penetration to develop a TIMES MARKAL model with exogenous demand load growth. This study highlighted that demand side management strategies can lead to a significant delay in the investments needed for new generation capacity from renewable resources whilst focus on improving the operation of the existing installed thermal capacity can be done. A different model also shown in the literature is the energy storage study on another small "isolated" island, Sao Miguel, in the Azores, by (Cross-Call, 2013). This study focused on a least-cost unit commitment model analysis to determine the expected cost savings from introducing energy storage into existing electrical power grid networks. Additionally, (Silva, 2013) provided a multi-criteria decision method to compare energy storage and other planning options for sustainable development on Sao Miguel. (Parness, 2011) also explored the sustainability options on Sao Miguel, giving attention to the optimal charging strategies for electric vehicles needed to reduce electricity and transportation costs and to minimize CO_2 emissions.

The use of system dynamics for energy policy studies of isolated island electrical power grid systems are limited compared to other areas of system dynamics application. One such study by (Balnac et al. 2009) used a tool called Threshold-21 (T21) for applying system dynamics to aid in policy making in an integrated manner. The study provided a T21 electrical power sector model of the isolated islands of Mauritius. Although supply and demand load were endogenous to the model it assumed a least-cost-first rule when allocating demand to the different generating sets. This study allowed for a better understanding of the Mauritius' power sector and provided an initial structure of an electrical power grid model with scope for improvements. Our work differentiates from (Balnac et al., 2009) in that thermal generation capacity expansion and capacity costing emerges endogenously within the model. This allows for a more complete understanding of the long-term self-evolving dynamics surrounding the capacity investments within the system.

Additionally, this paper, for the first time in the literature, investigates applying pure system dynamics modelling to isolated electricity systems on islands unlike the (T21) tool used by (Balnac et al., 2009). It presents a thermal capacity expansion model of a single utility based, isolated island electricity system that accounts for endogenous costing of capacity and capacity margins. This initial model will use exogenous demand. This provides the best basis for the thermal capacity expansion analysis to give insights into the key drivers and indicators of such systems. Our work also forces a higher level of endogeneity (the capacity margins as it relates to peak demand, demand and electricity supply within the system) for these types of systems as opposed to previous studies seen in the literature. The model encapsulates the above stated aims of the isolated island electricity system model structure. It determines the demand driven thermal capacity margins and related embedded capacity costing effects/causes on the long-term thermal capacity investment decisions and provide applicable development and utilization policies.

2.1 **Isolated island system: Sao Miguel**

In order to fully appreciate the need for modelling an isolated island system, we detail here the essential characteristics of such island systems. Also provided is the relevant context for our case study. Electricity systems that are singular and do not have physical interconnections to other grid systems are considered to be remote/isolated. Most island systems around the globe will meet these criteria's except the much larger islands such as the United Kingdom which have grid interconnections to other mainland systems. Isolated island electricity systems will normally have only one energy supplier without liberalize energy markets (it is not economically viable because of the very small sizes of the islands). These systems are also mostly dependent on foreign oil and gas and hence will be greatly affected but cannot influence (due to small size) the global oil and gas markets. Additionally, some isolated island such as the Azores are dependent on larger mainland governments who externally determine their energy prices and policies (EDA, 2008; ERSE, 2012). Consequentially, and with great application to this work, these energy systems are less complex than interconnected grid systems and systems that have liberal energy markets. They are also autonomous and can give an excellent case study for sufficiently understanding the evolution and futures of self-evolving electricity systems.

The chosen island of this study, Sao Miguel is the largest island in the Azores, both in terms of size and population. It was chosen because it meets the necessary criteria's of an isolated island and also has ongoing extensive research into its energy system with lots of data (MIT-Portugal, 2013). The prevalent characteristics of Sao Miguel can be stated as an island that has a growing tourist economy and traditional sectors of fishing and farming, giving it the most diverse economy and energy needs of the nine islands of the Azores. According to (Cross-Call, 2013) tourism represents a growing share of electricity demand on the island and introduces new dimensions to its power supply. Tourism gives major seasonal fluctuations within the demand profiles and influences the perception of the electricity demand capacity margin on the island. This results in the need for additional generation capacity for these limited time periods and/or for long-term needs. If left un-addressed these higher demands spikes can filter down to poor power quality and intermittent blackouts because of security of supply violations. In response, the Azores' island energy planners need to consider how the power system will adapt and perform in future years. An important first step will be to understand how the socio-techno-economic aspects of a thermal generation dominated system can evolve from present to future for such an island system. This can be achieved with the use of the system dynamics methodology for the generation capacity mixes of the island.

In greater details, as a single electric utility, Electricidade dos Acores (EDA), serves all nine islands of the Azores as a fully regulated utility. Understanding the investment decisions needed is imperative to EDA since it owns all of the thermal capacity on the islands. This is in contrast with electricity supply in mainland Portugal, where deregulation of the electricity system was completed in 2006; hence it is subject to a liberal market structure. Interestingly, Sao Miguel electricity customers pay the same retail electricity rates as mainland Portugal according to national law. However, due to the fact that the Azorean islands energy system is more sensitive to volatile changes in oil prices; hence high prices means much higher energy production costs and higher resulting tariffs than the mainland Portugal. Effectively, the Azorean electricity tariffs are subsidized by the rest of Portugal (Cross-Call, 2013). This implies that EDA is required to follow least-cost planning procedures when investing in capacity additions or other grid enhancements.

According to (EDA, 2014), the EDA paid 40–65% more for fuel oil used to generate electricity on Sao Miguel than the Portuguese average. Other key observations about the energy system on Sao Miguel are that the existing technical system structures are fairly good; the island meets N-1 electricity transmission criteria standards and has capacity reserve margins well above 20%. For this island system a significant amount of generation capacity sits idle most of the year (EDA, 2014). The annual electricity consumption load has grown more than 3% a year for the last 5 years and the future demand is expected to keep rising by that same margin since there is a set of projected investments which will be responsible for additional electricity consumption (EDA, 2008). Tariff prices for electricity are also expected to continually rise by 2-3% per year over the next few years (ERSE, 2012). With these un-deterministic and complex dynamics the most obvious solution based on today's market and system structure will be to use more renewable energy sources. Elements of this can be seen within a national decree to achieve 75% renewable electricity on the islands by 2018, with an intermediate goal of 50% renewable by 2015. In pursuit of this, the Azores including Sao Miguel have added some wind capacity to put with their geothermal sources in recent years, providing around 5% of the annual generation (Cross-Call, 2013). However, there are no clear insights into the effects of these dynamics and the hastily adopted renewable policies. Is there any justifiable further investment needed into thermal capacity or renewables given the amount of idle capacity on the island. As a first step, our work in this paper seeks to understand how this prominence of thermal generation capacity and the large amounts of idle capacity margin will evolve assuming there is little or no renewables present in the system. This study will develop an initial thermal generation model of Sao Miguel and provide the necessary analysis that can lead to fruitful policies surrounding generation capacity mixes for the future of this and other isolated island electricity system.

3. **Thermal generation capacity model**

This work is based on a general mental model feedback loop diagram detailed in Figure 1, similar to (Ford, 1997), that accounts for and explains the delays and dynamics of installing new capacity to an existing electricity system. Shown are three main balancing loops that reflects the structure of this system. The loops attest to the facts that there is no electricity markets on the island and electricity tariffs are exogenously determined. Endogenously determined tariffs would give a different representative system structure. Our work seeks to represent the Sao Miguel's electricity system and will not have any endogenous electricity prices or endogenous thermal fuel prices; however, endogenous demand can be incorporated later. As shown in Figure 1 the three main loops of the diagram includes the capacity costing loop which is being influenced by the exogenous electricity tariffs and thermal fuel prices, and has a balancing effect on the rate of thermal initiations. The second loop, the capacity construction loop also has a balancing effect on the thermal capacity initiations; with high amounts of thermal capacity the capacity construction loop balances the rate of thermal initiations. The final loop is the capacity margin loop which is also a balancing loop; higher exogenous demand implies a higher capacity forecast but this is balanced by the resulting capacity margin. For these systems the electricity demand is inherently affected by ‘external’ variables such as the population and the gross domestic product, which we do not account for within this model structure.

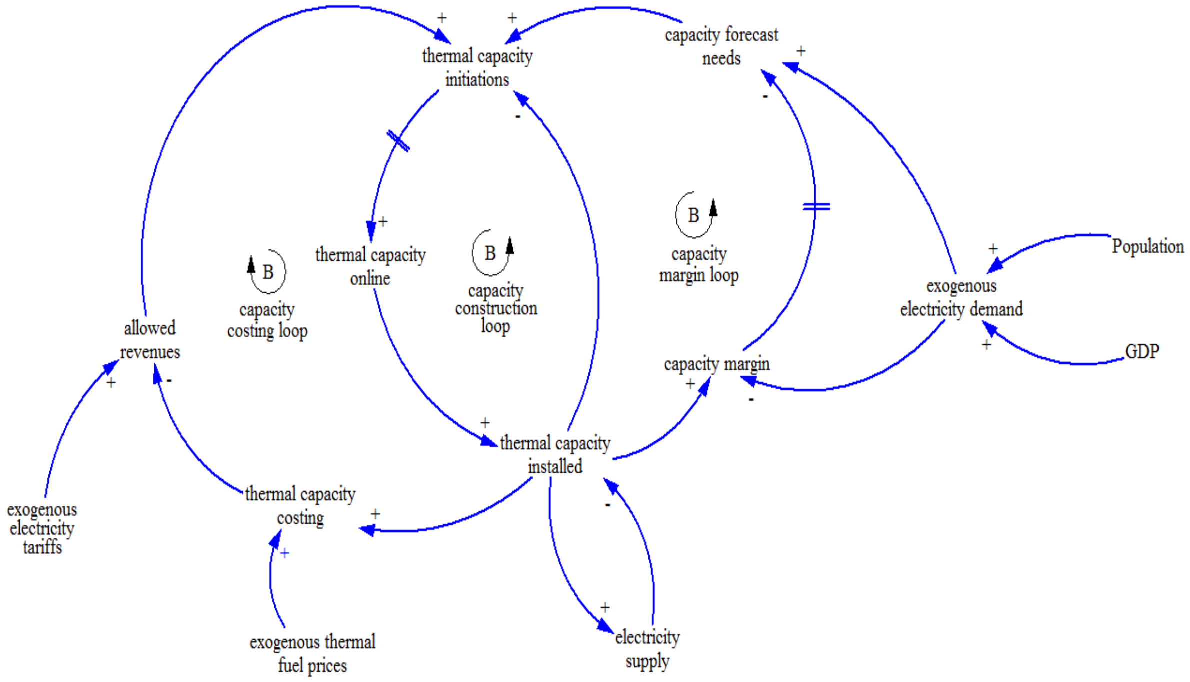

Figure 1. Mental model feedback loop diagram of the isolated island electricity system

3.1 **Dynamic Hypothesis**

As previously mentioned, the feedback loop diagram in Figure 1 represents the dynamic hypothesis of the thermal capacity expansion problem for the Sao Miguel case study. The dynamic hypothesis is centred on the three main balancing loops of the feedback diagram. This embodies the assumption that an increasing trend of the exogenous electricity tariff and thermal fuel prices in future drives the capacity costing loop to dominate the rate of thermal initiations. Also, with future increasing exogenous electricity demand, the capacity margin loop would tend to vary based on the investment time delay needed to adjust the capacity margin, as the system endogenously accounts for its capacity margin which is already over 20% (EDA, 2008). Additionally, the capacity construction loop as in (Ford, 1997) accounts for the delays necessary for new capacity to come online, which may be longer in this case, since the system is already heavily endowed with thermal capacity, against the backdrop that the forecasted demand load is very healthy (EDA, 2008; ERSE, 2012). Collectively, the installed thermal capacity and thermal initiation rates of Sao Miguel are expected to rise gradually and then taper off at a specific goal due to the capacity costing balancing effects on these variables. This can be attributed to the high cost of fuel and capital investments that will eventually restrict this growth. If thermal fuel prices are to increase by much more than the 40-65% above average prices already being paid then the thermal initiation rate might have accelerated restrictions. Figure 2 gives an indication of the trend experienced by the thermal fuel prices on the island over the past 10 years. It might be safe to assume that these prices will continue to rise in the future.

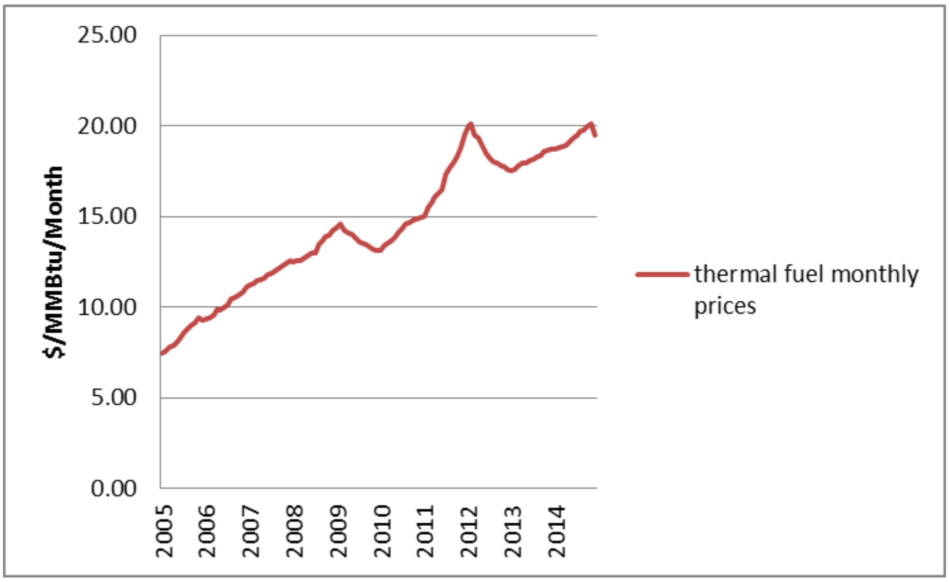

Figure 2. Graph of historical data of thermal fuel monthly prices

The monthly electricity demand is shown in Figure 3. This diagram indicates that the consumption has grown across all of the consumers from 2005-2014. The largest consumers are the residential and commercial end-users; however the largest increase in consumption over the past 10 years was reflected in the industrial end-users. If this island is to continue to rely heavily on tourism and other industrial sectors as stated in Section 2.1 then the energy demand will certainly continue to increase.

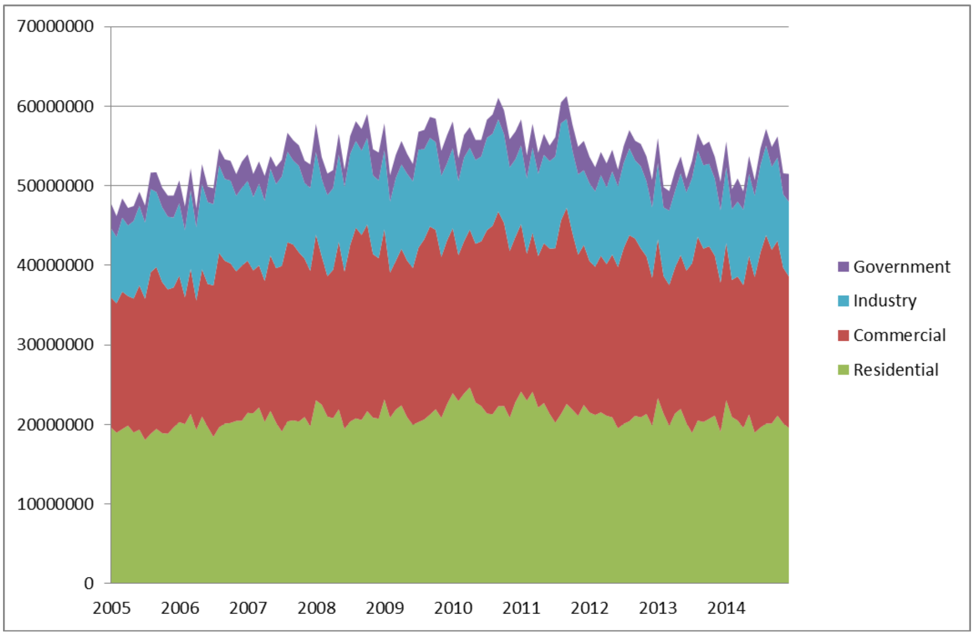

Figure 3. Breakdown of the monthly consumption (MWh) by sector

Data from Sao Miguel suggest that there will be an increase in thermal fuel prices and electricity demand over the foreseeable future. It is expected that the electricity tariff prices should increase in future also, but this depends heavily on the Portuguese mainland economy and resulting legislation. Interestingly, there seems to be a decrease in the electricity supplied by thermal fuel, as it drops from being very prominent in 2005 at about 80% to a share of about 45% in 2014. Non-thermal produced electricity increased from about 20% in 2005 to about 55% in 2014. This can be attested to the national push for 75% renewable generation supply of energy (Cross-Call, 2013).

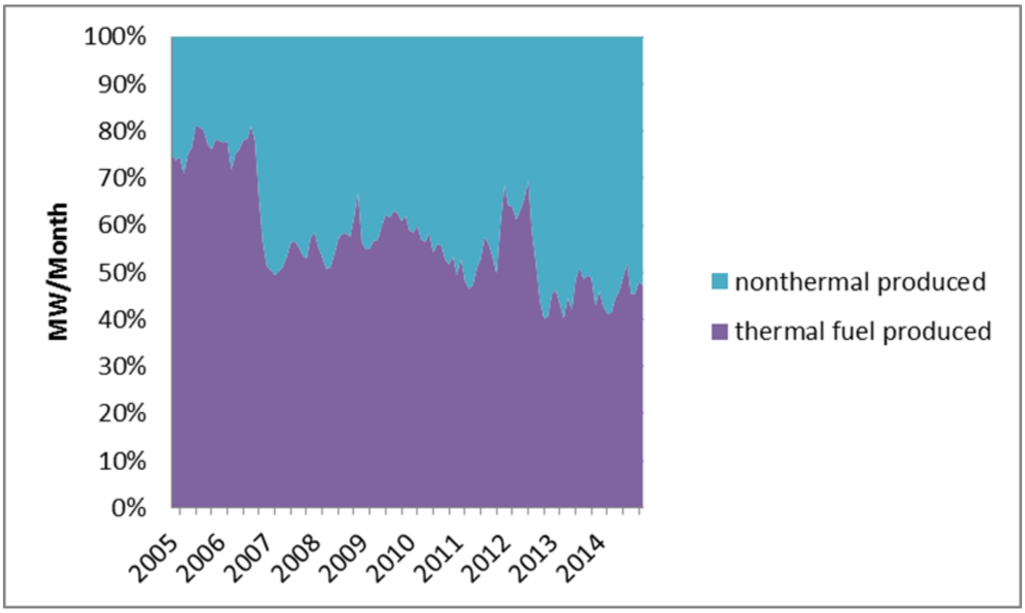

Figure 4. Historical data of both thermal and non-thermal electricity production

This drop in supply of thermal fuel produced electricity and the projected forecast of such does not necessarily imply that the thermal installed capacity on the island will suddenly drop. Decommissioning of these plants plays a crucial role, and with the unpredictability of renewables this delays the urgency to remove the extra thermal capacities. The stores of thermal capacity serve as the required capacity margin and also base load energy supplies. However, the installed thermal capacity and thermal initiations is expected to decrease in the future and these model variables should reflect S-shaped goal seeking archetypes of varying degrees. This is based on the rates of increases of the thermal fuel prices and other factors that will restrict their growth. This model will capture the dynamics of the installed thermal capacity for the island of Sao Miguel for the next 35 years.

3.2 **Model formulation**

The formal model diagram is derived and formulated from the mental model feedback loop diagram of Figure 1 to account for the stocks and flow variables within the system. The general structure for capacity expansion by (Ford, 1997; Sterman, 2000) is used as guidance for achieving the most plausible representation of the thermal capacity expansion problem on Sao Miguel. These main mappings are shown in Figures 5 and 6 (separated to facilitate a better visual for understanding) which together represents the single complete thermal model. The key stocks and flows are shown within the illustrated model diagrams. Figure 5 captures the dynamics of the financial side within the model and details the total costing necessary to facilitate thermal capacity expansion and the requisite cash flows (revenues) that can upkeep this amount of installed thermal capacity. Decommissioning of thermal generation also incurs a cost (IEA, 2009) and is endogenously accounted for within the model.

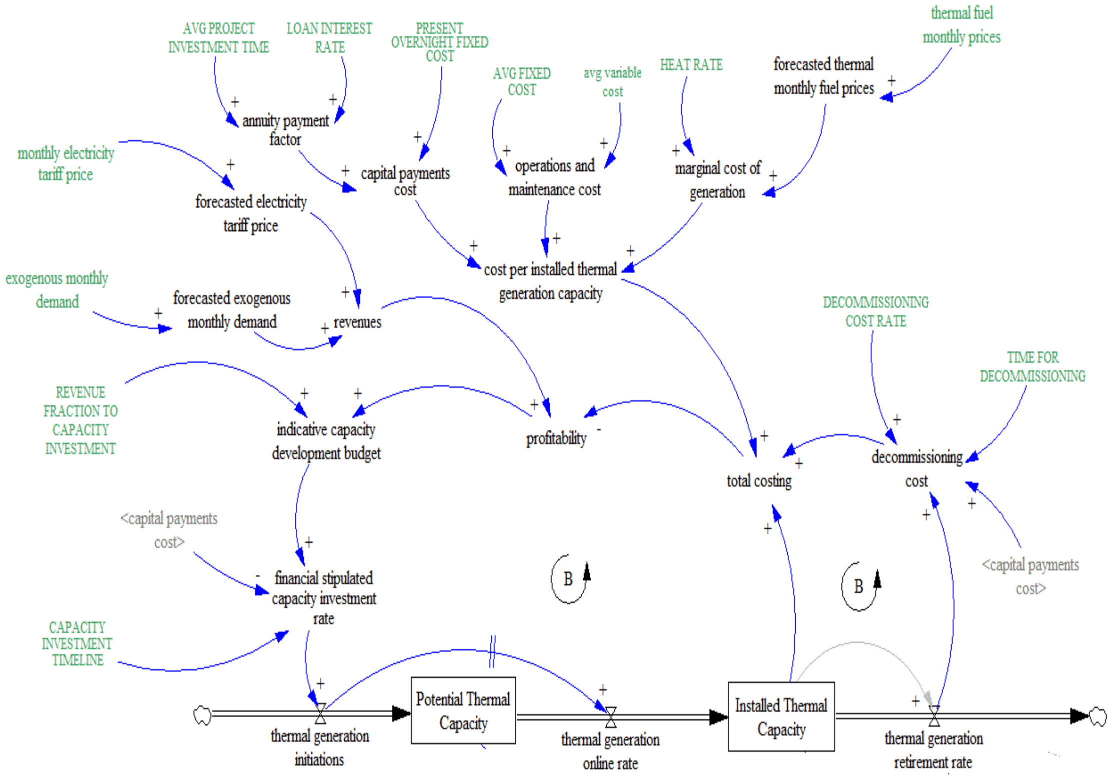

Figure 5. Formal diagram for the thermal capacity financial aspects within the isolated island electricity system

Figure 6 shows the dynamics surrounding the capacity margin and its related aspects within the system. The capacity margin is formulated as a goal adjustment to which the desired capacity-margin policies can be examined. Historical data of the thermal capacity prominence (a ratio of the thermal fuel produced capacity to total generation capacity on the island) is used to assist in the time-series forecasting of the amount of thermal electricity supply (historical data is shown in Figure 4) that is on the island. The exogenous demand and electricity supply gives an indication of the thermal generation capacity adjustments needed for these supply variations. The supply variation is then compared to the adjustments for the 'derated' capacity margin in order to inform the thermal capacity initiations. As mentioned previously, the model accounts for the construction and decommissioning time lags to ensure that the thermal initiation rates are sufficient to meet the demand forecast explained in (Sterman, 2000), following the work of (Ford, 1997).

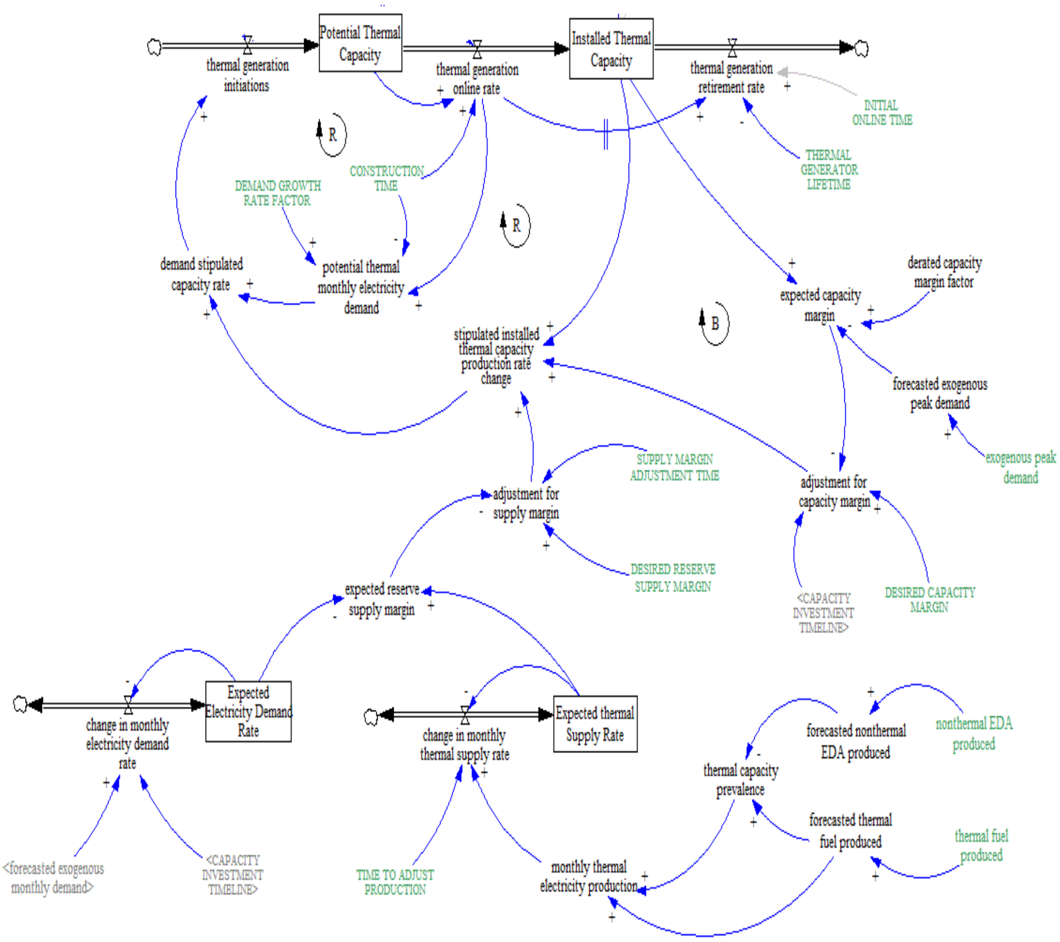

Figure 6. Formal diagram for the thermal capacity margin aspects within the isolated island electricity system

The developed model would give insights into the next 30-35 years of the system structure and variables and is resolved on a monthly time step basis starting from 2005 up to 2049. The investment decisions and policy analysis for thermal capacity expansion on Sao Miguel would be made obvious from this modelling work. As shown above, historical data from 2005 to 2014 of the exogenous variables in the model is used for determining appropriate data extrapolations using the vensim SMOOTH and FORECAST functions, along with some simplified linear function and least squares methods. These extrapolations are then compared and used as the respective exogenous inputs into the model.

4. Evaluation

Within the scope of this model the effects of the financial and capacity margin aspects on the system can be evaluated. Firstly, taking into consideration the demand growth, fuel prices and electricity tariffs trends we examine the installed thermal capacity and thermal capacity initiations rates in Sao Miguel. In all scenarios, the initial installed thermal capacity and initial potential thermal capacity is obtained from the historical data of Sao Miguel, for the initial time of January 2005. Model calibration time is given from January 2005 up to December 2014 whilst the simulation time goes from 2015 up to 2049. The average present age of existing thermal generators at initial time, January 2005 is also used in the model (EDA, 2014). Three main scenarios are used for the evaluations. These scenarios differ with regards to the electricity demand rate that can be forecasted for the island. The extrapolated input data for the exogenous thermal fuel produced and non-thermal fuel produced electricity supply is the same for all three scenarios.

4.1 **Scenario descriptions**

Reference scenario

We first develop the reference scenario which considers the “business as usual” case and represents what is most likely to occur under the current system policy for which the electricity demand rate forecasts (3% per annum increases), the exogenous electricity tariffs and thermal fuel prices reflects the evolution of the system based on its present state given from the extrapolated exogenous data.

Below average demand scenario

The below average demand scenario reflects a lower than the forecasted electricity demand within the system (less than 3% per annum). We set the exogenous thermal fuel prices to decay over the simulation time. Decay of the peak demand forecasted is also accounted for in this scenario.

Above average demand scenario

The above average demand scenario reflects a higher than the forecasted electricity demand within the system (greater than 3% forecasted per annum). Electricity tariff prices are left as in the reference scenario. We set the exogenous thermal fuel prices to grow over the simulation period. A growth in peak demand is also accounted for within this scenario.

4.2 S**cenario results analysis**

Figure 7 shows the monthly installed thermal capacity of all three scenarios. This installed thermal capacity appears to dip in 2017 in all three scenarios and then gradually rise for the rest of the simulation time up to about 116MW in 2049. As expected the above average scenario has the highest growth whilst the below average scenario has the lowest. It is observed here also that this slow growth indicates a move away from thermal capacity on the island. And the time lags for decommissioning and building thermal capacity on the island have a great impact on the reflected amount of installed capacity. In all three scenarios, it seems that the high cost of fuel is restricting this growth coupled with the recently enacted renewables mandate of the island.

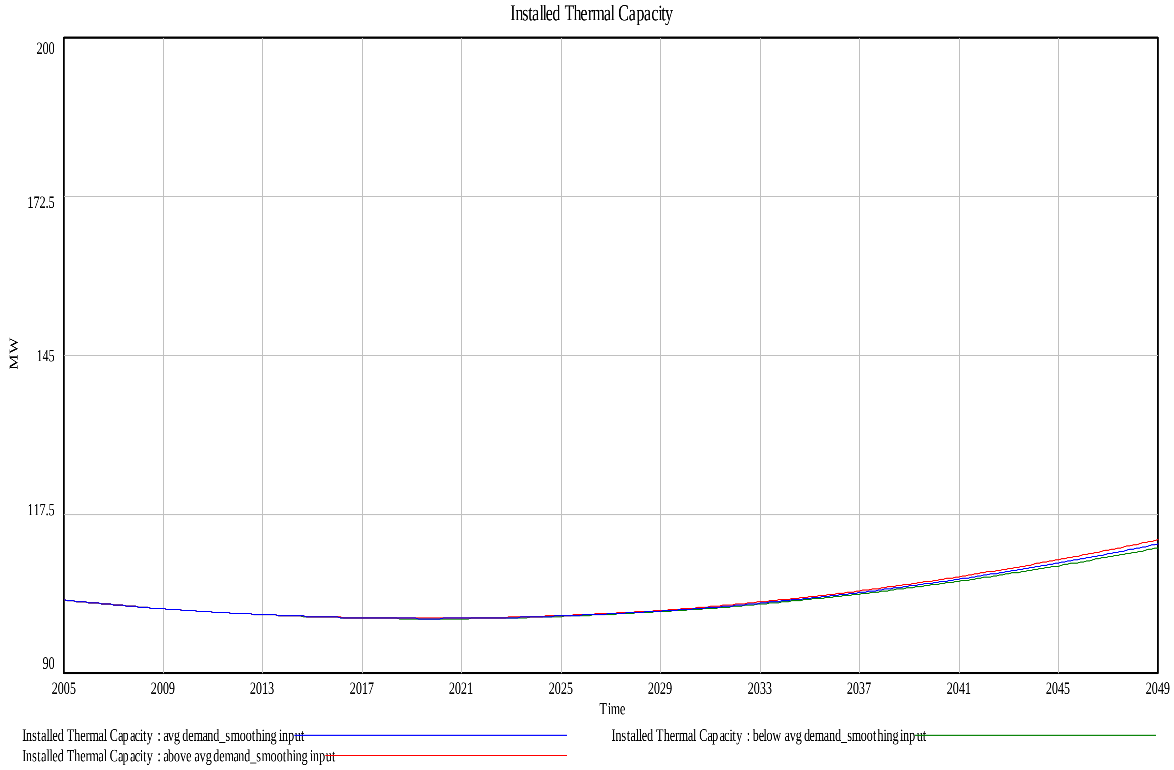

Figure 7. Installed thermal capacity for below average demand, above average demand and the reference scenarios

The thermal generation initiations reflect the amount of new thermal generation that is required on a monthly basis to meet the needs of the island. This is observed in Figure 8 for all three scenarios as being a goal seeking archetype implying that the balancing effects of the fractional rates of the capacity margin and financially stipulated parts of the system (shown in Figures 5 and 6) will dominate at some point. The above average scenario had the highest amount of thermal initiations throughout the simulation starting at about 1.5MW/Month in 2005 up to about 2.75MW/Month in 2049. The increase in thermal initiations as determined by the financial and capacity margin effects within the island is not very large. This can be attributed to the fact that thermal generation on the island is not seen as being very profitable anymore but there is a need to have a sufficient capacity margin of base thermal generation capacity.
embedded within the model.

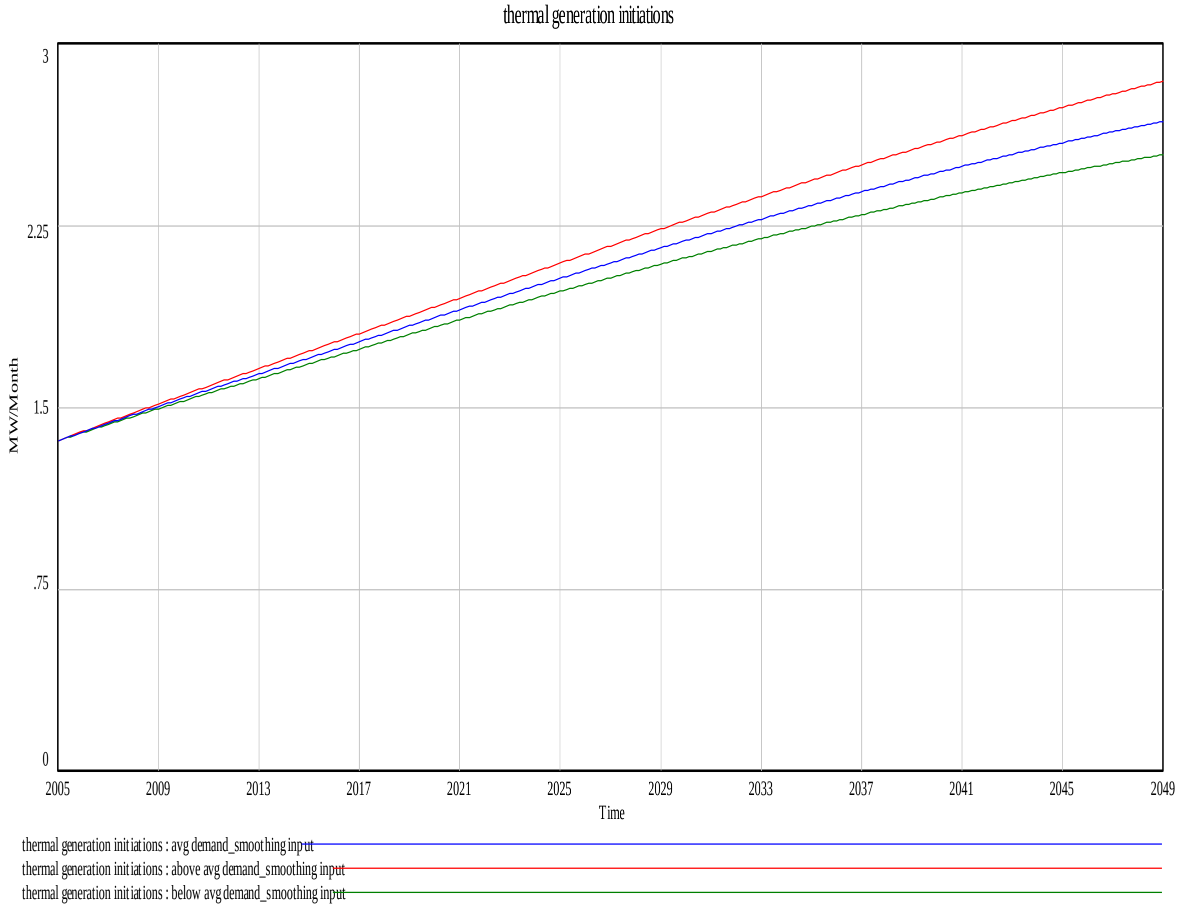

Figure 8. Thermal capacity initiations for below average demand, above average demand and the reference scenarios

Other interesting dynamics can also be observed from this model of the island system. By increasing or decreasing the capacity margin it was observed that in all three scenarios there were negligible changes in the installed thermal capacity and also the thermal generation initiation rates. This can be attributed to the fact that the island’s installed thermal generation is greater than 20% of the needed capacity margin, with a notable amount of installed generation capacity not presently in use (EDA, 2014). However, if the delay associated with policies for adjusting the capacity margin is made larger, then the installed thermal capacity and thermal generations were also larger in the long-term. A smaller delay also implies a lower amount of thermal capacity installed and thermal generation initiations for the island during the simulation period. This is similar to Ford‘s (1997) conclusions on the lead time for capacity projects to be shorter to ensure having enough financial bases for project completion. We note here that drastic capacity margin policies on Sao Miguel will have negligible impacts on the thermal generation capacity of the island. However, the accuracy of the demand forecast and the time lag for making capacity investments based on capacity margin are very relevant, and is definitely the most important for this island electricity system. The profit margin and financial drivers within this system seems not to have a great impact since all tariffs are externally determined and imposed on the island. The exogenous tariffs and thermal fuel prices are an exogenous consequence of the capacity investments and operating cost of the system and decided outside of the island hence the wastage of installed thermal capacity noted above. This can provide the opportunity for more economical generation mixes (to include different types of renewables) for the island electricity system. A richer understanding of the thermal capacity expansion problem of isolated islands follows from this with the evaluation of additional scenarios to be done later.

5. Conclusions

This paper presents a system dynamics model of the isolated island electricity system of Sao Miguel having a very high dominance of thermal generation. The model is used to analyse the dynamics surrounding the addition of new thermal generation to this system. Preliminary results and evaluations show that a focus on the capacity margin in this island does not significantly affect the long-term thermal initiations and installed thermal capacity. However, if a longer or narrower timeline to adjust the capacity margin as a policy is employed then there are significant effects on the installed thermal capacity and thermal initiation rates. These decisions seem to steer the long-term investment outlooks and provide the gaps for the optimal generation mixes of the system. The forecast for demand growth was also highlighted to be a factor on the island system but the financial incentives from this does not seem to impact the installed thermal capacity and long-term profitability of the system. The model of the system uses many key variables such as electricity tariffs and fuel prices as exogenous factors.

Future work will include further analysis of the economic focused aspects of the model. Here we will look at a higher level of detail for the costing of capacity. Additionally, consideration will be given to how thermal fuel prices are an endogenous consequence of capacity investments and operating cost within the island system. A look at the demand as influenced by the tariff prices will also be look at. bThe ultimate objective will be to determine how this system will adapt to future smart grid enabling technologies and renewable sources, and electricity demand uncertainties. Having endogenous demand within the system is a target of future model modifications.
Other dynamics and results that can exist within this system will also be looked at in the future, especially the financial based aspects within the system structure (such as differentiation of the development budget and capital payment costing). Later iterations of the model will include renewable sources on the island and energy efficiency mechanisms. Additionally, the grid analysis of power quality problems common with renewables will be a point of focus of these newer models.

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