A SYSTEM DYNAMICS VIEW OF ENERGY DEMAND AND SUPPLY IN SMALL ISLANDS

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ABSTRACT

The paper summarises preliminary research on feedback relationships and structures among stakeholders that make up the unique energy profile of an autonomous island. The model builds on data from the islands of the Greek archipelago. Despite being a small-scale application, there is a complex socio-economic structure with convoluted stakeholder interests in place that can provide insights into the current debate on technology choice in energy policy. The real world problem addressed is the great financial cost of electrifying island's not connected to a mainland grid in conjunction with a state policy of uniform subsidised tariffs. The objective is to design demand-side interventions that are able to identify appropriate technologies, early adopters, potential niche markets and amalgamate this into an optimal integrated policy to mitigate that cost.

Keywords: *islands, demand-side*

1 INTRODUCTION TO THE UNOCONNECTED GREEK ISLANDS

The energy systems on the Greek islands of the Aegean exemplify five main characteristics in varying scales across the archipelago that also underlie their problematic behaviour:

1. High costs of electricity generation that is subsequently sold at subsidised rates to end-users.
2. Distribution level local grids and limited interconnections to neighbouring islands.
3. A growing residential consumption mainly attributed to rising income and readily available electric appliances.
4. A growing, highly seasonal and energy-intensive tourism sector.
5. A limited range of currently utilised supply options resulting in heavy reliance on imported fuel oil for the generation of electricity and heating.

The Public Power Corporation (PPC) solely operates the autonomous power systems of the Greek unconnected islands through its Island Directorate. The cost of generating one kWh of electricity on the islands ranges from €0.11 to €1.28 (PPC 2002). The retail price for the household sector is about €0.08/kWh (the standard household tariff is uniform across the country for social equity purposes). This price difference amasses each year to an unavoidable gap in the finances of the corporation. For 1998 it has been reported in the press to stand at €205 million (£133m) and rising.

The introduction of more efficient technologies to provide the same energy services to customers can potentially yield great economic benefits for consumers and the Public Power Corporation (PPC) alike. The benefits of such kind of demand-side management to the operator can accrue through investment deferral and optimal plant loading, i.e. reduced fuel consumption. The current paper centres on setting a simulation exercise to capture the agents and their decisions, which is the necessary step to assess the aforementioned impact on costs. This latter element is a major objective of the ongoing research. Namely, the model sets up a demand/supply structure on basic assumptions, rules for capacity expansion that were devised from literature and interviews and, finally, it touches on substitution dynamics among energy service appliances.

The broader aim is to prove efficient demand-side technologies can halt the rate of capacity expansion and thus save money compared to a BAU case. It is then a question of policy making to decide how much of potential savings can be fed back into support for efficient technologies, in what form and for how long. The key objective is to meet the load at all times for all users' needs by utilising market forces to kick of an energy-efficient technology market which can show convincing benefits to both supplier and consumer and thus overcome the barriers of commercial deployment.

2 REVIEW OF THE CURRENT SITUATION

2.1 Energy Use

Fuel oil, diesel and petrol are the predominant fuels in the islands for electricity generation, transportation and the agricultural sector. Figure *1* below shows the relative distribution of fuels in energy supply typically found across the Aegean. Gasoline is consumed almost entirely in transportation. Diesel is principally consumed for heating and electricity generation by the Public Power Corporation (PPC). Most of the heavy fuel oil is used for power generation too (Balaras et al. 1999, 24:335-350;Mihalakakou et al. 2002, 26:1-19).

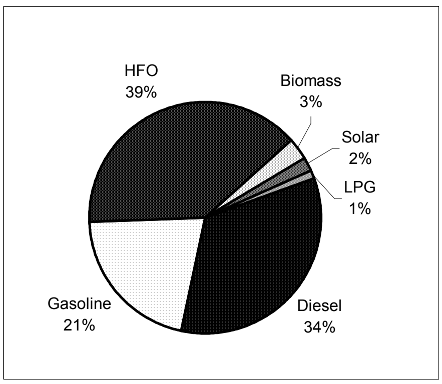

Figure 1: Distribution of energy supply per fuel in the Dodecanese.

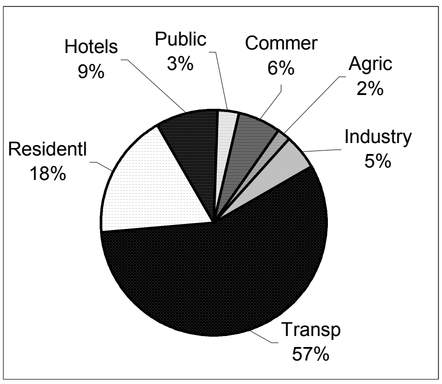

Figure 2: Useful energy consumption per economy sector for the Dodecanese.

Generation sets present on the islands are in the range of 80-1000kW.

2.2 Electricity

The pie chart in Figure 2 is based on data from the Dodecanese and is a pattern met across the smaller islands of the Aegean Sea. The residential sector and hotels together account for 26% of the consumption and the energy vector concerned is predominantly electricity. The hotel and commercial sector weigh much more in relevant terms, as they are operational half of the year (Balaras, Santamouris, Asimakopoulos, Argiriou, Paparsenos, and Gaglia 1999, 24:335-350;Mihalakakou, Psiloglou, Santamouris, and Nomidis 2002, 26:1-19).

Electricity consumption by sector reveals a particular increase for the domestic and commercial sectors. There could be many reasons behind these increases and there have been no conclusive studies on the issue to date. The most likely reasons are tourism - domestic as much as international and rising standard of living. Domestic electricity consumption between 1992 and 1996 increased by 25% in the Cyclades. Increase in the tertiary sector was 60% while both industrial and agricultural electricity use in the Cyclades increased by 30% for the same period (Balaras, Santamouris, Asimakopoulos, Argiriou, Paparsenos, and Gaglia 1999, 24:335-350;Mihalakakou, Psiloglou, Santamouris, and Nomidis 2002, 26:1-19).

Net electricity production and peak power demand between 1996 and 2001 show an average increase 40-45%. Figure 3 presents the case for a selection of islands across the Aegean. Peak power demand has been observed to occur in August that is the most touristic month of the year and there is increased air-conditioning, lighting and hot water demand. For the rest of the year demand lies substantially lower than that (Balaras, Santamouris, Asimakopoulos, Argiriou, Paparsenos, and Gaglia 1999, 24:335-350;Mihalakakou, Psiloglou, Santamouris, and Nomidis 2002, 26:1-19).

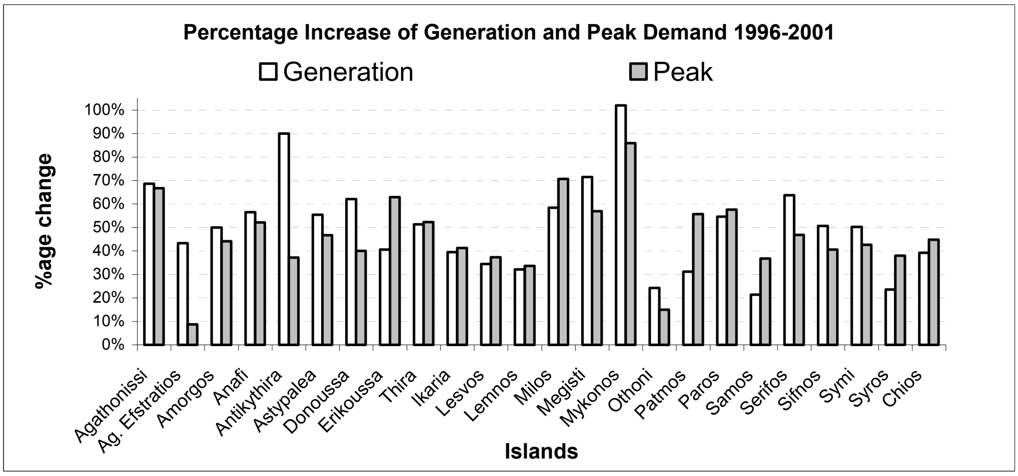

Figure 3: Power generation and peak demand increase for selected islands.

2.3 The Domestic Sector

Table 1 shows the great dependence on modern energy services, which in turn indicates rigid energy consumer behaviour. As long as the real costs of electricity production are not reflected on island consumers' bills, it is difficult to prove the conservation benefits to customers given that the study quoted in the table below showed the majority seemed indifferent to energy conservation practices, did not keep sufficient records of energy bills and were not informed on the energy efficiency of appliances (Haralampopoulos et al. 2001, 26:187-196).

Table 1: Electric appliance penetration in 571 households of Mytilene.

Type of appliance	Households by no. of appliances					Total appliances	Penetration (%)
	0	1	2	3	4		
Oven	*20*	*544*	*7*	-	-	*558*	*97.7*
Refrigerator	*3*	*529*	*35*	*3*	*1*	*583*	*102.1*
Electric water heater	*203*	*365*	*3*	-	-	*371*	*65.0*
Kitchen el wtr heater	*396*	*173*	*2*	-	-	*173*	*30.3*
Washing machine	*63*	*502*	*6*	-	-	*514*	*90.0*
Dish washer	*415*	*152*	*1*	-	-	*154*	*27.0*
Iron	*36*	*525*	*5*	*4*	*1*	*551*	*96.5*
Television	*12*	*406*	*128*	*22*	*3*	*740*	*129.6*
Freezer	*489*	*22*	-	-	-	*22*	*3.9*
Microwave oven	*549*	*15*	-	-	-	*15*	*2.6*
Toaster	*560*	*11*		-	-	*11*	*1.9*

2.4 The Tertiary Sector

The sector consists mainly of hotels, public sector (schools, hospitals etc.) and commercial (e.g. restaurants, shops etc.). The hotel sub-sector spends most of the energy available for the sector. In the case of the Dodecanese the relative share is 50%, 16% and 34% respectively (Mihalakakou, Psiloglou, Santamouris, and Nomidis 2002, 26:1-19). Taking under account the hotel sector is operational for half of the year; its consumption has a great impact on the energy supply of an island. For the islands of the Aegean, the hotel sub-sector seems a candidate segment of the appliances market to introduce technologies that cut down on energy bills. Hotels account for 9% of total energy consumption in the Dodecanese. The energy is mainly used in water heating, air conditioning and lighting (ALTENERII 2001). The simulation model however only examines adoption of these technologies in the domestic sector as its smooth consumption pattern allows better study of the suggested substitution algorithm.

The main driver behind the increasing energy demand of hotels is tourism arrivals. Tourism has a great impact on seasonal population that in consequence stresses capacity levels to meet base and peak loads that are physically impossible to meet unless there is generation increase on the island. There are rare and limited interconnections among islands that would allow extended load management options. There has been no restriction on the efficiency range of electric appliances so far by the government.

Increased generation has an immediate impact on the costs of the generated power, as either the gensets need to run close to rated output, the operator has to utilise older stand-by and inefficient gensets or eventually invest in expansion of the power plant. The first two occasions add to the running costs of the operator whereas the latter comes in as a fixed cost. In addition, the cost of the outages and the lost revenue of foregone sales should be included in the evaluation of the cost of not meeting the load. That figure can then provide the basis for comparing alternative interventions.

2.5 Case Study: Serifos island

The small island of *Serifos* has been chosen as a representative of an unconnected island of the Aegean Sea in order to demonstrate more detailed data on the underlying characteristics of the problem.

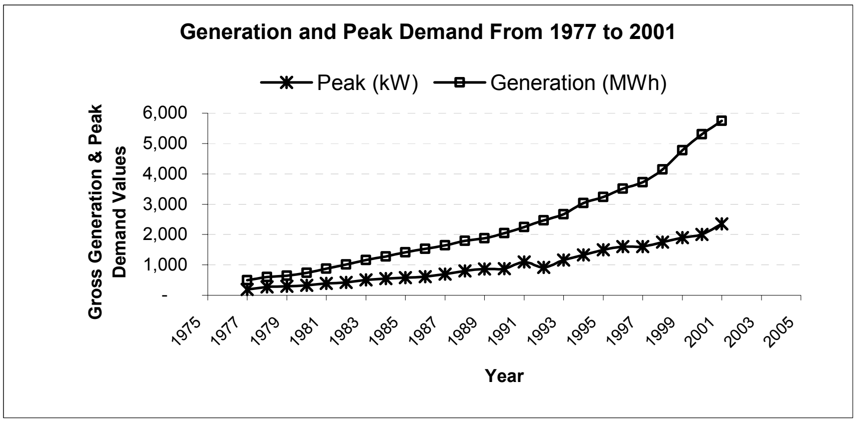

Figure 4: Historical generation & peak demand for Serifos.

The island has been facing increasing demand growth over the past 25 years with no sign of stabilisation (Figure 4). The clear exponential growth exemplified suggests there is a dominant reinforcing loop at play.

Similar graphs are found in the official annual summary of island electrification of the unconnected islands. Future consumption and peak demand growth are forecasted simply by drawing a line assuming about the same growth rate (PPC 2002). This, creates a situation of a 'self-fulfilling prophesy' as the future growth of any exponential growth requires multiplication of effort to mitigate its effects. As a result all attention is drawn to fulfilling the projected demand as required by law.

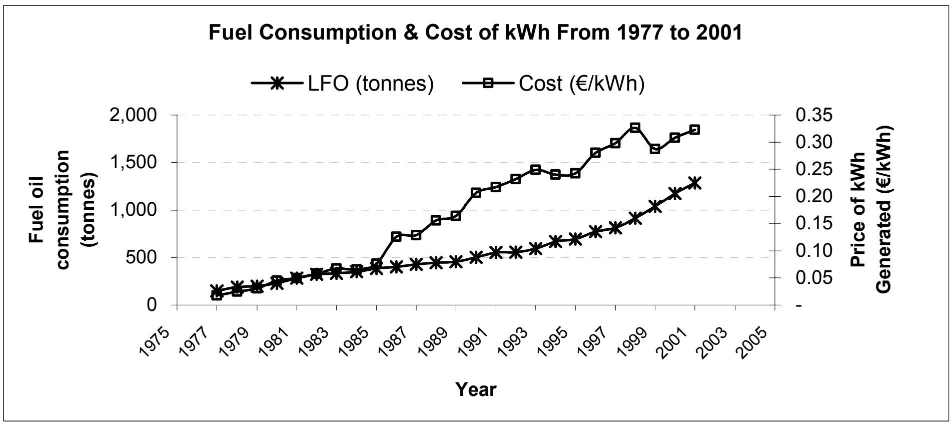

Figure 5: Historical fuel consumption & cost of kWh for Serifos.

Looking at the fuel consumption and generation cost of kWh data for the same time series the pattern is repeating albeit with periodical fluctuations in the cost of electricity. These oscillations are assumed to be due to the operating costs based on loading of the plant throughout the year (summer/winter) and the fluctuations of tourism arrivals. Causes in the price of fuel are ignored.

3 BUILDING THE SIMULATION EXERCISE

It is quite apparent from the case of Serifos that peak demand and consumption over the past three decades cannot incessantly grow. One would expect the system will eventually reach saturation and balance in either of two ways:

i) Energy consumption rate slows down significantly when households reach the required comfort level with respect to electricity appliances and, furthermore, tourism arrivals stabilise or,

ii) The island reaches it natural carrying capacity for power plant additions to accommodate tourist and inhabitants when further expansions degrade the natural environment so that the flow of inhabitants and visitors halts.

However, given that costs already outweigh revenues and the foreseeable future is likely to bring more wealth and thus energy spending, as it has been suggested in section 2.3, the system would likely collapse financially before anything else. One can now define the horizon of our simulation exercise to the short- to medium- term. Thirty years should be enough to allow the full effect of a demand-side intervention to settle.

3.1 The Dynamic Hypothesis

Drawing together the elements presented in section 3 above, the following Causal Loop Diagram (CLD) in Figure 6 elaborates further on the proposed dynamic hypothesis responsible for the problematic behaviour (high costs) on the Greek islands.

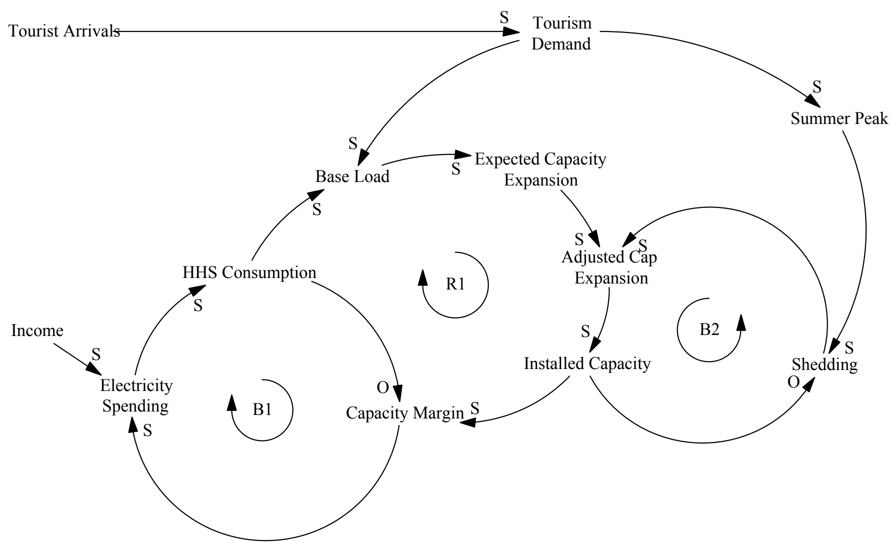

Figure 6: Telling the story with a Causal Loop Diagram.

The CLD consists of two balancing (B1 & B2). All the elements are interlinked demonstrating the endogenous reasoning of the dynamic behaviour whereas there are two exogenous elements, household income and tourist arrivals. Going around B1, an increase in household (hhs) consumption leads to an opposite direction change, i.e. decrease, in the capacity margin. Moving around the loop, a decreased margin will likely cause reduced electricity expenditure subject to income, as the possibility of outages is higher. Eventually, the loop closes by forcing hhs consumption to decrease.

Assuming a similar initial change but following loop R1, one ends up generating a further increase in hhs consumption. This reinforcing effect is assumed to be at play, for example in the case of Serifos, being dominant and responsible for the exponential growth pattern. The disrupting role of tourism is central to the dynamics of the system and is effectively acting as an agitator once a year peaking in August. On one hand, it intensifies the base load profile, which distorts the forecasting data and amplifies response, i.e. greater one-off capacity investments. On the other hand, it initiates peaks of random nature, duration and timing that can cause extremely fuel consuming operating conditions, outages or even propagate into the forecasting horizons amplifying even further any investment imperatives.

The former effect is captured within R1 by being added directly to the base load. This indicates that it is assumed largely predictable. The latter impact of peaks forms itself a balancing loop that feeds into an adjusted capacity expansion suggesting that power shedding is unacceptable due to the social remit of the PPC and the decision-making in place acts to mitigate any gap.

To summarise, the more the foreign and domestic tourists, the higher the energy requirements during the summer. As soon as there are repeated losses of load in the summer, the PPC will have to add capacity to stick to its public service obligations. However, during the winter demand is roughly 20% lower than in summer (Haralampopoulos, Fappas, Safos, and Kovras 2001, 26:187-196). As incomes grow (also due to tourism) and electricity comfort is lacking, this capacity will be absorbed by the households. The next power shortage is not likely to arise until a few summer seasons depending on tourists arrivals which is exogenous to the system (bound to the international economy and competition). This circle is repeated over the years leading to the exponential growth seen for Serifos since the dominant loop is R1. As long as measures of energy efficiency are not institutionally initiated the demand will always rise due to the intricate dynamics of the island economies (high building rate, increasing volumes of tourism and rising standard of living).

3.2 The Residents and Tourism

The model assumes an island of 1,000 households with the following appliances:

Table 2: The typical household's pool of appliances in the Average island.

Description of appliance	Number	Rating (W)	Cons each for1hr (kWh)	Operation details
Incandescent light bulbs	5	100	0.10	5 hours each a day. Winter darkness substituted by summer late nights.
Space heater (electric)	1	2000	2.00	2 hours per day for 6 months each year.
Water heater (electric) [50°C for 80lit]	1	4000	2.60	2 hours per day.
Refrigeration [131lit]	1	90	0.50	24hrs figure. All year.
Air Conditioning	N/A	-	-	No A/C yet.

That amounts to an average consumption 310 kWh a month. The peaks of the household sector are assumed to be covered by capacity expansion to meet summer peaks therefore have not been explicitly modelled. Indeed, there is hardly any occasion where out-of-season peak demand exceeds installed capacity (PPC 2002).

Also, assume that each tourist comes on a two-week holiday package and receives the following energy services:

Table 3: Services to a typical tourist on a two-week holiday package.

Description of service	Number of appliances	Rating (W)	Cons each for 1hr (kWh)	Service use details
Lighting	4	100	0.10	8hrs per day (assume 1 bulb per commercial place visited)
Air Conditioning [per 15sq.m.]	1/2	1000	1	2hrs in room, 1hrs in shops & 2hrs in entertainment. 5hrs in total.
Hot water [50°C for 10lit]	1	2000	0.33	1 shower per day. Equivalent to 2hrs use as service not customised (losses).
Dining (refr'n) [131lit]	1/2	90	0.50	24hrs operation. Everyday.
Cleaning services	1/2	2800	1.30	Laundry: 2hrs/week
(laundry+dishwasher)	1/2	3200	1.30	Dishwasher: 2hrs/day

Each tourist loads the system by 245 kWh on a monthly average and carries a peak demand of 2.5 kW.

3.3 The Technology Substitution Sub-model

The critical component to the objectives of this paper is the introduction of an additional sub-model that basically isolates a consuming technology out of the electricity services basket of households.

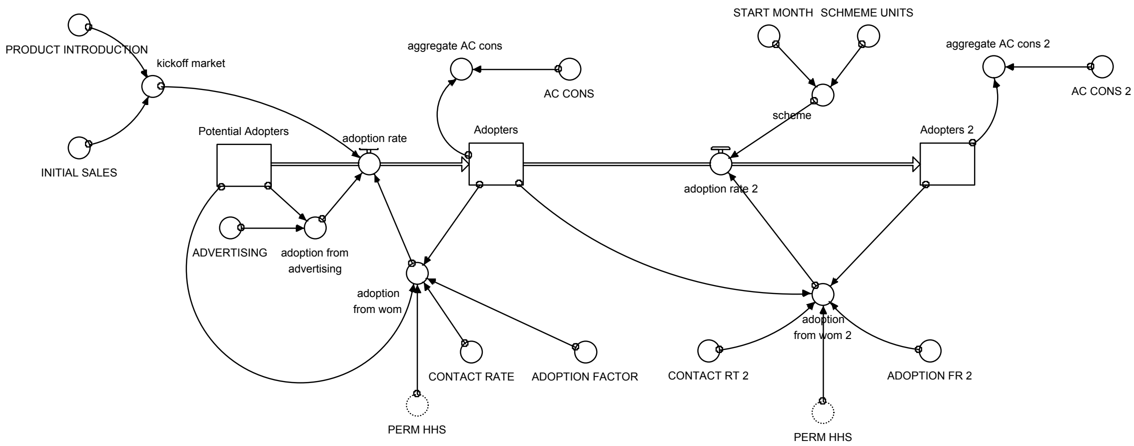

Figure 7: The technology spread and substitution curve.

It is assumed this technology is an air-conditioning units that was not originally included in the list of services in Table 2. The concept is that a market for the service develops until some point that a more efficient mark of the unit is available.

The timing and size of a supposed efficient units demonstration scheme decided by the policy-makers, as well as parameters relating to word-of-mouth effect, will define the substitution function. The policy-maker has to be able to assess the cost of the scheme with respect to the expected benefits but also intervene in the word-of-mouth dynamics of the population. It should be noted that this component has been parameterised to demonstrate its potential impact during simulation and does not constitute a culmination in research on substitution dynamics in the context of the Greek islands or the assessment of costs and benefits to producer and consumers.

4 OVERVIEW OF SIMULATION RESULTS

The initial condition for which the model is tested simulates a situation where there is only increasing household consumption. After an initial investment the system stabilises at 755 kW installed capacity. During the simulation there are two occasions where the consumption rate (forecasted) comes close to available supply and the expansion mechanism is put at work to mitigate that (Figure 8). At year 15, installed capacity is up 50% to 1,100kW and ten years later it has to increase by another 400kW.

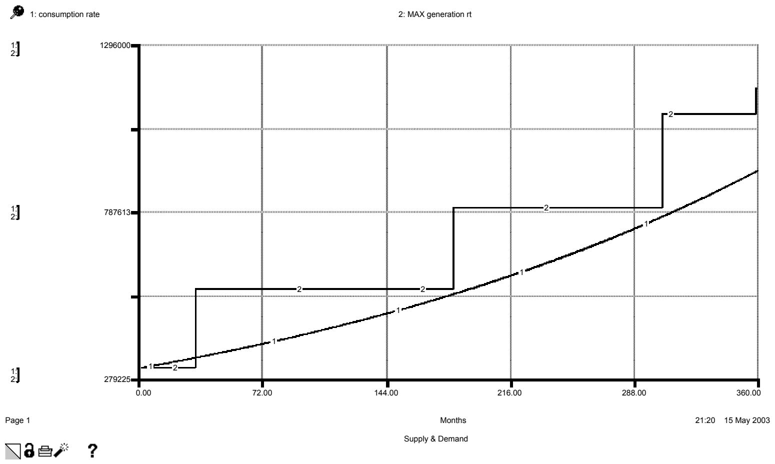

Figure 8: Max generation and consumption rates. No efficient technology or tourism.

The following test (Figure 9) is assuming a new energy service (i.e. electric air-conditioning units) is available to the households from the start of the simulation and then eventually replaced with its efficient (at 1/3 rating) version available at month 100.

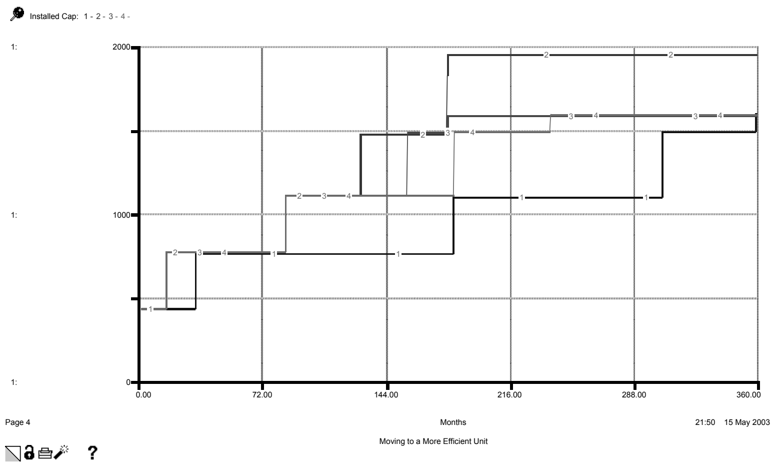

Figure 9: Replacing with more efficient equipment.

Line -1- represents the original situation as in Figure 8. Line -2- is the capacity expansion with the new energy service technology becoming dominant and available in the original consumption rating only. There is additional capacity investment and also change in the timing and amplitude of all additions likely to incur relative additional costs to the system (i.e. the time value of money having to invest now rather than later).

The calculation of that cost is beyond the reach of this paper but forms an integral part of the broader research topic. The installed capacity for Line -2- capacity stands at about 470kW more than Line -1- by the end of the simulation. Lines -3- and -4- indicate a 'softer' and 'harder' institutional promotion of the more efficient version respectively. It is noted that the impact of these two modes is not as significant as the introduction itself. This can be attributed to the nature of the service (air-conditioning) designed to be in high demand, only available to households and reaching saturation within the simulation horizon. However, the major impacts of efficiency are investment deferral and size of additions as can be noted in both lines. By the end of the simulation, installed capacity is as low as 20% compared to Line -2-. Figure 10 shows the substitution curves at play behind the impact of efficiency.

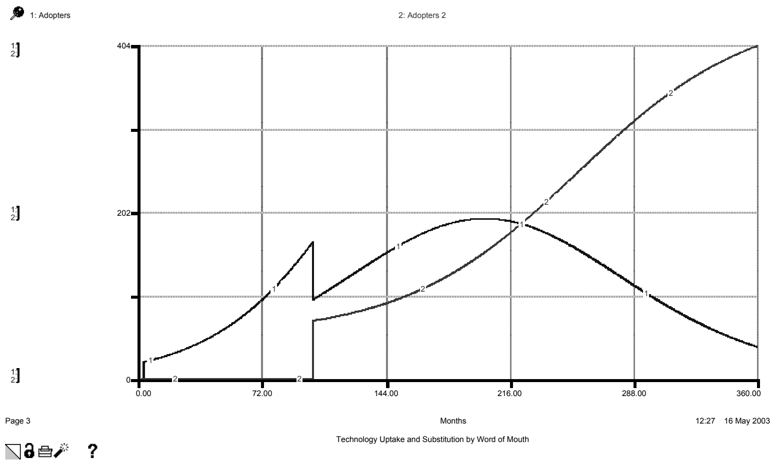

Figure 10: The substitution curves.

The final test introduces a wave of tourists.

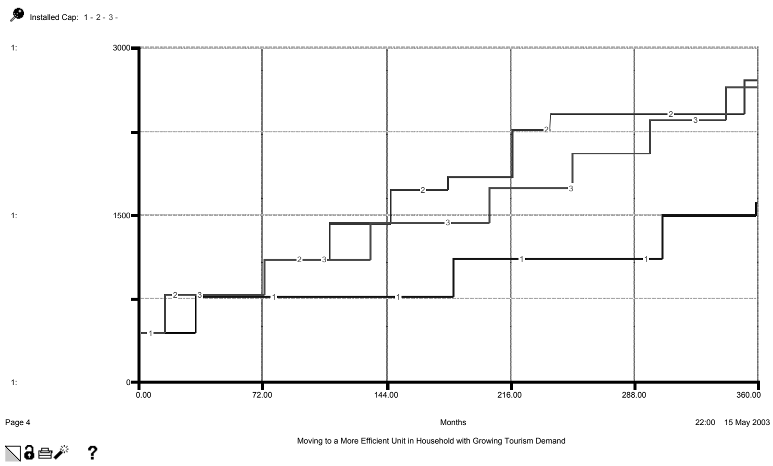

Figure 11: Impact of tourism on capacity expansion.

In Figure 11 above Line -1- represents the original no A/C unit and no tourism condition for comparison. Then, a seasonal, varying but steadily increasing wave of tourists is introduced at the beginning of the simulation along with the new energy service (in its original rating mark). This situation is represented in Line -2-. The situation seems to be spiralling out of control with very short and erratic capacity additions. Allowing the intervention of more efficient A/C units to take effect, there is a noticeable impact on timing of the expansion (i.e. deferral) and less on scale as sketched in Line -3-. However, the system still expands well beyond what can be intuitively considered an economic sense in comparison to the initial situation (Line -1-). That confirms the design of the simulation model, which had to capture the very disrupting role of uncontrolled tourism demand, and indicates towards the justification of great generation costs referred to at the start of this paper. One can envisage the mismanagement of resources being due to this inability to control such a situation, especially when the operator's basic institutional lever seems to be building more capacity as in the case of the PPC!

5 CONCLUSIONS

The preliminary simulation exercise undertaken in this paper proves the great utility of System Dynamics methodology to analyse and understand a complex management structure with cause-effect relationships and a mixture of physical and policy-making arrangements. The benefit of looking into islands is that simulation is attempted on an energy system in its most basic configuration but still found in the real world. Among the benefits of examining autonomous island energy systems are the traceable demand and supply characteristics, the availability of historical data in a comparable format and a straightforward local economy structure with recognisable links outside their physical boundary.

Despite its limitations, the model raises questions and dialogue about the future of energy policy in the Greek islands. Most significantly, it sketches a micro-world where the links among sectors of the economy, stakeholders and exogenous factors although simplified for modelling purposes still maintain significant validity to the real case. Eventually, this exercise unveils the structures that can turn the islands' energy system into a healthy and even profit-making organism. Further research on the topic aims to unveil a viable set of options to make that change possible to a policy-maker.

On the actual lessons learnt, despite the efficiency gains of a technology being exogenous to an island, once such an improvement is commercially available, policy-makers and the system operator can provide incentives to bring about the expected benefits. Determination of the nature, timing, size and relative advantage of candidate strategies is possible though a tool such as proposed here. One could intervene in boosting retail entrepreneurship, draft regulations for replacing old equipment or introduce a subsidy for substitution – a dynamic cross-sectoral model can relatively assess the results of such a variety of measures. The tourism sector has proved to be a major energy consumer with great impact on the size and cost of the system despite its periodical appearance.

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