Imperial College London
Centre for Environmental Policy

Seasonal power peaking and the diffusion of demand-side technologies

Modelling socio-economic and technical dynamics in the Greek islands

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ABSTRACT

The research focuses on the Greek islands of the Aegean archipelago that are not connected to the national grid. Their electricity systems run at a great cost to the rest of the country because electricity tariffs are kept the same as those of the mainland. However, the real cost can be ten times that in continental Greece, due to exclusive use of relatively small diesel generators operating there, as opposed to the varied continental generation mix that includes heavy duel oil, natural gas, hydro and wind power, and which is 64% indigenous lignite based. In addition, power peaks and overall consumption in the islands have been increasing almost exponentially due to the highly seasonal (June-August) tourism wave that further drives capacity additions subsequently left unused for the rest of the year.

The key aims of the thesis are:

- To build a simulation model to capture and comment on the dynamics of the power system development and associated costs in the islands, incorporating and studying behavioural characteristics and feedbacks of stakeholders using the methodology of System Dynamics.
- By means of this model explore scenarios and success factors for the diffusion of demand-side power saving equipment, considering learning curves, substitution dynamics and the interaction with the local economy's competitiveness.

The outcomes of the research address the following issues:

- The exploration of strategic options to reduce the costs of energy services in the islands without hindering the local economy, while continuing to satisfy the current and future demands for energy services.
- How might the interests and objectives of consumers, local business, and the utility operator towards sustained community growth be balanced through the introduction of innovative demand side management and new technologies.
- The critical parameters in technology commercialisation in the Greek islands and their interactions with existing perceptions of social policy, local economic structures and local technical competence.

In addition to the above, a role-playing simulator is proposed and briefly tested on post-graduate students of the Centre for Environmental Policy of Imperial College London.

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GLOSSARY

A/C	Air-Conditioning
AOSIS	Alliance of Small Islands States
APS	Autonomous Power System
BAU	Business As Usual
BEP	Break-Even Point
CAD	Computer Aided Design
CF	Capacity Factor
CLD	Causal Loop Diagram
COP	Coefficient of Performance
CRES	Centre for Renewable Energy Sources (GR)
DSM	Demand Side Management
DSWH(S)	Domestic Solar Water Heater System(s)
DT	The Time Step of the simulation
EER	Energy Efficiency Rating
ELAC	ELectric Air-Conditioning
ESIF	European Solar Industry Association
EU	European Union
GDP	Gross Domestic Product
GIS	Geographic Information System
GNTO	Greek National Tourism Organisation
gr/kWh	Grams per kilo Watt-hour
GSEA	Greek Solar Energy Association
GWh	Giga Watt-hour
HTSO	Hellenic Transmission System Operator (GR)
IEA	International Energy Agency
kW	Kilo Watt
kWh	Kilo Watt-hour
LiBR-H2O	Lithium Bromide-water
LOLP	Loss of Load Probability
LPG	Liquid Petroleum Gas
LR	Learning Rate
MW	Mega Watt
NH3	Ammonia
NH3-LiNO3	Ammonia-lithium Nitrate
NH3-NaSCN	Ammonia-sodium Thiocyanate
NOA	National Observatory of Athens (GR)
NSSG	National Statistical Service of Greece
NTUA	National Technical University of Athens (GR)
O&M	Operation & Maintenance
PPC	Public Power Corporation (GR)

PR	Progress Ratio
PV	PhotoVoltaic
R&D	Research and Development
RAE	Regulatory Authority (GR)
RD&D	Research, Development & Demonstration
RES	Renewable Energy Sources
SD	System Dynamics
SFD	Stock and Flow Diagram
SIDS	Small Island Developing States
SRAC	SolaR assisted Air-Conditioning
SWH(S)	Solar Water Heater System(s)
TJ	Tera Joule
TWh	Tera Watt-hours
UF	Utilisation Factor
UNEP	United Nations Environment Programme
W	Watt
WTO	World Tourism Organisation
WTP	Willingness To Pay

1 INTRODUCTION: THE PROBLEM AND HOW IT IS ADDRESSED

The background, aims and objectives, expected outcomes as well as an outline of the methodology of the research are summarised in this chapter. A comprehensive problem description, the research questions and boundaries are also presented. It begins with a brief outline of the essential background.

1.1 THE BACKGROUND IN BRIEF

This thesis mainly concerns two wider issues. Primarily, it attempts to address the pragmatic and pressing need for better, more and cleaner electrical and heat energy to satisfy the development of isolated island communities. Secondly, it explores elements of the commercialisation process of sustainable energy technologies in an increasingly competitive environment that demands ever-shorter times for technological innovation and market adaptation.

The combination of small size, limited local natural resources (or restrained financial resources when there is a technical potential, e.g. for investment in renewables) and high fuel transport costs make islands ideal niche markets for early diffusion and testing of innovative technologies and associated policy-making. This research is adopting both these urgencies, looks into the principles and dynamics involved in new and clean energy-related technology promotion and suggests a tool to analyse commercialisation pathways in niche applications.

The thesis focuses on a particular set of islands, Greek islands of the Aegean archipelago not connected to the national grid. This focus facilitates the description of research aims and objectives based on real issues in specific locations while also permitting cross-examination and discussion of modelling results with existing and accessible stakeholders.

The energy costs of unconnected Greek islands are a significant burden for the rest of the country. There is a strong tradition of energy, and other, indirect subsidies administered by the Public Power Corporation (PPC), with the political aim of countering the 'inefficiencies' of island economies to ensure the meeting of nationwide socio-economic targets The greatest example of this is that electricity tariffs are uniform across Greece. They are calculated on the basis of a generation mix wholly owned by the State and based more than 60% on cheap indigenous lignite (IEA 2006), which does not reflect at all the technologies and real costs of power generation in the islands.

The inherent political goals of the social policy followed, generate the expectation that all commodities found on the mainland should be available to the same degree to island communities for the same price. With respect to energy not only the commodity but also the method of delivering it does not take into account the technical constraints (e.g. logistics) or, in the case of renewable energy sources, annuls their benefits as the real costs are not reflected in the price of electricity and no externalities are formally accounted for. Since economic constraints are paid for by State concessions, or indirect subsidies, these costs are rarely felt by the consumers, whether inhabitants or visitors. As a result their consumption remains in effect unmanaged and the demand keeps on surging only to be served by more inefficient supply in a vicious cycle. The steady rise of tourism as a dominant source of income makes the hotel and services sector the main cause of the problem. More specifically the demand for cooling comfort by both residents and visitors drives the demand peaks of the summer season; a widely accepted fact as will be seen in the literature review.

1.2 AIMS & OBJECTIVES

1.2.1 AIMS

This thesis has two aims:

- Build a simulation model that captures the dynamics of the islands' energy systems and portrays the behaviour of stakeholders and its impacts by integrating sectors and concepts not conventionally considered part of utility management, thereby providing a tool that might enhance the role of energy policy making in the islands.
- Explore the potential and critical parameters in the uptake of innovative demand-side technologies, to assess whether and how these technologies could provide a better service to consumers and improve the financial performance of the small island utilities without impeding the local economy.

The analytical approach applies principles of Systems Thinking[1] and employs non-linear simulation modelling in an in-depth cross-examination of local social, economic and environmental circumstances.

1.2.2 OBJECTIVES

- Identify key economic and social stakeholders and factors that characterise the relationship, feedback effects and interdependencies, and dictate transitions and shifts in the energy systems of the Greek unconnected islands.
- Study the marginal costs involved in supplying power to the island communities and assess the costs of electricity provision.
- Identify the interaction of consumers' choice, preferences and habits and explore their sensitivities to parameters of the local economy and technology promotion.
- Discuss policy options and combinations of policies that might reduce costs of power to the islands, promote the diffusion of innovative technologies and challenge the current inefficient and costly paradigm.
- Propose a role-playing computer-based simulator and assess its potential in training policy-makers and students on topics of energy-policy and the Greek islands in specific.

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[1] Systems Thinking is a conceptual framework consisting of empirical knowledge and a set of tools that has been developed over the past fifty years to study and manage complex feedback systems, such as one finds in business and other social systems. For an overview refer to "The Fifth Discipline" handbook (Senge 1990). Foxon and Pearson in their 2008 paper on *sustainable innovation* (SI) adopt systems thinking as one of their two guiding principles for policy makers to 'promote a transition to sustainability' (Foxon & Pearson 2008). The thesis in a way is examining *sustainable diffusion* of demand-side equipment as innovation is not deemed viable in the context of the islands (Appendix B).

1.3 METHODOLOGY

The thesis is built on three tools:

1) Extended bibliographical research

2) Consultation & interviews

3) Simulation modelling

The process of narrowing down the geographical focus of the research follows the pattern in Box 1 below:

Box 1: Geographical narrowing-down of research

Remote communities & islands	→	General and energy related issues facing such communities. Keeping the context with the International perspective of the research.
Mediterranean islands	→	A set of islands of roughly similar size groupings, destination attraction & visitor profile. Used in construction of competitiveness index in the model.
Unconnected Greek islands of the Aegean Sea	→	Pressing power supply problems and rapid development. A more homogeneous albeit varied study environment.
Medium & medium-large islands of the South Aegean	→	These islands include some of the most rapidly growing islands that need immediate attention. Extended bibliography exists.

1.3.1 LITERATURE REVIEW

A wide variety of sources were initially consulted on the broader topics of energy policy and management, island and small island state development, experience and learning curves, energy technology markets, climate change, utility finances operation and engineering. Eventually, four themes constitute the main bulk of the research, namely:

- Power consumption, renewable energy, and demand-side management in the islands of the Mediterranean and selected international cases.

- Economics, dynamics and case studies of niche market development in the energy sector (barriers to entry, market structures, word of mouth, and technical progress), learning and experience curves.

- Economics and finance of consumer choice, production, producer-consumer surplus, utility and product pricing.
- Systems Thinking as a tool for addressing complex systems with feedback effects and the use of Systems Dynamics[2] (SD) modelling in energy- related literature.

1.3.2 INTERVIEWS

The first round of interviews was conducted with identified key stakeholders in Athens between 2002 and 2003. These interviews explored the assumptions held from an initial literature screening put on draft model structure and provided the platform for planning the research. These meetings had the format of consultation. Reinforced assumptions following those sessions provided the Causal Loop Diagrams that sketch the dynamic assumptions of any SD model and produced the first heuristics of a crude draft of the simulation model. A second round of consultation took place between 2006 and 2007 to reiterate the assumptions of the final draft of the model and validate the choice of scenarios, technologies and conditions of the simulation runs. Site visits were performed in the same periods as the interviews.

Contact was established with the Public Power Corporation (PPC) and members of staff in its Island Directorate and the Renewables Office, the Centre for Renewable Energy Sources (CRES), the National Technical University of Athens (NTUA), the Regulatory Authority of Energy (RAE), the National Observatory of Athens' (NOA) Sustainable Group, the Ministry of Development, large private companies involved in energy, and manufacturers of domestic solar water heaters (DSWH).

[2] System Dynamics is an integral part of Systems Thinking that takes the additional steps of constructing and testing a computer simulation model. The difference from other approaches to studying complex systems is the use of feedback loops. Stocks and flows help describe how a system is connected by feedback loops which create non-linearity. Running "what if" simulations to test certain policies on such a model can greatly aid in understanding how the system changes over time. The seminal work of Derek Bunn and Erik Larsen who looked at "how more regulatory intervention in managing the construction and retirement of plant can provide the circumstances by which the new market system can behave with more stability in the way it was intended" in the early days of the UK power market deregulation can be referred to for demonstration of the methodology (Bunn & Larsen 1994).

1.3.3 MODELLING

Given the complexity, non-linearity and historic perspective of the issues involved, a dynamic simulation model is developed to represent a typical island energy system. The model simulates the reactions of the system to impulses from tourism, technology availability, fuel price, and household income. The model embraces the insights and observations arising from the literature review and interviews, providing the ground to discuss future scenarios and intervention policies.

1.4 PROBLEM DEFINITION & BOUNDARIES

1.4.1 PROBLEM DEFINITION

The energy systems on the grid unconnected (also referred to as autonomous) Greek islands of the Aegean Sea exemplify five main characteristics in varying scales across the archipelago. These characteristics also underlie their problematic behaviour:

1. High costs of electricity, most of which is generated by expensive stacked diesel and HFO units, which is subsequently sold at subsidised rates to end-users.

2. Predominantly mid-voltage (20kV) and distribution level local grids and limited interconnections to neighbouring islands that would allow load sharing.

3. A highly seasonal and energy-intensive tourism sector.

4. A growing residential consumption mainly attributed to rising incomes and growing numbers and usage of readily available electric appliances.

5. Limited use of renewable energy resources due to licensing, planning, system balance and social acceptance bottlenecks resulting in heavy reliance on imported fuel oil for the generation of electricity and heat.

The Public Power Corporation (PPC) solely operates the autonomous power systems (APS) of the Greek unconnected islands through its Island Directorate. The total cost of generating one kWh of electricity on the islands ranges from €0.11 to €1.20 (Betzios 2003b;PPC 2002); Kaldellis, who has extensively researched and written on the energy situation of the islands over the past 10 years, estimated mean electricity production of medium and medium large islands at €0.15 to €0.40 per kWh (Kaldellis & Zafirakis 2007). Figure 1 shows the historical growth of kWh cost in selected islands.

In a recent conference on the issues facing the energy sector of the Greek unconnected islands, the average variable cost based on 2006-7 fuel prices was calculated at €0.11/kWh while the full cost according to the PPC was reported at roughly €0.145/kWh, more than twice the value of €0.66/kWh for the mainland (IENE 2008). Once the fuel price increases of 2007-8 were considered, conference participants estimated the mean running cost would jump to €0.135/kWh, with the full cost approaching €0.17/kWh.

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-cost difference amasses each year to an unavoidable gap in the finances of the corporation. For 2001 it was estimated to stand at €340 million and rising[3] (Betzios 2003a) while the PPC itself estimates it at €442 for 2007, in a paper presented by Nikos Boulaxis of RAE at a recent conference(IENE 2008). If this figure is correct, that represents a 5% debt increase rate per annum!

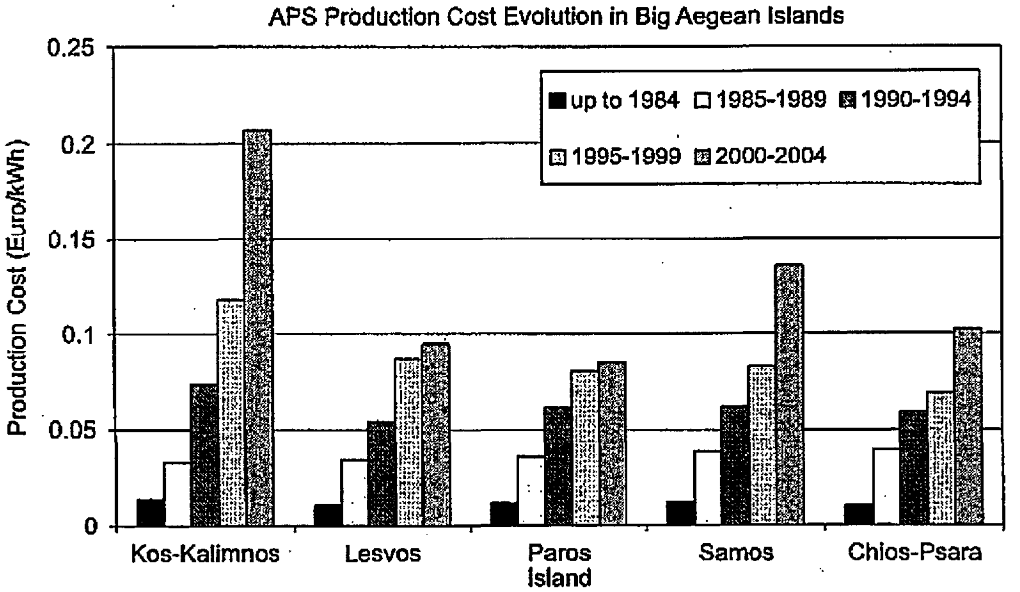

Figure 1: Cost evolution of electricity in the unconnected Greek islands of the Aegean Sea (Kaldellis & Zafirakis 2007)

1.4.2 BOUNDARIES

In brief, the research is concerned with an island's incumbent energy system and its management, the consumers and their habits, and, finally, any economic, trade or environmental policies affecting its evolution. With respect to system intervention, demand-side equipment for air-conditioning is chosen by researching the literature and statistics of power consumption also because there is previous experience of

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[3] Excluding Rhodes and Crete.

successfully introducing a technology to a similar service, i.e. hot water and domestic solar water heater systems (DSWHS). The ensuing simulation should allow for policy interventions that could be implemented at the local level even if initiated by central administration. As an example, decisions about the promotion of tourism in the country are nationwide, centrally planned and executed, therefore will be considered exogenous. So are airlines' and tour operators' destination development practices. However, a government policy that subsidises installation of more efficient air-conditioning units is a legitimate intervention for the purposes of the thesis. The building rate and the carrying capacity of the island for tertiary activity would be within the boundaries but out of the scope of this study. Further clarification on the boundaries of the research is provided in the chapters and sections of the thesis in places where the author realises the need to make it explicit.

1.5 THE RESEARCH QUESTIONS

1. Are there ways to reduce the costs of energy services in islands without hindering the local economy, while continuing to satisfy the current energy service needs of the people and manage their evolution?

2. Could the interests and objectives of consumers, local business, government planners and the utility operator towards sustained community growth be balanced through the introduction of innovative demand side management and technologies?

3. What are the critical parameters in technology commercialisation in the Greek islands and what are the interactions with existing perceptions of social policy and local economic structures?

1.6 CONTRIBUTION

In this thesis the author expects to have contributed to the following:

- The understanding of the dynamic interaction, feedback effects and non-linearities among energy policy making, socio-economic sensitivities and disruptive technology promotion in fragmented energy systems under central administration.
- Plausible national and local policy suggestions to influence investment in demand side management and a tool to aid the socio-economic study of such systems.
- An insight into the use of System Dynamics in the analysis of small-scale energy systems and the challenges of point (discrete) events in time-continuous dynamic modelling.

1.7 EXPECTED OUTCOMES

The research aspires to provide:

- An economic appraisal and utility cost benefit analysis for the selected demand-side policies proposed in the context of the chosen island(s).
- A simulation model that can assess the impact of government policies, ranging from fuel pricing, to industry subsidies and tourism promotion, on the financial performance of island energy systems.
- A set of strategic recommendations for the utility operator and policy-makers to decrease the expenses involved in autonomous island power supply, while maintaining or enhancing access to good quality energy services.
- A first draft version of a role-playing simulator.

1.8 OUTLINE OF THE THESIS

Chapter 1 INTRODUCTION: THE PROBLEM AND HOW IT IS ADDRESSED

As seen already it lays out the aims, objectives, expected outcomes and provides the background to the research.

Chapter 2 THE GLOBAL PERSPECTIVE ON ISLANDS

Draws the global relevance of the research on issues that the Greek islands also face and makes a case for the pressing need to deal with the sustainable development of island communities.

Chapter 3 THE GREEK ISLANDS

Provides an overview of the key socio-economic and energy features of the Greek islands in focus, makes the case and draws the setting for policy intervention on the demand side and summarises elements of potential use in the modelling exercise.

Chapter 4 CRITICAL LITERATURE REVIEW

An extensive critical and comparative review of published research and policy documents supplemented by selected interviews with institutional and research agents, the regulator and the utility. Develops topics raised in the previous chapter, identifies gaps in the contemporary research and discusses experience in past and current policy in energy in the islands. It further identifies sources of data for the construction of the simulation model.

Chapter 5 SOLAR TECHNOLOGIES & THE GREEK EXPERIENCE

A chapter dedicated to explore and exploit the know-how of the Greek solar water heater market; an international success story. Seeking for similarities and spill-over learning for the envisaged solar assisted space cooling as well as an empirical guidance for the progress ratio itself. Also studying the national experience in solar photovoltaic and the existing demonstration projects of solar cooling in the country.

Chapter 6 BUILDING THE SIMULATION MODEL

The chapter consolidates all previous analysis into a simulation model through a detailed methodological approach to capture the correct dynamics, interrelations, feedbacks and non-linearities of the islands in question. The model is behaviourally calibrated and tested. Modelling decisions are explained and observations made where academic value ensues.

Chapter 7 POLICY DESIGN AND EVALUATION

Having configured a model that integrates socio-economic behaviourism, utility management rules of thumb and policy levers for the diffusion of efficient technology, a number of scenarios and what-if cases are put to the test. The impact on utility, social, private and technological progress indices of performance is documented and commented upon.

Chapter 8 CONCLUSIONS, STRENGTHS AND LIMITATIONS AND FURTHER RESEARCH

The thesis is evaluated against the original aims and objectives. The main findings and insights are summarised and elaborated drawing from the entirety of the thesis. The approach and methodology as well as outcomes are critically assessed, limitations brought forward and potential future directions for further research proposed.

2 THE GLOBAL PERSPECTIVE ON ISLANDS

The aim of this chapter is to draw out the relevance of the research in the context of issues recognised globally but that also face the Greek islands. It also makes a case for the pressing need to deal with the sustainable development of island communities Consequently, this chapter outlines the global issues concerning small islands around the world. To keep within the scope of the thesis, bibliographical sources relating mainly to the work of the broader United Nations network have been reviewed since it is this body that leads the bulk of research in those communities and worldwide.

Structure of Chapter:

2.1 INTRODUCTION & BACKGROUND
2.2 ECONOMY AND TRADE
2.2.1 Tourism
2.3 ENVIRONMENTAL THREATS
2.4 ENERGY AND ISLANDS
2.5 POLICY ISSUES
2.6 CONCLUDING REMARKS

2.1 INTRODUCTION & BACKGROUND

Small islands on the globe are scattered over a range of physical and socio-economic conditions. These in turn generate particular demands on the natural environment and the human society alike. Examples of physical characteristics are related to geographical location, meteorological conditions, size, proximity to other land areas and ecology. Socio-economic issues include population size and growth, type of administration, natural resources and the activity of the economic sectors. In terms of geographical location islands can be classified as follows (UNEP 2008), also depicted in Figure 2:

i) The Caribbean islands,
ii) The Indian Ocean islands,
iii) The Pacific Ocean islands,
iv) South Asian islands,
v) The Atlantic Ocean islands and,
vi) The Mediterranean islands.

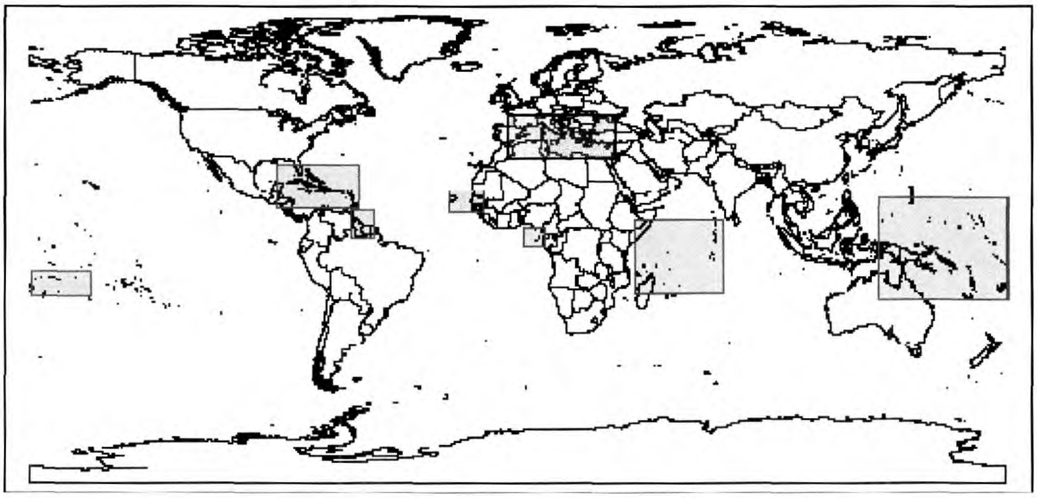

Figure 2: Map indicating main small island groups (UNEP 2008)

A political separation is often made between *sovereign* and *non-sovereign* islands. In international donor terminology sovereign islands are also referred to as SIDS (Small Island Developing States) and their great majority is found in the first five categories above. Due to their fragility, small islands have received much attention as the concern on the environmental state of the planet and climate change developed in the 1990s. Box 2 summarises UN's activity related to small islands.

Box 2: Summary of key dates and developments in UN's SIDS policy
Compiled from (SIDSNET 2008;UN 1994;UNEP 2008;UNESCO 1999a;UNESCO 1999b)

The special development needs of small island developing States received an unprecedented boost at the United Nations Conference on Environment and Development, convened in June 1992 in Rio de Janeiro. In chapter 17 of Agenda 21, the comprehensive plan of action adopted by Governments during the Conference, the international community explicitly recognised the special constraints to the sustainable development of small island developing States. That recognition led the General Assembly to call for a Global Conference for the Sustainable Development of Small Island Developing States, which was held in April-May 1994 in Bridgetown, Barbados.

During the World Summit on Sustainable Development, Johannesburg (August-September, 2002), Governments reaffirmed the special case of small island developing States, and called for an international meeting on their sustainable development. The General Assembly decided to convene an international meeting in 2004 to undertake a full and comprehensive review of the implementation of the Programme of Action on Small Island Developing States. The Global Programme of Action (GPA) – for the Protection of the Marine Environments from Land-based Activities – Coordination Office provides the overall coordination of UNEP's programmatic delivery in Small Island Developing States since March 2003.

The international meeting took place in Port Louis, Mauritius, in January 2005. This resulted in a renewed political commitment by all countries for the further implementation of the Programme of Action and the Mauritius Strategy. As per this Strategy, the United Nations is requested to mainstream SIDS issues within the mandates of its agencies, funds and programmes to facilitate coordinated implementation at national, sub-regional and global levels.

On 23 November 2005, Food and Agriculture Organization (FAO) held a Special Meeting of Heads of State and Government of Small Island Developing States. The meeting considered action proposals recommended by the Ministerial Event of 18 November and adopted Rome Declaration highlighting principles and actions of critical importance to SIDS.

The Intergovernmental Preparatory Meeting for the 15th session of the Commission on Sustainable Development (New York, February-March 2007) featured a SIDS Plenary. UN-DESA SIDS Unit convened an Expert Group Meeting to begin consideration of a framework for monitoring progress towards the mainstreaming of the Mauritius Strategy of Implementation (MSI) within the United Nations system in New York in April 2007.

It has long been recognised that small islands, whether states or not, are facing similar problems mainly due their ecological fragility and the vulnerability of their small economies to internal and external shocks. Their small territorial and population size, limited natural resources and isolation from main markets, high transport and infrastructure costs, vulnerability to natural disasters and to the impulses of the international economy have been recognised by the international community as significant bottlenecks in the development of their people (Chandra 2009;INSULA 2008;Weisser 2004).

The following sections elaborate further on issues that affect islands' economies, mainly drawing on references from the second half of the 1990s where the bulk of the research and reporting has taken place. The topics discussed in this chapter were selected so as to develop a broader understanding of the global dimension of the problems that islands face and of the contribution of this thesis.

2.2 ECONOMY AND TRADE

The major assets of small islands are mainly marine and coastal resources, their natural beauty and their people. The UN sees human resource development as fundamental to general economic well being, to serve as a base for long-term sustainable growth and improved living standards (UN 1994;UNDP 2000). The disadvantages deriving from their location and physical characteristics directly affect economic life as in many cases natural resources cannot meet the rising standard of living and population growth. As a result resources are overused, rapidly depleted and degraded, creating a vicious circle of unsustainable resource exploitation (UNESCO 1999a).

In a broader perspective, the remoteness and dispersion of islands, especially of archipelagic islands, places them at a distance from trading partners. This separation gives rise to high transportation costs and infrequency of marine and air transport services, on account of the islands' low trade volume. Another significant constraint of their small size relates to a small labour force, whose limited size precludes the development of a critical mass of technical skills. At the same time the unit costs of social and physical infrastructure are high on account of low demand and sub-optimal use (AOSIS 2001).

New liberal arrangements in international economic activity have made island economies very vulnerable to shocks as there is an increasingly high degree of openness and narrow domestic specialisation for the export market (SIDSNET 2008). On the other there is near total reliance on imports, in most cases, of both consumer and investment goods, including technology and energy, which translates into high domestic prices (UNESCO 1999a). Even when per capita incomes are relatively high, the trading imbalance is decreasing absolute national savings, which are needed for critical infrastructure investments. The scale of such investments is particularly difficult to meet by national savings in SIDS, which suggests that the level of confessional assistance by international donors should not be decided only on the basis of islands' GDP. There is on-going work to construct vulnerability indices which go beyond GDP per capita, for the purpose of identifying the most deprived and risky areas (UNESCO 1999a).

Reliance on imported fuels burdens island states' financial budgets, stranding funds that could be used for other environmental, educational or development purposes. Therefore, promoting greater renewable energy penetration that is reliable, cost effective and well managed could gradually benefit island states by offsetting amounts of expensive fossil fuels. In the context of non-sovereign islands, potential benefits arise in being less prone to disruption of fuel supply due to weather and transport conditions, less storage and associated health and safety hazards. Central governments of non-sovereign islands in almost all cases fund the extra cost of delivery; thus it has been suggested that national treasuries might seriously economise in the long-term through investing in renewable energy (AOSIS 2001;Jafar 2000;Yu, Taplin, & Akura 1997).

2.2.1 TOURISM

Tourism in islands has adverse effects on freshwater, energy, food, land use and waste management and it is responsible for much of the recorded deterioration in this resources especially in the Pacific islands (PIFS 2002). Intense tourism exploitation can deteriorate the environment to a level where it has an adverse effect on tourism and the economy is weakened as a result. Tourism is an economic opportunity but is a threat to further development if not properly managed (WTO & Todd 2003). It has been argued that stakeholders of emerging tourism destinations should ensure sustainable development initiatives are encouraged, to prevent deterioration of their resources and to safeguard continued availability of resources in the future (Chandra 2009).

2.3 ENVIRONMENTAL THREATS

For the islands of the Pacific, the Caribbean and the Indian Ocean in particular there is significant and continued deterioration of the marine environment. Problems are mainly from: *marine spills* – oils, chemicals and other hazardous materials; *ship borne wastes* – oil, sewage and garbage; *sand extraction*, *seabed mining*, *transport of nuclear materials* and *watershed destabilisation* (UNESCO 1999b). Freshwater availability is a major issue and is worsening in almost all islands, characterised by constant shortages and/or deteriorating quality, with acute consequences for agricultural production and human health. In specific islands, intensive groundwater extraction is lowering groundwater tables to levels that allow saline intrusion. In addition to freshwater, untreated or partially treated domestic wastes and industrial effluents are posing a threat not only to groundwater aquifers but also to coastal zones. Intensified competition for land use has led to land degradation and land-based marine pollution, particularly in the Atlantic and Indian oceans, the Mediterranean and the Caribbean (INSULA 2008).

Energy generation options can have a great impact on the ecological performance of the islands. Transportation of fossil fuels increases risks of oil spills. Renewable energy technologies, in particular solar PV, require proper handling of battery chemicals. Energy policy on islands has a direct benefit tackling energy and environmental issues together (Weisser 2004;WTO & Todd 2003). For example, waste-to-energy schemes of appropriate sizes or scalable landfill gas installations could tackle increased waste generation and energy demand in peak seasons with a single installation. Water desalination is another example, where proper energy planning can have a synergistic affect on other environmental strains.

Yu et al. (Yu, Taplin, & Akura 1997) assert that 'environmental protection and ecosystem conservation should be integrated in the energy policy making processes, however, their value has not been determined in terms of market systems'.

2.4 ENERGY AND ISLANDS

Box 3 summarises the global issues affecting the energy systems of islands, according to a major study of the Alliance of Small Island States (AOSIS), updated with information from the International Scientific Council for Island Development (INSULA). AOSIS was established under the auspices of UN's Department of Economic and Social Affairs to function primarily as an ad hoc lobby and negotiating voice for small island developing States (SIDS) within the United Nations sessions.

Box 3: Summary of main global energy-related issues on islands

Based on: (AOSIS 2001;INSULA 2008)

ACCESSIBILITY
Accessibility to energy services varies widely within and among island regions. In the Pacific islands app. 70% of the people do not have access to modern energy services, with many living on remote islands or isolated rural areas. This compares to a global 30% of population with no access to modern energy services. Meeting the basic energy requirements and socio-economic needs of people with subsistence income remains top priority. In other regions it is less a problem of access but rather of affordability. Accessibility should be considered along security of supply and affordability of prices. Storage capacity should also be improved to minimise disruptions in islands where such problems exist.
RURAL ENERGY
The provision of energy services to rural areas and remote islands remains inadequate due to often dispersed and isolated nature of the population as well as the high costs of energy. Lack of adequate infrastructure or services. Ability to contribute towards costs of services and infrastructure hindered by low incomes. Although in some islands there have been efforts for integrated approaches to rural development (education, health, agriculture) penetration is still relatively limited.
FINANCING THE ENERGY SECTOR
Securing funding for development of the energy sector is a major bottleneck for remote islands. Within individual countries there is lack of financial resources and necessary capacity to support longer-term financing and programmes. AOSIS believes it can mobilise investments necessary by allowing CDM projects but not those related to sinks. Those would divert away funds for sustainable energy provision that links to general sustainable development issues.
ENERGY EFFICIENCY
Most islands are unable to make radical shifts in their energy mix over the medium term; consequently energy efficiency could prove vital to accommodate for rising demand and/or reduce prices. Need to look at all stages for efficiency; i.e. production, distribution and use.
ADVANCED FOSSIL FUEL & NUCLEAR TECHNOLOGIES
Majority of these technologies although mature in industrialised countries are still not suitable for smaller developing countries. It is seen that it requires resources that should better be put in the first instance to renewable resources. The current scale of the technologies makes them inapplicable to islands.

RENEWABLE ENERGY
Recognised as priority but plays a relatively minor role in the total energy balance at present. General need for increased development and utilisation. Implementation of better financial schemes for smoothing capital costs, improved system efficiency, and well-structured demonstration and training activities and programmes.
ENERGY-RELATED ISSUES IN TRANSPORT
Predominant consumer of imported energy. A growing concern in all islands. Energy per capita is very high if marine and aviation bunker fuels are counted. Linkages to tourism sector are evident. It is difficult to address the problem as the technology (cars) is to imported standards. Innovation in fuel technology are necessary along procurement policies to fit local circumstances. Support public transport.
INTERNATIONAL COOPERATION
Critical situation faced by SIDS underscores the need for intensifying national, regional and international cooperation in order to move towards sustainable patterns of production, distribution. External funding is of vital importance while they play a complementary and catalytic role in promoting sustainable development. Need to create favourable environment to investment from external private sector. Adopting relevant policies, fiscal incentives and long-term investor security. International community must support this.

2.5 POLICY ISSUES

Population and economic growth are often accompanied by growth in energy use. Electricity use is linked to economic growth more than population (UNDP 2000). Renewable energy does require start up costs often outside SIDS capacities. On the other hand the uncertainty of oil price is extremely disruptive and not sustainable for island states. In addition, one form of renewable energy could not be enough, but rather a mix of policies and systems (AOSIS 2001;Chandra 2009). In the aforementioned AOSIS publication, Prof Albert Binger, Director of the Centre for Environment and Development at the University of the West Indies, asserts there is no universal definition of renewable energy, and when considering sustainable energy we need to match this with the energy needs. It is important to understand the needs in order to get the services required. One must look at the gaps between the resource base and the services available. The choice of the energy resource/s to develop determines the funds left for other investments. The economic costs of developing the resource should not disrupt the well being of the economy.

Energy conservation is of outmost importance to the islands as it is a scarce resource and an expensive import. Proper demand side management has not been extensively sought after, as it requires adequate institutional backup and advanced technology, neither of which is easily transferable to islands due to their dependence on governing country, lack of personnel or remoteness (Briguglio 1995;Wade 2002;Weisser 2004).

2.6 CONCLUDING REMARKS

Small islands are sensitive both to environmental and economic conditions. In those islands and small island states where tourism has been replacing more traditional subsistence economies, the demands to service the visitors can further exacerbate the environmental fragility of the ecological and cultural systems that initially attract the visitors. Studies have shown that intense tourism can adversely affect the economy. Among the services residents and visitors are in growing demand of is electricity. The lack of or limited local resources means that imported fuels not only endanger environmental disaster but make power expensive when it exists. Demand side management and energy conservation is increasingly put on the table by leading experts who also suggest that each case (i.e. island or island complex) needs to be looked at in detail to customise solutions.

In the forthcoming chapters, the research focuses to the Greek islands first with an overview of their socio-economic situation and an introduction to their energy profile followed by a detailed literature review of their power systems along with other topics related to the research.

3 THE GREEK ISLANDS

This chapter provides an overview of the Greek islands of the Aegean Sea, including some essential political background and a more detailed review of the major energy related issues. The aim of this chapter is to describe key features of the broader geographical area of the research and to identify the most critical issues that need to be taken into account during the modelling exercise. These are concisely summarised at the end of the chapter. The Critical Literature Review chapter follows, in which the contribution of the thesis is analysed in more detail.

Structure of Chapter:

3.1 PREAMBLE
3.1.1 The Local Economy
3.2 REVIEW OF THE ISLAND ENERGY SYSTEMS
3.2.1 Energy Use
3.2.2 Electricity Use
3.2.3 Power Generation
3.2.4 Peaks & Capacity Factor
3.2.5 Capacity Expansion
3.2.6 Capacity Margin
3.2.7 Space Cooling
3.2.8 The Residential Sector
3.2.9 The Tertiary Sector
3.3 ELEMENTS FOR THE DESIGN OF THE SIMULATION MODEL
3.4 SUMMARY & CONCLUDING REMARKS

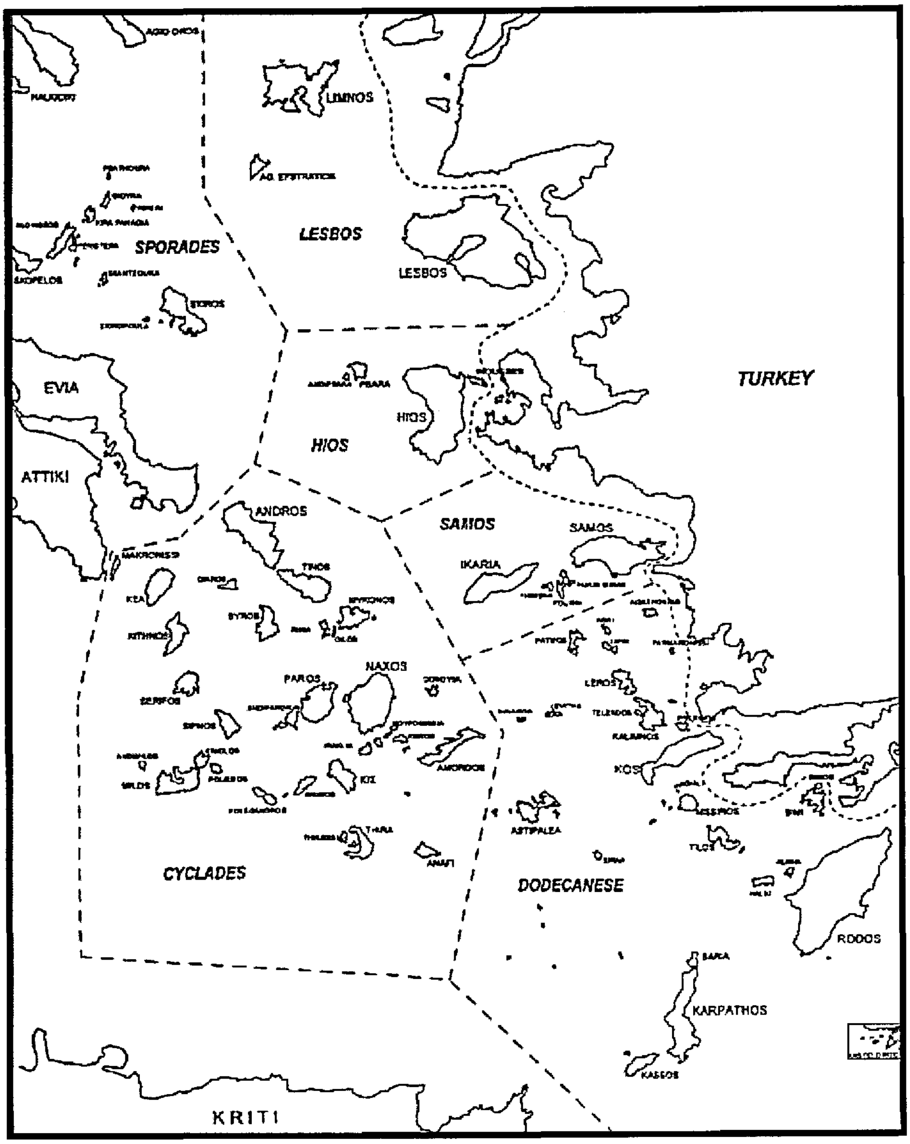

Figure 3: Map of the Aegean Sea (1:3500000) (Kaldellis & Zafirakis 2007)

3.1 PREAMBLE

The Greek islands of the Aegean Sea (Figure 3) provide a credible set of case studies that can be compared on the basis of similar parameters. Below is a summary of the main reasons that allow the required homogeneity:

<u>The geopolitical and social aspect.</u> There are dozens of islands, isolated by definition, but close enough and under uniform culture, language, administration, currency and legislation.

<u>The political situation.</u> EU law takes precedence over national legislation drafting the general policy directions, particularly in the energy sector. There is thus good information on the policies likely to affect the energy environment in the islands in the future by examining EU legislation and regulatory advances. Table 1 provides a sample

of the legal framework for energy policy in the Greek unconnected islands. In effect, the Public Power Corporation is the sole operator of utilities in the islands. By mandate it is also legally responsible for the uninterrupted supply of power to them.

The business environment. The liberalisation of the Greek power market in February 2001 met with great interest in renewable energy projects by the private sector (more than 50% of submitted applications for generation licenses) (ICAP & Delos Communications. 2001). In addition, approximately 80% of the substantial Greek solar water heater market is served by Greek manufacturers (Kaldellis, Kavadias, & Spyropoulos 2005). There is thus adequate information on the technical and economic performance of environmentally friendly technologies under the consumption and regulatory conditions of Greece and the islands.

Power demand. Electricity demand in the islands grew by nearly 50 percent between 1996 and 2006, a rate which according to the Energy Regulatory Authority (RAE) will require some 6,000 megawatts (MW) of additional capacity to guarantee adequate supply through 2015 (EIA 2009). During the 1998-2007 decade consumption increased by 3.7% per year on average, while the peak for the same period increased by 4.7% on a year by year basis. Researchers have estimated the mean annual demand increase at roughly 10% in the unconnected Greek islands (Kaldellis & Zafirakis 2007). As will be seen in this chapter, air-conditioning nationally represents a clear cause of demand surge over the past decades, which led to forced outages in 2002 (150 MW), 2003 (70 MW), 2005 (165 MW) and 2007 (500 MW)! In July 2004, the year of the Athens' Olympics, demand outstripped supply in an embarrassing black-out (HTSO 2008).

Law 2773/1999 Art. 11 Par. 1 / updated by 3426/2005

Regarding the installation of thermal power units in the autonomous Islands.

"The generation license for unconnected islands is granted by application of the interested entity to the Minister of Development in consultation with the Regulatory Authority for Energy according to the conditions and specific requirements set forth by this bill and the Licensing Guidelines which are primarily concerned with the technically competent and cost effective operation of the electrical system and the overall protection of the environment."

Law 2773/1999 Art. 11 Par. 2 / updated by 3426/2005

"When emergency needs to the goal of uninterrupted power supply to the unconnected island arise, the PPC is granted generation licenses according to the Licensing Guidelines by Decision of the Minister of Development in consultation with RAE. The licensing term expires with the end of the emergency."

Law 2773/1999 Art. 11 Par. 3 / updated by 3426/2005

"In the case of Isolated Micro-grids and for as long as they are granted exclusion according to the statutes of Article 26 of the Directive 2003/54/EC (EEL. 176) [...], generation licenses are only

granted to the PPC according to the procedure, rules and conditions outlined in the Licensing Guidelines. The PPC is responsible for the uninterrupted power supply of the Isolated Micro-grids as well as the long-term financial operation of the electrical systems of those islands in accordance to the statutes of Case d of Paragraph of Article 23 of this Law." NB: All unconnected islands except Crete are characterised as Isolated Micro-grids according to Law 2773/1999 since their power consumption was less than 500 GWh in the base year 1996. However, the relevant exception that confirms the power supply to the sole care of the PPC had not been yet granted by the European Commission when checked in late 2008 (Directive 254/2003/EC Art. 26). Thus, the Greek State is applying Article 11 Paragraph 4 of the Law above which states the PPC has the final right to a generation license if the public bid does not bear results or the matter is of utmost urgency.

Table 1: Excerpts from the Law that dictates policy in the islands

The Greek islands are on both the Adriatic Sea and the Aegean Archipelago. The islands of the Adriatic are connected to the national grid. The islands of the Archipelago, where roughly 5.6% of the population resides (nearly 600,000 people mainly in small remote communities), can be broadly grouped in those of the South and North Aegean (GSNSSG 2006).

- The North Aegean complex consists of five big islands (Lemnos, Lesvos, Chios, Samos and Ikaria) with about 201,000 inhabitants in total, according to the 2001 census, and numerous smaller islands (Aghios Efstratios, Psara, Inousses and Fourni), with close to 4,000 inhabitants.

- In turn, the South Aegean consists of two main complexes:

  - Cyclades (pop. 110,000 in the 2001 census) is a group of twenty-nine islands whose major islands are Andros, Mykonos, Naxos, Paros, Santorini, Syros and Tinos.

  - Dodecanese (pop. 188,500 in the 2001 census) consists of twenty-nine islands and is located in the south-eastern Aegean between Crete and Turkey. Major islands are Kos, Rhodes, Kalymnos, Kassos, Leros, Patmos, Karpathos and Astypalea.

3.1.1 THE LOCAL ECONOMY

The permanent population statistics presented in Figure 4 demonstrate differing trends in the Aegean Sea islands.

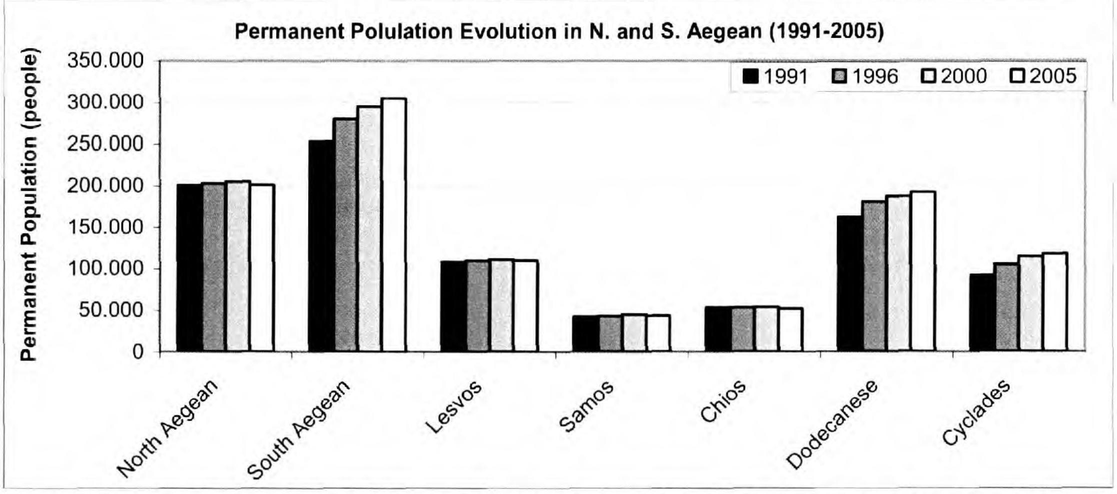

Figure 4: Permanent population evolution in the Aegean Archipelago region (Kaldellis & Zafirakis 2007)

Traditionally, islanders across the Aegean Sea have been occupied with agriculture, fisheries, cottage industries and poultry farms (GSNSSG 2006). Tourism has increased dramatically in the last decade and is considered the main cause, along with raising standards of living, for the rapid growth of energy consumption (Haralampopoulos et al. 2001;HTSO 2008). The South Aegean region (including the Cyclades and the Dodecanese) shows a persistent population increase over the last 15 years. It can perhaps be attributed to the rise of income from tourism that can sustain social and economic life on the islands all year round. Table 2 reinforces such a proposition. It can be observed that the islands of the South Aegean receive many more visitors per local inhabitant and square meter in comparison to the North Aegean. During the 1980s, GDP per capita on the islands was 97.5% of the national average compared to 76.1% during the 1970s, mainly attributed to tourism (Leledakis, Goumas, & Samouilidis 1987). By the mid-1990s this figure dropped slightly to 93.8% (Eurisles 1997) while earlier in this decade it dropped even further to 90.3%, according to data compiled from Eurostat's website, however, the South Aegean region on its own was still 117.3% above the country's average GDP per capita.

Table 2: Basic data for the Aegean archipelago region (GNTO 2009)

Prefecture	Population (2005 estimate)	Area (m^2)	Annual tourist arrivals (2004)	Major islands
Lesvos	107,050	2,154	135,023	Lesvos, Lemnos
Chios	52,337	904	46,360	Chios
Samos	43,015	778	114,445	Samos, Ikaria
Cyclades	110,400	2,572	325,917	Paros, Siros, Naxos, Mikonos, Andros
Dodecanese	192,714	2,663	1,556,250	Rhodes, Kos, Kalimnos, Karpathos

In addition, the North Aegean region is not as well linked to major ports in the mainland and it consists of larger islands with stronger and more stable local economies that have not become as dependent on tourism as a source of income. Even in the larger islands of South Aegean where local industry, mainly for agricultural processing, still plays an economic role, tourism has been steadily growing to be the major if not the main source of income (Haralampopoulos, Fappas, Safos, & Kovras 2001).

3.2 REVIEW OF THE ISLAND ENERGY SYSTEMS

3.2.1 ENERGY USE

Fuel oil, diesel and petrol are the predominant fuels in the islands for electricity generation, transportation and the agricultural sector (Figure 5). Figure 6 shows the relative distribution of final energy use typically found across the Aegean. Gasoline is consumed almost entirely in transportation. Diesel is principally consumed for space 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;Mihalakakou et al. 2002). The transport, residential and tertiary sectors are the largest consumers of energy, with the exception of a few bigger islands where local industry, mainly for agriculture, is still an existing but contracting economic sector (Haralampopoulos, Fappas, Safos, & Kovras 2001).

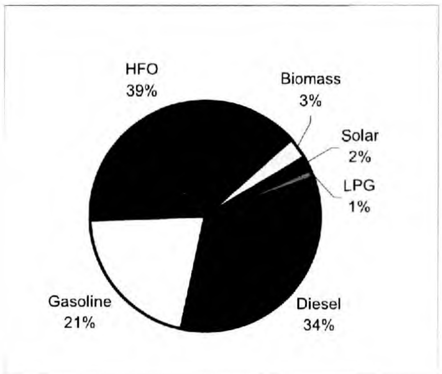

Figure 5: Distribution of energy supply by fuel in the Dodecanese (Mihalakakou, Psiloglou, Santamouris, & Nomidis 2002).

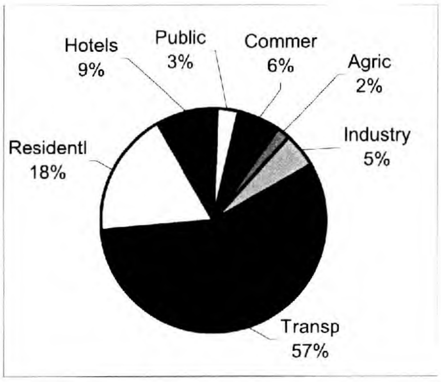

Figure 6: Useful energy consumption per economy sector for the Dodecanese (Mihalakakou, Psiloglou, Santamouris, & Nomidis 2002).

The annual diesel consumption of all the Autonomous Power Systems (APS) in the region approaches 100,000 t and another 400,000 t of heavy fuel oil (mazut). The specific consumption varies between 200 to 300 gr/kWh with a mean at slightly less than 250 gr/kWh (Kaldellis & Zafirakis 2007).

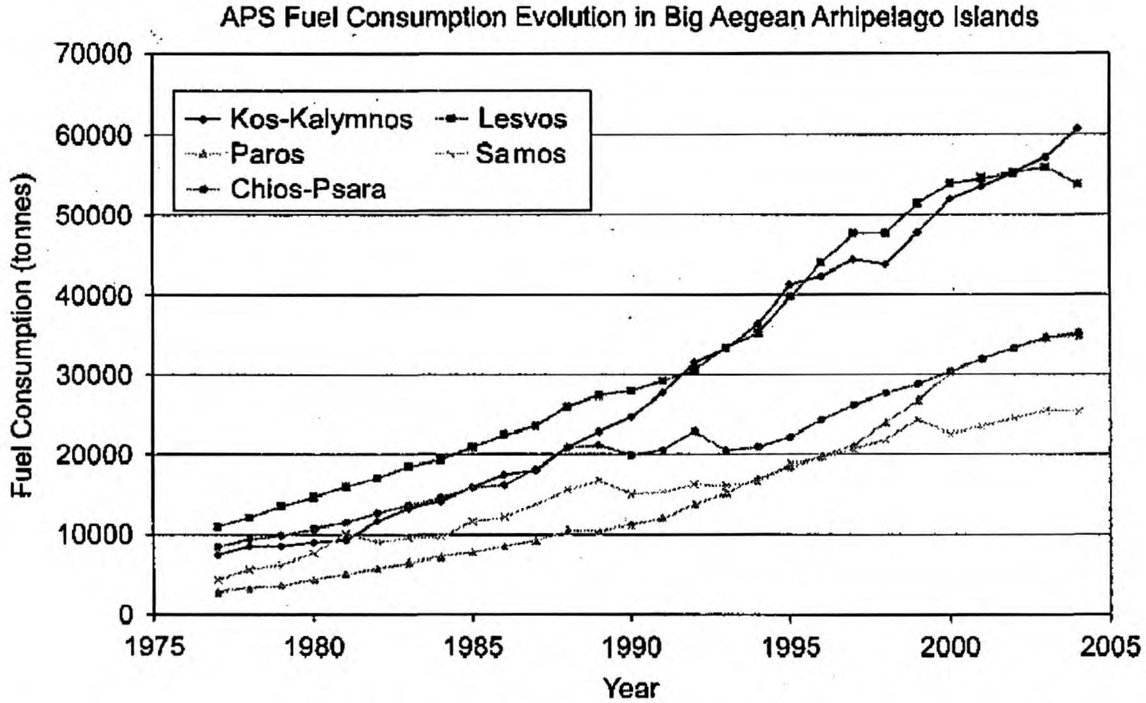

Figure 7: Consumption of fuel in large APS of Aegean islands, 1977-2004 (Kaldellis & Zafirakis 2007)

As can be observed in Figure 7 above consumption has been steadily rising since the electrification of the islands in the 70s. The fluctuation may either indicate swings in popularity of islands as destinations for holiday-makers or varying engine working conditions, i.e. using stand-by output for mid-load applications when there is lengthy lack in capacity investment. Such dynamics are incorporated in the modelling exercise of this thesis.

3.2.2 ELECTRICITY USE

Electricity consumption by sector reveals a particular increase in the domestic and commercial sectors. There could be many reasons behind these increases and there have been studies documenting a definite effect of the tourism industry on the power system and other resources of the islands (Daskalaki & Balaras 2004;Kaldellis & Zafirakis 2007;Karagiorgas, Tsoutsos, & Moia-Pol 2006;Karagiorgas et al. 2006). These are examined in more detail in the Critical Literature Review in Chapter 4 of the thesis. Mihalakakou and Balaras have conducted the most in depth and perhaps unique sectoral analysis of energy consumption of the last decade, according to the bibliography reviewed. Domestic electricity consumption in the Cyclades rose by 25% between 1992 and 1996. The 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, & Gaglia 1999;Mihalakakou, Psiloglou, Santamouris, & Nomidis 2002).

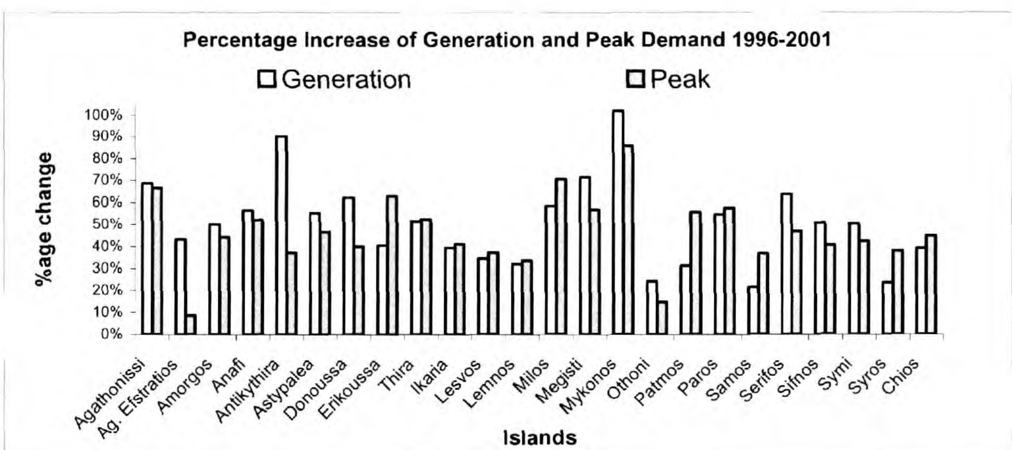

Figure 8: Power generation and peak demand increase for selected islands (PPC 2002)

Net electricity production and peak power demand between 1996 and 2001 show an average increase of 40-45% over the five year period according to PPC records (PPC 2006). Figure 8 presents the case for a selection of islands across the Aegean. The figure also confirms a laborious study by Kaldellis, who concludes at a 10% long-term mean annual escalation rate (Figure 9) since 1975 for medium, medium-large and a selection of large islands, as categorised in subsequent paragraphs.

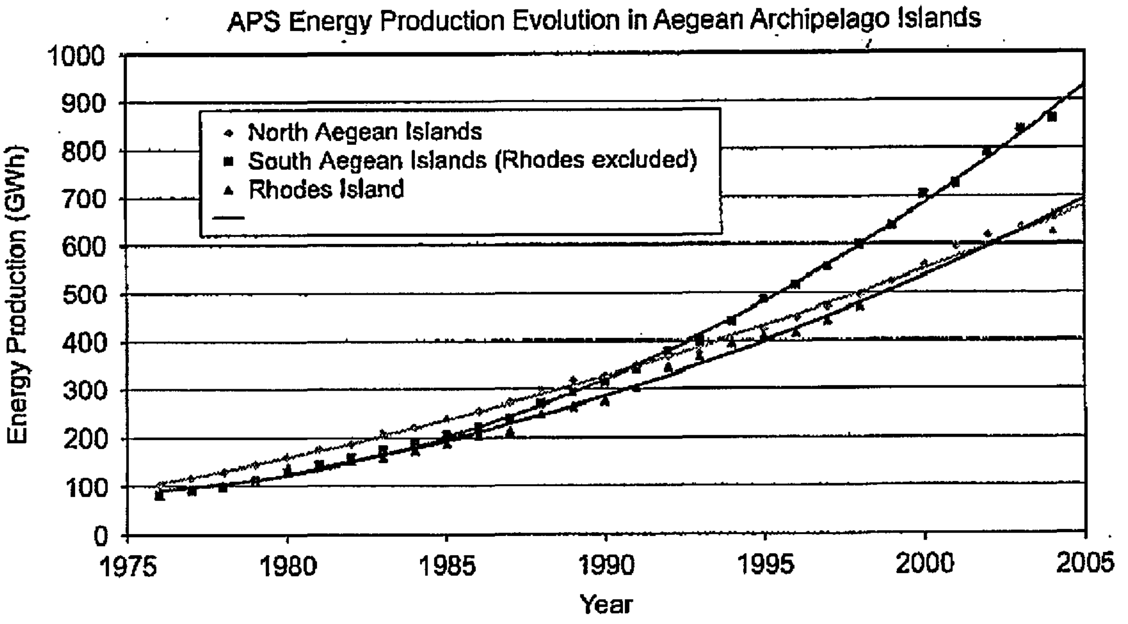

Figure 9: Electricity generation in the Aegean Archipelago islands, 1976-2004 (Kaldellis & Zafirakis 2007)

3.2.3 POWER GENERATION

There are 32 autonomous power stations (APS) which provide the bulk of the electricity needed on the Greek unconnected islands of the Aegean Archipelago (PPC 2006). The total installed capacity of APS is approximately 800 MW, while their generation in 2005 reached almost 2200 GWh (RAE 2007).

The generating sets found in the islands APSs are mainly running on heavy fuel oil (mazut) and diesel, while among the unconnected islands there is a gas turbine only in Rhodes. In total there are 220 operating, according to the PPC (PPC 2006). The rating varies from 100 kW to 36 MW for Rhodes. Rhodes as well as Crete, the two largest islands of the region that maintain significant infrastructure, are excluded from this study because their size and stable permanent population throughout the year separate them from the type of islands under the study. It can be observed in Figure 10 that most thermal power units are in the 1,000 order of magnitude which mainly concerns medium and medium large islands such as Sifnos, Serifos, Skyros, Kythnos and others that shall be examined in later chapters in detail. Those islands' APS have started back in 1976 with a few hundred kW of demand which followed exponential trends into the thousand ranges within 30 years. The APS themselves can be grouped in five categories, as presented in Table 3.

Table 3: Aegean islands classified according to the installed capacity of their

Category (scale)	APS installed capacity (MW)	Islands
Small	< 1	Agathonissi, Aghios Efstratios, Anafi, Antikithira, Donousssa, Othoni
Medium	> 1 and < 9	Amorgos, Astipalea, Kythnos, Serifos, Sifnos, Simi, Skyros
Medium Large	> 9 and < 20	Ikaria, Ios, Karpathos, Milos, Patmos
Large	>20 and < 50	Andros, Lemnos, Mykonos, Santorini, Syros
Very Large	> 50	Chios, Kos-Kalimnos, Lesvos, Paros, Rhodes, Samos

Most of the generating units have been in operation for the past 20 years and as a result several units present serious operating faults, keeping them out of service for significant amounts of time (Boulaxis 2007). As a result their actual output has been calculated at 15% less than their rated power, especially in the busy summer period where electricity supply is most critical (Kaldellis & Zafirakis 2007).

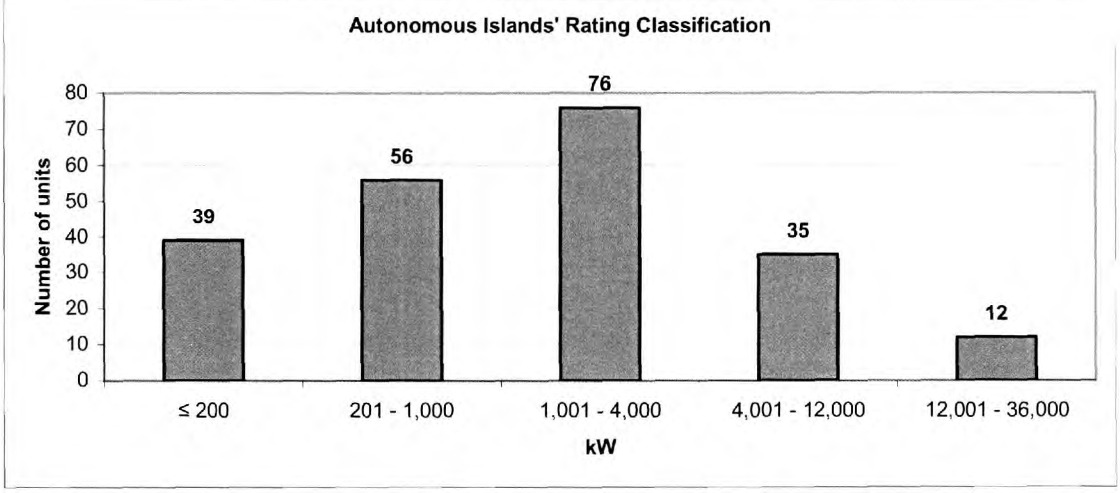

Figure 10: Operating thermal units in the Aegean according to their rated power (PPC 2006)

3.2.4 PEAKS & CAPACITY FACTOR

The capacity margin of the APS is yet another symptom of the ineffective management and the nature of demand in the islands. As exemplified in Figure 11 the safety margin is very low forcing generating sets to work in their extreme emergency (or stand-by) ratings (Figure 11). As a result apart from increased fuel consumption in many cases serious malfunction leave the inhabitants and visitors in the dark.

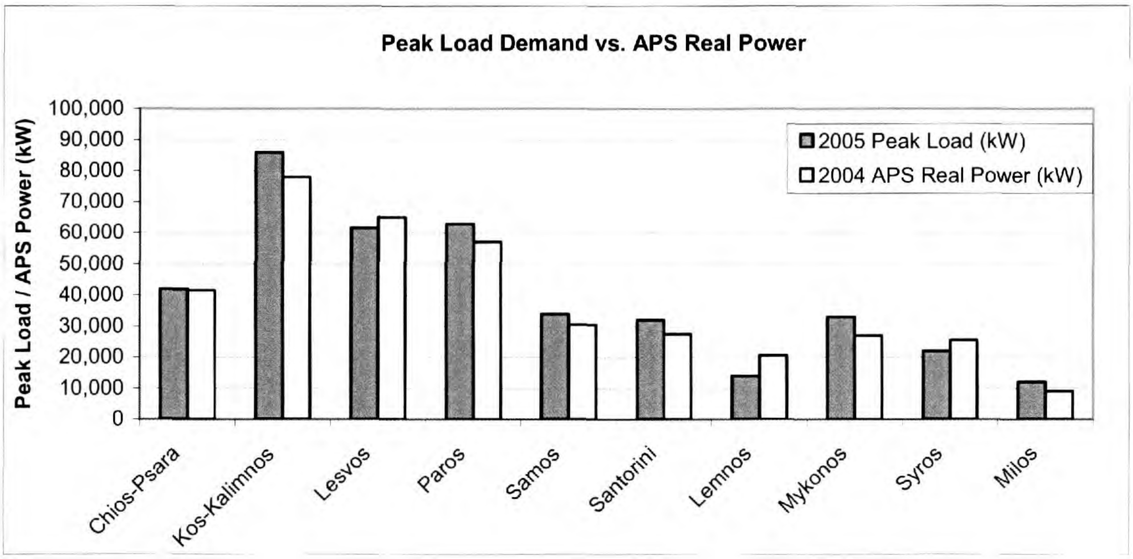

Figure 11: Peak power demand against actual power delivered by APS (Kaldellis & Zafirakis 2007)

The peak power demand increase since 1975, Figure 12, has been following a similar mean increase rate of 10% as that of the power generation seen earlier in Figure 9. The increase is parabolic and in cases approximates exponential growth for the islands of the South Aegean Archipelago, which this thesis will focus on.

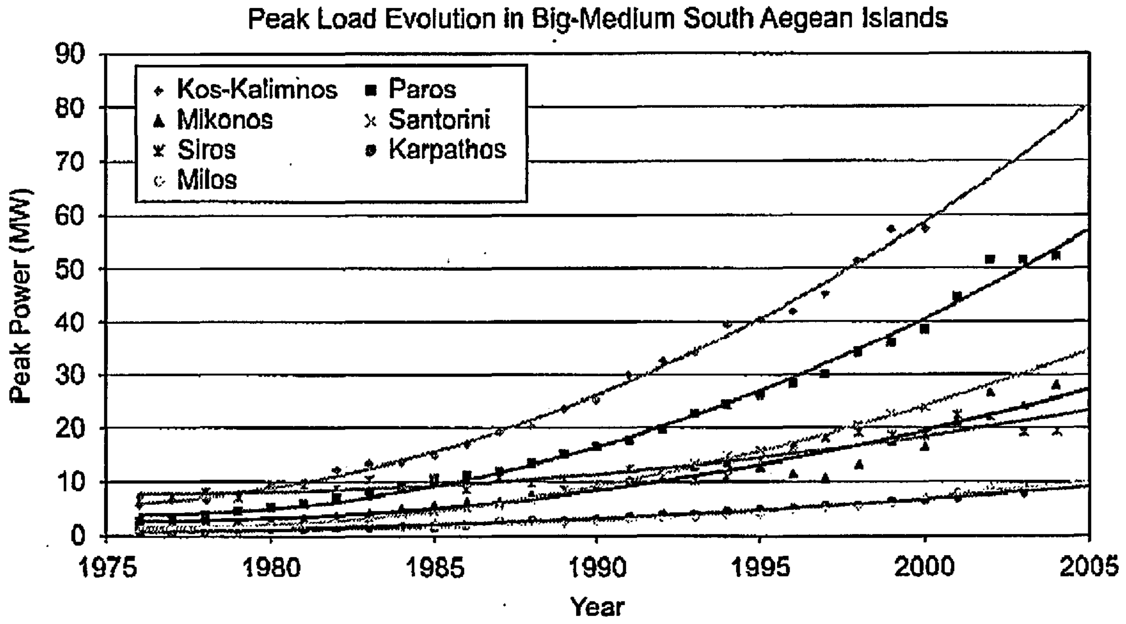

Figure 12: Peak load evolution in medium-large islands of the South Aegean islands, 1976-2004 (Kaldellis & Zafirakis 2007)

The capacity factor of APS according to the official statistics of the PPC[4] is found at an average of 21% (excluding Crete and Rhodes) while only 10 APS have values above 25% (PPC 2006). When asked (Zovanos 2006), the PPC offered a number of possible reasons why the Capacity Factor (CF) is so low; these mainly have to do with the age of the generating sets and the extreme demand fluctuation which is examined further in the next paragraph. Again, looking for a cause draws researchers to one source: tourism. Kaldellis (Kaldellis & Zafirakis 2007) specifically states that "the continuous increase of electricity needs is only partially attributed to the permanent population growth" pointing towards the transient population and making observations quoted earlier and across this thesis.

3.2.5 CAPACITY EXPANSION

A severe setback to the proper management of power generation is the intense load fluctuation on both a daily and a seasonal basis. On occasions the summer peak may be five times higher than the minimum winter demand. Even on the same day on a given island, one can observe fluctuation of ±60% of the corresponding daily average. Detailed figures for one of the islands will be presented in the modelling chapter. Figure

[4] The PPC produces a report on island electrification each year, with great detail on costs, consumption, peak, an inventory of generating sets and statistics dating back to early 1970s. However, it is very hard for a researcher to have access to these reports. They are kept for internal use and considered sensitive data. The author managed to get a full copy of the 2002 report and various extracts of the 2006 version.

13 and Figure 14 show the relevant annual and daily load curves for a selection of islands respectively.

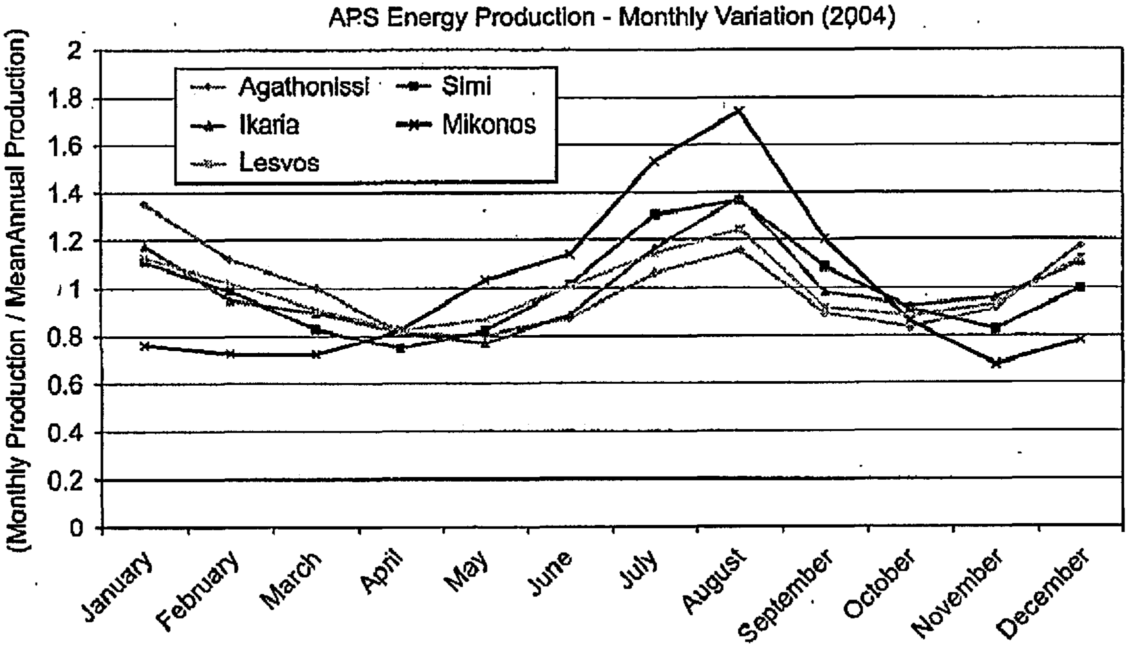

Figure 13: Annual electricity consumption variation in the Aegean Archipelago (Kaldellis & Zafirakis 2007;PPC 2006)

It is commonly accepted by people in policy making (Bakis 2007;Betzios 2003b;Boulaxis 2007;Kaldellis & Zafirakis 2007) that the demands placed by the tourism sector have outstripped the capabilities of the islands' power plants. The investment required after years of neglect is such that the necessary prioritisation stumbles on conflicts of interest among the numerous islands. As a result, plant managers and the policy makers at the Public Power Corporation are left with desperate measures. The common practice is three-fold: either push engines, new or outdated, to extreme working conditions with negative effect on consumption, reliability and lifespan, or treat replaced engines as mobile fire-fighting units dispatched to the likely trendiest islands for the season, or hire emergency diesel and gasoline power generators at a hefty price (Betzios 2003b;Regulatory Authority of Energy 2005).

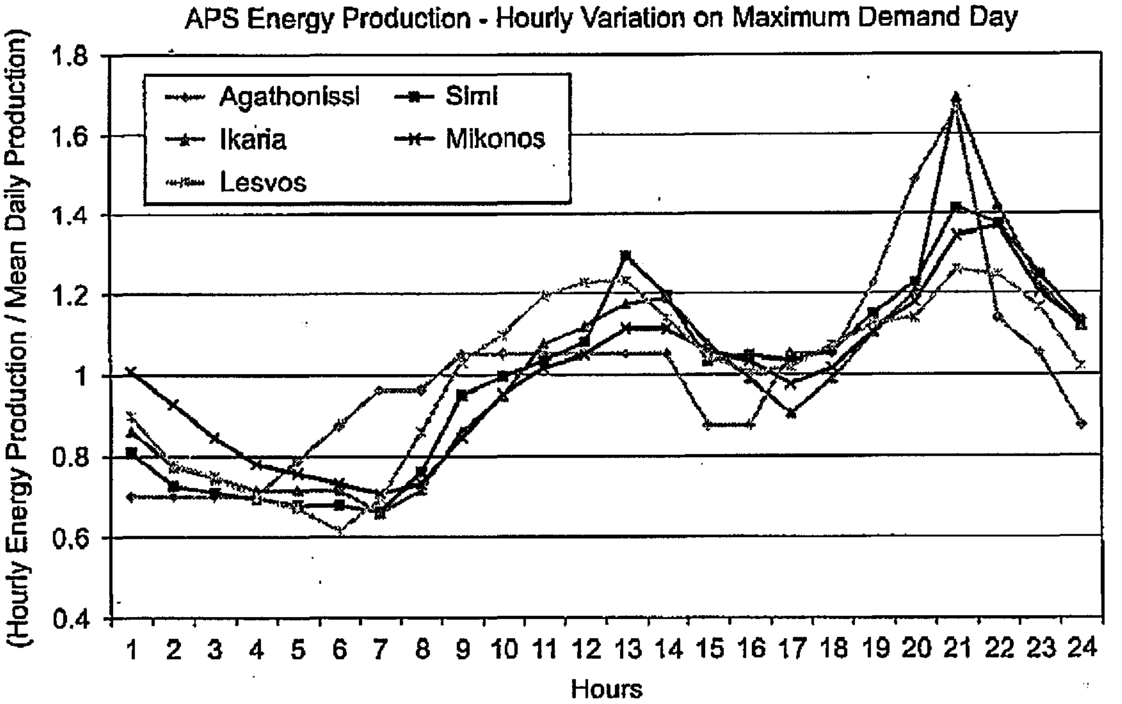

Figure 14: Daily electricity variation in the Aegean autonomous islands (Kaldellis & Zafirakis 2007;PPC 2006)

To compare, the graphs from a study paper on international low energy cooling from 2007 in Athens are copied in Figure 15 below. On the left hand side graphs, MSVI stands for Monthly Seasonal Variation Index which is the monthly power consumption over the monthly average consumption throughout the year. Similarly, on the right hand side graphs, HSVI stands for Hourly Seasonal Variation Index defined as the electricity consumption for a certain hour over the mean daily consumption.

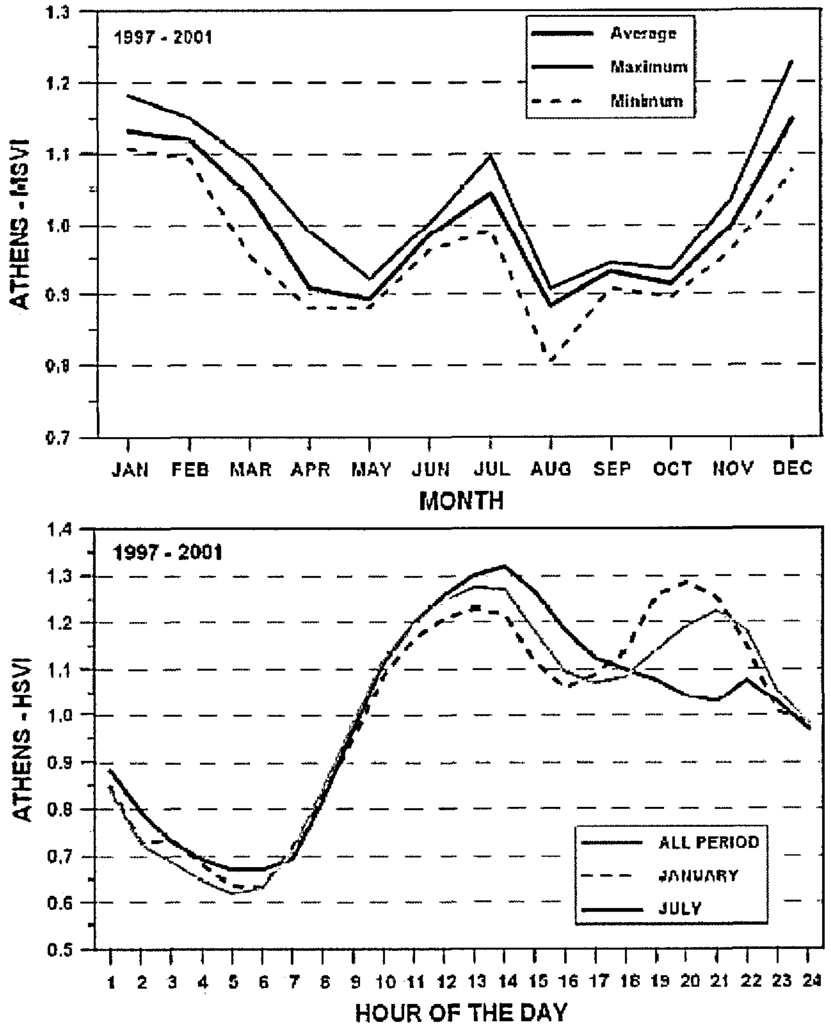

Figure 15: Comparison of monthly and hourly consumption variation (left & right respectively) for Athens (Psiloglou & Giannakopoulos 2007)

In May 2006 the Ministry of Development approved the installation of 85.7 MW of additional units across 13 islands. However, two years later not only were the installations still in the bid preparation stage but the short-term approach and lack of strategy was on full display. In May 2008, the Regulatory Authority convened and, despite critical comments on their decision, licensed the temporary installation of 12.75 MW spread over three medium large islands (Regulatory Authority of Energy 2008b), and approved and licensed the hire and installation of a total of 67.2 MW in 17 islands from private companies to combat summer peaks at a cost (Regulatory Authority of Energy 2008a). However, at the same time RAE claims that power rentals would have paid of proper investment within five years and is highly critical of the practice. In effect, almost all the unconnected islands had urgent power needs in the summer of 2008 and RAE on their own estimates came up with a much higher gap of 86 MW that would need to be filled to maintain the capacity margins required!

The Regulatory Authority openly puts the blame for the situation in the islands on to the PPC for their reluctance in proceeding with capacity expansions that have been approved and licensed by RAE. The Authority reckoned in 2008 that 50 MW of hired power could have been avoided if the units licensed earlier had been installed as expected (Regulatory Authority of Energy 2008a). The delay is estimated at between 3-8 years, with an average estimated at 5 years from the moment a proposal gets the green light mainly due to lack of funds, planning and other legal delays, local resistance to expansion as most plants that used to be in the outskirts have now been engulfed by households and in many occasions simply neglect of the utility (Betzios 2002;Kaldellis & Zafirakis 2007;Regulatory Authority of Energy 2008a;Regulatory Authority of Energy 2008b;Zovanos 2006).

The cost of hiring in generating sets in emergency situations varies from 700-1,000 €/MW per day for medium and medium large APSs and up to 2,000 €/MW for small islands. The RAE estimates that the hiring cost over 3-4 years basically equals the cost of buying the equipment outright (Regulatory Authority of Energy 2008b).

The common practice to determine the capacity margin requirement is empirical. It is surprisingly difficult to get a specific figure from the PPC (Zovanos 2006) but RAE's personnel who must have been also struggling with the same question, reveal the rule of thumb used (Regulatory Authority of Energy 2008a;Regulatory Authority of Energy 2008b). On formulating its decisions on PPC license applications the PPC refers to the "established practice for determining the stand-by power in the islands (by which reserve capacity equal to the largest unit of the APS should be maintained)". However, as will be seen below, this is arbitrary because it is not proportional to the size of the APS and the corresponding risk of peak demand it might face, .

3.2.6 CAPACITY MARGIN

When it comes to demand forecasting, the PPC uses exponential extrapolation, with weighting based on a 10 year trend while looking 10 years ahead (PPC 2002). Those figures are used in conjunction with the arbitrary rule of thumb as described above in deciding capacity investments. This may suggest systematic boom and bust cycles in capacity margins which further exacerbate instability in capacity expansion decisions.

Table 4: Illustration of capacity planning & its effects

PEAK DEMAND PER MEDIUM AND MEDIUM LARGE ISLAND						
Island	**Peak 2007 as projected in 2001 (kW)**	**Actual Peak 2007 (kW)**	**Diff of actual to projection**	**Installed Cap Increase 2001-2007**	**Reserve Margin 2007**	**Reserve Margin 2001**
Amorgos	3,897	3,150	-19%	67%	45%	39%
Astypalea	2,537	2,150	-15%	177%	51%	13%
Kythnos	3,755	3,180	-15%	108%	41%	20%
Patmos	4,706	4,950	5%	42%	21%	20%
Serifos	3.866	3,020	-22%	191%	48%	0%
Sifnos	5.873	5,490	-7%	65%	38%	31%
Skyros	5,871	4,360	-26%	43%	32%	20%
Symi	3,340	3,350	-0.3%	80%	51%	42%
Ikaria	9,340	7,500	-20%	43%	24%	15%
Karpathos	8,517	9,150	-8%	36%	41%	41%
Milos	12,447	10,390	-17%	25%	16%	29%

Compiled from: (PPC 2002;Regulatory Authority of Energy 2008a)

In support of this suggestion, Table 4 above shows the difference between what the PPC projected for 2007 in 2001 and the actual figures of that year. The table focuses on medium and medium-large islands of the Aegean Archipelago. What is also compared is the reserve margin in each of these two points in time. Despite a good margin already back in 2001 for Amorgos, Sifnos and Symi the PPC invested in those islands, thereby raising the margin even further. For Patmos and Karpathos we see no change in the margin despite significant capacity expansion - not as impressive as most islands in those 7 years though. This indicates a balanced expansion decision for those two islands which goes against the criticism of the methodology. It might be a coincidence, however. It can be explained by the fact that Karpathos is a less touristic island with a stable off-season population, while Patmos is a Christian pilgrimage site (St John apparently wrote the Apocalypse there) that maintains visitors and tertiary operations throughout the year. Thus, the islands' historic demand evolution is such that the exponential function used happens to provide a milder extrapolation, which appears to allow better control of investment planning. Such dynamics will be further explored in the modelling section of the thesis.

Table 4 suggest that in most islands when investments are decided they seem to be exaggerated, as if there was some pressure in the system which bursts into a major step investment. These large additions in capacity might be actually leaving the island with more power than it needs, creating a sense of over abundance to households and tourism professionals that the utility does not moderate. Thus, they buy electric comfort and services with no consideration of efficiency or the vicious cycle of rising demand this creates. And little should they care, since neither is this reflected in the tariff they pay nor are they assisted/trained in managing their consumption.

Subsequently, more financial resources than needed are committed in islands where recent expansion materialised causing further delays in investment in others such as Milos in Table 4. The delays there squeeze the capacity margin which by the rule of thumb generates needs for larger investments as time progresses. Effectively, this creates a re-enforcing loop behaviour which again will be further examined in the modelling section.

Looking further into the effects of the reserve capacity rule of thumb, Figure 16 provides another set of insightful comparisons.

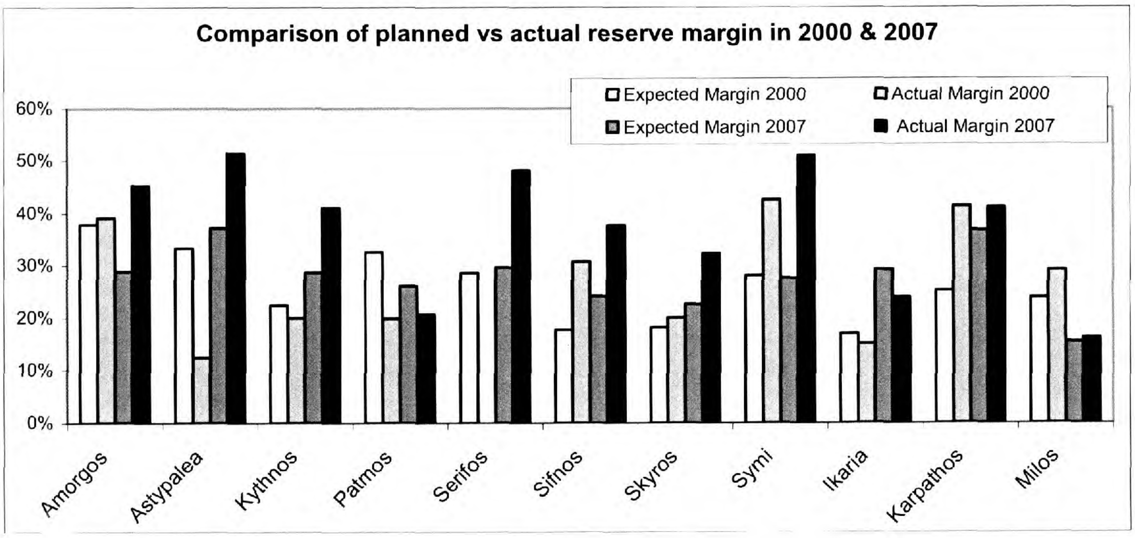

Figure 16: Reserve margin by rule of thumb and in reality for 2000 & 2007 (PPC, 2002; PPC, 2006)

In most islands shown in the graph investment has caused the real reserve margin in 2007 to be at a higher level than the rule of thumb recommended in 2000. This occurred in some cases, even when in 2000 the actual margin was already higher than the required margin, i.e. Amorgos, Sifnos, Symi, Karpathos and Milos. This observations show severe cases of over-capacity or insufficient allocation of capacity expansion resources. In almost all cases, the actual margin exceeds the theoretical one used for planning.

In conclusion, although the use of the rule of thumb does provide an indication of where investment is needed it is rather random and effectively wrong. The largest unit on an island which is used a metric for the rule of thumb, may be totally out of proportion to the size of the APS or the demand trend and thus causes amplification of requirements. In addition, the demand trend itself is calculated on the assumption that demand will definitely increase exponentially and there are no demand-side programmes in place to try and control it (Betzios 2003b), thus further amplification may be triggered there.

3.2.7 SPACE COOLING

According to Greece's most established market research company, ICAP (ICAP 2008), there was a 350% increase in split A/C unit sales between 1994 and 2000, of equipment that is mainly used in households, small-medium shops and small offices. After that period the market dropped, albeit still maintaining Greece among the top three countries of the A/C market (ICAP 2008). As nearly 70% of the sales take place once the summer heat actually affects the population, milder summers in the two years after 2003 decreased demand (Figure 17). On the other hand, the central unit market (fan coils) for equipment used in office blocks, hotels and large spaces had a mean annual increase of 4.6% between 1994 and 2005.

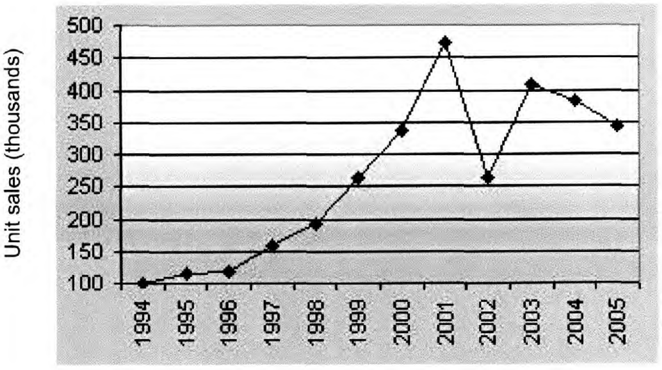

Figure 17: Sales of split A/C units (ICAP 2008)

Power demand in Greece correlates with ambient temperature. The Hellenic Transmission System Operator HTSO, in its 2008 report about the future of the electricity grid, makes the case that air-conditioning has been the major cause of this new phenomenon over the past decade (HTSO 2008). Figure 18 below compiles the data into a diagram that illustrates this observation.

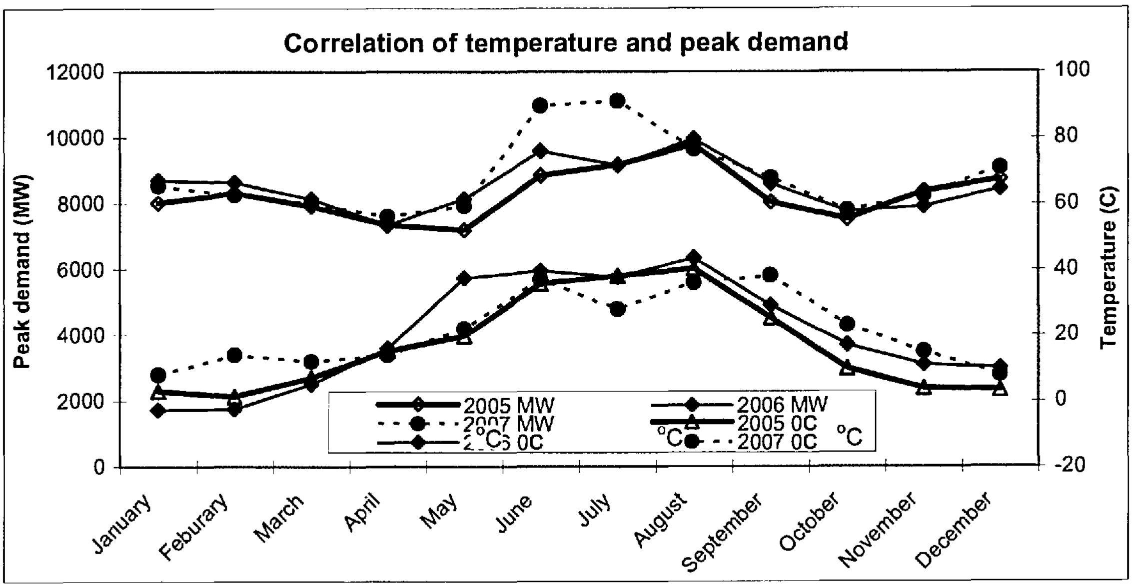

Figure 18: Correlation of temperature and peak demand in Greece (HTSO 2008)

3.2.8 THE RESIDENTIAL SECTOR

Table 5 shows the extent to which island households are equipped with modern appliances and which thus can absorb the available capacity. While some of the appliance ownership levels have reached saturation, there are more still lagging behind. In addition, the quoted study (Haralampopoulos, Fappas, Safos, & Kovras 2001) did not take into account electric air-conditioning units, whose popularity increased over the past decade, as explained earlier.

Table 5: Electric appliance penetration in 571 households of Mytilene. Source: (Haralampopoulos, Fappas, Safos, & Kovras 2001)

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

The table shows a great dependence on modern energy services. As long as the real costs of electricity production are not reflected in island consumers' bills, it is difficult to demonstrate the conservation benefits to customers, given that the study quoted in the table above showed the majority seemed indifferent to energy conservation practices, did not keep sufficient records of energy bills and were not informed about the energy efficiency of appliances and night tariffs (Haralampopoulos, Fappas, Safos, & Kovras

2001). Although the study refers to the capital of one of the largest islands that has a diverse economy (administrative centre, university, trade) it is assumed to be representative of islands in the Aegean Archipelago as it maintains the main characteristics of an isolated island. These are remoteness, high transport costs, growing energy demand, fossil-based and outstripped installed capacity and a progressive ascendancy of the tourism sector and its related commercial services.

3.2.9 THE TERTIARY SECTOR

The sector consists mainly of three sub-sectors, hotels, the public sector (schools, hospitals etc.) and commercial establishments (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, & Nomidis 2002). Taking into account that the hotel sector is operational for less than half of the year; its consumption has a great impact on the energy supply of an island. 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 main driver behind the rising energy demand of hotels is tourism. Tourism, international and internal, has a great impact on an island's seasonal population (Figure 19). This consequently stresses capacity levels to try to meet base and peak loads that are physically impossible to meet without a power output 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 or substantial demand-side management (DSM) policy so far by the government (Balaras, Santamouris, Asimakopoulos, Argiriou, Paparsenos, & Gaglia 1999;Daskalaki, Balaras, & Tsagrasoulis 2003;Energy Work Group 2003;Mihalakakou, Santamouris, & Kovras 2001).

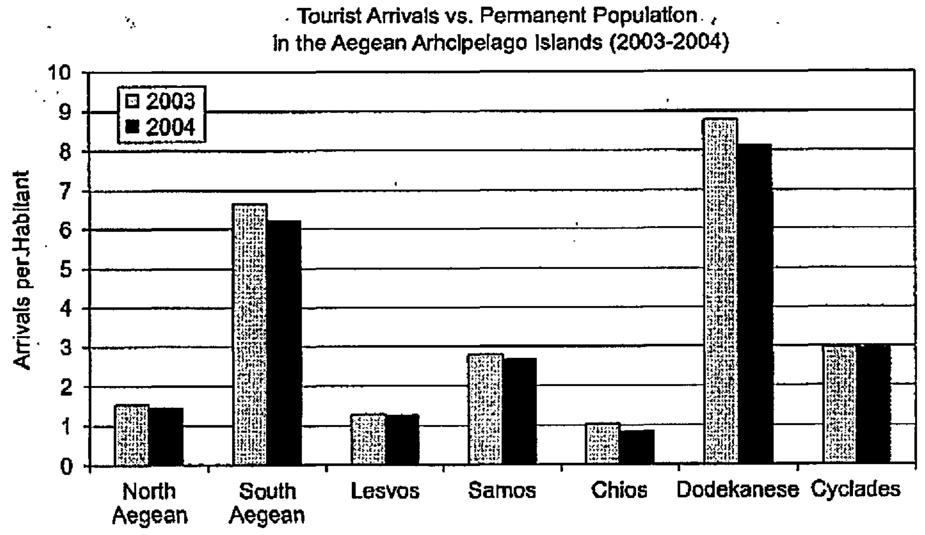

Figure 19: Tourist arrivals against permanent population in the Aegean (Kaldellis & Zafirakis 2007)

Obtaining a higher power output instantaneously to meet summer peak loads has an immediate impact on the costs of the generated power, as either the gensets need to run close to or above rated output, or the operator has to utilise older stand-by and inefficient engines (Bakos 2002). This adds immediately to the running costs of the operator. When investments in new permanent capacity take place, the fixed cost takes many more years to pay back due to low utilisation factors. 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, i.e. the value of lost load. That figure could then provide the basis for comparing alternative interventions.

3.3 ELEMENTS FOR THE DESIGN OF THE SIMULATION MODEL

Before concluding the chapter, a number of key observations that can be drawn in the design of the simulation model are summarised in bullet form below.

- Mean year-on year demand increase is 10% in the unconnected islands.
- Demand peaks occur for short periods of time in the summer.
- Tourism is the main cause of the demand surge seasonally and historically.
- Air-conditioning stands out as the technology that most affects demand peaks.
- The PPC is effectively in practice and legally the sole supplier of power.

- The income of households has been rising due to tourism, and so has population, since touristic islands can support extended local economies. As a result, demand for electricity services through newly introduced appliances has been also increasing.
- Peak and consumption curves of electricity since the 1970s appear parabolic if not exponential.
- The PPC's forecasting methods create a reinforcing loop of capacity expansion beyond the carrying capacity of the islands' resources.
- The PPC's mandate does not include any form of institutionalised DSM intervention. The unwritten underlying assumption is an ever expanding supply-side that by nature has very limited options.
- The simulation should develop over a 50 year period to capture the dynamics since electrification and to assess policies for the critical 20 years ahead, as the current paradigm is not sustainable even in the short-term, due to the accumulating financial losses.
- The management of the utilities is complex, as on the one hand the utilisation of the installed capacity is very low because of lengthy off-season periods, while one the other hand in the short summer frenzy the reserve margin is on many occasions insufficient.
- Generating engines are outdated or worked in conditions that they are not supposed to and as a result running costs are even higher. On the other hand, fixed costs take a long time to pay back, again creating conflicting objectives for a proper capacity expansion policy.
- Fuel consumption rises as engines are run on their stand-by ratings to serve mid-load.
- Because of the forecasting function and the planning procedure, investment occurs in large steps that overshoot the real needs and as a result some islands get more than they need while others risk power shortages.
- The capacity margin is by rule of thumb aimed to equal the largest unit of the APS.
- The delay from approval of investment to actual installation might be anything from 3 to 8 years. However, as mobile generating sets are in use across the Aegean Sea,

the realisation of a capacity expansion need may also delay as the capacity needs to be persistent.

- The research focuses on medium and medium-large islands of the Aegean Sea.
- The generating engines of the APSs for the islands concerned are in the 200 – 4,000 kW range.

3.4 SUMMARY & CONCLUDING REMARKS

Unanticipated demand trends due to the seasonality of the relatively new phenomenon of tourism over the past decades and the inability or even unwillingness to try and properly forecast the real demands of the islands led to expansion planning based on average consumption figures. As a result investments were either left to lag behind peak demand for years or when finally enough pressure had gathered in the system the PPC proceeded with expansions beyond financial sustainability. As tourism developed into a main income for the islands and the whole economy in the 1980s and 1990s, engineers at PPC lacking proper investment policy were forced to keep online older equipment that should have been otherwise decommissioned

A reliable network, or rather a profitable business, of selling and shipping fuel to the islands has emerged. In the late 1990s, another private sector business also sprouted: that of generating set rental. An easy cure but to the detriment of PPC's finances nevertheless, as RAE claims. Thus, the situation "locked-in" symptomatic pain-killing cures that reduced its resources to address capacity in a strategic optimised manner. On the other hand, renewable energy, which is only a recent struggling technology in the country, has been set back by arguments over its technically feasible share in the energy mix and confusion over appropriate support policies specifically for the islands (to be discussed further in the Critical Literature Review). Even if there is the technical potential in the islands, it is not only national policy that is divided about how to harness it. In many cases locals are opposed to wind farms, partly because most islands are of small area and barren geography, making wind turbines visually dominant in the scenery.

Tourism kept growing rapidly along with the local economy and permanent population that became energy-service hungry as GDP per capita grew and appliances became more available since the 1970s when tourism gradually started taking over the local economy. Still however, the consumption of the permanent population followed a much more timid trend. As a result the gap between summer and winter peaks widened significantly.

The conclusion is that central government should have and still could bring the PPC, development and tourism policy-makers together, as well as the public works department that is also responsible for land use, with the question: how should we efficiently and appropriately run our islands, which provide a major source of income, promote our culture and image to the outer world, maintain sites of international heritage in culture and nature and where a sensitive and significant segment of the population resides. It has never been within the PPC's job description to consult about let alone direct national policies of this depth. Their mandate was to provide electricity when and where asked, as a public good provided by the State. This thesis discusses the PPC's role and involvement in the conservation of energy and the efficiency of its use, while addressing the research questions set in the introduction.

The following chapter provides an extensive literature review of the power systems of the unconnected islands, looking for behavioural patterns and the dynamics of key relationships, to assist in the simulation model building exercise.

4 CRITICAL LITERATURE REVIEW

This chapter provides an extensive critical review of key academic papers that have addressed the use and supply of electricity in the Greek islands and relevant broader energy issues. The aim is to gain a deeper comprehension of the current situation and critically assess the validity of this thesis' objectives and its contribution to work carried out so far. The literature was identified according to whether it addressed either certain techno-economic or policy concerns, or referred to relevant technologies, or discussed observation-based specific island problems. It is equally important though in a Systems Thinking approach to understand the researchers' policy motives, the regulatory environment which guides their arguments and positions that reflect attitudes of stakeholders. In some cases, therefore, references are made to sources on the national or international agenda that have a relevance to the arguments raised. Literature is complemented with empirical knowledge and interview data where necessary.

Structure of Chapter:

4.1 INTRODUCTION

4.2 THE DEMAND SIDE: ENERGY EFFICIENCY AND DSM

4.3 THE SUPPLY SIDE AND RENEWABLE ENERGY

4.4 THE COST OF POWER & ENERGY SAVINGS

4.5 EXTERNALITIES IN THE ISLANDS

4.6 INCOME ELASTICITY & DEMAND GROWTH

4.7 FEEDBACK EFFECTS & CAUSALITY IN MODELLING

4.8 ENVIRONMENTAL SENTIMENT

4.9 CONCLUSIONS

4.1 INTRODUCTION

The bulk of the published research on the energy systems of the Greek islands was carried out from roughly 1995 onwards. The 1990s was the decade when global environmental threats and means to combat them were intensely put on the table and Greek researchers became more inquisitive about the practices in their own country too. This interest coincided with Greece's rapid electricity consumption growth; from 9.1 TWh in 1990 to 16.4TWh in 2004, a staggering 81%, nearly 6% per annum (RAE 2007)! It was also early in the last decade that the annual electricity peak shifted to what is now a characteristic of the Greek electricity system: the summer mid-day peak that has been in previous chapters attributed to the advent and uptake of cheaper air-conditioning units. The energy issues of unconnected islands did then start receiving the attention of researchers. The concept of decentralised generation that was explored as an option for the future development of networks needed niche applications and test beds to prove its benefits; the Greek islands provided such a platform and that experience contributed to the publication of a number of papers from Greek researchers.

Concurrently, the Greek energy market was being pushed to open up, which finally took place in 2001. Energy data became more available and more accessible, as interest in sector reform and private investment grew. The financial burden of island electrification began being more widely discussed. During that period, private power investors were taking positions. Given PPC's hegemony of thermal power, players in the RES sector had more chance of a viable business model and showed a particular interest in the islands, hoping for government concessions to generate renewable power there. The PPC did not lag behind, however; it established a subsidiary for renewables that had less risky opportunities to work on the available technologies, since it already had its own wind maps, a friendly regulatory framework for licensing and vested interests to invest in the islands and elsewhere. The independent Regulatory Authority created by law in 1999, gearing up for the liberalisation, streamlined its role and operations gradually and was making itself present by 2002, while a strengthened CRES (Centre for Renewable Energy Sources)[5] undertook the bulk of the research on renewables and

[5] The Centre for Renewable Energy Sources is the national Greek centre for Renewable Energy Sources (RES), Rational Use of Energy (RUE) and Energy Saving (ES). CRES was instated as the national coordination centre in its areas of activity by Laws 2244/94 (Production of Electricity from Renewable Energy Sources). CRES was founded in September 1987 by Presidential Decree 375/87. It is a public entity, under the auspices of the Ministry of Development, General Secretariat of Research and Technology and has financial and administrative independence. Its main goal is the promotion of RES/RUE/ES applications on both the national and international levels taking environmental impacts, resulting from the production and use of energy, into consideration.

made critical data available to the private sector. Papers on energy in the islands started thinning out by 2005, as it became apparent the State was anxious to absorb the contracted piped and liquefied natural gas and thus focussed on the development of gas networks and promotion of its use. A major victim of that policy was the termination of tax credits and subsidy towards domestic solar water heaters, which is discussed in detail in the forthcoming chapter dedicated to solar technology experience in Greece.

The knowledge gathered in that decade of research and since is invaluable and in this chapter an attempt is made to draw out key insights and findings and identify relevant gaps in the literature. We begin by examining the demand side.

4.2 THE DEMAND SIDE: ENERGY EFFICIENCY AND DSM

The IEA's 2006 review of the Greek energy sector (IEA 2006) confirmed that the country had no specific energy efficiency strategy, an observation also made in their 2002 review. The lack of progress in the field can be traced back even further, to the mid-nineteen-nineties when academics looked into the energy consumption statistics, suggested the need for a plan of action to save energy, and proposed new tools and methodologies (Hadjilambrinos 1996;IEA 2002;Mourelatos, Assimacopoulos, & Papayannakis 1995). Box 4 summarises the IEA's comments and those recommendations which have particular reference to the electricity sector.

The IEA encourages the use of market-oriented instruments and voluntary agreements with industry as well as more stringent building codes. For the short-term, however, it urges more immediate measures, such as price modifications, taxes and information campaigns. Energy intensity is also a major issue; it has been steadily increasing above the IEA European average and approaching that of the USA (Hondroyannis, Lolos, & Papapetrou 2002;IEA 2002), although it has shown signs of stabilisation more recently (IEA 2006).

Box 4: Summary of IEA observations on the energy efficiency of Greece (IEA 2006)

Greek energy policy seems to be overly supply-side oriented and stronger emphasis should be placed on the demand side. [...] Developing a comprehensive energy efficiency strategy with measurable objectives/targets, ensuring cooperation among relevant ministries, could help to balance Greek energy policy. [...] A reactive approach merely transposing EU directives may miss particular policy opportunities in Greece. Reducing the rate of increase and managing peak demand are the main challenges for future Greek energy efficiency policy (...)

The government is using energy pricing and taxation to achieve social objectives, such as equal cost of energy across the whole country. This practice distorts the energy market and it may also discourage energy efficiency efforts. Social policy objectives are crucial, but they can be addressed more efficiently through direct support.

Selected recommendations:

- Formulate a comprehensive and clearly structured policy framework for improving energy efficiency with measurable targets as an integral part of a long-term energy policy strategy.
- Establish an effective monitoring system to achieve energy efficiency targets, and ensure that all programmes are evaluated objectively, preferably by a third party.
- Ensure the continued co-operation between all the ministries involved in energy efficiency in the development and implementation of such a plan.
- Consider the introduction of more market-oriented instruments. These could include cost-reflective energy pricing and information and awareness initiatives.
- Utilise the experience from other countries in mandating energy suppliers to achieve energy efficiency targets.
- Introduce effective policies to reduce electricity demand at peak times.

The IEA is also condemning the focus of consecutive Greek administrations and the PPC on the supply side, even when it comes to renewable energy. Reflecting official policy directions that are usually linked to sources of R&D funding, the country's researchers have been focussing on the supply side as will be seen in the papers reviewed in the following paragraphs.

The IEA suggests that a strategic and consistent demand-side plan could help the country reduce risks of power interruption and shorten the gap of winter base and summer peak loads. Effective demand-side management (DSM)[6] could have significant effects on island energy consumption. The islands represent only 8% of the total national electricity consumption, however. Official nation-wide studies tend to average out specific impacts of such measures or demand-side technologies on islands thus concealing the potentially significant competitive merits (or economies of remoteness and isolation, one might say) of island niche markets. Consequently, the priorities of national energy policy have not been considering the likely heightened importance of DSM in the islands. Hadjilambrinos has suggested since the mid-nineties that letting geographical cost variations come into the tariff structure in isolated and remote areas would allow the competitive advantage of renewables to break through without necessarily raising prices for consumers, as such a policy would merely require a shift of subsidies from conventional to renewable resources (Hadjilambrinos 1996). A similar view was also adopted by the IEA, which proposes instead to continue the social policy towards marginal remote communities via taxation which does not distort the energy market (IEA 2006). As Section 4.5 discusses, such a scenario might be possible, with

[6] The term DSM entails actions and/or programmes that influence the quantity or patterns of use of energy consumed by end users, such as actions targeting reduction of peak demand during periods when energy-supply systems are constrained. Peak demand management does not necessarily decrease total energy consumption but could be expected to reduce the need for investments in networks and/or power plants.

the full internalisation of the environmental and social costs of conventional electricity production.

A few researchers have looked more deeply into the benefits of energy conservation in the islands. The focus has been on commercial installations, mainly hotels or buildings, which are reviewed in the following papers. Balaras *et al.* (Balaras, Santamouris, Asimakopoulos, Argiriou, Paparsenos, & Gaglia 1999) ran a number of energy conservation simulations for all sectors and types of dwellings and a range of applications in the islands of the North Aegean. They demonstrated significant savings (35%-65% lower heating demand) and short payback times (2-4 years for cogeneration in the agricultural industry) that could delay capacity expansions, i.e. defer the capital and running costs of Autonomous Power Systems (ASP). Balaras and his colleagues identified significant bottlenecks and policy failures, however, such as sporadic educational and professional campaigns, incoherent financial support, sparse demonstration projects, low availability of technologies, inadequately trained technicians and lack of institutional guidance. Nevertheless, the authors suggest that these shortcomings are all part of an agenda that could be dynamically dealt with by an aggressive plan and collaboration between the central administration and local authorities.

Haralampopoulos (Haralampopoulos, Fappas, Safos, & Kovras 2001) conducted an extensive survey of energy use in the town of Mytilene, Lesvos, in association with the National Statistical Service of Greece (NSSG). Mytilene is an administrative centre and also houses most of the University of the Aegean. There, Haralampopoulos found that past efforts by the State since the late 1970s to intervene in building insulation, energy efficiency and tariff restructuring, did not manage to achieve convincing results. The observation available at the time of his study was that from 1980 both peak power demand and net generation more than quadrupled, averaging a doubling every five years (PPC 2002), i.e. an average annual growth rate of more than 10%. In his study Haralampopoulos notes that there were at the time two thirds (67%) of households without thermal insulation at all, while less than one tenth (9.2%) had double-glazing, electricity contributed to one tenth (10%) of space heating and three fifths (59%) of water heating, and less than one tenth (8%) of households subscribed to the night tariff. Although recognising the potential for savings, improved efficiency and pinpointing the causes, such as the high prices cited by households for replacing incandescent with fluorescent or other lighting, the paper does not suggest a framework for quantifying the expected benefits of a more aggressive programme nor even propose where such a programme should focus. Thus, no economic arguments are put forward for the policy maker or local utility operator to consider when reviewing their policy stance.

Mihalakakou *et al.* (Mihalakakou, Santamouris, & Kovras 2001) have also suggested major diversions from the business-as-usual (BAU) demand growth in scenarios that involved energy conservation measures and extensive introduction of renewable energy sources, albeit while failing to specify whether the figures obtained refer to the technical, accessible or economic potential. Despite analysing the savings by economic sector and fuel, the study does not assemble an economic appraisal of the results that could lead to a financing strategy and related policies towards enhancing energy conservation or increasing the share of renewables on the islands.

4.3 THE SUPPLY SIDE AND RENEWABLE ENERGY

The Greek islands are located in a geographical area favoured by very appropriate conditions for the development of both wind (Figure 20 & Figure 21) and solar power (Figure 22). The latter figure compares the Greek potential to other European locations. There might also be significant geothermal potential in the islands. According to the Institute of Geology and Mineral Exploration (IGME) a string of active volcanoes in the Greek islands has the potential to provide the country with up to a quarter of its electricity needs (IENE 2008). Recently, the new Minister of Development announced the wish to push ahead with a plan of six 'green' islands in the Aegean Sea (Voutsadakis 2009). A primary criterion for their choice was the geothermal potential of the islands. Out of the six, Milos and Nissyros have high enthalpy fields (120 to 350 degrees Celsius) while lower enthalpy ones (120-150°C) are found in Lesvos, Chios, Santorini and Samothraki (*ibid.*).

New renewables such as wind, solar, small hydro, and biomass have increased rapidly in recent years, but still contribute only a small share of 1.6 Mtoe to the national total energy supply, or 4.9% of 32.74 Mtoe TPES in 2004. The total installed electrical capacity of new renewables in 2006 was 683 megawatts (of which 522 MW is interconnected) (HTSO 2008). Of this, more than eight tenths (85%) is wind, a tenth (11%) small hydro while the rest is solar, biomass and PV. Additional installation permits have already been granted for 1,000 MW of capacity (87% of this for wind), and about 20% of this capacity was already under construction in 2006 (IEA 2006). The primary developments are taking place in the wind energy sector where capacity has increased by an average of 30% annually in terms of capacity between 1990 and 2003, while almost 30% of national total capacity was installed during the period 2004-2005. Most recent developments are quoted from an interview of Yiannis Tsipouridis, president of the Hellenic Wind Energy Association, to the English version of Greek daily Kathimerini where he revels that Greece added 114 MW to its installed wind energy potential in 2008, down from 125 MW in 2007 and 173 MW in 2006[7].

The main bottlenecks in the development of RES in the islands are recognised in the literature as being of an institutional rather than of a technical nature. Although the legal framework has been provided by the European Union, implementation of favourable legislation by the Greek government has lagged behind, accompanied by inappropriate market measures and lack of public education (Balaras, Santamouris, Asimakopoulos, Argiriou, Paparsenos, & Gaglia 1999;Kaldellis & Zafirakis 2007;Mirasgedis et al. 2000).

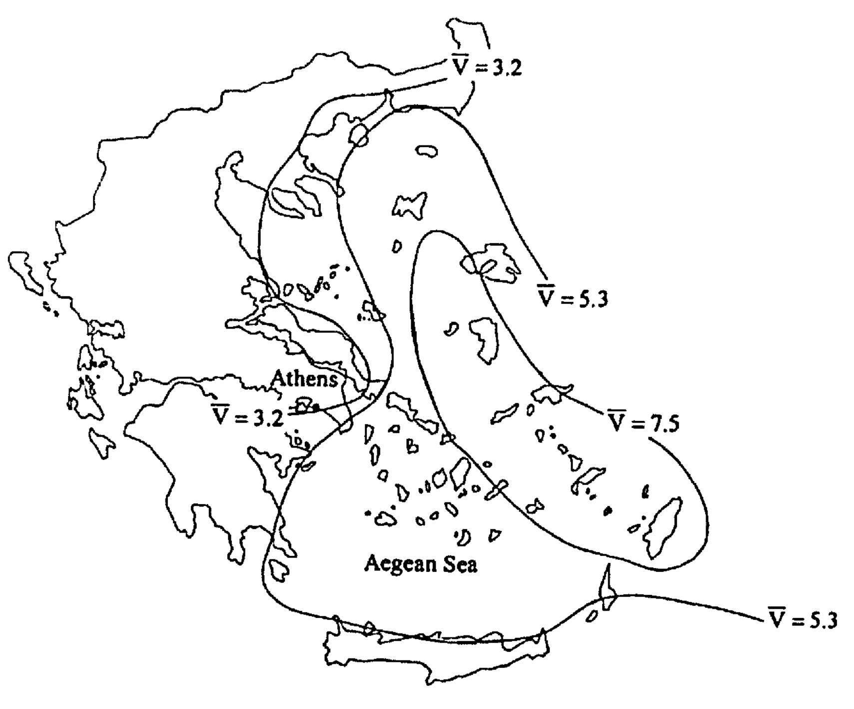

Figure 20: *Wind potential estimates for the Aegean Sea at 30m ASL (Kaldellis, Kavadias, & Christinakis 2001)*

[7] http://www.ekathimerini.com/4dcgi/_w_articles_politics_100016_04/02/2009_104398

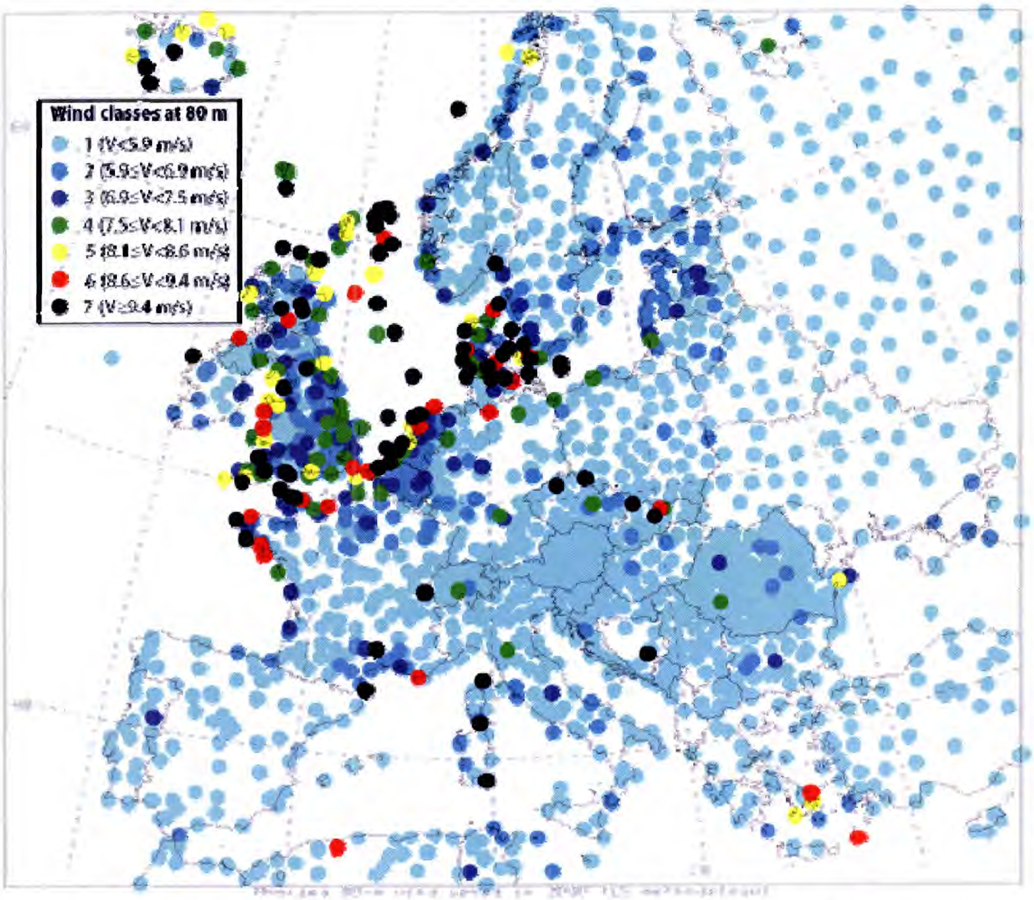

Figure 21: Comparison of the Greek wind potential at 80m ASL (Archer & Jacobson 2005)

During the first efforts to increase the share of renewables on the island grids, the so-called 'first generation hybrids'[8] failed to convince of their benefits, as they were merely just hooked up to the system causing frequency and voltage fluctuations – controlling equipment and optimisation algorithms were not available to the operators of the microgrids on islands. The uneasiness about trusting intermittent sources of power meant that local operators limited the use of renewables to auxiliary use, which studies found permitted less than a 10% share of the total power demand (Bakos 2002). However, a few studies, especially those including hydro/wind hybrids, have shown in that in some circumstances even up to 85% penetration of the renewable share could be safe (Bakos 2002;Bakos & Soursos 2002;Kaldellis 2002b;Kaldellis & Kavadias 2001). An unreasonable blanket 20% cap on renewable generation share in an island's mix which was heavily campaign against by researchers and developers was promptly removed (Pligoropoulos, Androutsos, & Bakis 2001). In February 2003, RAE tackled the

[8] According to Yorgos Betzios who was involved in such a system in the early 1980s in the island of Kythnos such systems consisted of a few if not a single wind turbine linked to the local network lacking any significant optimisation, automation or practical guidance in their operation. Their employment was left to the operators of the diesel generators who once the researchers were leaving the islands were going back to the liquid fuel habits & customs (Betzios 2003b).

issue of RES planning in the islands by publishing the methodology to determine upper limits for the renewable power percentage in the energy mix of each autonomous system separately and coupled the licensing to that figure. More recently by Decision 85/2007, RAE has clarified the picture for PV in the islands: the limit for those islands with wind parks already on them is 15% and 35% for those without either any installed or in the planning process. Developments in licensing of RES are summarised in Box 5.

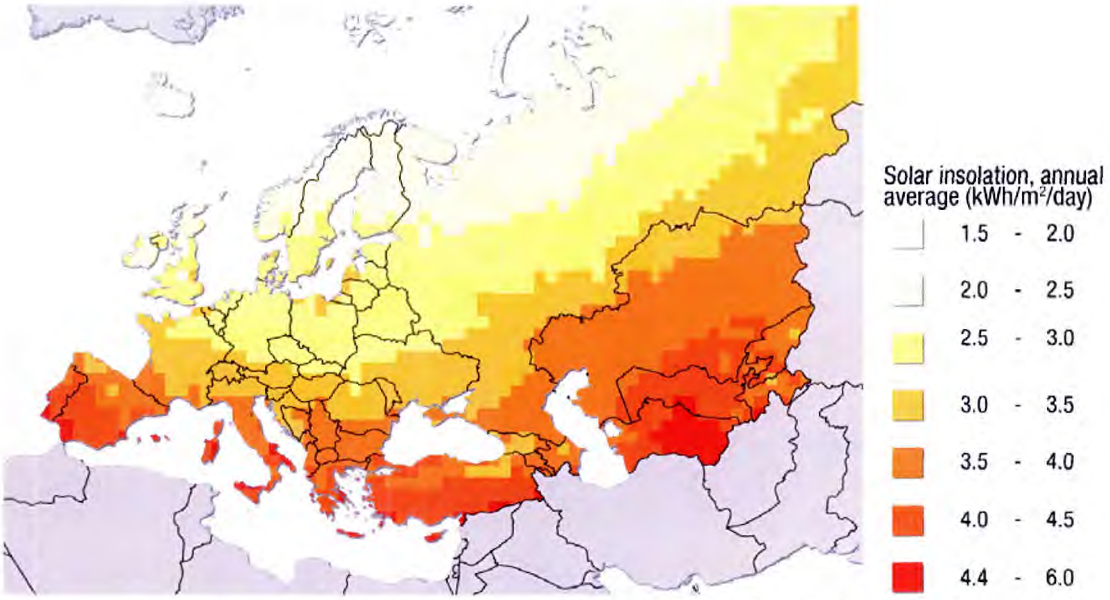

Figure 22: Annual solar insolation in Europe (NASA 2007)

Despite such progress, it is consistently observed when looking at the literature on the islands, that the problem is mainly framed as one of providing more for a growing demand rather than looking at what causes this soaring demand and acting pre-emptively on its causes (Betzios 2003a;Mirasgedis, Diakoulaki, Papayannakis, & Zervos 2000). Effectively, renewable resources are looked upon as one more capacity expansion option albeit of lesser environmental threat and - theoretically at least - providing long-term economic benefits, rather than part of an overall improved and sustainable management of a community's needs that takes proper account of both demand and supply side potentials. Worst still, conservation and DSM have been viewed as being beyond a utility's competencies or legitimate areas of intervention or authority, due to civil administration structures (EIA 2009;IEA 2006;Koroneos et al. 2005).

Box 5: Summary of key developments in RES licensing in Greece (adapted from (IEA 2006)

Greece suffers from a high level of local resistance and administrative barriers to new energy infrastructure. The government has introduced new laws for the simplification of the licensing procedure for Renewable Energy Sources (RES) systems, as well as for the industrial sector, including energy-related infrastructure (Law 3325/2005). In addition, the government is preparing a Special Spatial Plan focusing on areas of high RES potential, which will be completed at the end of 2006. In order for the Greek government to become sufficiently active in communicating its energy policy and the policy goals and constraints to the general public, Law 3438/2006 was recently passed in Parliament establishing the "National Energy Strategy Council".

The new law for the promotion of renewable energy sources, in combination with the amended joint Ministerial Decree 1726/2003 provide for a simplified, more efficient and accelerated process regarding the issue of new licences, especially the installation permit, where issue could take up to 24 months. In addition, the new law provides for the set-up of co-ordinating bodies, both on a civil service and a political level, aiming at the co-ordination of the licensing process control and the support of the authorities involved.

The RAE undertakes the first evaluation of a generation licence application pursuant to the EU Directive 2001/54/EC, which is the first of the three basic permits in a long series of central government and local authority approvals. The actual issuing of generation licences is carried out by the Minister of Development. It is easy to apply for a licence, but the process of awarding this is more complicated and over 90% of applications fail at the first stage.

There is one area, that of renewably powered desalination, where the supply led approach described before has been bravely taken beyond the strict engineering capacity expansion methodology and put to work synergistically to solve vital island problems. The potential desalination not yet been realised despite the favourable techno-economic indicators mainly due to, as in the case of wind few decades ago, investors being apprehensive, local authorities lacking the framework and funds, while the government maintains a narrow operational remit for the local utilities (Belessiotis & Delyannis 2001;Manolakos et al. 2001;Voivontas et al. 1999).

4.4 THE COST OF POWER & ENERGY SAVINGS

Mihalakakou *et al.* (Mihalakakou, Psiloglou, Santamouris, & Nomidis 2002), in their investigation of the island complexes of the South Aegean, recognise the need to 'secure energy at an acceptable cost' to islands in order to 'avoid negative impacts on economic growth'. However, the paper, as with the majority reviewed on the Greek islands (Bakos 2002;Dalianis et al. 1997;Leledakis, Goumas, & Samouilidis 1987;Pligoropoulos, Androutsos, & Bakis 2001;Voivontas, Yannopoulos, Rados, Zervos, & Assimacopoulos 1999;Zabaniotou & Giannoulidis 2002), does not go into potential financing mechanics of such interventions, or indeed offer a quantification of the possible negative impacts on economic growth, information vital for effective decision-making, but rather keeps to techno-economic descriptions and guidelines commonly linked to thermo-dynamic improvements.

This may be attributed to the unwillingness of the PPC to share marginal cost structure data, for islands in particular, an attitude condemned by researchers over many years (Donatos & Mergos 1991) and evident in a number of research papers where national data originally disclosed to the IEA is then recycled for national academic investigations (Dalianis, Petassis, Santamouris, Argiriou, Cartalis, & Asimakopoulos 1997;Mirasgedis & Diakoulaki 1999;Vassos 1997). The lack of a data to investigate the impact of seasonal and daily patterns of electricity demand on the marginal costs of power generation in the islands could have in the past deterred concerted effort. The introduction of such a methodology is among the objectives of this thesis complementing the lack of data with a bottom-up simulated construction of consumer profiles.

Bakos (Bakos 2002) conducted an aggregated supply side estimation of potential savings in the islands. His work is mainly based on a given historical demand that is not broken down by sector, neither is he concerned with the relative impact of energy uses in the overall efficiency of the system. Instead, he focuses on the operation and sizing of a hybrid wind/hydro which proves to be a highly worthy investment in techno-economic terms. Similar conclusions on the techno-economic excellence of renewable and hybrid installation are reached by Kaldellis in a few of his papers concerned with island installations (Kaldellis 2002b;Kaldellis & Kavadias 2001;Kaldellis, Kavadias, & Christinakis 2001), although he goes further than Bakos in that he deals extensively with variations of parameters in time and is very much focussed on past data to validate his models. Still, the discussions are limited in their approach to technical improvements rather than diffusion and other market variables.

4.5 EXTERNALITIES IN THE ISLANDS

Two studies of the island of Crete in 2000, based on EU projects, pointed towards new approaches to the evaluation of the economic and social impact of the generation mix of an island. Although Crete is the largest island in the Aegean Archipelago and the fourth largest in the Mediterranean, it maintains the characteristics of system autonomy and isolation, with expensive imported fuels, the predominance of thermal power and a soaring demand. Under the auspices of the EU ExternE programme, a team from the Laboratory of Industrial and Energy Economics of the National Technical University of Athens NTUA conducted an extensive enquiry into the external and social costs of the generating options on the island (Mirasgedis, Diakoulaki, Papayannakis, & Zervos 2000). Utilising formulas for the private, external environmental and social cost of electricity generation, the team examined three scenarios of RES promotion (Table 6) and suggested that the exclusion of externalities discriminates clearly against RES in favour of conventionally generated electricity.

Table 6: Cost of electricity generation in Crete by 2005
Source: (Mirasgedis, Diakoulaki, Papayannakis, & Zervos 2000)

Action Plan	Private Cost	External Cost	Social Cost
Annual Expenses (million €)			
Conventional	156.84	106.82	263.66
Renewable Constrained	164.04	87.02	251.06
Renewable Intensive	171.71	74.60	246.31
Electricity Cost (m€/kWh)			
Conventional	60.72	41.35	102.07
Renewable Constrained	63.45	33.66	97.11
Renewable Intensive	66.41	28.85	95.26

Employing the EU funded *MORE CARE* software for optimising RES utilisation in medium and large isolated systems, a team of academic and PPC engineers were able to evaluate the financial savings of wind power in the power system of Crete (Tsikalakis et al. 2003). The *MORE CARE* software utilises an array of advanced auto-regression modules, fuzzy neural networks and conventional optimisation methods for load and wind forecasts, which then provides a utility operator with short- and long-term operational options to maximise renewable output in generation. Using real load data-series it has been shown that wind power could reduce operational costs by 1.45%, which equates to €2.6 mil for 2000, with a significant impact on emissions, which were quantified (e.g. 8% less CO2 and 6% less NOx) but not monetised in the study (Tsikalakis, Hatziargyriou, Papadogiannis, Gigantidou, Stefanakis, & Thalassinakis 2003).

Apart from the EU-induced research above, not much else can be found on the subject relating to the islands. In 2005 researchers from the Aristotle University of Thessaloniki (Koroneos, Zairis, Charaklias, & Moussiopoulos 2005)looked at maximum penetration scenarios for RES in the Dodecanese islands under three scenarios. They seemed, however, not well thought out as what comes out as the best scenario is the random one: based on a threshold that is not rooted in any legal limit or scientific explanation. While they introduced Life Cycle Analysis (LCA) in their modelling, unfortunately, this was done after they had the results of their modelling on the already chosen scenario. Nevertheless, as they have not claimed to be performing an environmental but a cost optimisation, the insight might nevertheless be valuable. Yet, there is little or no insight because the study borrows normalisation and weighting factors from Holland since there are no such figures in Greece yet! The study merely applies a generic methodology to the option it already chose and makes no conclusive finding about it at the end.

In a recent work Tsoutsos and students from his laboratory at the Technical University of Crete conducted a study of the visual impact of a proposed wind park on a province of the island (Tsoutsos et al. 2008). They applied a methodology borrowed from Spanish researchers[9] that involves a visual simulation of the proposed site and installation, using advanced CAD and GIS tools in order to explore public acceptance. Such a scientific approach is a step ahead from Kaldellis' questionnaire approach, which merely summarised people's views on qualitative factors (Kaldellis 2005).The newly introduced method works on an innovative co-ordinates and vector assessment of the visual impact and also accounts for the evolution of the impact as both the growth of the park and the surrounding communities is accounted for. It also allows specific recommendations not only as to the siting of the turbines but a viable economic evaluation model of civil works, restoration and other externalities. Their effort is commendable and the value of such a methodology is critical to the further development of the sector and especially wind. Based on 3MW generators, the 34,000 MW of wind power for which applications exist with RAE equate to some 11,000 turbines - and this at a time when proposed wind farms of around 300MW are being widely challenged on aesthetic and environmental grounds.

It is customary in Greece for residents in the vicinity of wind parks to be severely against such installations, evoking populist rhetoric such as that "the huge wind mills will continuously groan spreading headaches, causing teeth to rattle, wrecking our nerves and even affect libido" (published on November 24, 2008 in the daily "Ta Nea" http://www.tanea.gr). In the same article, Yorgos Peristeris, president of the Renewable Generators Association of Greece, states that it is estimated that the public is holding back roughly € 2.5 billion of investment in RES. Tsoutsos work, if adopted by the State, believed in by developers and supported by stakeholders could make ends meet and Greece achieve its 2010 Kyoto target of 25% above 1990 levels for CO_2. Data from 2003 suggests it was already at +23.5% and +24.4% in 2006 (EEA 2009;IEA 2006). Finally, the country managed to be the first member of the Protocol to be suspended from the U.N.'s carbon trading mechanisms (i.e. Joint Implementation known as JI and CDM the Clean Development Mechanism) as a punishment for non-compliance in April 2008[10].

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[9] Hurtado, J.P., Fernandez, J., Parrondo, J.L., Blanco, E., *Spanish method of visual impact evaluation in wind farms*. Renewable & Sustainable Energy Reviews

[10] ENDS Europe (April 23, 2008): http://www.endseurope.com/14996

4.6 INCOME ELASTICITY & DEMAND GROWTH

In 1990 the Economics Department of the University of Athens conducted a comprehensive study of the Greek residential sector (Donatos & Mergos 1991). While the elasticities calculated and the energy use figures are outdated, some conclusions may remain valid today. So long as the heavily State subsidised tariffs are still in place along the growing electricity demand – albeit in a decelerated fashion from 11.3% annual average rate of growth for the period 1961-82 to 5.3% between 1992-2002 (Energy Work Group 2003) – maintaining a nearly 4% annual average currently (IEA 2006). The study indicates a residential demand which is price inelastic and income elastic as well as a positive cross-price substitutability of electricity with LPG for cooking and water heating. Despite this being a significant finding for policy-making, that particular fuel never really became established in the country (Energy Work Group 2003) as electricity locked-in to the economy during the rapid electrification of the country in the 1950s as a better and more versatile energy carrier.

Regional fluctuations in residential demand were not discovered as the structure of the demand and systematic variations were omitted due to the nature of the pooled data. This is a grave simplification for the purposes of understanding residential demand in the islands, as it completely ignores the potential sensitivities of and variations between remote and isolated energy systems. The islands were averaged along mainland figures in the pricing policy of the PPC and given the tariffs established on the long-run marginal costs of a generation mix dominated by cheap local lignite, keeping externalities out of the equation (Dalianis, Petassis, Santamouris, Argiriou, Cartalis, & Asimakopoulos 1997;Mirasgedis & Diakoulaki 1999).

The study detects no impact of changes in appliance ownership and efficiency on electricity demand either. However, air-conditioning might have shown little impact since it was a small market at the time of the study. In any case, a variable for cooling-degree days was not included in the model. The 1992-2002 decade alone saw an increase between 200-300% of air-conditioning unit sales for households and offices (Daskalaki, Balaras, & Tsagrasoulis 2003). A well planned new tariff regime for the islands could alleviate the costly operating patterns of the local utilities by shifting demand during peak periods. This thesis aims to look into this as a potentially valid policy option for demand-side power management.

In the mid-1980s Leledakis and colleagues (Leledakis, Goumas, & Samouilidis 1987) reviewed official government and PPC reports and found that energy demand in the Cyclades island complex 'has grown more rapidly than the rest of Greece, following the regional per capita income, which increased 6.60% in the period 1970-80 while it grew only 4.92% in all of Greece'. No further elasticities could be evaluated because of lack of data but they assumed a positive correlation among incomes and electricity on the islands, which has also been shown by appliance ownership in Table 5 of Section 3.2.8. The study suggested potential substitution effects on the supply side, especially for wind power and the limited geothermal resources there are. The tertiary and domestic sectors did not prove to appropriate for substitutability at the time of the paper. However, the comparison was made on the subsidised publicised tariffs and ignoring the intrinsic incentives for the operator to avert uncontrollable demand growth and variability. In addition, the technologies looked at, although solar-related, do not include a service for air-conditioning which is a very relevant and major consumer service now.

Targeted island studies were a trend of the 1990s, mainly due to the international interest in renewables and the increase in the flow of European and State funding towards less developed regions. On the contrary, in the 1980s the bulk of academic work focused on the continental Greek energy system, the Public Utility's objectives and indigenous lignite. The decision-making tools were engaged mainly in forecasting growth functions, network expansion, large plant management and dispatch, or were broad energy-economy models for policy makers (Donatos & Mergos 1989;ICAP & Delos Communications. 2001;Leledakis, Goumas, & Samouilidis 1987;Samouilidis & Mitropoulos 1983;Skiadas, Papayannakis, & Mourelatos 1993;Vlachou & Samouilidis 1986). The methodologies developed in the 1980s, mainly by a team of academics at the Technical University of Athens (NTUA), have been propagated in the research of island energy systems quoted across this chapter.

As a result, the island studies are either found to be centred on supply-side solutions or adopted a top-down approach to demand. Thus, for example, the econometric fuel substitution model developed at the Energy Policy Unit of the NTUA (Vlachou & Samouilidis 1986) provides a comprehensive sectoral breakdown of substitutability and complementarity between electricity and other fuels. However, the assumptions held are not valid for the fuel supply constraints of (i.e. transport and storage) and electricity generation limitations (i.e. costs and sharp seasonal demand) of islands.

On a similar note, in the study of energy investment and economic growth by Samouilidis et al. (Samouilidis & Mitropoulos 1983) and later revisited by Hondroyannis (Hondroyannis, Lolos, & Papapetrou 2002), the national economy aggregates can even out the effect of the distinct structure of island economies. Moreover, the resulting elasticities and conclusions are not reversibly applicable to islands. This is because on the one hand energy systems on them are autonomous in their scope and limited in their links to the rest of the local economy, while on the other hand, those links are broken in the off-season winter period, or accumulates in the mainland through taxes on tourism receipts and premiums on related services.

4.7 FEEDBACK EFFECTS & CAUSALITY IN MODELLING

The linearity of the modelling approaches is a common feature observed in the papers reviewed on Greek island energy. Objective functions and constraints are limited to interpreting or providing solutions to static linear problems and suffice in a variety of optimisation techniques (cost-benefit, scalar optimisations, etc.). In some cases, multi-objective functions are deployed, working on Pareto efficiency sets (Koroneos, Michailidis, & Moussiopoulos 2003;Mavrotas et al. 2003). However, they maintain a narrowly focussed techno-economic orientation whose scope refuses the policy-makers a perspective of actors beyond the narrow specifications of the technical application under examination, i.e. they tell us little about the behavioural patterns of operators, investors or consumers.

A study by the Athens University of Economics and Business (Christodoulakis & Kalyvitis 1997) introduced interactions and a few cause-effect relationships among energy, prices and production factors of the economy, in a model that incorporated some endogenous variable dependence. However, the model is sized to a national economy and feeds in changes of aggregate demand growth that the algorithm then splits by fuel and sector. Despite the excellence of linking EU policy initiatives to domestic output, labour and energy consumption, the breadth of the model would not be adequate for application to an island, especially when it comes to adoption rates of individual consumers. On the other hand, despite being solely concerned with wind power parks, the extensive sensitivity analysis proposed by Kaldellis (Kaldellis & Gavras 2000) is quite comprehensive and sized to an island economy whilst still maintaining the vital exogenous links to the world and the national economy (inflation, exchange rates, stability etc.).

The observations on the impacts of those parameters on payback for wind installations could provide generalised insights into similar considerations by the utility or the government when inquiring whether to subsidise new consumer energy equipment. Nevertheless, there is a suspicion that most of the rates assumed in the models of Kaldellis and others (Koroneos, Michailidis, & Moussiopoulos 2003) do not link back to nor update the original parametrical assumptions of the simulation. Thus, the necessity of such an extensive sensitivity analysis, which is still lacking the dynamic analytical aspect of Christodoulakis' approach. Realising this shortcoming, Kaldellis went on to analyse the time-dependence of his variables (Kaldellis 2002a), albeit at a national scale this time. Having managed to match his simulation with the past performance of the wind power sector, the study importantly separates out electricity price escalation and capital cost as the main influencing parameters on technology investment. Those observations can be adapted for the case of demand-side equipment for the objectives of the thesis and are taken into account when developing the model, as described in later chapters.

Papers on the causal relationship between energy and the economy (Hondroyannis, Lolos, & Papapetrou 2002;Samouilidis & Mitropoulos 1983), have suggested that energy prices should be credited with much of the effect on the national economy and energy consumption as well as serving as a measure of efficiency of industrial conversion (incl. power generation) although this link was not adequately clarified. Marginal costs of electricity generation on the islands are crucial in assessing the success of a demand-side intervention and quantifying the benefit to the utility operator to justify further support.

Hondroyiannis et al. (2002) drew a correlation of energy consumption, inflation and economic growth. However, their conclusion strangely does not hold for the domestic sector which is reckoned as an exception to their claims of a correlation just established. Quoted directly from source, residential consumption "is mainly determined by long-run trends in wealth, by international trends and fashions, by consumption tastes and habits, which are not directly associated with fluctuations of economic activity". With respect to conservation, Hondroyiannis proposes but does not scientifically support, that improvements in economic efficiency would activate energy conservation mechanisms, which in turn would affect the growth process positively. Such causality assumptions are to be thoroughly examined in the context of an island economy through SD simulation by means of the model built.

4.8 ENVIRONMENTAL SENTIMENT

Social and environmental considerations in energy decision-making have surfaced in Greek policy-making only over the past decade, through policy debates and initiatives in the EU[11] and the growing availability of new fuels (Christodoulakis et al. 2000;Christodoulakis & Kalyvitis 1997;Dalianis, Petassis, Santamouris, Argiriou, Cartalis, & Asimakopoulos 1997;Energy Work Group 2003;Mirasgedis & Diakoulaki

[11] European Commission (1995) Externalities of Energy, DGXII (Joule Programme).

1999;Stavridis 2003;Vassos 1997). Realistic comparisons were made possible, as wind power has increasingly become an international commercial 'green' technology (IEA 2003). The introduction of natural gas in the country by bilateral contracts with Russia in the mid 1990s contributed to a wider choice of supply options, with varying degrees of environmental performance (IEA 2002;Pligoropoulos, Androutsos, & Bakis 2001;Stavridis 2003) most of which were significantly better than the environmental profiles of lignite and of fuel oil.

The national report to the UNCED (UN's Conference on Environment and Development) accepted that the limited environmental awareness of the Greek population was among several institutional and structural weaknesses in promoting sustainability (Fousekis & Lekakis 1998). By 2005 great progress had been made. Greece has ratified and entered into force most of the multilateral environmental agreements and its citizens deemed the environment very important; indicated in Figure 23. As energy consumers though, the citizens of Greece have not yet attained a high level of environmental consciousness related to their behaviour and decisions (EEA 2005).

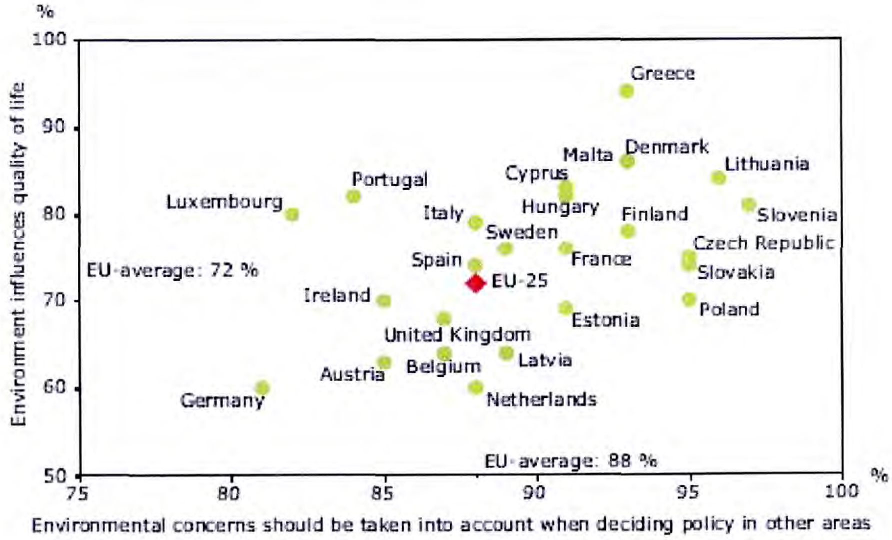

Figure 23: European opinions on the environment's influence on the quality of life and the perception of the environment's importance in the policy-making process (EEA 2005)

Consequently, a major working hypothesis of the thesis and the subsequent model configuration is that a demand-side management strategy has to appeal largely to the personal utility or business value derived from consumer energy equipment. On the one hand, any new technology put forward should be looking to reduce demand peaks and provide growth controllability. On the other hand, adopters are only likely to be attracted to those technologies as long as at least the same energy service (i.e. hot water, space cooling, refrigeration etc.) is received with an added value.

4.9 CONCLUSIONS

Carrying through the issues met in Chapter 3 and following from the analysis in this chapter, it can be concluded that there are clearly areas for improvement in energy generation, consumption and demand side management in the Aegean Sea islands. These have been well documented by Greek researchers. However, the technologies in place at the moment and the approach to decision-making are currently based on a traditional engineering supply side approach. Researchers have seen virtually no practical application of their research on which to advance their theory and research, and thus have been inevitably recycling the same concepts, albeit with improvements in methodology or another geographical area in focus.

Gradually though, during the past decades the effectiveness of this utility dispatch approach to energy services has become severely constrained in the islands, mainly due to the growing standard of living and the increase in a service hungry transient population on the islands. Over the same period, numerous studies have been completed stressing the need for and benefits from extensive utilisation of clean and renewable technologies for generation and conservation of energy. Nevertheless, renewable sources such as wind and active solar, which have become more popular in the last decade, are seen essentially as another supply option, rather than a tool complementary to conservation, which could diminish the energy intensity of the islands and their tourism sector, along with energy service provision. The rapid growth of the wind sector, however, paved the way towards a friendlier regulatory and institutional environment for other technologies and, most importantly, mindsets to follow.

According to the IEA, Greek energy policy needs measurable objectives, collaboration among Ministries and market-oriented instruments, to make progress in DSM. The niche economics of the islands must be visible when it comes to energy policy making, otherwise they tend to be covered under national averages, which fails to address their particular circumstances, constraints and opportunities. Low technology availability, inappropriately trained technicians, few demonstration projects, incoherent financial support and lack of institutional guidance are among the barriers to the adoption of energy conservation.

Nevertheless, it remains an issue how to match the needs of the stakeholders involved, accommodate for services required for the local economy with minimal disruption to the perceived lifestyles and still ensure economic viability. So far, the approach has been linear. Most papers reviewed were looking for an objective function to set their optimisation maxima on. Those that discussed policy tended to lack a framework or methodology to accommodate both tangible and intangible variables. Those that did have a framework, like some sort of cost benefit analysis, for example, hardly provided any vision of pathways to the future but rather a snapshot of the present.

Appropriate, effective policy formulation means recognising the challenges of transition and has to make it as smooth as possible for the people who after all are going to benefit or suffer from any change, while simultaneously making non-incremental changes in the island energy systems. In the context of this thesis, in order to do this it is important first to be able to understand current needs, how they have developed, how and to what extent they are fulfilled and which mechanisms or norms could be challenged to service those needs differently but with the same or better final utility. As part of an attempt to move the analysis forward, this thesis attempts to build a simulation process that models an island with evident stakeholder presence alongside traditional utility planning and in the light of modern theories of technology adoption. In System Dynamic terms, the costs and benefits of key stakeholders are compared against each other in feedbacks that provide insights from capacity development to subsidy design and destination attractiveness (i.e. tourism receipts).

The next chapter seeks to elaborate further on the solar technologies experience of Greece and especially the successful Domestic Solar Water Heater (DSWH) market. It is important to understand the factors that led to the uptake of the equipment and the creation of a competitive manufacturing sector. Solar photovoltaic as well as demonstration solar cooling applications are examined too.

5 SOLAR TECHNOLOGIES & THE GREEK EXPERIENCE

The aim of the chapter is both to summarise the lessons learned from over 30 years hands-on practice in solar water heaters and critically assess the market and technological potential of solar cooling to date. It also briefly examines the solar photovoltaic market in search of lessons to be learnt. Applications of related technologies to the tourism industry are of special interest. The expected outcome is a set of assumptions for the modelling part of the thesis, as well as to ensure the reader of the validity of the approach in answering the issues of the Greek islands at hand. The literature sought focuses on the European and particularly Greek market and experience[12].. According to research by ESTIF (European Solar Thermal Industry Federation) the EU market grew by a staggering 47% in 2006 (Hopwood 2007). Solar cooling at the same time appears both as a stand-alone and a complimentary technology to water/space heating that is nearing market conditions (Holter 2007).

Structure of Chapter:

5.1 THE GREEK SOLAR WATER HEATER (SWH) MARKET
- 5.1.1 The European Experience & Greece
- 5.1.2 The Development of the Domestic SWH Market
- 5.1.3 Drivers & Barriers of the Market
- 5.1.4 Costs and Payback
- 5.1.5 Environmental and Other Benefits of SWHS
- 5.1.6 A Critique of Subsidies, Grants and Intervention
- 5.1.7 Central Systems
- 5.1.8 Policy Failures

5.2 SOLAR PHOTOVOLTAIC APPLICATIONS

5.3 SOLAR SPACE COOLING
- 5.3.1 Introduction
- 5.3.2 Brief Introduction to the Technology
- 5.3.3 Outlook and Installations in Greece
- 5.3.4 Market Outlook in Europe
- 5.3.5 Experience in the Mediterranean

5.4 ELEMENTS FOR THE SIMULATION MODEL

5.5 SUMMARY & CONCLUDING REMARKS

[12] According to research by ESTIF (European Solar Thermal Industry Federation) the EU market grew by a staggering 47% in 2006 (Hopwood 2007). Solar cooling at the same time appears both as a stand-alone and a complimentary technology to water/space heating that is nearing market conditions (Holter 2007).

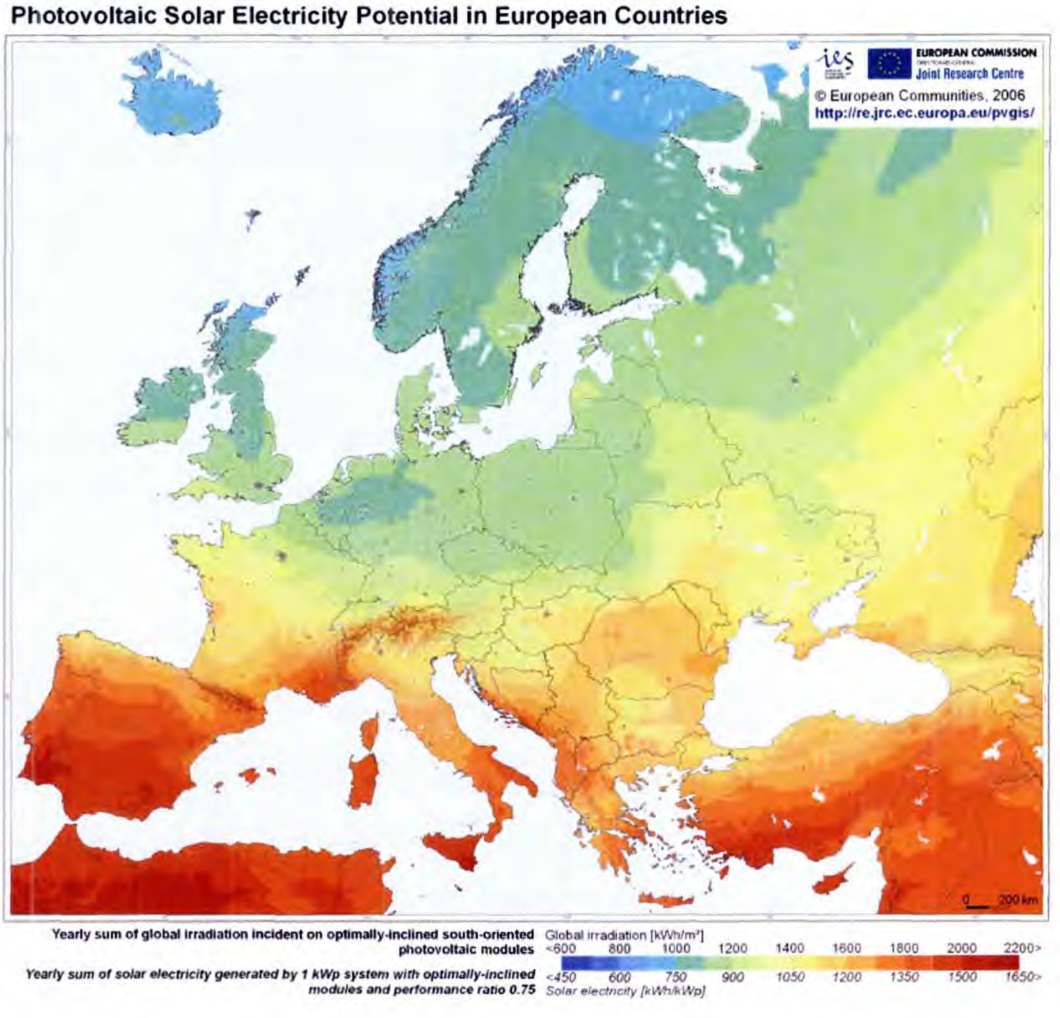

Figure 24: Solar PV potential in Europe (JRC 2007)

5.1 THE GREEK SOLAR WATER HEATER (SWH) MARKET

5.1.1 THE EUROPEAN EXPERIENCE & GREECE

This section reviews critically the literature on the use of solar water heaters and DSWH systems (DSWHS), particularly with reference to Greece, summarises the main points of the debate and the lessons learnt from experience. The expected insights relate to the development of the market, the structure of costs, any figures on the learning and in general any figures of soft elements to be of help in the construction of the technological component of the simulation model of the thesis.

It can be observed that the degree of development of national markets in SWH does not depend purely on location. Figure 24 shows the insolation in Europe. Despite their low scoring in this characteristic Germany and Austria have become leaders in domestic solar water heater (DSWH) installations, as Figure 25 illustrates. Growing environmental concern seems to be increasingly the driver for governments who provide market instruments to support installations (EIA 2009;IEA 2006).

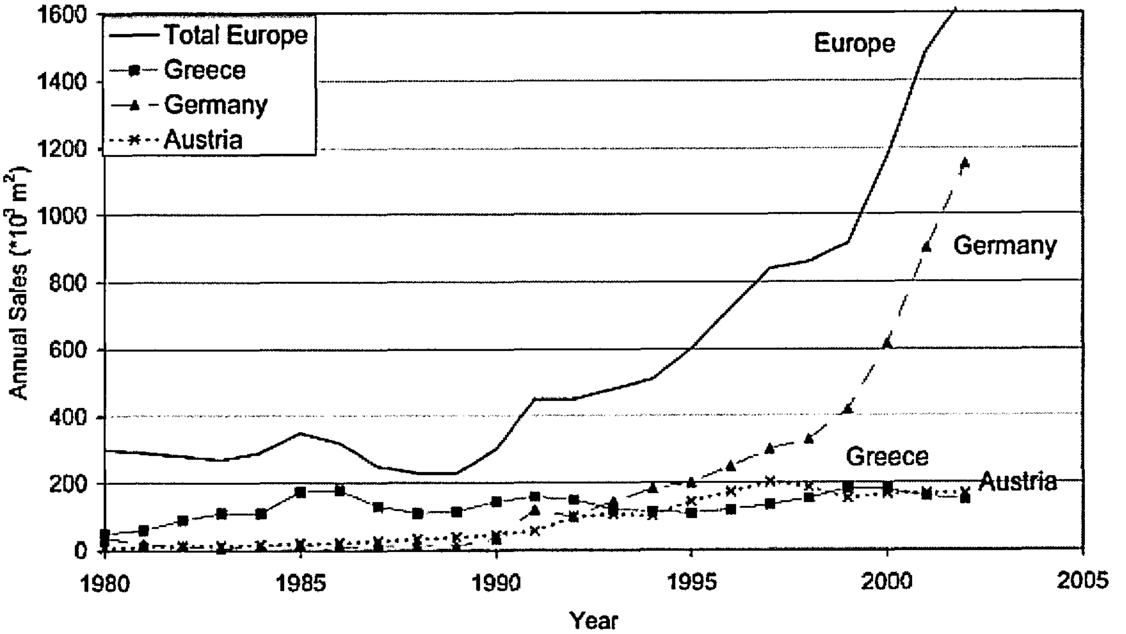

Figure 25: Annual sales of DSWHS in Europe (Kaldellis, Kavadias, & Spyropoulos 2005)

Greece has a large potential for passive and active solar energy applications, given the relatively high annual solar irradiation level, as can be seen in Figure 26 (the dark areas are of the over 1,600 kWh/m2 shade in the scale). Some of this potential has been realised. For example, in 2004, sales of new solar water-heating systems were estimated at a total capacity of 179 kW peak thermal (kWpth), increasing total installed capacity to approximately 2 GWpth, meaning that Greece has the second-highest installed solar thermal capacity in the EU after Germany (IEA 2006). Germany is the leader with 30% of total installations in the Union followed by Greece (25%) and then Austria at 20%. Other countries follow behind with France (5%), Spain (4%), Italy (3%), Denmark (3%), Portugal (1%) and 9% for the remainder (Kaldellis, Kavadias, & Spyropoulos 2005).

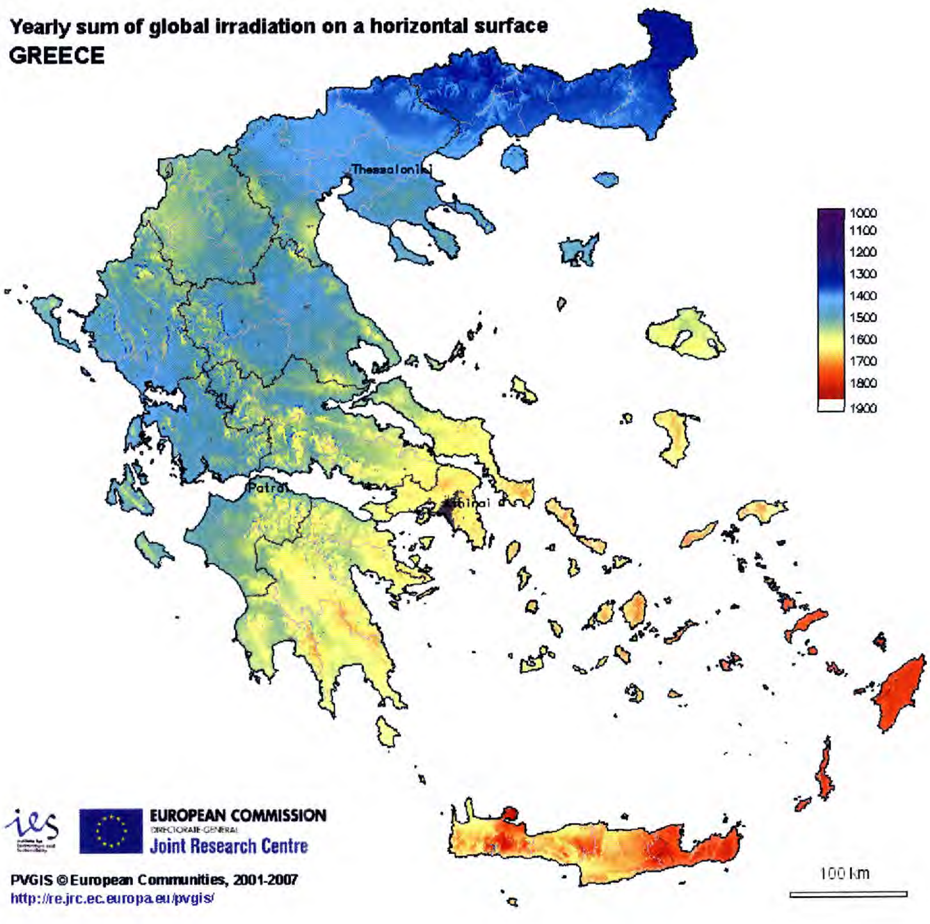

Figure 26: Annual irradiation (kWh/m^2) in Greece (JRC 2007)

5.1.2 THE DEVELOPMENT OF THE DOMESTIC SWH MARKET

The solar water heater market of Greece was established during the 1980s, through a mixture of institutional, fiscal and regulatory measures that, despite the lack of an integrated approach, achieved the building of one of the first such markets in Europe (Haralampopoulos, Paparsenos, & Kovras 1997;Kaldellis, Kavadias, & Spyropoulos 2005;Karagiorgas, Tsoutsos, & Berkmann 2003;Tsoutsos 2002). The ensuing growth of the market, coupled with the appropriateness of the technology to local technical and entrepreneurship competence, was such that an exporting industry also developed alongside the nationwide network of resellers and installers. By 1985 sales jumped to 200,000 m2 per annum averaging 140,000 m2 in the 1988-2002 period, while the market eventually cooled off (Kaldellis, Kavadias, & Spyropoulos 2005). Figure 27 shows the fluctuations of the market from 1980 to 2003. In 2003, manufacturing over-capacities were reported, with the sector's capacity utilisation at 50% driving many manufacturers out of business and disrupting the price structures of exporting enterprises in the sector (ESTIF 2003).

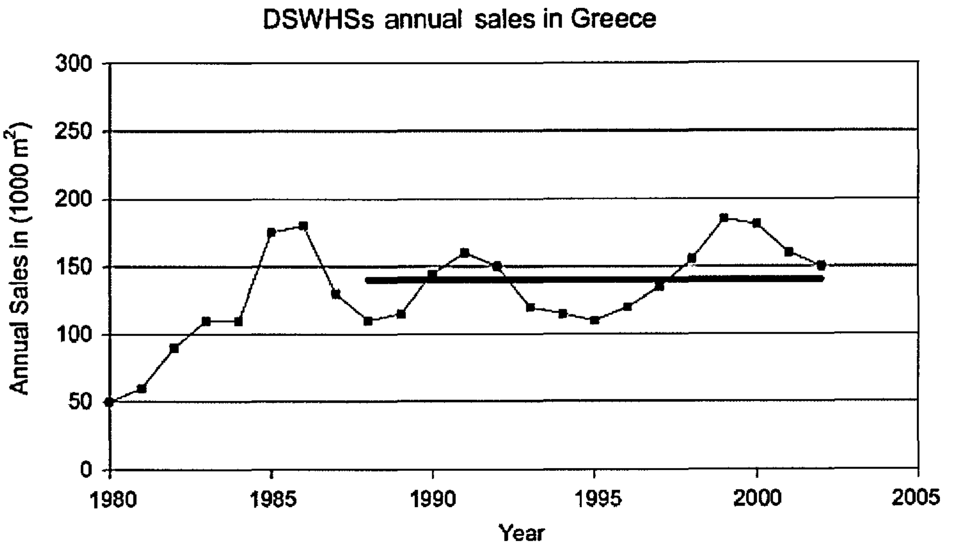

Figure 27: Sales of DSWHS in Greece (Kaldellis, Kavadias, & Spyropoulos 2005)

The theoretical conversion efficiency of collectors in Greece can reach up 800 kWh/ m^2/year at the most favourable places in Southern Greece (Figure 28). The usual average of energy gain for most of the studies though ranges from 350 to 500 kWh/m^2/year depending on the geographical location and size of installation which is compared to about half as much in Germany and reaching 2/3 of this value in some parts of Southern Austria only (CRES 2001).

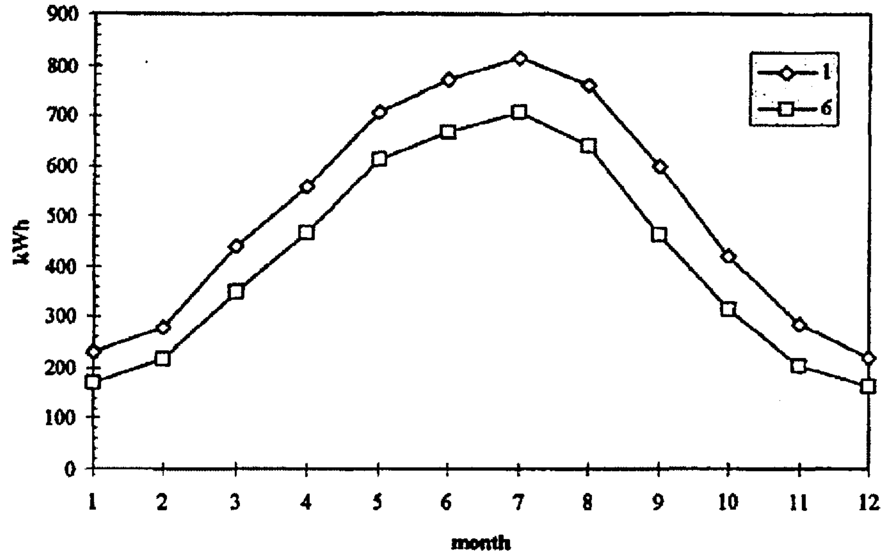

Figure 28: Monthly solar irradiation for extreme South (1) and extreme North (6) of Greece (Haralambopoulos & Spilanis 1997)

About 90% of the market is for thermosyphon closed-circuit type (based on natural circulation of the water due to thermal expansion) whose output matches the favourable climatic conditions of the country (Figure 29); they are also cheaper to make and can withstand the relatively mild weather conditions in the country (Haralampopoulos, Paparsenos, & Kovras 1997). Nevertheless, in a study of consumers' published in 2004 one third of domestic solar collector owners reported technical problems with their installations, such that they were eventually abandoned (Sidiras & Koukios 2004b). These failures were mainly caused by installations carried out by untrained plumbers and related to piping and insulation problems. Most of the manufacturing faults were phased out early on, with the establishment of the Greek Solar Industry Association, which introduced compliance to standards as a prerequisite for membership (Kaldellis, Kavadias, & Spyropoulos 2005).

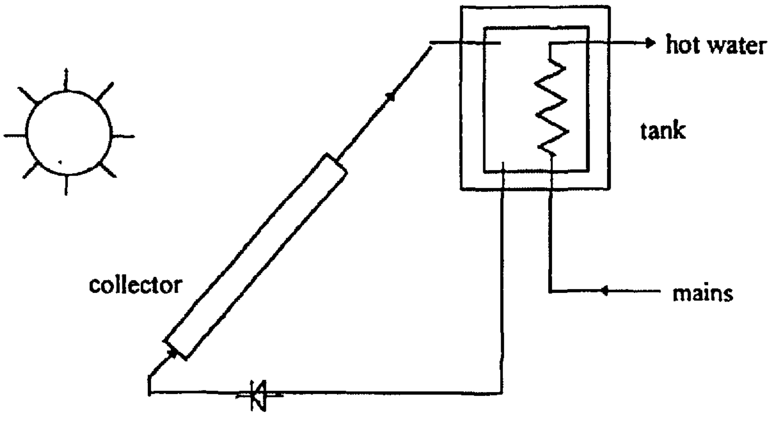

Figure 29: A sketch of a typical DSWH system

Significant information about the state of the market can be extracted from a study on behalf of Eurostat, submitted in 2001 (CRES 2001). At the start of 2000, about 45 manufacturers/assemblers were still active in Greece, with a collective capacity of 300,000 m^2 annually, covering most of the domestic market, while three major importers supplied an additional 5,000 m^2 annually. Total installed area at the start of the millennium was approximately 2.96 million $m^{2,}$ out of which 99% are household systems for hot water, 0.75% are large scale for the tertiary sector and only 0.17% used for combined uses (hot water, air-conditioning, space heating) in industry. In 2000 the energy produced from solar collectors amounted to almost 8% of the electricity consumption of the residential sector and was almost entirely attributed to domestic systems.

The geographical distribution of installations in general follows population density, although the distribution is not unexpectedly significantly skewed towards higher insolation regions. The percentage of households owning a DSWH is said to be14% (one in seven) in Athens, which is also the national average, 6% in Thessaloniki in the North (one in sixteen) and an impressive 17% (one in six) in the islands, where tourism and brown-outs do affect decision making further (Sidiras & Koukios 2004a). A different study by CRES reckons, however, that 20-22% of the households own a DSWHS on average (CRES 2001). Scepticism is common about the figures of the market.

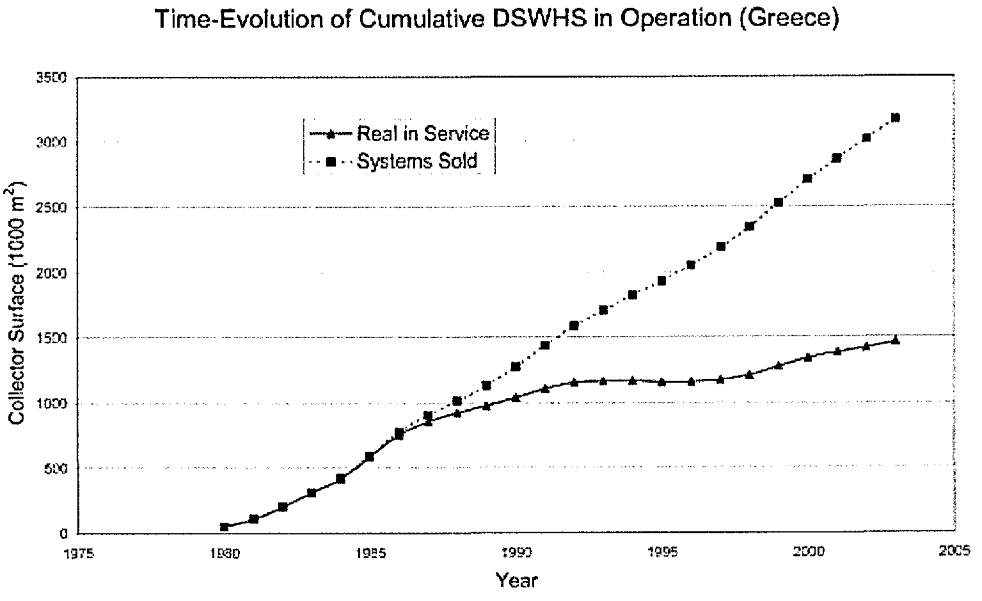

Figure 30: Systems sold vs. systems in operation (Kaldellis, Kavadias, & Spyropoulos 2005)

Kaldellis et al (Kaldellis, Kavadias, & Spyropoulos 2005) in a 2005 paper significantly challenged the success of the Greek market, by claiming to have revealed the real situation of the solar water heater market in the country. According to the authors, the situation is rather disappointing as the sales volume is complemented by a remarkable rate of decommissioning that can be deduced from Figure 30. Devising a more detailed approach for calculating the annual retirements than the Eurostat report (CRES 2001), whose results were also reflected in the Altener Programme report (Kaldellis, Kavadias, & Spyropoulos 2005;REACT 2004), they claim only 50% of what CRES and REACT presented is actually in practical operation. Effectively the market has reached saturation level with slight increases of the functioning installation stock since the early nineties; a conclusion which an extensive study by Sidiras and Koukios also reaches (Sidiras & Koukios 2004a). A very encouraging observation, however, is that existing customers do replace the equipment once it is damaged or at the end of its life. This figure has been shown to reach up to an impressive 90% of existing customers who almost instantly replace their equipment after about 12-15 years of service life (ESTIF 2003).

5.1.3 DRIVERS & BARRIERS OF THE MARKET

The major contributors to the success of the market have been identified as follows:

- Advertising campaigns both by the private sector and through public support
- Exhibition sales
- Straight-forward design, available parts and easy assembly of equipment favoured by prevailing climatic conditions
- Great new construction rate of block of flats
- Favourable installation surfaces, mostly flat roofs – easy access
- Financial incentives such direct subsidies and tax cuts which, however, were eventually undermined by high inflation rates

The major advertising campaigns took place in the period 1984-1986, with the support of the national government across all media, and then again in 1995 on the public power corporation's electricity bills. It is widely accepted that the advertising campaigns have led the market, raised awareness and consumer interest (Argiriou & Mirasgedis 2003;Balaras et al. 2007;CRES 2001;Kaldellis, El Samani, & Koronakis 2005;Sidiras & Koukios 2004a). As a result, the demand driven market was booming until 1987 with an estimated 300+ manufactures/assemblers of solar systems in operation.

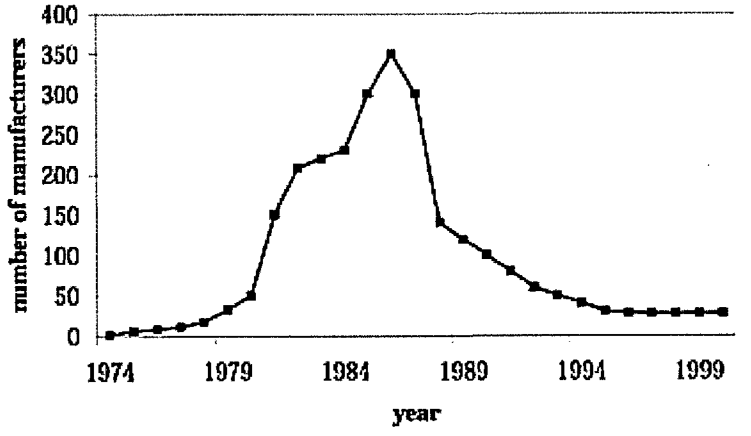

Figure 31: Development of system manufacturers (Sidiras & Koukios 2004a)

After 1987 the market did start to slow down mainly due to:

- Financial constraints reducing the rate of building construction
- Falling oil prices as the world was coming out of the 1970s oil price shock repercussions
- Rigid, low and stable electricity prices controlled by the government that have since raised large political costs that make them very difficult to change.

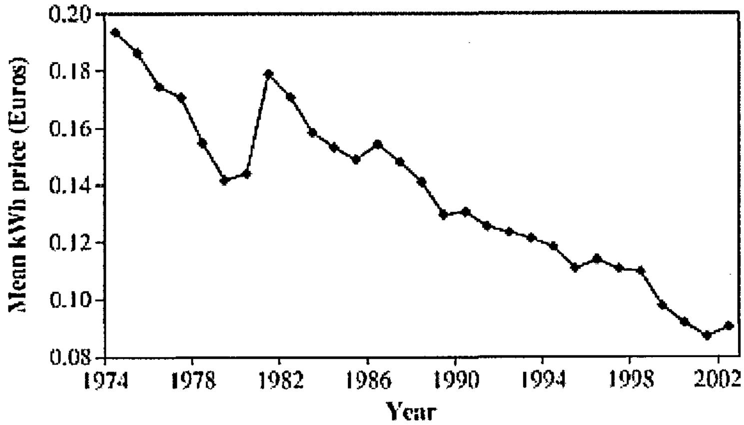

Figure 32: Evolution of the kWh electricity price (in 2002 €) (Sidiras & Koukios 2005)

The rapid growth and establishment of the market in the 1980-1992 period has been attributed to a favourable set of market-based, albeit unconcerted, incentives and political events (Argiriou & Mirasgedis 2003;Kaldellis, El Samani, & Koronakis 2005;Kaldellis & Zafirakis 2007;Karagiorgas, Botzios, & Tsoutsos 2001;Santamouris et al.). Had the lessons been learned well during that early period and the benefits understood and communicated earlier and wider, those initial conditions could have still sustained a remarkable market. The fact that central solar systems never managed to take off despite a 50% financing against capital costs provided by the Greek state via the Operational Programme for Energy (1996-2000) for hotels and industry perhaps shows the missed opportunity to reach the purchasing/investment consciousness of potential buyers' (CRES 2001). However, there remain significant lessons to be learnt and adopted for the research question at hand.

Box 6: Summary of the financial incentives for DSWH. Adapted from (Kaldellis, Kavadias, & Spyropoulos 2005) & (Argiriou & Mirasgedis 2003)

The incentives for the purchase of a DSHWS were first applied in 1978 (i.e. Statute 814/78), in the form of income tax reduction, representing 75% of the system cost at that time (1978 rates), in case that the purchase cost did not exceed 10% of the citizen's annual income liable to tax. Later, this amount was slightly modified (decreased to 60%) by Statute 1473/84. Considering that the above tax reduction had been expressed in constant numerical values (in local currency), the impact of this incentive faded rather fast due to the high inflation rates of that period (1980–1990).

The implications of tax incentives and other measures can be seen in Figure 34. During this high inflation period, soft loans were also allocated for the purchase of solar systems, covering up to 70% of the system purchase price while in 1982 a law provided 50% grants on the total cost of the system that unfortunately came with a complicated bureaucratic procedure and consequently failed to reach its objectives.

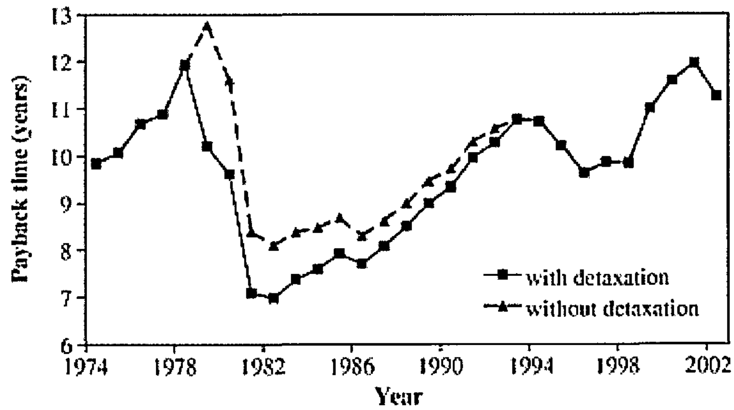

Figure 33: Impact on tax incentives on system payback (Kaldellis, Kavadias, & Spyropoulos 2005)

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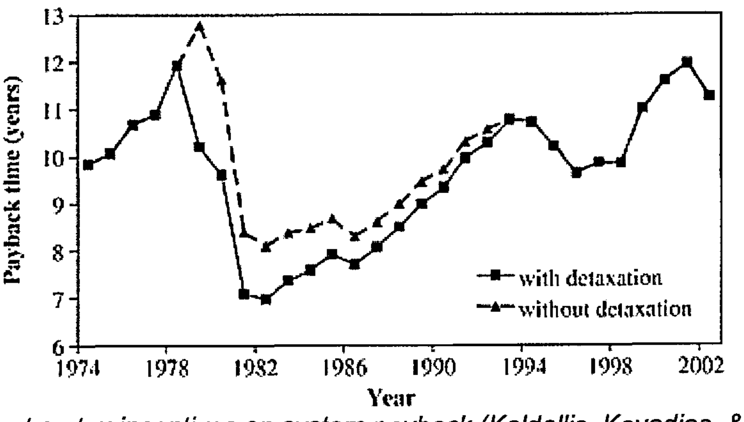


Figure 34: Impact on tax incentives on system payback (Kaldellis, Kavadias, & Spyropoulos 2005)

In 1995, an attempt to support the DSWHS market was made by Statute 2394/95. According to this law, 75% of the purchase and installation cost of all renewable energy systems is exempted from the individuals' taxable income. Hence, support could obviously originate from legislation and programmes fending for the whole renewable energy sector. Even according to the law 2394/95, the final tax deduction strongly depends on the taxable income of the DSWHS owner. Considering that the regular income tax rates are equal to 15, 30 and 40% (according to the taxable income) and neglecting that any tax return is realized normally 1 year after the DSWHS purchase, the final subsidization amount is between 11 and 30%, (e.g. 0.75*0.40).

Since January 2004, there are no governmental actions supportive to the DSWHSs' purchase by individuals, as the national energy policy is almost exclusively focused on stimulating the imported natural gas penetration in the tertiary sector.

The instability of the market until now and its expected progress (Sidiras & Koukios 2004a) is attributed to the levels of financial support and advertising campaigns rather than research and development in the design of the systems or any innovative technical improvements. The penetration of solar heat usage has been disassociated from degree of solar irradiation from studies of North and South Europe markets and is rather down to the incentives each State provides to utilise that excess heat (Kaldellis, Kavadias, & Spyropoulos 2005).

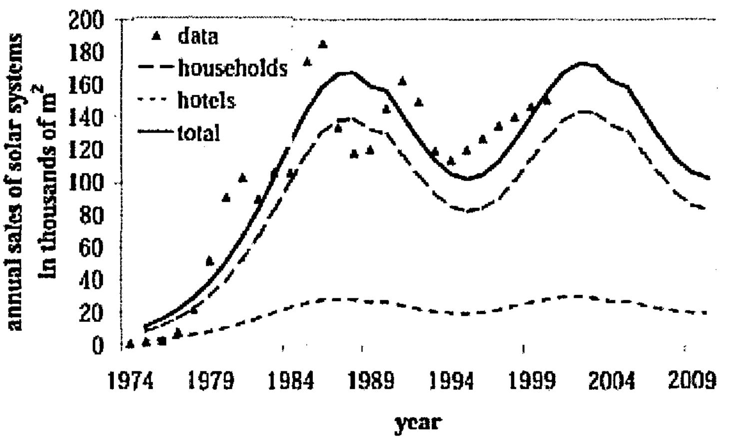


Figure 35: Historic and projected DSWHS sales (Sidiras & Koukios 2004a)

In another of their questionnaire studies, Sidiras & Koukios (Sidiras & Koukios 2004b) found that among the major barriers for purchasing a SHWS for households was the high price (25%), followed by other economic priorities (19%) and renting the house the family lived in (18%). Long payback and difficulty of installation were also on the top five, with 14% and 12% respectively. For the hotel/hostel sector, high cost was by far the main barrier, followed by high payback (24%) difficulty of installation (16%) and other priorities (15%). Aesthetics played an occasional role while word of mouth did not seem to affect any of the sectors. In contrast, experts and the solar industry thought that the opinions of others did matter up to 10% while the solar industry has attributed rented accommodation as one of the major obstacles to their market.

The results can be compared to a 1983 household study two decades earlier by a subsidiary of BP, Calpack, where the main barriers identified were cost (34%), difficulty of installation (26%), lack of energy-saving incentives (13%), payback (9%) and aesthetics (8%). It can be observed that cost remains the main issue, whereas aesthetics were dealt with effectively. Ownership has become an important factor while other economic priorities came about. Actually, that BP study mentions that in the households questioned in the early 80s, owning a SHWS was third priority after a trip abroad and a colour TV!

The drivers for the market, according to the survey (Sidiras & Koukios 2004b), were an amalgamation of the main points put forward in advertising campaigns. Reduction of hot water cost, self-sufficiency, availability of hot water and quality of life. Finally, the households' view of the factors affecting the development of the market were primarily available income, awareness and incentives whereas the tertiary sector scored high on standardisation, quality control and incentives.

5.1.4 COSTS AND PAYBACK

Despite a very good distribution network for purchasing a DSWH, the major barrier for acquisition is still distorted price disadvantages against electric and fossil fuel alternatives, as well as long paybacks that can exceed service life, making purchase conditionally feasible to impossible when financial incentives are absent (Argiriou & Mirasgedis 2003;Diakoulaki et al. 2001;ESTIF 2003;Kaldellis, Kavadias, & Spyropoulos 2005).

In a long study of the solar heater market Kaldellis reports that despite nominal prices of DSWH systems having increased by just under 13% between 1995 and 2003, in real terms they have decreased by 9%. More specifically, a typical DSWHS for a single-family dwelling (collector area 2-3.5 m^2 and 120-200 litre storage) has dropped by almost 15% in Euro terms (Kaldellis, Kavadias, & Spyropoulos 2005;REACT 2004). The authors also claim that the sector's technological progress in the assembly and materials of the units also reduced indirect costs through improved reliability and O&M costs.

A significant finding is that the payback period depends on the usage habits of individuals, the season and the time of day. During the winter months the solar energy gain of a DSWHS is determined by the solar potential and the system's efficiency, the remaining demand covered by conventional solutions. In the summer however, there is an excess of supply due to longer days and higher solar irradiation and as a result the energy gain of a system is determined by the load profile. That pattern described and examined in detail by the payback calculations of Kaldellis et al (Kaldellis, Kavadias, & Spyropoulos 2005) bears a significant impact on the utilisation factor (UF) of a system. Kaldellis et al. come up with a UF range of 25-40%. They conclude that the payback of a DSWHS depends primarily on:

- The turnkey price of the system including installation
- State subsidy
- Annual M&O costs
- The present value of the substituted conventional energy carrier

- The available annual solar energy at the installation location
- The annual utilisation factor, i.e. the use pattern of the consumer

The cost of a typical 2.5 m^2 system with a 150-170 litre storage tank is quoted at €310-350/m^2.

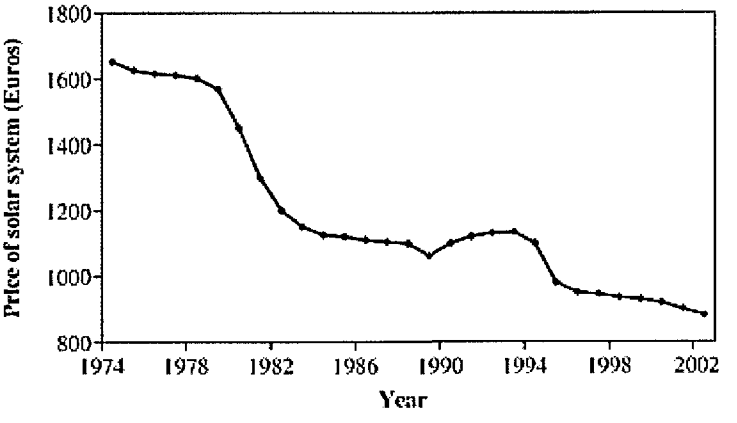


Figure 36: Average cost of DSWHS (in 2002 €) (Sidiras & Koukios 2005)

Kaldellis et al. suggested that "it is almost impossible for an individual to install a DSWHS [...] on the basis of pure financial criteria". Others introduce the concepts of payback through energy savings that subsidised tariffs distort and lobby for direct or indirect financial support to alleviate the pricing failure (Sidiras & Koukios 2005). Allowing an upper acceptable payback period of 9.5 years, only Southern Greece at the maximum available State subsidy (30%) allows installation to be fulfilled. Reversing the calculation for Northern Greece, Kaldellis et al. find that a 35% subsidy would be necessary to make installations viable in conventional financial terms (Kaldellis, Kavadias, & Spyropoulos 2005). Other studies, find that 4-6 years is the acceptable and expected range of payback in the Greek economy for the purchase of durable goods (Kaldellis, Kavadias, & Spyropoulos 2005;REACT 2004). However, oil and gas prices over the past few years seem to have reduced comparable payback times to as low as 3 years and up to 5 (Argiriou & Mirasgedis 2003). As a matter of fact, almost all providers offer a five year guarantee on the panel, the electric element and the tank.

A crucial finding in the plot of annual total SWHS demand (excluding substitution) for households and hotels over the 1978-2002 period by Sidiras et al. (Sidiras & Koukios 2005) is that in that period the economic behaviour of the buyers, i.e. their purchases, correlates to the cost of the DSWHS (Figure 37 juxtaposed with Figure 36). Price hikes in the latter correspond to reduced sales in the former.

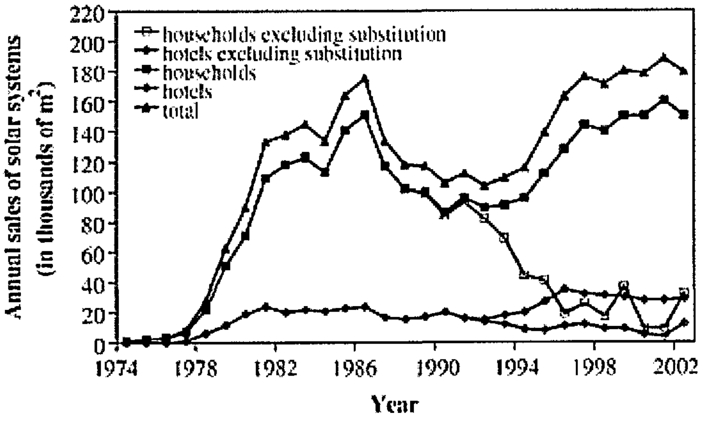


Figure 37: Annual sales to hotels and households (Sidiras & Koukios 2005)

In the same study, Sidiras et al. expose the results of an extended questionnaire study to households, hotels, industry and technology developers. The average payback was calculated at 5 years for households and 6 years for the tertiary sector (mainly hotels). Apparently, technical experts' and researchers' results showed an 8 year payback which shows that either consumers are evaluating more than economics in their payback or perhaps that academics can't figure out the market. The paper does not comment but in any case, according to previous quotes, the 5-9 years payback is within the acceptable range for households and small scale hotel/hostel applications.

Sidiras et al. (Sidiras & Koukios 2005) also conducted an in-depth and seminal study in the SWH market of Greece through questionnaires and payback calculations. Despite the stabilisation of the market and the declining cost of DSWHS, there is an impressive drop in sales which is attributed to the longer payback periods, traced to the declining prices of electricity on which payback is based, being the predominant fuel, and the absence of any subsidies balancing the environmental and social benefits of such benign technologies. The payback time of an average DSWHS has increased by approximately 40% over the past 20 years! The average purchase price of a solar collector unit was found to be €880 +/- 140 at 2000 prices. In addition, it was shown that payback can differ by up to two years between Northern and Southern Greece, justifying the geographical cap on subsidies existing since in various RES and EE programmes.

5.1.5 ENVIRONMENTAL AND OTHER BENEFITS OF SWHS

Diakoulaki et al (Diakoulaki, Zervos, Sarafidis, & Mirasgedis 2001) performed a wider CBA, introducing not only the cost savings for energy conservation but also the environmental impact decrease and the social benefit of employment in the appraisal of SWHS. The detailed study found that in the cases of all three building types examined (households, hotels, hospitals), when the substituted fuel is electricity, solar water heating is the preferable social choice even when environmental and employment benefits are put aside. In the case of hotels though, it is recognised that their seasonal operation does not allow the maximum exploitation of SWHS installations. Another major conclusion of the study was that according to strictly private economic criteria, no SWHS installation in any building type will ever score above 1 score in a Cost Benefit Analysis (CBA), justifying the need for elaborate and well-thought out policies aiming at supporting the SWHS market. Diakoulaki, as well as Kaldellis (Kaldellis, El Samani, & Koronakis 2005), found it impossible under the circumstances, lack of incentives, for SWHS to compete with natural gas even considering externalities. Considering their substitution potential for electricity and diesel in the islands, the social benefit could potentially pay the cost of incentives in private investment.

Box 7: The development of SHWS in Greece, according to (Argiriou & Mirasgedis 2003)

Phase A: Starts in 1975 when the first massive sales of solar thermal collectors began and ends in 1984. During that period, the sales increased steadily due to the oil and currency crises and the adoption of tax incentives in favour of solar systems.

Phase B: Covers the period from 1984 to 1986. The sales were really boosted as a result of a large advertising campaign sponsored by the Hellenic government and also because of the fear that the application for the first time of value added tax (VAT) in the Hellenic economy in January 1st, 1987, would increase the consumer prices.

Phase C: From 1987 to 1993, when the market remained practically stable and then decreased. The stability of the Hellenic market during that period compared to the market collapse elsewhere was due to its already important size and also to the quality and efficiency of the solar thermal products that had improved significantly meanwhile. Again, a large-scale advertising campaign, financed by the Greek Solar Energy Association (GSEA) and the "Organization for the Promotion of Hellenic Products" (an agency for promoting exports) improved the image of solar thermal systems.

The tax deduction incentive was maintained at the beginning of this phase but waived later on. The cost of electricity, the application of the VAT and the continuous devaluation of the national currency, maintained the solar thermal systems at the top three positions of the demand of consumer durables. Despite the incremental manufacturing & efficiency improvements of the solar thermal systems, the market started decaying. Several factors contributed to this, analysed in the section on policy failures.

Phase D: From 1994 until 2003. The solar thermal market has become practically stable. In 1999 of the 420 000 m2 of glazed collectors sold in Europe, 50% was sold in Germany. Greece followed with 160 000 m2, amounting to a market share of 18% at the European level.

In the islands, however, natural gas is not and will not be available on the scale required, due to the costs of the civil works and transport required. Even if some of the islands do get linked up to the national power grid, solar applications and all other renewable energy technologies will remain candidate mainstream providers of energy services because of the favourable climatic conditions & the opportunity of cutting demand at source. The coincidence of seasonal hot water demand and the tourist wave in addition to the high, albeit hidden, cost of the main energy carrier, i.e. electricity, make the islands a still promising market for SWHS (Kaldellis, El Samani, & Koronakis 2005).

Haralambopoulos and Spilanis (Haralambopoulos & Spilanis 1997) performed a systematic study of the environmental benefits of SWH in 1997. They focussed on the emissions avoided from the burning of local lignite, the predominant national fuel. Despite stock DSWHS figures that later studies found not to be accurate (Argiriou & Mirasgedis 2003;Diakoulaki, Zervos, Sarafidis, & Mirasgedis 2001;Kaldellis, Kavadias, & Spyropoulos 2005), the error in their 1993-based numbers is small; 687 ktonnes of CO2 and 6.3 ktonnes of SO2 are estimated to have been saved in that year due to the operation of DSWHS across the country.

In 2000, assuming 1.1kg of CO2 is emitted for the generation of 1kWh, the avoided CO2 emissions amounted to 1.26Mtonnes; almost 1.2% of the total emissions for the year (Ministry for the Environment 2001)

5.1.6 A CRITIQUE OF SUBSIDIES, GRANTS AND INTERVENTION

There were no specific targets for the market size each time tax incentives were introduced (REACT 2004); therefore it can be considered that the planning for the market was of the somewhat accidental or trial-and-error type. For example, the early laws provided the tax reduction as a credit of currency expressed in numeric figures. Its impact faded away rather quickly due to high inflation in the 1980s (consistently reaching double digits). However, the tax claim worked in a very straightforward and simple way for the consumer: pin the receipt with the tax return, avoiding costly and complicated bureaucratic schemes. This proved to work well with potential adopters, combined with major promotional campaigns on TV and PPC's branches, with the support of the State and the European Community through the Greek Solar Energy Association (GSEA). There are researchers who propose that the development of the Greek solar hot water sector was exclusively market-based with a large number of producers/sellers and consumers/buyers involved. The non-market factors, such as media campaigns, standardisation, public awareness, were important but it has been argued that they should be reintroduced now that the market has stagnated and reduced from 180,000 m2 in the 1980s to 120,000 m2 in recent years (Sidiras & Koukios 2005).

The existence of the GSEA since the very early days played a major role in the development of the sector. The sustained consumer trust in the products has been built from the very early days of the market due to the association's proactive role in establishing standards and promoting technical and manufacturing improvements and keeping competition within a collaborative framework to the benefit of all. The successful applications early in the market's development were crucial to sector growth, building the image of a proven technology for the product (Argiriou & Mirasgedis 2003;Kaldellis, Kavadias, & Spyropoulos 2005;REACT 2004).

Box 8: The Hellenic Solar Energy Association

The first units producing solar thermal systems were established in the mid-1970s. The capacity and quality of each installation varied depending on the manufacturer. In 1978, the major manufacturers formed the Greek Solar Energy Association (GSEA). The aims of GSEA are the study, promotion, the scientific and technological development of solar energy, the collaboration among its members and their representation in national and international instances. The primary goal of GSEA is the production of high quality and reliable solar thermal equipment, which can provide to the consumer the advantages offered by solar energy.

In order to become a member of the GSEA, a company has to comply with the following:

- It must produce its own solar equipment in a factory belonging directly to this company. The factory must dispose all the licenses required by the law for its operation.

- The production manager must be a mechanical engineer, graduate of a technical university or a technological school of engineering.

- The products have to be tested and certified by accredited laboratories of the European Union, according to the current international (ISO) or European (CEN) standards.

- The measured efficiency of the solar equipment should be higher than a strict threshold value imposed by the GSEA itself.

- The solar water heaters and boilers must dispose the CE-mark, according to the law; the test report has to be issued by an accredited testing laboratory.

Due to the above, the participation of a manufacturer in the GSEA is already a quality mark by itself. It is therefore not surprising that the GSEA members control the major part of the domestic solar market and exports. Today, GSEA has 17 member companies. Their size, production capacity and turnover may vary depending on their product range; some firms do not produce only thermal solar systems but other systems too, like air conditioners or central heating system components. The majority of these companies produce conventional flat plate collectors. The 80% of their annual production covers the domestic market and the remaining 20% is exported. The 90% of exports is towards EU countries and the remaining 10% is exported worldwide.

The ESIF (European Solar Industry Federation) was created after initiatives of the GSEA. Members of the ESIF are the national associations of 11 country members. ESIF represents its members at the various instances of the European Union; it lobbies and contributes to the preparation of actions for the development and dissemination of solar energy, and contributes to the preparation of European standards related to solar energy applications. The importance of the GSEA is underlined by the fact that the Hellenic solar thermal market gained a leading position a long time before the publication of the Green Bible of the European Commission and the summits of Rio de Janeiro and Kyoto that enhanced the use of renewable energy sources.

Major research has never been carried out by the industry, however, and has played a small role in the development of the market. The need to develop a network of own installers who later developed into one-stop shops for solar technology and in many cases main promoters of such products in remote areas, is considered another cornerstone of the success of the early days (Kaldellis, Kavadias, & Spyropoulos 2005;REACT 2004).

State subsidies as solar systems grants are widely seen as the method to incorporate the environmental and social benefits of solar water heating in the equation. Kaldellis claims that there is a common agreement among researchers that the avoided environmental and social costs due to the use of DSWHS represent only 50% of the purchase price of a basic system with a ten year operational life (Kaldellis, El Samani, & Koronakis 2005;Kaldellis, Kavadias, & Spyropoulos 2005). Researchers and the industry also agree that the abolition of direct support for the purchases by individuals has devastating results for a healthy, profitable and exporting industry.

The Greek market has reached saturation point, despite captive customers replacing the equipment almost automatically after 12-15 years of service while greenfield installations have been increasing at a slow pace by the mid-late eighties as the advertising and awareness campaigns started thinning out (Kaldellis, Kavadias, & Spyropoulos 2005). Since 2004, when tax incentives for the domestic system were abolished, the future of the market has looked bleak even if it is widely recognised that it has not reached its full potential that further and consistent institutional, financial and marketing manipulation can fulfil (Argiriou & Mirasgedis 2003;Kaldellis, Kavadias, & Spyropoulos 2005;REACT 2004).

5.1.7 CENTRAL SYSTEMS

In the hotel sector, most installations are simply scaled up versions of household systems averaging 15 m2. The market has not picked up as much, however, despite the coincidence of the peak tourist season to peak hot water and cooling demands (refer to Figure 35). As was mentioned earlier in Section 5.1.4, the utilisation factor UF does significantly affect the payback, which could be a key reason behind the slow development of this market sector. The historical pattern of central systems sees an early growth, reaching a peak of 30,000 m^2/year by 1987, which is a year earlier than the household peak, totalling 200,000 m^2 installed, and eventually stabilising at 380,000 m^2, i.e. 25,000 hotel/hostel units providing hot water to 2 million tourists per year in a total of roughly 12 million visiting the country (Sidiras & Koukios 2004a).

Third Party Financing (TPF) through Guaranteed Solar Results (GSR) contracts was introduced by CRES; it has proved extremely pioneering albeit the practice has been ignored by governments, let alone initiate any new trend or interest in the sector (Argiriou & Mirasgedis 2003;Kaldellis, Kavadias, & Spyropoulos 2005;REACT 2004).. GSR contracts and State-EU financing of renewable energy investments did, however, kick-start a number of solar thermal applications that were nevertheless limited to low and mid water temperature applications in the agrofood, textile, domestic chemicals and beverages sectors. The viability of such installations still depended at the margin on the relevant prices of fossil fuels, while in many cases poor performance has been associated with inadequate maintenance (Karagiorgas, Botzios, & Tsoutsos 2001).

Subsidies for centralised and industrial applications vary from 35-50%, depending on geographical location and the efficiency of the system. These are not directly related to any particular solar technology but do support renewables and energy conservation in general and require the investors to come up with a major chunk of the investment. As an additional measure of commitment, the final 20% of a subsidy's capital payment is passed on only after the completion, operation and monitoring of the system.

In specific terms, during the Operational Programme for Energy 2000-2006, 50 solar thermal projects were initiated, of which 47 applied to hotels. Almost all (49) of the applications were for hot water production of which only one was coupled to a heat pump for space cooling. Only two applications utilised the more advanced technology of evacuated tube collectors rather than the standard and less efficient flat panel type (Argiriou & Mirasgedis 2003). The size of applications was very small compared to the aspirations for the programme even if the average costs were reported at €390/m^2 which compares well to an average of €200-250/m^2 for domestic systems (ibid.).

These findings seem to show that the sector is averse to new technologies and adopters are merely interested in taking advantage of the funds that are available to improve their cash flows through inflated service and equipment invoices according to personal experience of the author. As has been noted earlier, much of this must be attributed to the luck of information by the State, marketing by the companies and training of installers/resellers. The failure of the Operational Programme for Energy for the sector is revealed by a closer look at the evaluation results. Of the €1.08 billion available only €6.3 million (0.53%) were absorbed by solar thermal applications. The area installed was 17,759 m^2 over 5 years, an average of 3,552 m^2 compared to 60,030 m^2 for DSWHS per year for the same period; that is a mere 6% contribution to the overall sales.

5.1.8 POLICY FAILURES

Low electricity tariffs have been mainly held responsible for the wider adoption lag of renewable and alternative energy technologies in Greece, and such is the case for the solar water heater market (Kaldellis, Kavadias, & Spyropoulos 2005;REACT 2004). Retail electricity prices have been kept almost constant for over a decade now, in an attempt to control inflation. Unfortunately, the State was also directly assisting the liquid fossil fuel market by persistently keeping taxation low. Finally, since the introduction of natural gas from Russia and Algeria, the country has committed to major procurement contracts that are still significantly unfulfilled, reaching only 55-60% absorption so far. Not reaching the quota will bring about a major policy failure, thus tilting the economic balance of the involved Ministries' plans towards more funds and effort committed to the promotion of natural gas consumption rather than anything else that directly competes, such as renewables.

The 20% penetration of SWHS is not at all satisfactory, given the high level of solar irradiation in the country (Diakoulaki, Zervos, Sarafidis, & Mirasgedis 2001). State funding policy has a social and economic duty to introduce environmental and economic benefits of solar water heating not otherwise accounted for and to create a level playing field for alternatives. Instead, rather crudely, the Greek State decided in 2002 to reduce and by 2004 totally wipe out the 75% of system cost deduction off the individual's taxable income that was calculated as a direct subsidy of 10-30% (Kaldellis, Kavadias, & Spyropoulos 2005). It was a severe blow for the national SWHS sector and Greece's EU commitment to 100,000,000 m^2 by 2010.

Sporadic and occasional information campaigns and distribution of marketing material to consumers by the State are also considered a major pitfall of the deterioration of the market. On the other hand, declining sales significantly limited the budget for sustained and major marketing strategies (Argiriou & Mirasgedis 2003;Kaldellis, Kavadias, & Spyropoulos 2005). The lack of systematic technical and sales training of craftspeople and small businesspeople is a further barrier to the market, leading to indifference and ignorance to new solar technology products among local installers beyond what the resources of private firms can afford while expanding their distribution and sales networks.

Despite the impressive early establishment of a network of installers and resellers, the sector failed to create an environment of continuous technical development, as Kaldellis and others (Argiriou & Mirasgedis 2003;Kaldellis, Kavadias, & Spyropoulos 2005) already mentioned. Argiriou goes further by calculating that only 3% of all domestic systems have been connected to an additional heat exchanger to utilise space heating, thus increasing the energy gain and therefore the utilisation and payback of the system (Argiriou & Mirasgedis 2003), in a market which is predominantly served by central diesel boilers.

In 2000 the energy production of solar thermal systems was utilised at an impressive 99% for hot water applications (1,139 GWh) in the domestic sector. Hence, there is a very substantial market size to be covered. Even focussing on the domestic sector, where 1 in almost 5 households have DSWHS installed, hot water covers 10% of the energy consumption when solar water heaters could fulfil up to 80% (Kaldellis, Kavadias, & Spyropoulos 2005;Sidiras & Koukios 2005). There is a great incentive to proceed with an additional heat exchanger to save up to 60% on space heating (Argiriou & Mirasgedis 2003). The Lykovrissi Solar Village project demonstrated a solar energy fraction (percentage of the total thermal load covered by solar energy) of 55% through inter-seasonal storage systems (Papakostas, Papageorgiou, & Sotiropoulos 1995;Sidiras & Koukios 2005). It remains a bitter question why such installations were not replicated commercially, despite the subsidies available by the State and the EC.

The current diffusion stagnation can be traced to two main reasons (Sidiras & Koukios 2005) for the domestic sector:

1. The decline of financial feasibility due to the politically induced real drop of electricity prices, since electric water heaters are the main incumbent competitor of DSHWS, and,

2. The saturation of that segment of the market that includes innovative buyers and high income households, which have been responsible for the market so far.

Sidiras et al, go on to suggest, however, that in the three decades that the market has existed, this situation has been faced twice before and boldly countered with non-market based activities such as advertising and awareness campaigns.

5.2 SOLAR PHOTOVOLTAIC APPLICATIONS

Solar photovoltaic applications in Greece have been traditionally limited to off grid specialised applications, such as telecommunications. During the 1990s, however, a series of laws were introduced to support greater RES utilisation but also to clarify land use, network access and feed in tariff rates (Tsoutsos et al. 2004). Consequently, it can be said that the legal framework and early institutional experimentations with support schemes are now maturing, while lessons are learnt and new institutions understand their role (the System Operator, the Regulator and the restructured publicly listed Public Power Corporation).

The PV market is still infinitesimal although it has grown significantly since the mid-nineties (Figure 38). Most of this growth, however, came from what is termed the traditional market of telecom, irrigation and other remote power applications and government demonstration projects (Tsoutsos, Mavrogiannis, Karapanagiotis, Tselepis,

& Agoris 2004). The main barriers identified by Tsoutsos were licensing procedures, limited capacity of the national transmission grid and public acceptance.

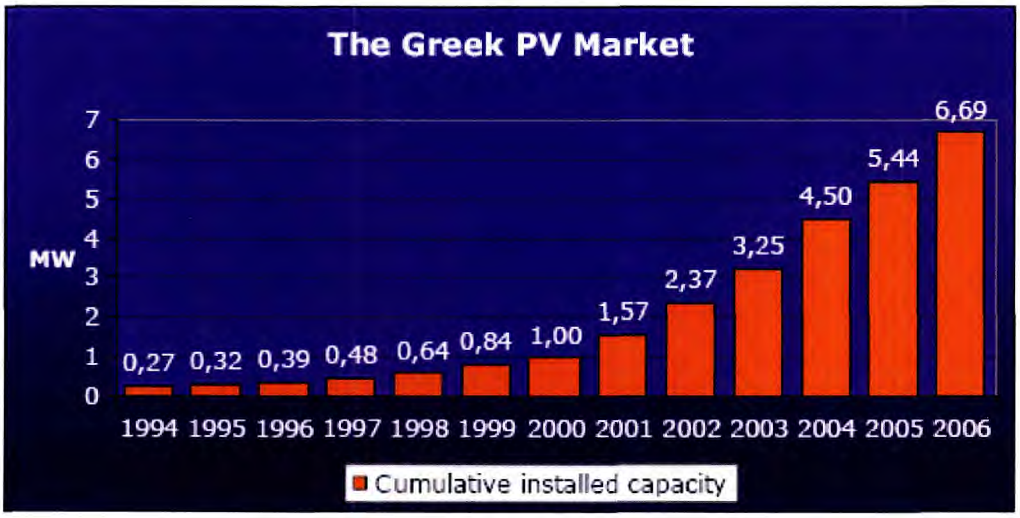


Figure 38: The development of the Greek PV market (Psomas 2007)

In 2006 the government announced a programme to support the development of 505 MW of PV power through a customised feed-in structure until 2010 (originally with an option for another 10 years of support). The response was unprecedented; in total 7,947 application were submitted for a total 3,756 MW by 2008, forcing the government to stop accepting more applications in 2008, as a significant bottleneck developed. The regulatory authority reckons that they cannot exceed an assessment rate of 50 applications per week when the Statute on the subject (3734/09) requires 650 projects of <150 kW alone a week (Lampaditou 2009)! Currently, there are 17 MW installed (from roughly 7 MW in 2006), another 72 MW have received installation licenses and a further 123 MW have a generation license already.

The present government is very ambitious when it comes to PV energy. The government's goal is to have at least 700 MWp installed by 2020. With currently a total installed power of 17 MW, the market will have to grow by more than 40% a year to achieve this (Psomas 2007). Recently, new legislation came into force and combined with interesting investment incentives, the Greek market appears very promising (see Box 9).

Box 9: Legal framework and support policies for Greek PV

Financial support for the construction of PV parks has been generously provided by the State, primarily as part of the so-called Operational Program for Competitiveness (OPC) and the investment incentives under Statute 3299/2004. The OPC has drawn resources from the EU Third Community Support Framework to provide state aid to alternative energy sources. State aid accounts for 30% of the eligible cost of the projects and can go up to 50% in the case of construction of transmission lines connecting renewable energy plants to the electricity grid. OPC is now subject to the Fourth Community Support Framework.

Statute 3299/2004 introduced substantive and procedural changes to the regime of state aid to corporations and provides for various types of incentives (i.e. cash grants, leasing subsidies, tax relief and a cash grant for payroll expenses relating to employment created by an investment). The law was partially amended at the end of 2006 to be harmonized with the new regional aid map that will apply to the EU for the period from 2007 to 2013.

Statute 3468/2006 on RES introduced an additional incentive for the generation of electricity from PVs. According to article 24, every producer of electricity from RES who obtains a production license has to pay, when starting his commercial activity, a special rate to the Greek Transmission System Operator (HTSO) amounting to 3% of the sale price, excluding VAT. However, this same article exempts PV producers from this obligation. The feed-in tariff system that was launched guaranteed €0.40 to €0.50 per kWh over a 20 year period. Accompanied by a relaxation of the licensing procedure and the possibility for combination of these benefits with investment grants and subsidies between 30 to 55%, calculations of payback showed that an even better return on investment than in Spain was possible in certain market segments. However, the guaranteed 20 year fixed feed-in tariff structure introduced by the Statute had to be revised as it proved too generous.

A new feed-in-tariff (FIT) regime was introduced in Greece on January 15th 2009. FITs will remain unchanged for the next two years (from 0.45 to 0.50 €/kWh depending on location and size). There will be a regression of FITs as of August 2010 (0.26-0.33 €/MWh by 2014). Eventually, the feed-in tariff will be arranged in relation to the system marginal price SMP. Nevertheless, a developer can sign a grid connection agreement thus locking the FIT before this deadline, and then get another 18 months to finalize installation. This practically means that FITs remain unchanged till early 2012.

Applications for permits already filed (more than 3 GWp) will be served until the end of 2009. Regime for newcomers still unknown (no more applications are accepted at the moment). Until then, a newcomer has the option of acquiring an existing company which has a permit. A 40% grant will still be valid on top of the new FITs for most of the systems (minimum investment eligible for grant = 100,000 €). A separate program for rooftop PV will be introduced later in 2009, aiming at 750 extra MWp (timeframe for this target is still unknown). Rooftop systems will receive a higher tariff for 20 years but no grant. The new law introduced a tender process for PV systems >10 MWp. Details on how this is going to work are expected later in 2009.

In two papers concerned with specific commercial tourist installations of PV panels (Bakos & Soursos 2002a;Bakos & Soursos 2002b), the authors perform a financial discounted cash flow for the installations at hand and evaluate the benefits for the private customer. It is recognised that the value of such installations depends on comparisons conducted by consumers between production costs and electricity prices, for utilities between production and opportunity costs and, for government with relative weighting priorities regarding social benefits and avoided social costs. Despite acknowledging the need for such cost-benefit analysis, no further analysis is provided in the papers but a generic textbook commentary on a graph indicating the gains in cost reductions of technology by increased use of alternative power.

The weakness here is that learning and experience curves in current literature refer to an international market. Island installations even if widespread can have minimal effects on these gross rates. However, the thesis holds that there must exist curves and rates of learning to retail, install and service consumer energy equipment. Such curves and experience rates must be in dynamic cause and effect feedback with the island system itself, i.e. an endogenous variable. Furthermore, due to the commercial nature of the installations, Bakos' financing only considers available subsidies and does not go as far as calculating the overall system savings and impact on system capacity expansion if such installations were to become commonplace. Thus, the utility operator's viewpoint is missing.

It seems that the government is too keen on solar PV but not on SWHS. According to the author this might have to do with the fact that solar PV installed capacity is included in RES targets that the government committed to and certainly receive a lot of media attention where it is common politicians to focus too. The State is also under pressure to open up the electricity market and reduce the dominance of the PPC and through the feed-in tariffs provided the private sector is more likely to install a maintenance free and guaranteed sales PV park rather than a CCGT (combined cycle gas turbine) plant to compete in the market.

5.3 SOLAR SPACE COOLING

5.3.1 INTRODUCTION

Although this thesis and the ensuing simulation model does not aim to technically or financially appraise any specific technology on its operational merits against any other, it has clearly focussed on solar space cooling and the generic field of solar assisted air-conditioning as the candidate appliance that could significantly alleviate the problems at hand and assist in answering the research questions formulated at its outset. Consequently, a light techno-economic description of the main concepts and developments around solar space cooling are first presented in this section, followed by lessons learnt in Europe and then in Greece along with the potential for market success. Finally, a section examines the development of such technologies in the broader Mediterranean area to broaden the understanding of the application, have a wider sample of case-studies to draw modelling assumptions from and last but not least establish the validity of the necessity of such a technological intervention. The latter with respect to economics, sustainable development and policy.

5.3.2 BRIEF INTRODUCTION TO THE TECHNOLOGY

The following is adapted from a technology appraisal paper by Tsoutsos (Tsoutsos et al. 2003). There are four types of equipment that can provide solar air conditioning (SRAC) in a variety of configurations, such as hot or cold energy storage, continuous or intermittent operations, type of collector, operating temperature and controller types, to name a few.

- Absorption Cycles
- Adsorption Cycles
- Open-Cycle Cooling Systems
- Solar Mechanical Processes

Integrated solar cooling systems, though, operate on either absorption or adsorption systems.

5.3.2.1 ABSORPTION CYCLES

Out of the two, continuous absorption cooling has received a greater market focus. The technology financially competes well when a cheap source of heat in the range of 100-200°C is available. Their additional benefit is that such systems can be retrofitted over existing HVAC installations that are water based. *Liquid absorption systems* utilise solar collectors to harness the heat they need. Such configurations use two working fluids, a refrigerant and an absorbent for the refrigerant.

LiBr–H2O (lithium bromide-water) solutions have been successfully researched into and have become common for air conditioning (A/C) applications. Systems operating on such substances have brought about lower costs as second generation LiBr–H2O absorption cooling systems operate with flat-plate solar collectors assembled on a common SWH frame and requiring short piping are thus able to be installed in restricted spaces. A numerical simulation of a LiBr absorption cooling system by Tsoutsos (Tsoutsos, Anagnostou, Pritchard, Karagiorgas, & Agoris 2003) showed daily collector efficiency of about 35% and a daily conversion efficiency of solar energy to cooling of about 12% which seems low but is pretty satisfactory at this stage in the technology's development.

One class of research on fluid pairs is focussing on ammonia–salt solutions, such as ammonia–lithium nitrate (NH3–LiNO3) and ammonia–sodium thiocyanate (NH3–

NaSCN). These systems provide certain advantages such as lower generator temperatures (which allow operation with simple flat-plate collectors), lower evaporation temperatures in comparison with LiBr-H2O systems and higher coefficient of performance in comparison with NH3/H2O systems. Research also focused on solid sorption systems, mostly used for solar refrigeration. Usually these use NH3 as refrigerant and SrCl2 (strontium chloride) as absorbent.

Currently available LiBr-H2O systems have a COP (coefficient of performance) of 0.6-0.7 for simple effect chillers and require inlet temperature of 75-90°C while double effect chillers require water at 120-160°C but achieve a COP of 1.2-1.5 (Garcia Casals 2006).

5.3.2.2 ADSORPTION CYCLES

Their majority is based on the silica gel–water system. Two separated chambers contain the sorption material operated in a cycle in a two-stage adsorption loop. As it can utilise rejected low-temperature heat from other processes, it is an attractive option for improving energy conservation and efficiency. The technology has developed mainly in Japan although Tsoutsos (Tsoutsos, Anagnostou, Pritchard, Karagiorgas, & Agoris 2003) reports installations in Europe in industrial processes where excess heat is commonplace. The combination of an adsorption chiller with solar collectors offers a technically simple and energy saving solution, especially in Southern European regions such as Greece, according to Tsoutsos.

5.3.3 OUTLOOK AND INSTALLATIONS IN GREECE

There are four installations of solar cooling in Greece, the major ones of which are a cosmetics warehouse of 22,000 sq.m. in Attica (broader Athens) and a 209 bed hotel in Crete (SOLAIR 2008b). The Rethymnon Village hotel will be looked at in more detail in the following. According to a market survey of Greece by SOLAIR in 2008 (SOLAIR 2008a) about 100,000 houses are built each year adding to an existing stock of 2,510,759, of which 84% are single dwellings 12% of which were built during 2002-2007.Despite the overall market being significant for symmetrical growth, the hotel stock statistics are more relevant to the aims of this thesis (Figure 39).

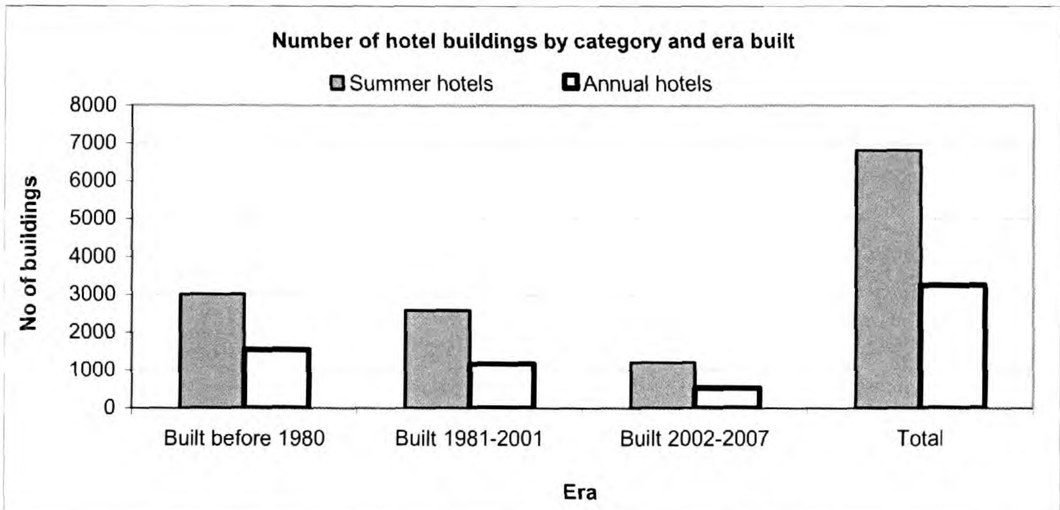


Figure 39: Graph of hotel stock by type and age (SOLAIR 2008a)

What is immediately observed is the prevalence of summer hotels which operate from April to October. The ratio to all-season hotels is roughly 70/30. It will later, during the modelling exercise, be shown that this ratio generates the extreme fluctuation of demand in the islands. Another observation involves the development of the sector. By 2001 there was a building stock increase of 86% and 76% from the 1970s for summer and annual hotels respectively. Within five years to 2007, a further 22% summer and 20% annual new built hotels popped up.

The Rethymno Village hotel in Crete is a B category (3 star equivalent) hotel comprising 100 rooms in a total area of 600 sq.m. Its solar field was installed in 2000 and is made up of 250 solar collector elements of 2 sq.m. each. The initial cost was 264,213€, financed 50% by the Greek State's Community Operational Programme "Energy" (Karagiorgas et al. 2007). The system supplies cooling in the main dining room through a 105 KWc chiller and hot water to the rooms. The solar cooling solar system is based on an absorption type machine. In the winter, the solar collectors produce water at 55°C that circulates through fan coils in order to heat the space. The chiller operates 7-8 hours daily (usually until 6 o'clock in the evening) at an efficiency of 60% covering up to 65% of the cooling demand (Karagiorgas, Kouretzi, Kodokalou, & Lamaris 2007). It is backed up by an LPG system while during operation the only electrical load the system uses is 0.5 kW for the primary and secondary pumps of the system. It has been estimated that 651 MWh of power are saved annually compared to a conventional electric air-conditioning system and the CO2 emissions are reduced by 1,095 kg a year (CRES 2005).

In a paper examining in depth the two main technologies for cooling (absorption & adsorption) in Greece, Tsoutsos et al.'s main conclusion is that these systems are marginally competitive with standard cooling equipment based on the electricity prices at the time of the publication of their paper that are still roughly valid today (Tsoutsos, Anagnostou, Pritchard, Karagiorgas, & Agoris 2003). They also point out that five years ago despite domestic cooling and heating consuming 7% of the country's energy, it was emitting 29% of the CO_2. It should be reminded from previous sections that between 1996 and 2000 split A/C unit sales tripled (Argiriou & Mirasgedis 2003).

In a economic evaluation of the two main systems against a conventional electric driven chiller, Tsoutsos (Tsoutsos, Anagnostou, Pritchard, Karagiorgas, & Agoris 2003) rightly included the available legislation on energy taxes while calculating annual savings and corresponding financial performance and explored combinations of tax and subsidy policies. The comparison was performed for two locations: Athens and Crete. Only the scenario with a 40% subsidy and an energy tax on conventional fuels concurrently produced competitive advantage for solar assisted air-conditioning (SRAC) while the solar systems showed a positive sensitivity to energy price inflation as expected. A social CBA would be an interesting insight but not performed. The authors or indeed any other research reviewed does not propose a pathway to the introduction and diffusion of such technologies that would include the right balance of incentives to adopters. This thesis goes a step forward in this respect and in addition examines a methodology by which such intervention provides an incentive for the utility operator (the state effectively in the case of the Greek islands) and making sure local economic interests are not jeopardised via taxes and other financial discrimination. Furthermore, while Tsoutsos wonders how to predict the date when these technologies will reach competitive application, the simulation of this thesis incorporates local market learning effects to a primitive albeit innovative fashion into the equation.

Table 7: Technical assumptions and economic attractiveness of large solar applications in the Greek buildings sector (all costs referred to 1995 constant prices) (Argiriou & Mirasgedis 2003)

	Residential heating	Residential cooling	Tertiary cooling
Assumptions			
Application	Household with a surface of 90 m^2	Building with a surface of 150 m^2	2700 m^2 of solar collectors
Diesel conservation (toe/y)	0.386	0	25.5
Electricity conservation (toe/y)	0.137	4.17	86
Investment cost (€)	3936	10 592	1 188 497
Electricity cost (€/toe)	930	930	930
Diesel cost (€/toe)	440		440
Subsidy (as a percentage of the investment cost) (%)	0	0	40
Load coverage (%)	35	100	61
Results			
NPV (€)	−875	30 064	226 027
B/C ratio	0.78	4.05	1.32

Table 7 presents a rather optimistic future for solar cooling especially for the residential sector which seems to perform outstandingly well without any subsidies at all. Although the authors specify it is for a location in Athens, they do not provide details of the costs included, any details on usage pattern assumptions or the technology choice and conventional technology comparison, in order to assess the validity of the claim in comparison to data from other studies. Their tertiary example, however, comes from an installed system at the cosmetics distributor "Sarantis" warehouse, 50 km North of Athens. While hotels are mentioned as a potential area of successful application of solar cooling, it is not further discussed. To the thesis author, the difficulty in hotels is that the adopters are the hotel owners for a service that their customers require indirectly so its dynamics should be examined differently as to whom and in what form costs and benefits finally accrue.

5.3.4 MARKET OUTLOOK IN EUROPE

As solar cooling is in its infancy, learning effects are expected or hoped to reduce the price as more and more installations are fulfilled. The cost reduction could come from anywhere in the world, however in this section the focus in the European market where there is already significant research and networks set up to support the technology.

In their 2007 paper, Balaras *et al.* reported a five-fold increase in the number of air-conditioning systems of cooling capacity above 12 kW within 20 years (1984-2004) in Europe while cooled floored area expanded from 22 million sq.m. in 1980 to over 150 million sq.m. in 2000. Annual energy use of room air-conditioners was 6 TJ in 1990, 40 TJ in 1996 and expected to reach 160 TJ by 2010 (Balaras, Grossman, Henning, Infante Ferreira, Podesser, Wang, & Wiemken 2007).

Karagiorgas *et al.* (Karagiorgas, Tsoutsos, Drosou, Pouffary, Pagano, Lara, & Melim Mendes 2006) conducted a survey of RES in the European tourism industry and identified a large number of solar thermal systems but only a few solar cooling systems. There is a variety of heat-driven cooling technologies in the market in the range of 40kW and over that can work well with solar thermal collectors as the heat source. However, larger applications are still costly and equally importantly lack practical experience and acquaintance among architects, builders and planners with respect to design, control and operation of these systems. There are no cost-effective smaller scale units for household level applications at the moment but some promising developments are underway as it shall be seen below.

The seminal European "SACE – Solar Air-Conditioning for Europe" project that ended in 2003 reviewed the state-of-the-art to provide a clear picture of the potential, the future needs and the overall perspectives of the available technologies (SACE 2003). Surveying projects from EC's CORDIS database and IEA's Solar Heating & Cooling Programme, the study reported among other conclusions that in the Southern European and Mediterranean areas solar assisted air-conditioning can lead to primary energy savings of 40-50% (compared to an electrically driven compressor of COP 3) at a related cost of saved primary energy standing at about 0.07 €/kW.

A follow up and currently running project supported by the European Commission is "SOLAIR - Increasing the Market Implementation of Solar Air-Conditioning Systems for Small and Medium-Sized Appliances in Residential and Commercial Buildings"[13]. Its objectives are to:

[13] SOLAIR is a project financed under Intelligent Energy Europe with thirteen partners from Austria, France, Germany, Greece, Italy, Netherlands, Portugal, Slovenia and Spain. SOLAIR was launched beginning of 2007 and will run until the end of 2009.

- Promote the market implementation of small and medium-sized solar air-conditioning appliances
- Focus on the residential and commercial sector, combining domestic hot water supply and space heating with air-conditioning
- Resolve major market obstacles: limited awareness on know-how as well as available instruments and the lack of information
- Create a set of instruments to assist the market growth of this technology
- Elaborate a set of measures targeting at the relevant key market actors
- Disseminate the activities on national level and Europe-wide

By the end of 2004, approximately 70 solar cooling installations were listed from the European surveys before SOLAIR, mainly consisting of medium-size (> 20 kW cooling capacity) and large-size systems (defined here as > 100 kW cooling capacity). The total installed cooling capacity amounts to 6.3 MW, the corresponding collector area to approx. 17500 m^2. The total number of systems currently in operation in Europe is not very well known, but may be estimated to 200 – 300 installations. Especially in southern European countries (e.g., Spain) an increase in small size solar cooling systems for residential application is observed. In general, the increase in the sales rate of small sized chillers within the last two years is promising. A survey (SOLAIR 2008b) reports about 280 installations in this capacity range, but not all of them may be driven by solar heat.

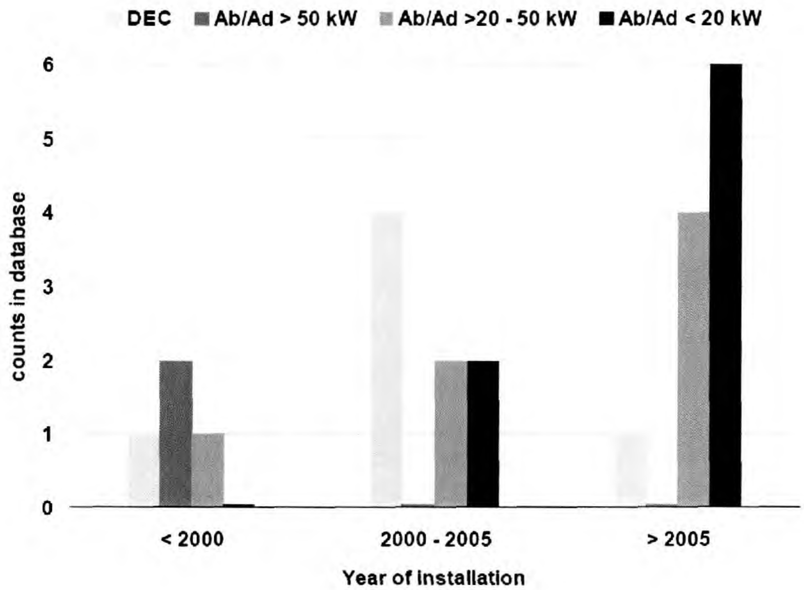


Figure 40: Systems in the SOLAIR data base, sorted by their respective year of installation (DEC: Desiccant evaporative cooling system (open cycle system); Ab/Ad: chilled water system with absorption or adsorption technology (SOLAIR 2008b)

The data base of SOLAIR contains 24 selected small and medium size installations; approximately 50% of them went into operation in 2006 or 2007 (Figure 40). The term 'successful running systems' therefore indicates promising system concepts and configuration, not necessarily adequate practical experience. Open cycle desiccant evaporative cooling systems (DEC) in the SOLAIR data base are of installation date before 2000, likewise chilled water systems with a rated capacity > 50 kW. The figure also reveals the trend in increase of small size systems < 20 kW chilling capacity, which were not really market available a few years ago (SOLAIR 2008b). SOLAIR also report that most pure chilled water installations show specific capacity values below 50 W per m^2 conditioned area.

5.3.5 EXPERIENCE IN THE MEDITERRANEAN

As the Greek islands were this thesis envisages to introduce solar cooling are competing for visitors to similar destination across the Mediterranean, it is attempted to assess the deployment of the technology as well as its potential specifically in this region and seek any empirical numbers of its operation.

Cyprus is one of the most sunny places in the Mediterranean for a typical house, of which Florides and associates (Florides et al. 2002) ran a simulation model to choose the best absorption set up based on lifecycle analysis. They found that compared to an electric system not only is such a system is competitive at the end of its life but it is actually cheaper by roughly €315 including a diesel back up (€19,880 compared to

€19,565 quoting the study). It is suggested that diesel could be also eliminated if the prices reflected the fuel's environmental burden, in which case larger storage could be afforded.

The REACt project under Framework 6 of the European Community started in 2005 and is now in its 3rd of four phases. It aims at the introduction of a self-sufficient renewable energy air-conditioning system for Mediterranean countries. In a 2008 paper (El Asmar 2008), among a number of hospitals in Lebanon and Morocco proposed to be studied there is also a tourist resort in Jordan. The paper confirms that space cooling demand coincides with maximum insolation in the hotter hours of the day, i.e. 1pm to 5pm, and it is minimal from 12 midnight to 7am. The average COP of the centralised system was found to be 2.2 with a standard deviation of 1. The systems (both ammonia absorption chillers and direct steam parabolic generators) were being manufactured and tested in Germany at the time of the paper being published so that there is no data on their performance.

The paper states the project's main socio-economic aim which is of no lesser significance to the technological aspect. REACt is seeking to "generate nodes of good practice, accelerate local skill development, and promote and encourage relevant stakeholders, on all aspects of innovative certified technology that is efficient, robust and suitable for standardized production and replication". In other words, it aims at increasing learning rates of local relevance that may consequently affect learning of the imported technology in its place of manufacture. This thesis in its modelling exercise will assume both learning effect as an aggregate though from experience gathered from the local DSWH market and international experience reported in photovoltaics and air-conditioning units cost progress ratio.

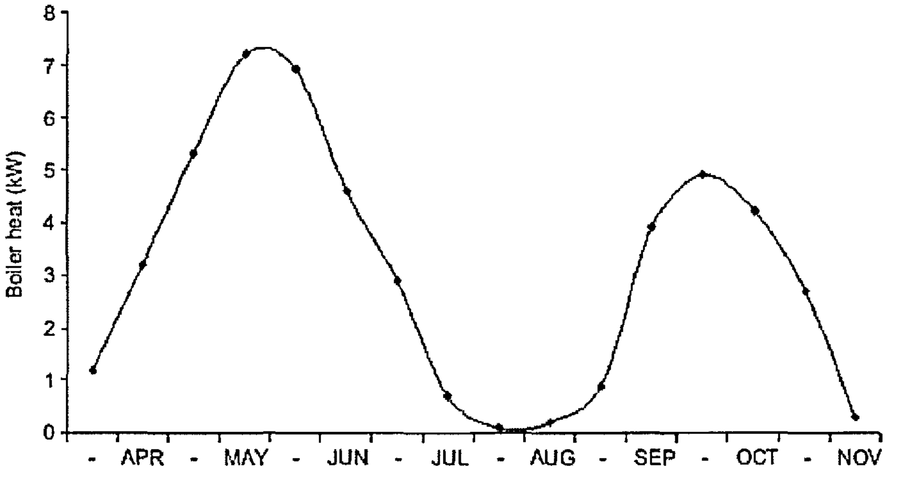


Figure 41: Monthly auxiliary heat consumption for cooling (Balghouthi, Chahbani, & Guizani 2008)

A water lithium bromide (LiBr-H2O) absorption chiller of 11kW combined to a 30 sq.m. flat plate collector area tilted at 35° from the horizontal also incorporating an 0.8 cu.m. storage was simulated in a 150 sq.m. typical building of Tunis by Tunisian researchers (Balghouthi, Chahbani, & Guizani 2008). Despite the meticulous work of assembling the data for the simulation the researchers to not make any financial calculations about the proposed system. They merely confirm that such a small scale system would be appropriate for residential applications as it matches the demand neatly and is also able to produce hot water with excess of solar energy it collects.

Most importantly the authors show that during the hottest and busiest months of the year in the Mediterranean (July and August) solar air-conditioning has no need of a conventional back up heat source. Such a situation could potentially reduce power peaks significantly, to the point of delaying capacity expansion in the Greek islands which experience very near similar climatic conditions and are the geographical focus of this thesis.

Spanish researchers report a similar effect of space cooling to that of their Greek colleagues. Namely, that the popularity of split electrically driven air-conditioning units has, due to the hot climates of both countries, led the power transmission and distribution networks to their technical limits. Because the Spanish electricity market is liberalised to a greater extent than the Greek one, prices have also been directly affected (Garcia Casals 2006;Hidalgo et al. 2008). Especially for Southern Spain, peak demand increased 20% year on year for both 2002-2003 and 2003-2004, reaching in 2004 35% in some substations while the summer peak exceeded the winter one for the first time in 2005 (Garcia Casals 2006). Garcia Casals found out that in a 150 sq.m. house that covers 75% of its hot water need by a DSWH, the solar contribution of the overall building demand in hot water and cooling drops to 8-10% while he points out that centralised systems apart from higher COP reaching up to 5, have a levelised cooling cost half that of single systems.

Researchers at the *Universidad Carlos III de Madrid (UC3M)* in Spain experimented on a 50 sq.m collector LiBr-H2O system and achieved an autonomous cooling period of 6.5 h in an average summer day of 2004 (Hidalgo, Aumente, Millβn, Neumann, & Mangual 2008). They then decided to test the market viability of such a system on a typical detached Spanish dwelling. Among other observations, they reported cost savings of 62% and CO2 savings of 36% compared to a conventional electric system for the duration of a cooling season.

5.4 ELEMENTS FOR THE SIMULATION MODEL

- There are established commercial agents and major players involved in solar thermal technology, thus introduction of cooling technology will presumably occur as soon as it makes commercial sense either as an import and even local manufacture.
- There is a good and tested network of technicians accustomed to the installation and maintenance of HVAC and DSWH systems across the country and islands.
- There are two types of learning. The international level where high level research, commodity material availability and structured financing affect the cost of a technology worldwide and then there is local learning. It can involve learning by installing, learning by using and learning by marketing. The simulation model assumes the former as an exogenous input while it endogenises the latter in its feedback loops.
- An experience curve for solar thermal can be deduced and adapted for solar A/C.
- There are several sources regarding the economics of solar A/C in the Mediterranean.
- Hotels were among the first demonstration applications; the hotel market is a test bed for researchers and overall the tourism sector seems an identified early niche. Thus, there is also data to construe demand patterns.
- Word of mouth and advertising did have a significant role, as did campaigning.
- It will be assumed that the subsidy will cover the total cost of installation as a working hypothesis. Financial incentives for DSWH such as tax incentives have

been undermined by inflation. Direct subsidy might be the most appropriate support measure for hotels as budgets are larger, more complicated and most likely solar cooling upgrade will be part of larger refurbishment in existing or upcoming energy efficiency programmes. It should induce further demonstration on which to base a best practice guide to enhance word of mouth.

- Acceptable payback is 5-9 years.
- Electricity prices do affect the finances of solar cooling significantly.
- Solar cooling can satisfy up to nearly 70% of A/C demand in the hottest months.

5.5 SUMMARY & CONCLUDING REMARKS

The chapter presented a concise report on the development of the Greek solar water heater market and the technology's European outlook. During the process, the information was organised in headings with figures, boxes and tables to help the reader correlate the lessons learnt to the future development of solar technologies and solar cooling in particular. The latter does seem to be a very promising technology that is very near market acceptance given the right instruments to push its early commercial adoption. It is concluded that the technology is there and success probably lies only in demonstration projects to achieve knowledge of sizing and configuration. While efficiencies could be improved, the technology proves potential financially sturdy for private investors, given the right support, in many of the case studies presented.

Greece has a unique potential to be a market leader in solar cooling and other new solar technologies. First of all, apart from excellent insolation, there is a strong and successful exporting industry[14]. Secondly, solar space cooling (and heating) is not only complementary to this industry but also fits the needs of the hotel industry really well. Appropriate design and sizing of installations can significantly reduce running costs of hoteliers compared with the currently embedded the technology. However, policy-planners need to draw more lessons from the development of the DSWH market. The chapter demonstrated how important closely knit promotional campaigns and support programmes were to market growth of solar water heaters. It seems that the human and

[14] In GSEA's (Greek Solar Energy Association) website one can find production, export, import and local sales records from 1982 to 2002. For 2002, production was 256,500m2 out of which almost half (120,000 m2) was exported.

entrepreneurship capital of the last 30 so years is being left unused. The decline in manufacturers is an example of this (Figure 31).

Lately, principles of financial support seem to be rebuilding in the case of solar PV that was very successfully launched a few years ago in Greece. The author expects that the institutional learning in supporting photovoltaics could spill over to other technologies and solar cooling in particular. There are already successful demonstration projects in the country and other Mediterranean locations to learn from. Market conditions would need to be monitored closely to take advantage of any niche applications that could drive adoption further.

Dissipation of information, successful demonstration installations to induce positive word of mouth, cross-disciplinary planning (e.g. energy, tourism, buildings), consideration of benefits and costs to stakeholders, good understanding of the broader economy where the technology is employed and open-minded energy policy seem critical to the successful introduction of solar cooling. Drawing on these lessons and all the previous chapters, the simulation model attempts to incorporate these into its equations and in addition undertakes to provide a motive for each main stakeholder – policy-makers, utility, adopter – to hold up the proposed intervention. The model building exercise is presented next in a step-by-step fashion.

6 BUILDING THE SIMULATION MODEL

This chapter is the culmination of the research so far. It aims to draw together the knowledge collected and analysis performed so far into a simulation that will reflect the dynamics and behaviours observed. It is equally designed to assist in assessing potential solutions to the problem posed. In developing the model, the author followed the steps proposed by Sterman, as summarised in Table 8. Step 1 was performed already in previous chapters, steps 2 & 3 are the subject of this chapter while 4 is touched upon here and completed in the next chapter, along with step 5, which is entirely elaborated there. The main assumption of the chapter here is that an 'example' island is being modelled; this is because replication of a single island's circumstances and characteristics is not the objective but rather the demonstration of the approach and the exploration of the overall dynamics. The same goes for the choice of technologies. The presentation of the model is as informative in its assumptions and as illustrative in its critical formulations as possible, trying not to crowd the presentation with too many equations. Because System Dynamics is a combination of simple integrating functions, the author preferred to explain the core of the technique and rely on graphical representation, hoping to enable the reader see both the trees and the forest as much as possible.

Structure of Chapter:

6.1 PROBLEM ARTICULATION & REFERENCE MODES
6.2 FORMULATION OF THE DYNAMIC HYPOTHESIS
6.2.1 Introduction to Causal Loop Diagrams
6.2.2 Telling the causal story
6.2.3 Subsystem Diagram
6.3 FORMULATION OF THE SIMULATION MODEL
6.3.1 The Demand and Supply Submodel
6.3.1.1 The Demand: Profiling the consumers
6.3.1.2 The Supply: The utility & capacity expansion
6.3.1.3 The Finances: Cost of power and results
6.3.1.4 Concluding remark
6.3.2 The Technology Diffusion Submodel
6.3.2.1 The competition habitat of the islands
6.3.2.2 Service benchmarking & cooling capacity
6.3.2.3 The simulation model & its SFD
6.3.2.4 The variants and the adopter stocks
6.3.2.5 The cost comparison
6.3.2.6 The competition indicator
6.3.2.7 The learning loop
6.3.2.8 Demonstration of the model's output
6.3.2.9 Testing the sub-model's behaviour
6.3.2.10 Introducing policy & decision-making
6.4 CONCLUSING REMARKS

Table 8: Steps of the modelling process (adapted from (Sterman 2000))

1. Problem Articulation (Boundary Selection)	• Theme selection – *What is the problem? Why is it a problem?* • Key variables – *What are the key variables and concepts we must consider?* • Time horizon – *How far in the future should we consider? How far back in the past lie the roots of the problem?* • Dynamic problem definition (Reference Modes) – *What is the historical behaviour of the key concepts and variables? What might their behaviour be in the future?*
2. Formulating the Dynamic Hypothesis	• Initial hypothesis generation – *What are current theories of the problematic behaviour?* • Endogenous effect – *Formulate a dynamic hypothesis that explains the dynamics as endogenous consequences of the feedback structure.* • Mapping – *Develop maps of causal structure based on initial hypotheses, key variables, reference modes [...] using tools such as [...] causal loop diagrams (and) subsystem diagrams.*
3. Formulating the Simulation Model	• Specification *of structure, decision rules.* • Estimation *of parameters, behavioural relationships and initial conditions.* • Tests *for consistency with purpose and boundary.*
4. Testing	• Comparison to reference modes • Validity of assumptions and behaviour • Robustness under extreme conditions
5. Policy Design & Evaluation	• Scenario specification • Policy design • "What if..." • Sensitivity analysis • Interaction of policies

6.1 PROBLEM ARTICULATION & REFERENCE MODES

Chapters 1-3 laid out in detail the objectives of this thesis and the likely dynamics that drive the problematic behaviour. The physical and conceptual boundaries (Section 1.4) were specifically drawn according to the research questions and aims. This chapter puts previous knowledge and understanding into a working simulation model to test the hypotheses and gain insights into the system behaviour.

The time horizon for the modelling exercise is assumed to be 50 years. This is to account for the simulation of the development of the systems from the late 1970s (see Figure 9 of Chapter 3) until the most recent records available to the author, in which period the problem is observable. At the same time, it allows foresight into the future for more than 20 years, which is double the time the PPC makes strategic plans for (although the policy intervention can be introduced at any point in the past as a "what if" scenario once the simulation model has been tested and calibrated).

System Dynamics seeks to characterise a problem in dynamic terms, that is, a pattern of behaviour unfolding over time which shows how the 'problem' arose and how it might evolve in the future. The Reference Mode is a critical element in the modelling process, essentially a set of graphs and other descriptive data that capture the dynamics of the problematic behaviour. As the name suggests, the Reference Mode(s) is referred to throughout the modelling exercise as the simulation is aiming to reproduce its pattern.

There are three graphs in Chapter 3 – Figure 7 (fuel consumption), Figure 9 (power generation) and Figure 12 (power peaks) – that describe the main manifestations of the problem. In reverse order as a reminder:

- Power peaks grow exponentially due to a dominant tourism sector and the widened use of air-conditioning and electrical equipment in general.
- Consumption also grows exponentially as permanent residents' income from tourism allows them to buy as much electric comfort (i.e. the services of electric appliances) as wished with little consideration of efficiency, since there is electricity abundance due to winter peaks being significantly lower than high-season ones.
- Due to the dominant use of stacked diesel and HFO power generators, the low capacity factor and the short peak season, running and capital costs result in financial losses of hundreds of million of euros each year, as tariffs are not allowed

to reflect the costs of generation in the islands and are kept in line with those of the interconnected grid in the mainland.

In relevance to what follows, it should be noted here that due to the income tourism development brought to the islands, there has been internal migration to the islands since the 1980s. Table 9 below shows the population increase in the decades 1981-1991 and 1991-2001. The rise is not supported by the net population growth (registered births minus registered deaths) for the Aegean islands, which according to the Greek Statistical Service[15] is only 0.146% (2008 est.) indicating a significant influx of people.

Table 9: Population increase in South Aegean islands compared to the national average Source: Ministry of Mercantile Marine, The Aegean and Island Policy[16]

	Population 1991 ('000)	Pop/sq.m 1991	% increase 1981-1991	Population 2001('000)	Pop/sq.m 2001	% increase 1991-2001
Greece	10.264	78	5,4 %	10.939	83	7 %
South Aegean	263	50	12,4 %	301	57	14 %
Dodecanese	*162*	*60*	*12 %*	*190*	*70*	*17 %*
Cyclades	*101*	*39*	*13,1 %*	*111*	*43*	*11 %*

Although the simulation aims to simulate an "example" or "average island" that encompasses the collected demand characteristics, observations and dynamics, the island of Sifnos is chosen in case more specific data might be needed and to maintain a comparison potential for the simulated island. Sifnos belongs to the Cyclades (see map in Figure 3 of Chapter 3) island group. It has an area of 74 km² and is 15 km long and 7.5 km wide with a permanent population of 2442 (2001 census, up by 24% since 1991). Sifnos belongs to the medium-large islands of the Aegean based on its installed capacity (refer to Section 3.2.3) while consumption and peak demand figures are within the average and median for the Aegean Sea unconnected islands, as in Table 10. Sifnos is also chosen not least because it is one of the two islands for which the author managed to obtain rare hourly demand data for the year 2001. The other being neighbouring Serifos which, however, does not show as a good match to the average and median figures as Sifnos did, it has a smaller population and it is less popular as a destination. In a similar fashion to Sifnos and most islands under examination, the simulated island will begin as a small system and grow as population and visitors grow to a medium and towards a medium-large power system within the study horizon.

[15] http://www.statistics.gr [Accessed 19/03/2009]
[16] http://www.yen.gr [Accessed 19/03/2009]

Table 10: Comparison of Sifnos to demand and consumption figures of the Aegean (PPC 2002;PPC 2006;RAE 2008a)

Peak Demand			
Period	Average (mean)	Median	Sifnos
1996-2001	11.5%	8.0%	7.2%
2000-2007	8.1%	7.3%	8.1%
Consumption			
Period	Average	Median	Sifnos
1996-2001	8.1%	8.5%	8.5%

The main reference modes for Sifnos are the historical trends for consumption and peak demand from 1977 to 2001 for which the author has continuous data (PPC 2002) and which are presented in Figure 42 below.

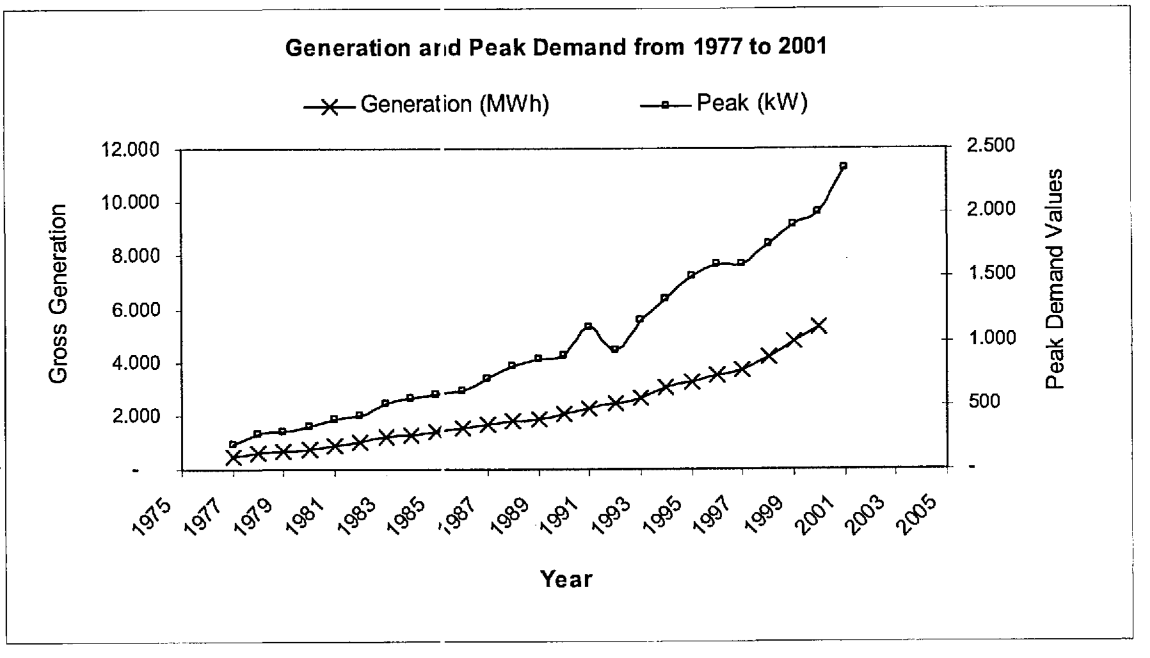


Figure 42: Reference modes for Sifnos; consumption & peak demand (PPC 2002)

Sterman's modelling steps suggest that once the reference modes are decided, their possible future trend should be considered next. In this case, the future is provided by the PPC's forecast on which the organisation plans capacity additions. Figure 43 plots the trend which is based on an exponential trendline. The trendline used by the author is checked against the figures from the PPC (PPC 2006) which result in a 2.5% error margin and a low standard deviation of 0.005949.

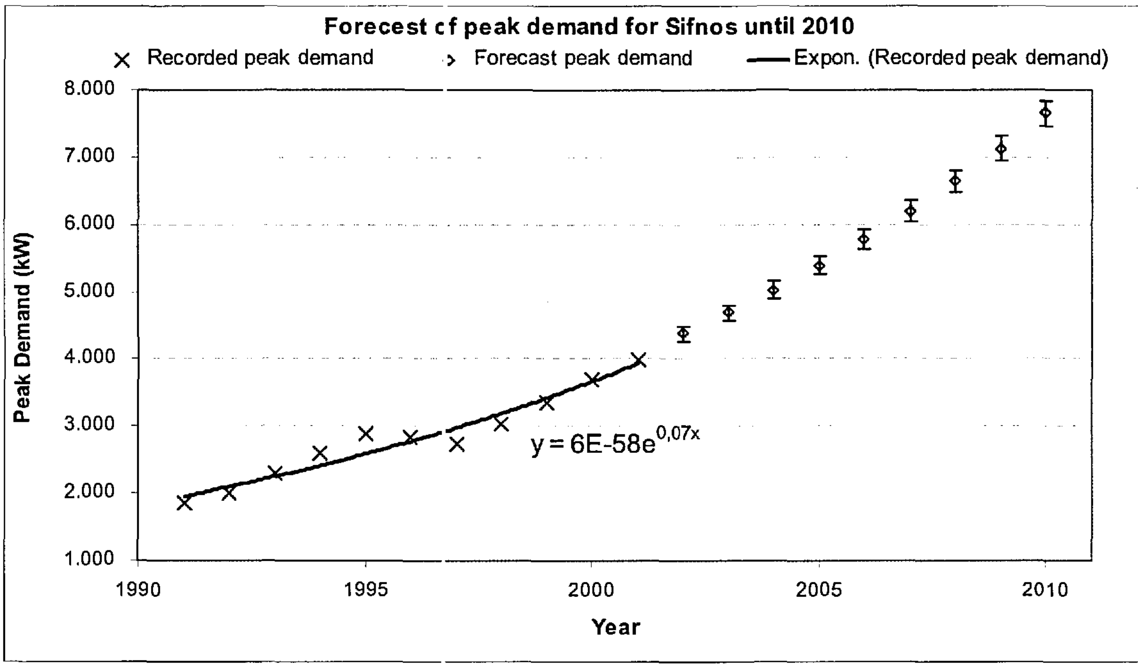


Figure 43: Forecast peak demand for Sifnos according to the PPC (PPC 2002)

More recent data on peak demand (RAE 2008a;RAE 2008b) shows an actual demand 10% below forecast on which however capacity expansion is based. This shall be further explored in forthcoming sections while this observation is coming into the hypothesis of system behaviour in the following. It is basically assumed a symptom of the uncertainty of the demand trend and the 'luxury' of security through over capacity that central government planning tends towards.

6.2 FORMULATION OF THE DYNAMIC HYPOTHESIS

6.2.1 INTRODUCTION TO CAUSAL LOOP DIAGRAMS

Before attempting to break down the problematic behaviour of the energy systems of the Greek unconnected islands, there is a brief introduction to the diagramming language that will be used. A Causal Loop Diagram (CLD) is a tool that helps a modeller articulate her/his understanding of the dynamic, interconnected nature of systems. CLDs can be thought of as 'sentences' which are constructed by linking together key variables and indicating the causal relationships between them. By stringing together several loops, a coherent story about a particular problem or issue can be created.

Causal Loop Diagrams are a popular Systems Thinking tool and are frequently the first step towards the construction of a System Dynamics simulation model. The CLDs consist of arrows connecting variables (things that change over time) in a way that shows how one variable affects another. Here are two examples of non-specialist topic

(Figure 44) of the two basic loops, the combination of which can portray complex systems of feedbacks.

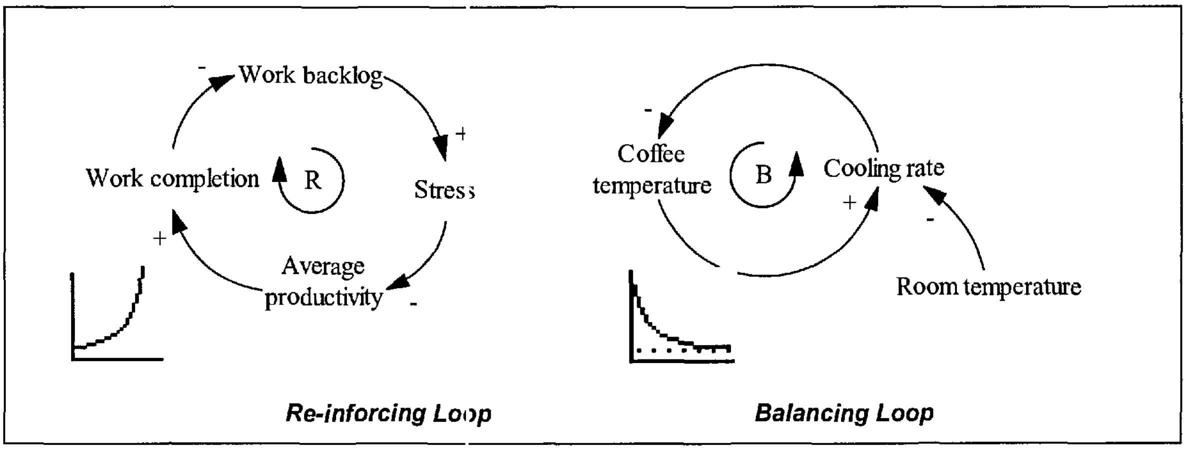


Figure 44: Example of main CLD construction loops

Each arrow in a causal loop diagram is labelled with an "+" or an "-."

"+" means that when the first variable changes, the second one changes in the same direction (for example, work backlog increases the stress on the left loop above).

"-" means that the first variable causes a change in the opposite direction in the second variable (for example, the more the stress the less the productivity again in the same loop).

In CLDs, the arrows come together to form loops, and each loop is labelled with an "R" or a "B." "R" means reinforcing; i.e., the causal relationships within the loop create exponential growth or collapse. "B" means balancing; i.e., the causal influences in the loop keep things in equilibrium and there is usually a goal the system tries to balance against as in the right hand side of Figure 44 above. Each of the loops above is bundled with a characteristic sketch of its behaviour over time.

When representing complex interrelationships, CLDs can contain many different "R" and "B" loops, all connected together by arrows. During the process of drawing these diagrams one can get a rich array of views into a complex problem. By understanding the relationships between variables, the delays and feedbacks in the system, the insight to a solution becomes easier to envisage in the entirety of an issue. The reader should not consider the following a conclusive description of the forthcoming simulation model, but an effort to abstract from the detail of the issues at hand and identify and focus on the dynamics of most concern.

6.2.2 TELLING THE CAUSAL STORY

According to the analysis of the Greek islands in previous chapters, this section attempts to weave the story along the objectives and research questions in terms of Systems Thinking. The real world situation the thesis is trying to investigate can be broken down into smaller segments for clarity. The first of which is where the reference modes appear, namely power consumption and peak demand over time. The CLD appearing in Figure 45 is an effort to describe the situation. The overall dynamic hypothesis as well as the envisaged intervention will be developed by adding loops to this original structure.

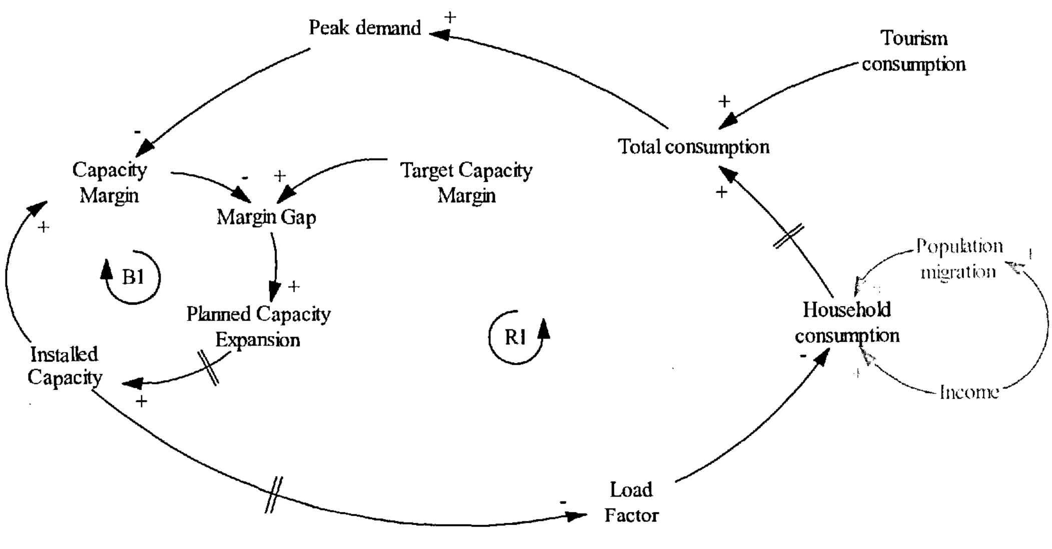


Figure 45: Demand-Supply CLD

The CLD consists of one balancing and one reinforcing loop. The system is driven predominantly by an exogenous factor: the tourism consumption, whose main characteristics are spiky peak demands during the short high season that put pressure on the capacity margin of the system (following the arrows at the top, starting from "tourism consumption"). The operator plans and builds capacity in order to keep the margin within the target. The double line (||) signifies system delay. In this case the planning, approval, purchase and installation of a power generating set. The detailed mechanics of the decision to add capacity, the forecasting function and the delays involved are examined in the description of the actual model in forthcoming sections.

The effect of the capacity expansion is twofold. On the one hand, it provides some relief to the system as it increases the margin, thus achieving PPC's remit and social obligation to provide uninterrupted electricity to the population. This is portrayed in balancing Loop B1 of Figure 45. However, as long as the exogenous tourism demand is surging due to more arrivals and the extended adoption of A/C, it basically pushes the system to continuous capacity expansion. Thus adding more power units becomes a symptomatic solution while demand keeps growing exponentially.

On the other hand, more installed capacity to face the demand spikes of a few intense weeks over the summer season, does keep a significantly low load factor for the island energy systems as demand was found to be as much as five times lower out of season. There is thus abundance of power to permanent residents during the rest of the year. As was seen in earlier chapters, electric comfort has been rapidly growing in the islands, a consequence of rising living standards due to tourism. Household electricity consumption is also rising because of the demands of a migrant population, a trend examined earlier in this chapter, who seek a share of the wealth tourism generates.

As a result, it can be said that eventually (i.e. with some delay), households absorb the installed capacity and turn it into a higher base- and mid- load, thus driving the exponential growth of consumption and peak even further. That is represented around Loop R1. It could be argued that the PPC in a sense favours winter demand growth as it improves the load factor and hence its cost indicators. That mentality further hinders the pursuit of energy use efficiency (Betzios 2003b).

The income and population growth are explicitly shown in the CLD here but are bundled in a single consumption growth function based on historical data analysis in the actual model since population or income modelling is not part of the research. Likewise, neither is income linked endogenously to tourism arrivals, an external growth function will be used instead according to literature review findings. The loss that the PPC is recording in its books every year from the electrification of the islands is, however, part of the research is. By adding a few extra loops in the original CLD, the escalating vicious cycle of costs is revealed.

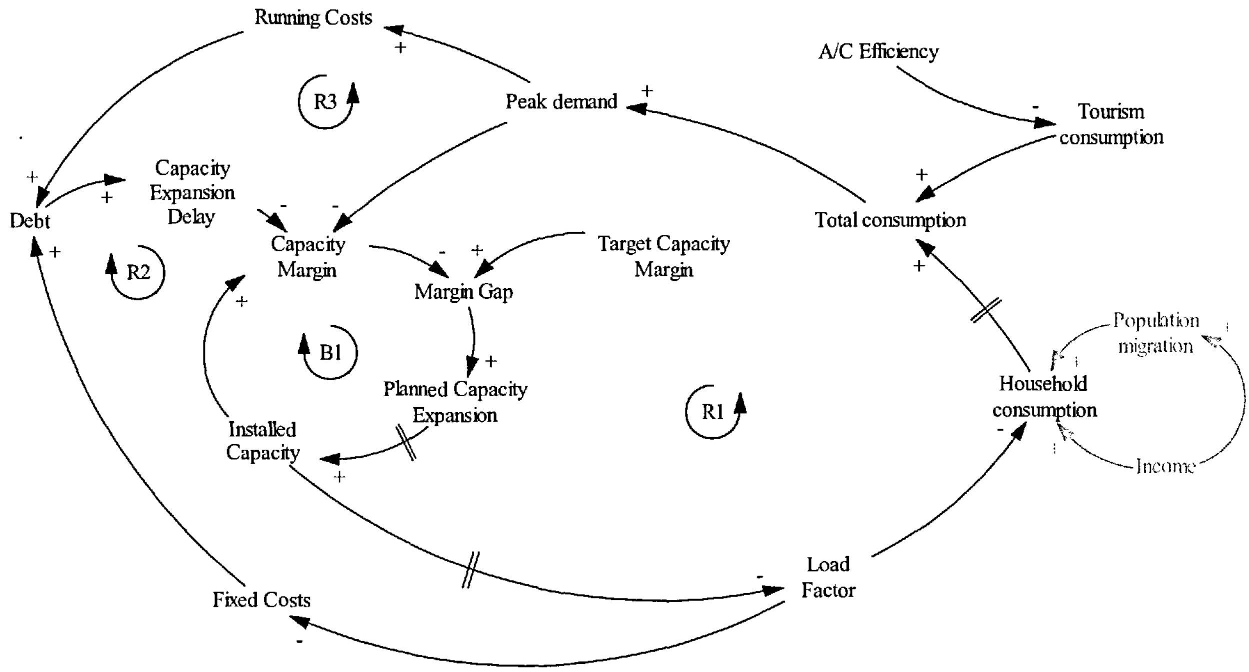


Figure 46: Adding the power cost element to the CLD

Figure 46 introduces the major working assumption of this thesis; namely that air-conditioning in commercial establishments is mainly responsible for the summer peaks. The service is provided as cooling comfort to visitors. The more efficient the appliances used the less the impact for a given coverage of the service in an island. Thus, the new element "A/C Efficiency" feeds negatively into the tourism consumption in the top right corner of the CLD.

There are also two more reinforcing loops now in the system. Loop R2 indicates that the lower the Load Factor (LF) the higher the fixed costs (effectively the cost of kWh). Accordingly, the debt grows and as a result of funds shortage there are delays in adding capacity which in turn widens any gap between the capacity margin and the target margin. The operator forecasts and proposes more capacity as they see the margin shrinking. When finally this capacity comes online, it reduces the load factor even further and this again has an escalating effect on costs and debt. Whilst explaining the model later, it will be shown how this pressure of planned capacity builds up due to delays and budget restrictions. The restraint of budget allocation and the underinvestment vicious cycle can be better understood if we consider not just a single island, but the multitude of them that the national utility has to manage and prioritise.

Loop R3's path is not that easily traceable in the diagram but has a similar effect on the finances and expansion schedule of the system: The running costs are sky rocketing in the summer as underinvestment means that existing engines run to their maximum and even emergency power rating and guzzling fuel. It was also established that on many occasions, in order to manage the loads, diesel generators are hired at the last minute at a high cost to the PPC.

The narrative above postulates that tourism is an external seasonal agitator that rules the dynamics. On the one hand, it distorts the forecasting data and amplifies the 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 demanding fuel consuming operating conditions and outages. This pattern in the case of Sifnos, for example, has been repeated over the years, leading to the exponential growth of power consumption and peak demand observed in earlier graphs.

How might the system be put under control and dampen the impact of tourism? Reducing visitor arrivals is not an economically sound option for a country of open-markets and furthermore is politically not plausible under a democratic regime. Otherwise, it could occur by market forces in a prolonged crisis of the sector, an extreme scenario examined in the ensuing simulation model but not allowing much control to the policy maker. Thus, the answer points to innovative demand-side management policies exercising sort of control of the energy system before peak growth manifests urgent capacity installations.

As long as measures of energy efficiency are not institutionally initiated the demand will always rise due to the intricate concurrent dynamics of the island economies (increasing volumes of tourism, seasonality, population increase and rising standards of living) and the planning process. Before addressing the issue of efficiency though, the author will first elaborate on the tourism demand itself, by adding one more element to the original CLD of Figure 46 before.

Figure 47 on page 131 elaborates a key underlying cause of the demand peaks; tourism. The thesis is concerned with it in order to establish a basic understanding of the link between cooling comfort and visitor arrivals, explore any causality and how it may ultimately affect energy policy, as well as take part in a potential solution. Examining the CLD, destination competitiveness is introduced as an exogenous factor. For the moment it can be considered a regional (i.e. Mediterranean, refer to Sections 2.2 & 6.3.4.1) average of cooling comfort against which visitors are comparing holiday packages. It will be later described in more detail. It assumes all other elements in the services basket visitors are receiving are held constant as in lab experiments. While the model could examine the impact of policy intervention on a variety of energy services within that basket, the thesis' aim is to explore and establish the validity of the approach and the development and application of a methodology rather than delivering an optimisation. Thus, the research focuses on a single service, i.e. cooling comfort. Expanding the ensuing methodology, if proved effectual, to more energy service could be a suggestion to further research.

According to Loop R4, the closer the local cooling coverage is to the regional average, the shorter the gap and the higher the competitiveness of the island(s). That potentially means more arrivals, leading to more capacity (e.g. shops & hotels) to accommodate and entertain those visitors, consequently more installations, expanding the coverage even further if convergence to the regional average did not occur by that stage.

At the same time, Loop B2 works in either of two modes. When the gap widens, due to say an improved standard in the region, it makes sure the local economy keep up by monitoring competition closely. In mode two, when air-conditioning units are reaching the end of their serviceable life, it makes sure these are replaced if competition dictates so. The event of arrivals decrease is faced in the model as a prolonged but temporary crisis and explored as a scenario. It is assumed that in such cases, commercial establishments serving visitors (the bulk of which effectively represents a carrying capacity equivalent) do not get torn down or disassembled, just closed down ready to be operational as soon as demand picks up again. Therefore, any A/C units remain in the stock of infrastructure. The introduced subsystem of Loops R4 & B2 is riddled with delays that can significantly distort its behaviour. Their impact will be further analysed when running the actual model.

In Figure 47 the expected next step would be to connect "A/C Installations" to "A/C Efficiency" in order to complete the image of how the struggle of the local economy to keep competitive in its market drives its energy system to extremes and a significant loss. At this stage though, the concept of an intervention is introduced. This is on the demand side of the problem and the efficiency of air conditioning in particular. An alternative technology is introduced that aims to reduce, if not eliminate, the inefficient but established electric units and thus raise the overall electrical efficiency of space cooling.

Figure 48 introduces an alternative technology that competes on price (in the model it effectively competes on a form of payback). The more installations, the more competitive it becomes. For example, importers learn how to procure and assemble the new technology more effectively, how to market it better, installers learn how to size it closer to needs, users get accustomed to its use and maintenance. Eventually, it might start getting manufactured in the country as the solar water heater did, a situation where more learning effects may well be initialised. The challenge is great though, and as long as there is a clearly prevalent option in the market, more demand for equipment will favour that (Mulder, de Groot, & Hofkes 2003). To set the reinforcing motion in practice (Loop R5) a support programme is necessary. This support could derive from the potential discounted future savings (debt reduction) from the introduction of the more efficient equipment in the islands. This process is portrayed through Loops R6 and R7. Could this be a way out for the islands' energy systems? Judging from the fact that a major path those reinforcing loops follow coincides with the loops that generate the peaking problems as explained previously, the effect could be as dramatic as the demand growth but in the opposite direction. Under what circumstances could that be? What are the critical elements to consider? Are there intuitive and counter-intuitive dynamics to be revealed? What would potential support schemes look like? These are the sort of questions the model is built for and are addressed during the simulation runs in forthcoming sections.

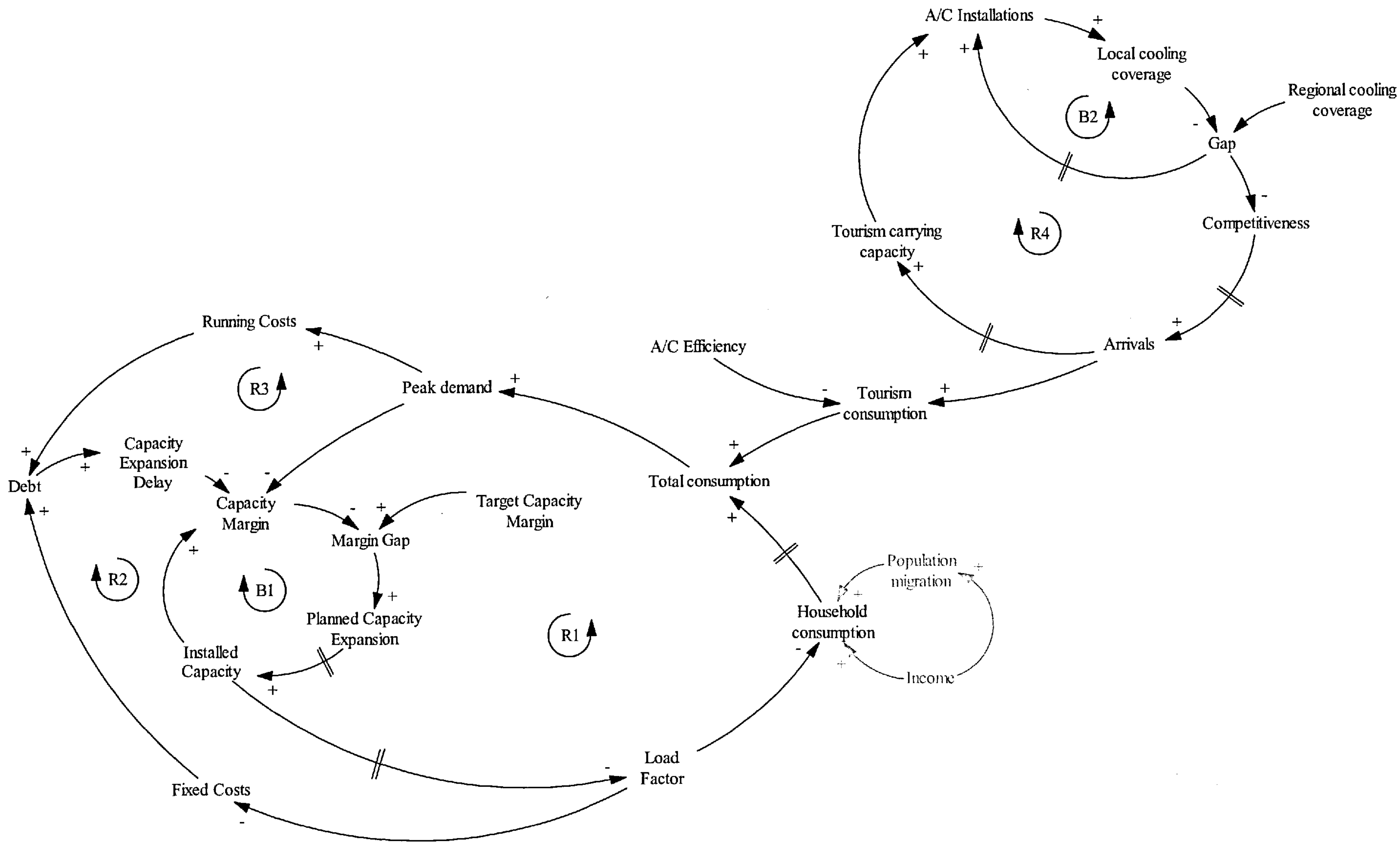


Figure 47: Elaborating on cooling comfort & destination competitiveness

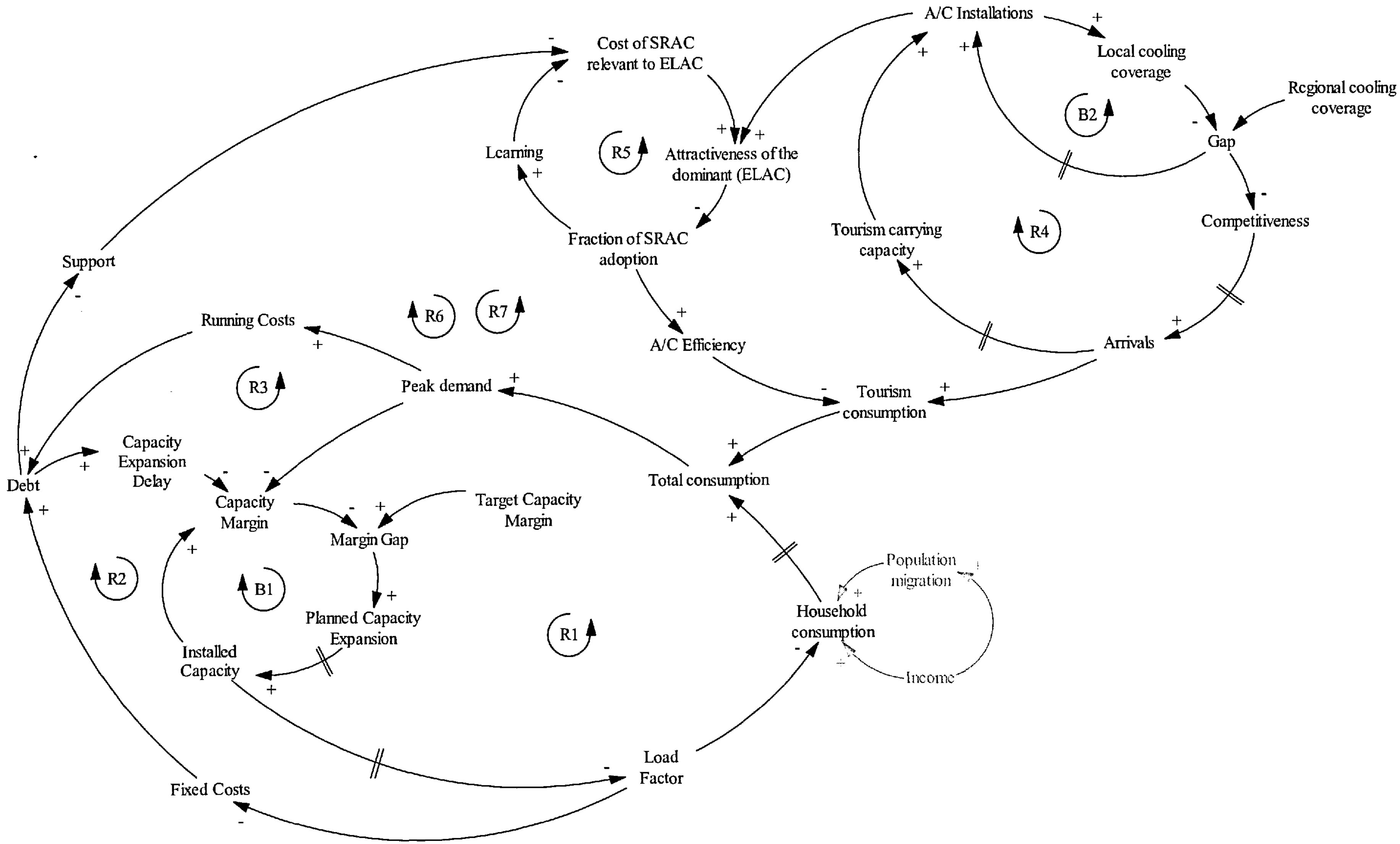


Figure 48: Introducing the policy intervention

6.2.3 SUBSYSTEM DIAGRAM

The final causal loop diagram of the previous section captured the dynamics of the key relationships at play in this thesis. It segregated domestic and tourism demand, effectively defining a base load accumulator and a peaks generator. It specified partial causality of the tourism to the household demand as the main driver of capacity expansion and the growth of the economy in general. Therefore, the tourism sector has been further elaborated with the objective of detailing the demand for one of its most power consuming services: space cooling. On the supply side there is a decision making process whose capacity expansion function (algorithm) will be derived from classic energy planning, localising it from literature and interview data. The Subsystem Diagram below represents a further step in understanding the design of the modelling exercise in the next section. It provides a vision of the likely components to be constructed indicating their expected main data links and the physical subsystems they belong to. These are the shaded areas starting clockwise from the top left corner: 1) the power consumption, 2) the power generation, 3) the financial log, 4) the competitiveness monitor and, 5) the diffusion dynamics.

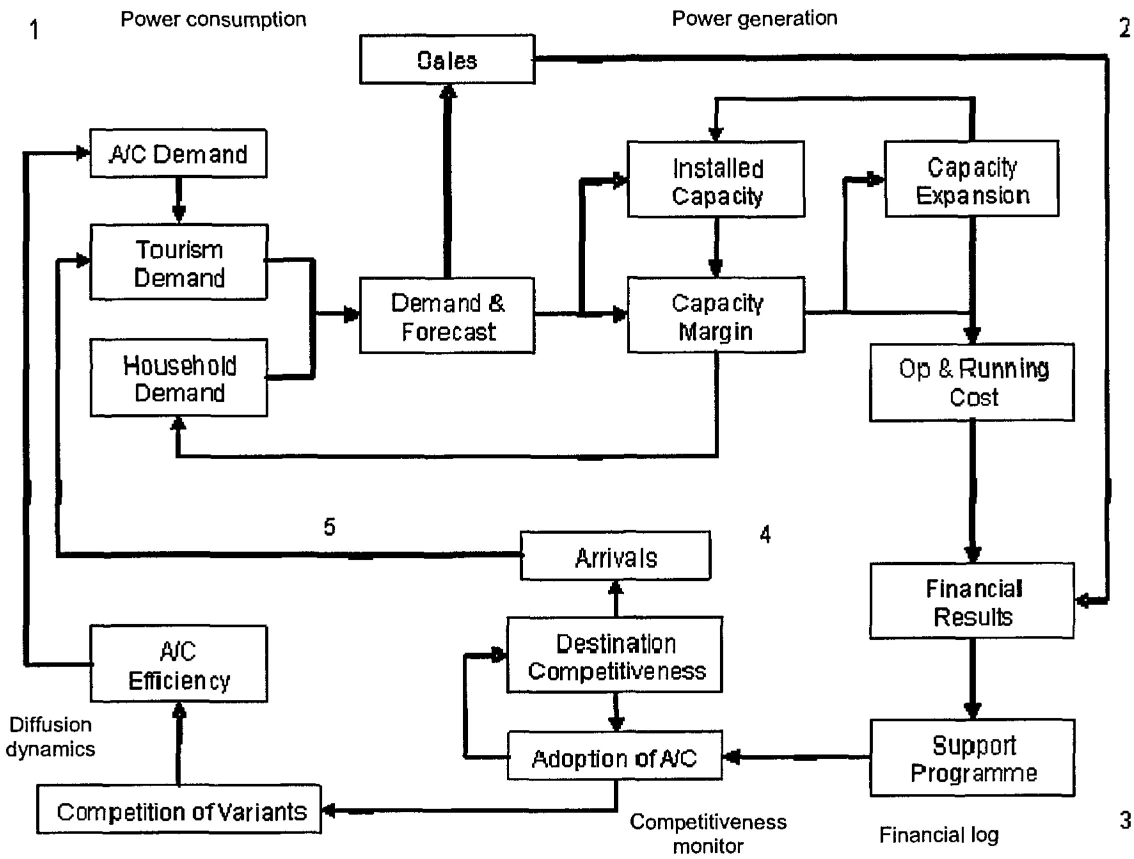


Figure 49: The Subsystem Diagram

In the following section, the model construction is broken down into two headings or sub-models. The major one is the Demand/Supply sub-model, which includes 1 and 2 and the financial component of 3 above. The other is the Diffusion submodel that includes 4 and 5 above. The support programme is studied in a subsequent chapter, as part of the scenarios.

6.3 FORMULATION OF THE SIMULATION MODEL

System Dynamics modelling is a time-domain modelling technique in which we set out to formulate and analyse, through time-based simulations, how cause-and-effect relationships work and produce variations over time.

All system dynamics models are created as simplifications of the real world and are designed to model a particular problem, rather than model 'the system' in its entirety (Meadows et al. 1974). The model must be designed to meet the requirements of a defined analytical study. That is, the model should be designed to answer a formulated question that arises from and addresses issues relevant to this question which becomes the basis for defining the modelling requirements (Sterman 2000).

As expressed by the founder of System Dynamics, J.W. Forrester, the explicit statements of policies, or rules, in a simulation model that govern decision making do so in accordance with conditions that may arise from the system being modelled itself (Forrester 1992). Thus, the SD methodology has been developed to embrace feedback and actually makes such loops essential in understanding the real world system and the research question(s) it aims to represent. In addition, modellers should take into account that 'true' conditions might not be available to actual decision makers and that systems are riddled with delays and distortions of information. Thus, one should not only base the representation of a system or related corrective actions only on numerical data but also "rich stores of information [...] from mental databases built up from experience and observation" (ibid.).

What is therefore an important component and asset of System Dynamics is its potential for learning and training in questions of a complex socio-economic nature where human behaviour and heuristics are equally if not more influential than deterministic techno-economic parameters. This is examined in one of Sterman's papers devoted to learning, where he confronts 'policy resistance' of systems in the effort to design more effective policies (Sterman 2001). Assuming that today's problems might often be unintended consequences of yesterday's solutions, he recommends the use of 'flight simulators' for policy making.

The views and principles from the work of shaping authors summarised briefly above, are adopted by this thesis. In the next paragraph, a similar overview is attempted for chosen references on the subjects relating more closely to this research work.

6.3.1 SYSTEM DYNAMICS IN ELECTRICITY & ENERGY

Roger Naill was one of the first to be systematically involved in the application of SD in the electricity sector, from as early as the 1970s (Naill 1977). His work was adopted by the United States Department of Energy (DOE) in the decades that followed, in their construction of an integrated model of the country's energy supply and demand, under the names FOSSIL1 and 2. Drawing from one of his major publications, the main thesis of his research was that the U.S.' previous energy transitions (from wood to coal in the 1800's and from coal to oil and gas in the early 20th century) followed a 'life-cycle' pattern of peak and decline due to technological advance and substitution. In the 1990s the evidence showed that a new transition was under way, which he set to describe and manage (Naill 1992). In this new transition, a key driver was not the emergence of a better and cheaper fuel but rather the depletion of natural resources. Thus the growing reliance on imports and increasing concern over issues of energy security. The first effort to model the new transition started in 1977 with COAL2, then FOSSIL1 in 1977 and FOSSIL2, which was developed in the 1980s. The model has been used in national energy policy since and its success is attributed to the inherent capabilities of System Dynamics listed by Nail (op. cit.), such as dealing with nonlinearities (resource depletion), stocks and flows (of resources and capital), feedback loops, dynamic behaviour and the need for energy policy analysis.

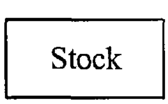
Later, on the same side of the Atlantic, Andrew Ford, under a growingly deregulated U.S. sector, delved deeper into case studies of particular regional electricity systems, decision making and the effect of efficiency on uncertainty and market cycles. More specifically, in the 1990s he examined the reductions in long-term uncertainty in planning through the introduction of energy efficiency. It has been established that through a proper policy positive feedback loops could diminish not only demand uncertainty but price uncertainty too (Ford 1990). Earlier in that decade, his work focussed on boom and bust cycles in electricity and the dynamics, impacts and consequences of plant construction. He managed to treat the deregulated electricity industry in terms of a commodity and draw in experience from other industries to provide learning and increase manageability (Ford 2001). He has written extensively on the aftermath of the California power crisis of reliability alerts and price spikes, suggesting and simulating alternative market structures for California and discussing whether these could contribute to international learning in electricity restructuring (Ford 2002). He has mapped and summarised the use and contribution of SD in energy policy making (Ford 1997) and has published a comprehensive book on the application of SD in environmental modelling (Ford 1999).

In Europe, the most notable and practical work in the application of SD in energy policy was led by Derek Bunn and Erik Larsen at the London Business School in the 1990s. On the occasion of the brave new world of deregulation and privatisation that the UK pioneered in that decade, the two researchers proposed System Dynamics as the appropriate tool to establish possible behavioral patterns of investors and the market as a whole. Foreseeing booms and busts in the market by cycles of over and under capacity, they developed frameworks for regulation and policy intervention in the construction and retirement of plant. They also incorporated the investor's sentiment and behaviour introduced, for example, as aversion to risk (Bunn & Larsen 1994). Their simulations of those early stages of the deregulated market, the pool system and the price signal mechanisms provided insights into potential stakeholder strategies, the volatility of the reserve margin, planning and uncertainty (Bunn & Larsen 1992). Investor behaviour has been analysed and studied in particular as it posed a threat to the system through the natural economic tendency of the private sector to focus on short term benefits, i.e. less capital intensive technologies. Effectively they managed to provide a proper theoretical framework for understanding and regulating the market phenomenon manifested also by the "dash for gas" in the early days of the UK's electricity market liberilisation (Bunn, Larsen, & Vlahos 1993).

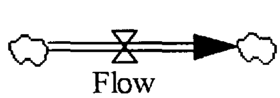
Although not conclusive, this brief overview of the hallmark applications of SD in the energy sector influenced the approach and mindframe of the author of this thesis. More references are mentioned as necessary in the rest of this work, while the two main handbooks for the practicalities of the modelling exercise were those of Sterman (Sterman 2000) and Ford (Ford 1999). Before proceeding to the actual step-by-step construction of the simulation components, the notation and symbols of SD are presented.

6.3.2 A BRIEF OVERVIEW OF SD NOTATION

The basic building blocks of a System Dynamics model are stocks, flows and auxiliaries that are linked through connectors. The procedure develops out of the Causal Loop Diagram(s) and many modellers recommend using those blocks when building the CLD (Ford 1999;Sterman 2000). In that case, it is called and Stock and Flow Diagram (SFD). We will be presenting the model in this notation, to make it visually comprehensible. Each of the building blocks may contain an equation, a constant, a variable or even a graphical function. The symbols of the building blocks are:



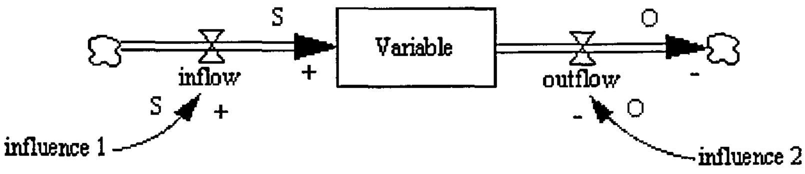
Otherwise referred to as Accumulation or Level. It is basically a first order integral. It has at least one flow connected to it.



Otherwise referred to as Rate. It dictates the rate of change, or derivative of an attribute. Most commonly feeding into or running out of a stock.

Otherwise referred to as a Converter. It carries information that determines the value of flows or other auxiliaries.

These components are combined in the following fashion:



In the example above, Variable(t) = Variable(t-dt)+(inflow-outflow)*dt, while the inflow and outflow could be any constant or function that could receive information from any other auxiliary or stock elsewhere in a model.

The simulation model of this thesis has one month as its time unit, the simulation horizon is 600 months (50 years) and its numerical simulation step DT is 0.125, i.e. one eighth of a month[17]. This means that a year is simulated in 12*8 = 96 steps.

Although Sifnos was chosen among the Greek unconnected islands for this chapter, the objective of the modelling exercise is to simulate the main dynamics observed so far and not to specifically and accurately reproduce Sifnos' numbers. Nevertheless, as suggested earlier, Sifnos can be postulated as an 'average' island and, where necessary, its local statistics will feed into the formulations, equations and algorithms of the attempted simulation. The following is a step-by-step demonstration of the main functions of the model and a summary of the major modelling decisions.

6.3.3 THE DEMAND AND SUPPLY SUBMODEL

There is no information to separate tourism from household demand, even going back as early as there are data from the PPC (i.e. the mid 1970s). Moreover, figures are available for total generation but not for consumption. So we 'built' an island from scratch based on the averages of observations from available published data. The objective is to reach a demand growth and cost structure that achieves the behavioural characteristics of those averages. Capturing the dynamic behaviour over time, not a detailed replication of an exact situation is the aim.

The author constructs the demand profile of a household and that of a tourist's visit, and then scales up according to estimates of households and visitors growth for the literature review. This is a bottom up approach. Capacity expansion is designed according to PPC's decision making processes, as studied in previous chapters from academic, PPC & RAE (the Regulatory Authority for Energy), publications as well as interviews with

[17] An excellent introduction to System Dynamics for energy policy by Michael Radzicki for the U.S. Department of Energy can be found at http://www.systemdynamics.org/DL-IntroSysDyn

representatives of the utility in the Islands Directorate and the RES Exploitation Office, researchers at the National Observatory of Athens (NOA), the Centre for Renewable Energy Sources (CRES) and the National University of Athens (NTUA), staff at the RAE, the Hellenic Transmission System Operator (HTSO), private energy companies as well as random island residents and tertiary professionals.

The final sub-model is calibrated against five observed characteristics of behaviour in the Greek islands:

a) An average growth rate of consumption over 30 years at approximately 10% ±2%

b) An average growth rate of peak demand over 30 years at approximately 10% ±2%

c) A mean load factor between 25-35%

d) The cost breakdown of fuel, O&M, overheads and capital costs at roughly 40%, 25%, 25% and 10% respectively.

e) Specific fuel consumption in the order of 240 gr/kWh (assuming diesel generators)

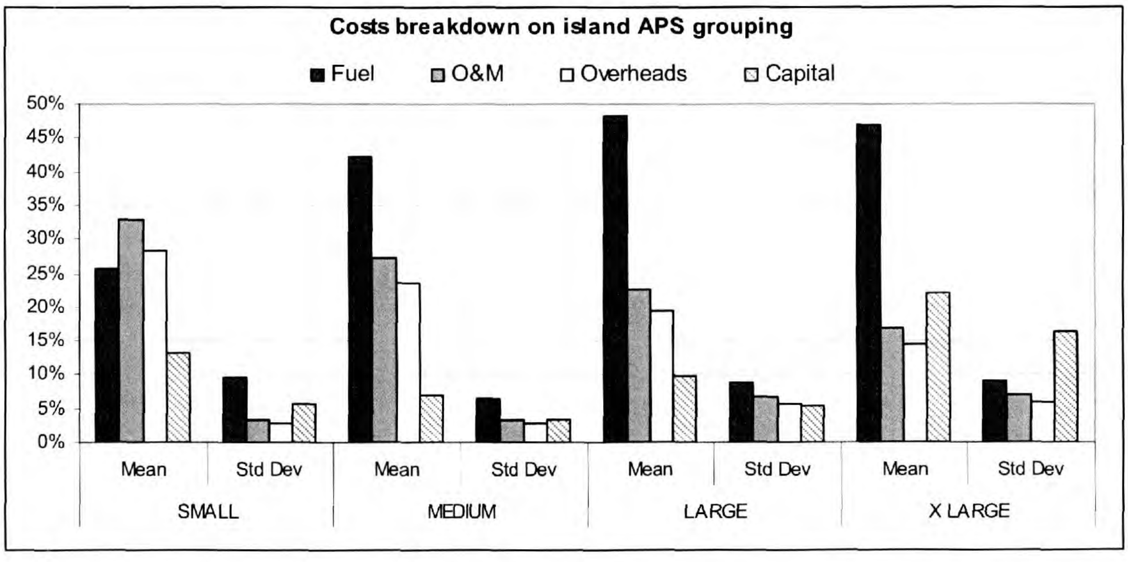


Figure 50: Comparing cost breakdown of islands (PPC 2006)

Figure 50 above elaborates further on the average figures of Point (d). One can notice the distribution of costs across different sizes of the Autonomous Power Systems on the islands. Alternatively, the graphs can be viewed as snapshots in the evolution of an island's APS. Our 'average' model island starts as a small system and within 20-30 years develops to a medium and towards a medium-large consumer. Our objective could be described as one of creating as much delay in this transformation within the simulation timeframe studying the costs & benefits of extended DSM deployment and how it might contribute towards a more desirable overall paradigm of island development.

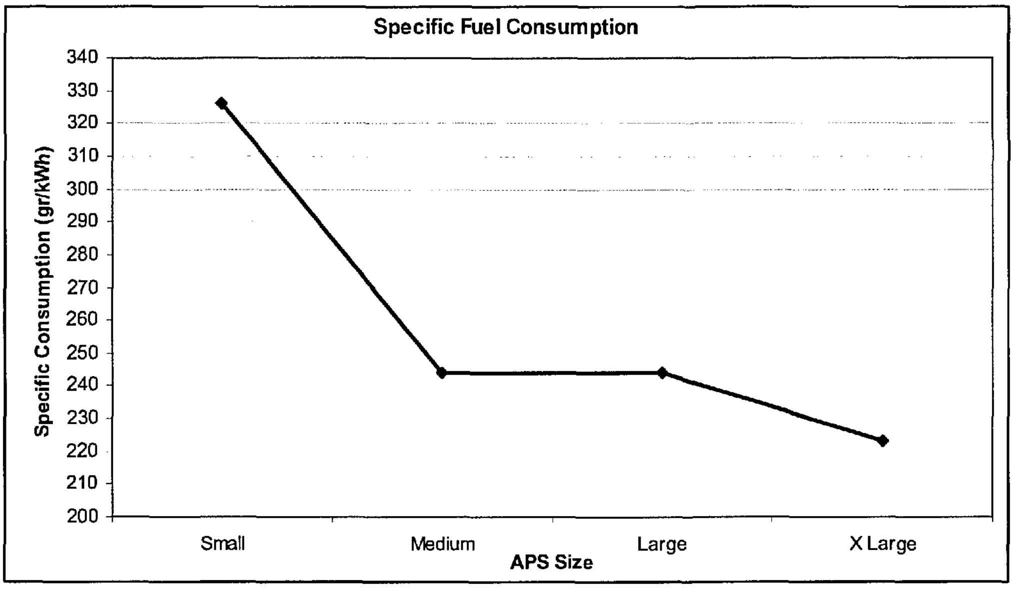


Figure 51: Specific fuel consumption of islands (PPC 2002)

Figure 51 illustrates the specific consumption of APS groupings referred to in Point (e).

6.3.3.1 THE DEMAND: PROFILING THE CONSUMERS

There are a few studies of the sustainability of Mediterranean hotels or tourism as a sector that do include elements of energy efficiency. However, these are often focussed on a particular technology (Mateus & Oliveira 2009;Papamarcou & Kalogirou 2000) and their electricity consumption statistics mainly include hotel based activities of guests (Daskalaki & Balaras 2004;Karagiorgas, Tsoutsos, & Moia-Pol 2006;Onut & Soner 2006). The thesis is concerned with the consumption pattern across all activities of a visitor during their stay. That would require statistics of the number of visitors on an island per day and the commercial only consumption (such as hotels, restaurants, night clubs etc.). It might be a cumbersome statistical collection, if carried out in detail, and it does not exist for the Greek islands. Given the growing importance of visitors, it seems an appropriate candidate for further research based on a survey, with close collaboration with the PPC and the National Statistical Service.

Faced with this data challenge, and by collating data from a number of sources reviewed so far, the author attempts to build hypothetical electricity consumption profiles of both visitors and households. The following calculations on population, households and visitors come from data from the General Secretariat of The National Statistical Service of Greece (GSNSSG 2006). In 2001, there were as many households registered as was the population census in Sifnos, i.e. 2,553 and 2,574 accordingly, which would appear to suggest one person per household! The strange statistic is explained by the fact that many maintain a summer house in the islands but do not stay there throughout the year. The census of 2001 actually recorded 2.55 members per household on average in Sifnos. For the number of residents recorded then, there should be roughly 1,000 active year-round households (2,574 people divided by 2.55 members per household). From this figure one can backtrack the active households in the late 1970s.

According population growth rates of Table 9 earlier in this chapter; in 1991 the population of Sifnos should have been about 2,320 and similarly about 2,000 in 1980. The average members per household fell from 3.39 in 1971 to 3.12 in 1981 according to the Statistical Service. Taking the median, one can estimate 600-620 households in Sifnos in the late 70s and early 80s. The generation for Sifnos in 1979 was 1,510 MWh which would mean about 200 kWh consumption per household per month. However, part of this consumption should be attributed to the seasonal visitors.

We estimate visitor numbers in the following way. According to statistics in the Association of Greek Tourism Enterprises website[18] that include studies of the World Travel & Tourism Council, a 4.5% annualised real growth until 2016 for Greece is foreseen. However, the economic crisis of 2008/09 is expected to affect visitor numbers and it is not clear what will happen until it subsides. Past national data shows an annual average growth of 4% between 1990 and 2000 which dropped to 1.7% between 2000 and 2005 at the aftermath of 9/11. Tourism statistics fluctuate greatly as travel is susceptible to trends, epidemics, conflict, income and influences ranging from the state of the stock market to oil prices. Since the 1950s however Greek tourism and tourism in general developed exponentially (Figure 52). For Greece, tourist arrivals grew from 33,000 in 1950 to over 10 million by the new millennium. Thus, the 6% average annualised growth over those fifty years shall be assumed within expectations for the future in the model's horizon. Figure 19 of Chapter 3 showed a 1 to 3 ratio of census residents to visitors in the Cyclades islands for 2003-4. Backtracking using the 6% just derived, results in a ratio of roughly 1 to 0.8 residents to visitors in the late 1970s, early 1980s. For a lower 4% average annual growth expectation in the simulation the ratio would be 1 to 1.2 residents to visitors.

[18] http://www.sete.gr [Accessed 22/11/2008]

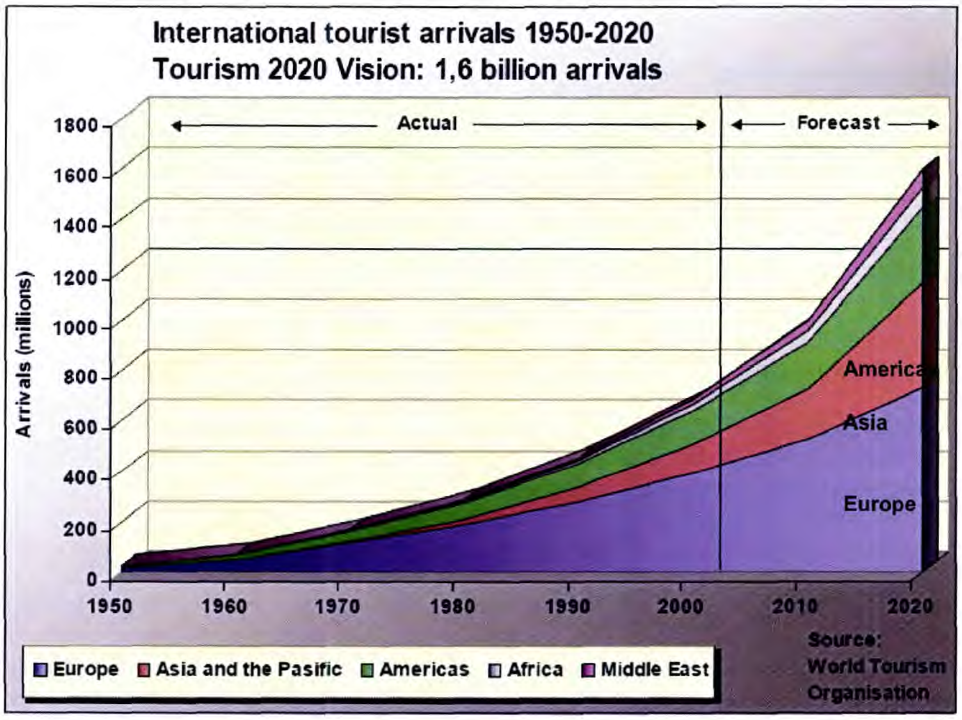


Figure 52: Expected tourism growth worldwide

(from the World Tourism Barometer of the World Tourism Organization, 2007)

Thus in a population of 2,000 in 1980 (assumed the starting year of the simulation), the simulated average island should be hosting about 1,600-2,400 visitors expected to rise to 7,500-8,000 within about three decades. A ramp function including a random number generator is used in the model to achieve a rising but fluctuating tourist wave as per the assumptions above.

The model assumes the following initialising conditions (start of simulation 1979-1980) for the consumption profile of a household in Table 11. This is assuming the 200 kWh per month per household derived before allowing for the consumption by households that are not occupied throughout the year in this way. Active households divided by census households is (~1,000/2,553) ≈ 0.4, thus 200 kWh per month multiplied by 0.4 is about 80 kWh attributed to seasonal households which are assumed utilised seven months a year makes (80kWh/12)*7 ≈ 48 kWh per month. This figure leaves about 152 kWh for the active households around which the profile in the table is built for illustration purposes.

Table 11: Household energy use profile

Description of appliance	Number of appliances	Rating per appliance (W)	Consumption each for 1hr (kWh)	Operation details	Monthly Consumption (kWh)
Incandescent light bulbs	5	100	0.1	6 hours a day average annually	76
Space heater (electric)	1	2000	2	2 hours per day for 60 days a year	20
Water heater (electric) [50oC for 80lit]	1	4000	2.6	15 hours of operation a month	40
Refrigeration [131lit]	1	90	0.5 (per day)	24/7 operation throughout the year	16
				TOTAL	152

Similarly, a demand profile is constructed for tourism, assuming a single visitor as the basis unit here (Table 12). For the visitors, the study builds a profile on an average 7 day stay (GNTO 2009) of European tourists who made up 71% of visits in the last census of 2001 (GSNSSG 2006). It should be noted that the consumption is finally given on a monthly basis as this is the unit of time of the simulation. The air-conditioning load is not included yet and will be discussed later. The consumption figure was adapted and improvised from studies of European & Mediterranean hotels' energy consumption that are revisited in detail in Section 6.3.4.2 "Service benchmarking & cooling capacity" (page 168) (Ali et al. 2008;IEA 2006;Mamounis & Dimoudi 2005;Onut & Soner 2006).

Table 12: Visitor energy use profile

Description of service	Number of appliances	Rating (W)	Consumption each for 1hr (kWh)	Service use details	Monthly Consumption (kWh)
Lighting	4	100	0.1	8hrs pd (1 bulb pp per commercial place visited)	97.33
Hot water [50oC for 10lit]	1	2000	0.33	9 hrs per day by thermostat	90.34
Dining (refr'n) [131lit]	0.5	90	0.5	24hrs operation. Everyday.	7.60
Cleaning services	0.5	2800	1.3	Laundry: 2hrs/week	5.65
(laundry+dishwasher)	0.5	3200	1.3	Dishwasher: 2hrs/day	39.54
				TOTAL	240

In the following we shall examine the Stock and Flow Diagram of the combined household and tourism demand.

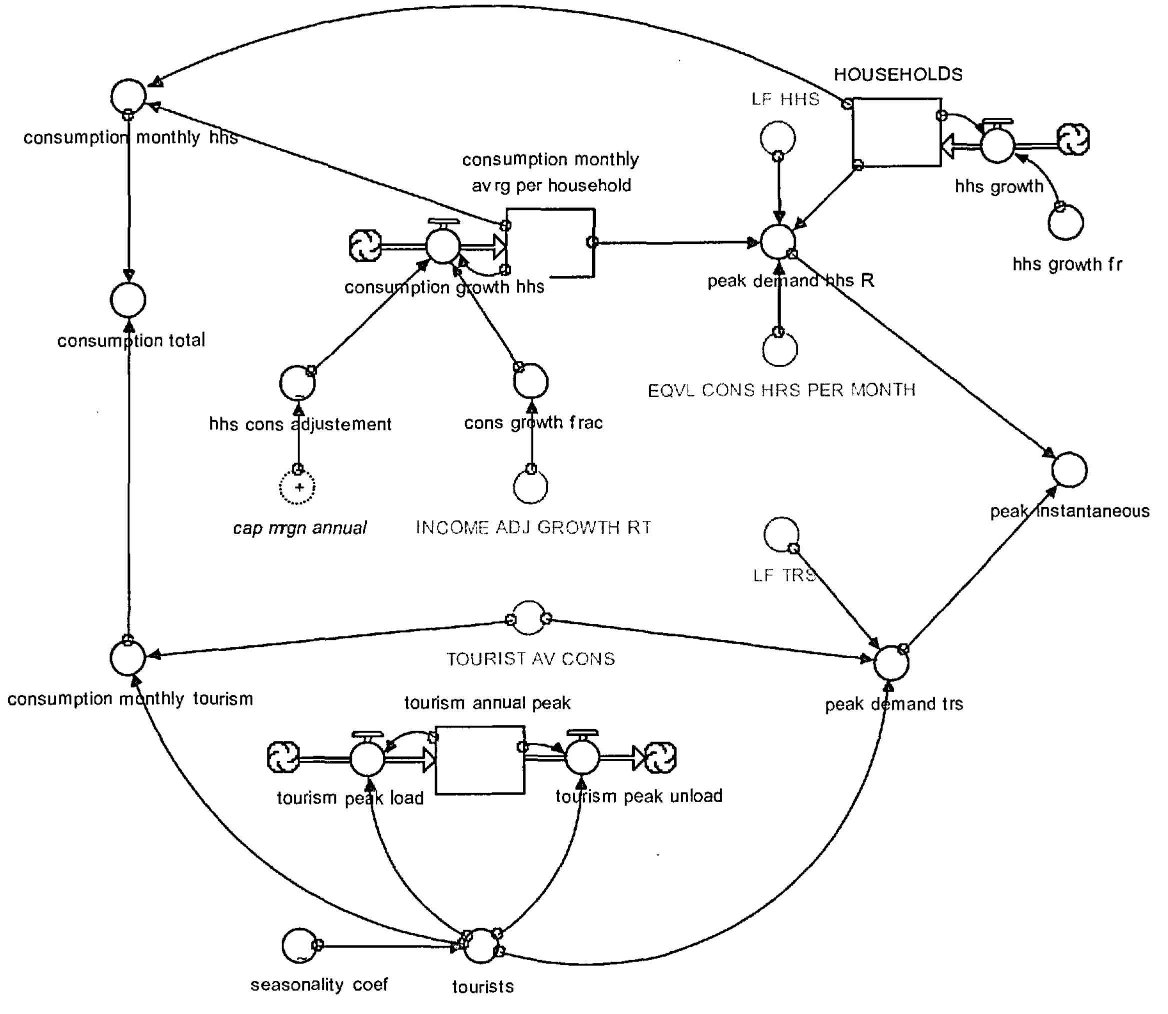


Figure 53: The supply and demand Stock & Flow Diagram

Starting from the middle top of Figure 53, there is the stock of the average monthly consumption of households. This figure is multiplied by the number of households, which is the stock on the top right hand corner, to provide the total household sector consumption per month on the far left of the SFD. The household peak is calculated through a load factor and a term to convert kWh to kW per month, as a month is the simulation time unit. The equation in the auxiliary (or converter) is simply:

$$\text{peak\_deman d\_hhs\_R} = \frac{\text{HOUSEHOLDS} * \text{consumptio n\_monthly\_ avrg\_per\_h ousehold}}{\text{EQVL\_CONS\_ HRS\_PER\_MO NTH} * \text{LF\_HHS}}$$

For the stock of households, the integrating function per DT of simulation is as follows:

HOUSEHOLDS(t) = HOUSEHOLDS(t - dt) + (hhs_growth) * dt
INIT HOUSEHOLDS = 600
hhs_growth = HOUSEHOLDS*hhs_growth_fr

INIT stands for the initial value in the stock. The "hhs_growth" figure is a cumulative household growth function defined by the "hhs_growth_fr(action)" which gives an annualised growth rate of 1.5% for the first 30 years as shown in Figure 54. As mentioned earlier, the 600 households represent the effective households that are operational throughout the year. The household growth combined with the average household monthly consumption growth together produce expected profile. It is assumed that the model thus accommodates for both income increase and migration.

The average monthly household consumption stock is fed by the household consumption growth rate "consumption_growth_hhs" as in the following. The equations of the simulation will be from now on presented within boxes for clarity. INIT indicates the initial value for the stock if there any included while INFLOWS and OUTFLOWS indicate the rate equations of any inflows and outflows from the stock listed alongside any auxiliary functions. The names of variables in the boxes correspond to those in the Stock and Flow Diagram being discussed.

```
consumption_monthly_avrg_per_household(t) =
consumption_monthly_avrg_per_household(t - dt) + (consumption_growth_hhs) * dt
INIT consumption_monthly_avrg_per_household = 152 (Betzios 2003b)

INFLOWS:
consumption_growth_hhs =
consumption_monthly_avrg_per_household*cons_growth_frac*hhs_cons_adjustement
```

The rate "consumption_growth_hhs" is a function of the growth fraction "cons_growth_frac" in the previous period, i.e. at (t-dt), and an adjustment on the available installed capacity, i.e. the capacity margin. The former is adjusted so that it gives a 0.8% annualised growth which is assumed to be the influence of income increase on electricity consumption, a figure only vaguely research and reported by Haralampopoulos but adopted for the needs of this work in his North Aegean residential energy use study (Haralampopoulos, Fappas, Safos, & Kovras 2001). The latter is a graphical function that incorporates the dynamic hypothesis made in the model's Causal Loop Diagram, where it was assumed household demand will increase when there is abundant power.

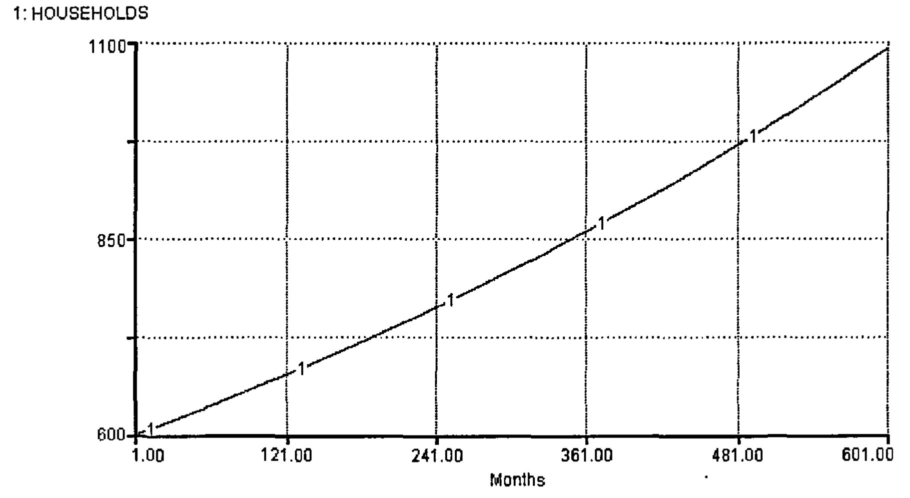


Figure 54: Household growth over the simulation horizon

The graphical function is a tool of system dynamics modelling when an equation cannot be established. The graphical function used in this case in Figure 55 (shown along its settings panel) halts growth below a capacity margin of 10%, allows only a fraction up to 20% which is also PPC's safety goal, then accepts whatever comes due to the rising income growth (i.e. set to 1) but amplifies it when the capacity margin is above 70%.

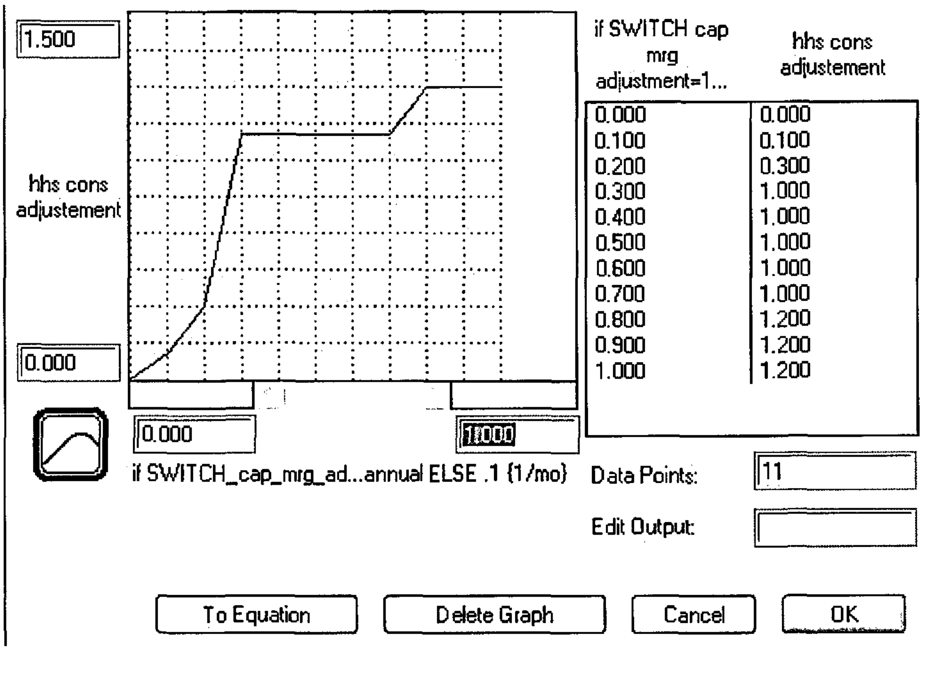


Figure 55: Graphical function for household demand capacity margin adjustment

The value of this formulation is in capturing behaviours or otherwise soft variables of the system. High capacity margins, effectively capacity margin overshoots, are caused by oversized capacity expansions. What can cause an overblown expansion? Perhaps an exaggerated forecast which in turn is caused by recent subsequent tourism spikes that on the one hand raise the forecast and on the other hand increase pressure on the system for additions. However, visitor spikes mean more income for the resident population that is translated to more comfort including energy comfort. The more appliances though, the higher the contribution of the households to the next peak and so forth. Figure 56 juxtaposes the household monthly consumption and the system's capacity margin,[19] illustrating the effect of capacity margin on the household demand as described above. As the capacity margin drops below the threshold of 20% the monthly consumption flattens. It is rapidly growing when it is above or near that figure.

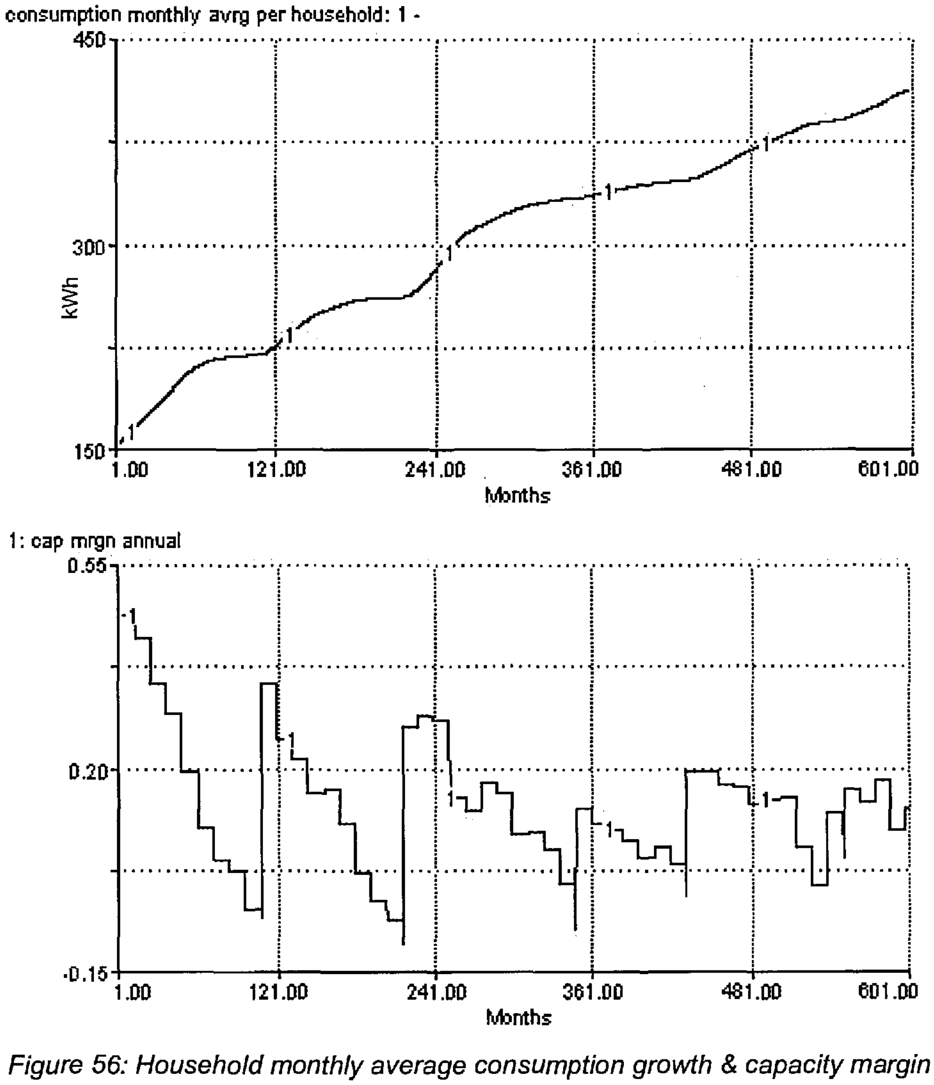


Figure 56: Household monthly average consumption growth & capacity margin

One can also notice in Figure 56 that the capacity margin tends to a mean. That indicates that the system learns how to deal with its demand and is led towards equilibrium. Tourism is the prime agent, or prime upsetter more likely, of this equilibrium.

---

[19] This method of presenting graphs in columns to explain causality and feedback effects will be used extensively in this thesis and is referred to as a *phase diagram*.

The growth function for visitor arrivals in Figure 53 is:

```
tourists = (500+RAMP(0.0075)*RANDOM(500,1000,474))*seasonality_coef
```

The stock of "tourism_annual_peak" in the stock and flow diagram is a contraption to capture the highest peak of visitors each year (each 12 month period in simulation terms). It can be effectively considered the carrying capacity of the island. The upper graph of the phase diagram in Figure 57 shows the increasing and fluctuating wave of tourists the function above generates (Line 1), as well as the figure captured by the aforementioned stock (Line 2). A similar stock and flow contrivance counts the total number of arrivals and reports it at the end of each year in the bottom graph of the figure.

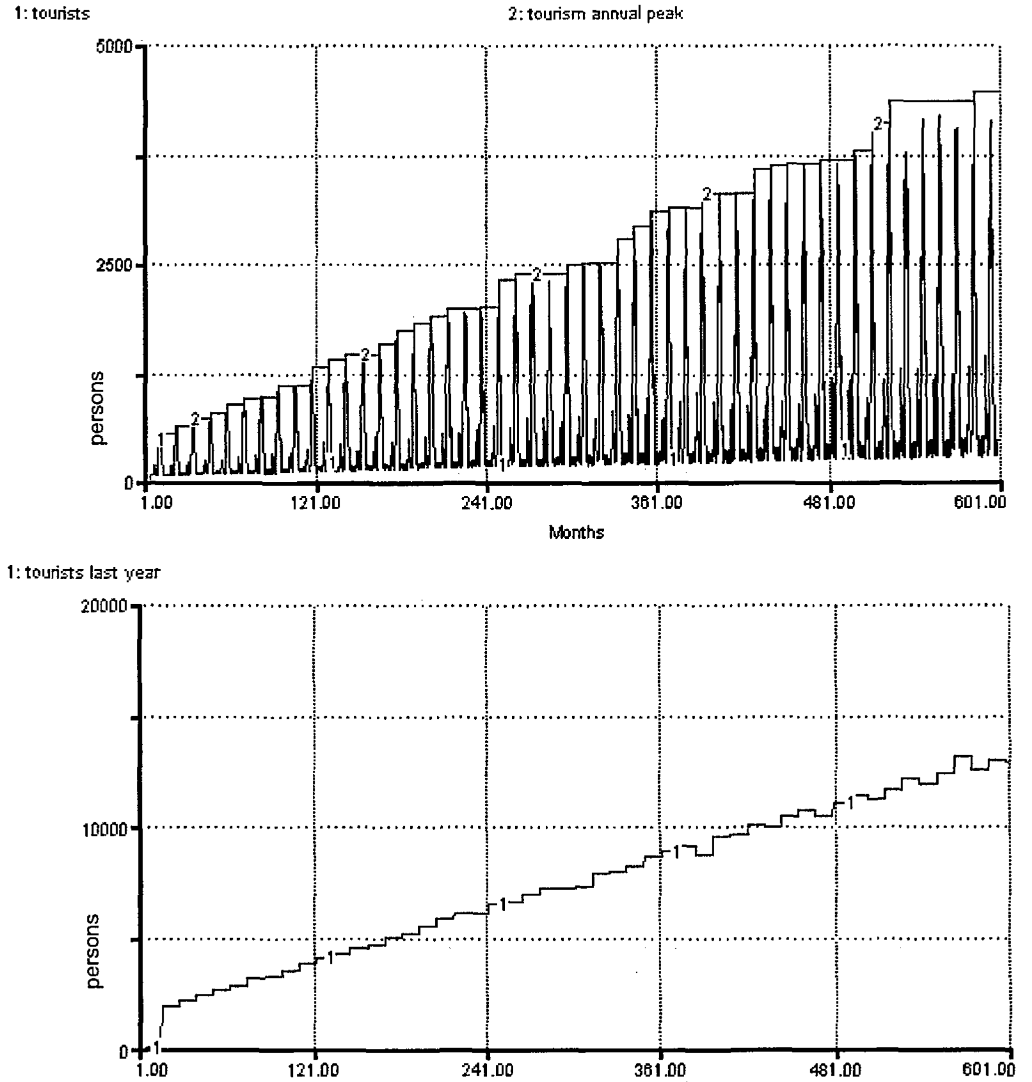


Figure 57: Tourist arrivals and growth

The visitors start from 1,800 and reach just over 8,000 nearing the third decade (month 360 across the horizontal axis). This is within what was specified earlier. The growth equation itself is made up of the software's built-in ramp function that provides a stable growth specified by the user and a seasonality coefficient.

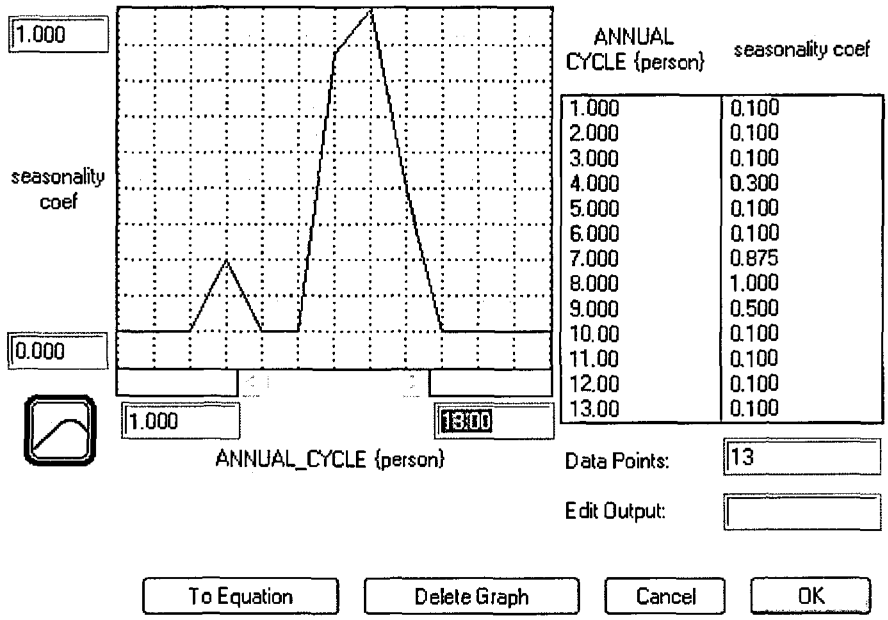


Figure 58: Graphical function for tourism seasonality(PPC 2002;PPC 2006)

The seasonality coefficient used is found in Figure 58. It is another graphical function over twelve months produced by the normalised peak demand of Sifnos. The normalising factor is winter peak demand.

The load factors of both the household and tourism sectors are used in fine tuning the demand profiles so as to achieve the required growth of the total consumption and demand. These are shown in Figure 59. At the top, the total consumption has an annual average growth of 9.2% over 30 years. That figure for the peak demand on the other hand is 12%. Both calibration points are within what was expected in Section 6.3.3.

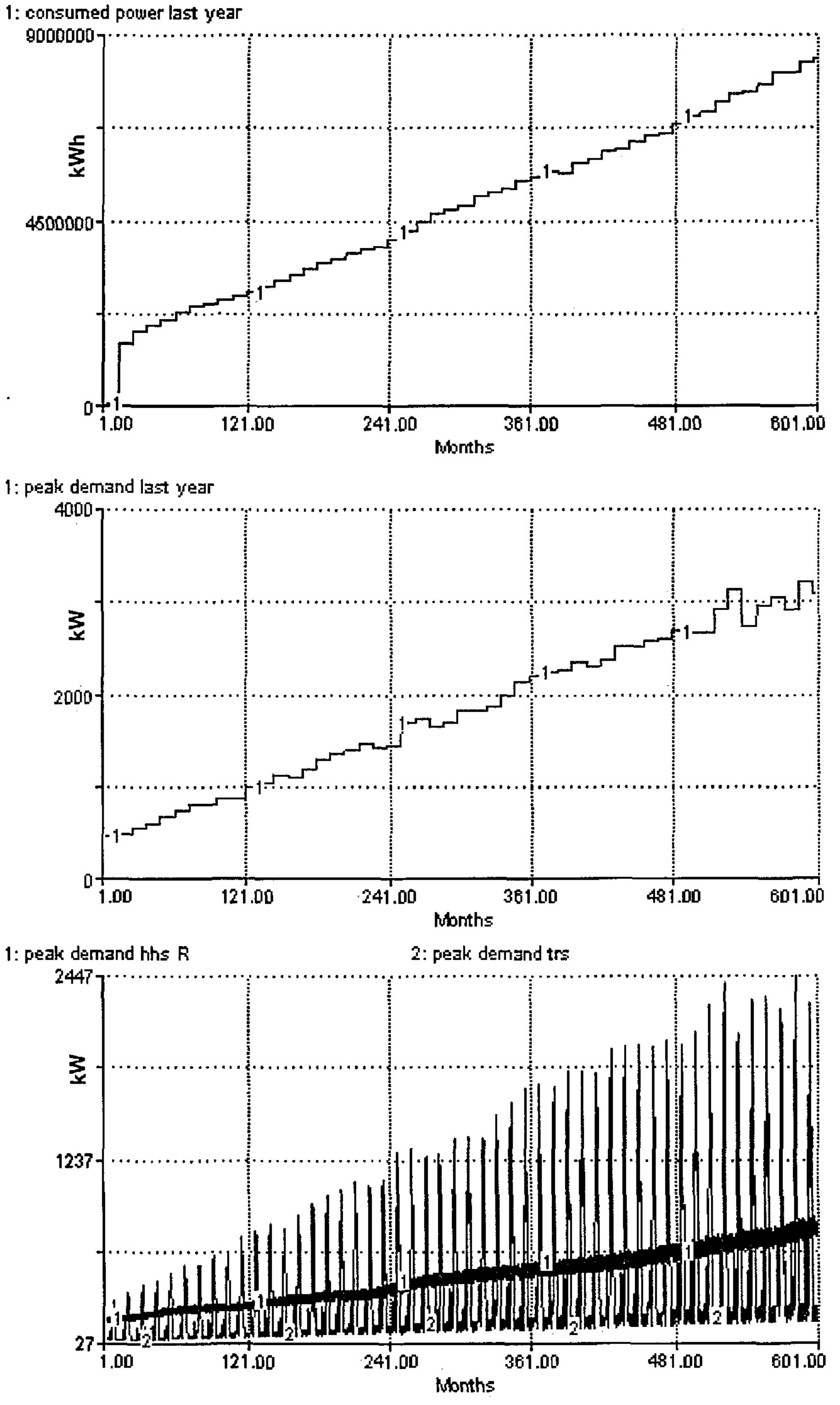


Figure 59: Phase diagram of consumption and peak demand growth

The final graph in the phase diagram plots the peak demand of the two sectors separately (Line 1 household against Line 2 tourism). It represents another characteristic of the real system where the summer peak is between 3 to 5 times greater than the off-season peak. The next paragraph examines the utility operational practices and how these interact with the constructed demand.

6.3.3.2 THE SUPPLY: THE UTILITY & CAPACITY EXPANSION

The supply sub-model incorporates loops that act like a hypothetical decision maker when it comes to adding capacity. In brief, there is a monitor of the capacity margin at each DT of simulation. Once this falls within a set of criteria, it recommends an investment based on an algorithm which enters a proposed capex (capacity expansion) stock. If the conditions for the expansion still hold at the end of the year, then the investment is approved and enters the installation pipeline. This procedure is made up of the simulation structure in Figure 60.

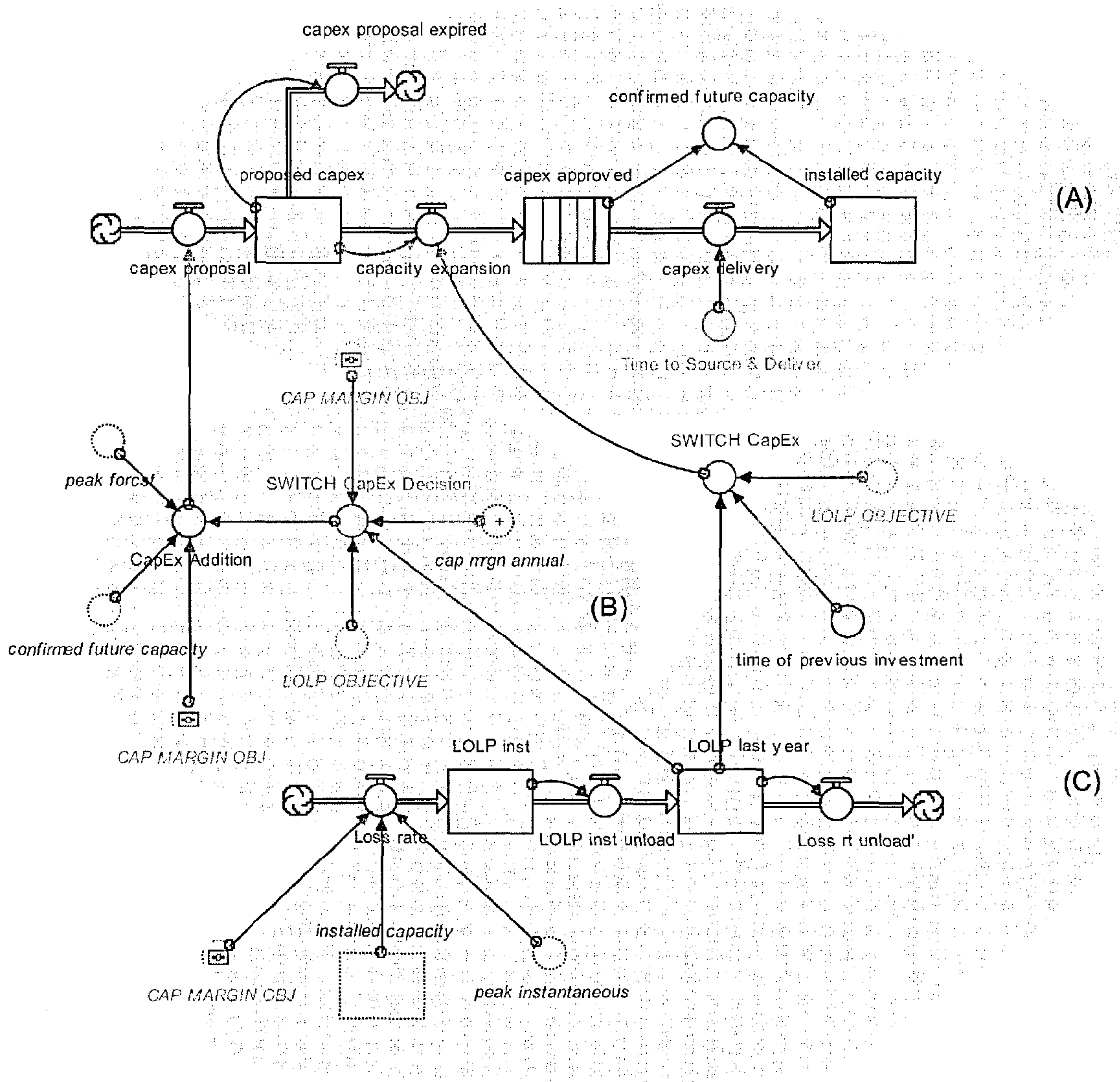


Figure 60: The utility & supply SFD

At the top – marked as (A) – is the main stock and flow configuration as in the brief description above. The rest of the structure – (B) & (C) – contains the elements that bring in the variables to make the decision. These will be examined first.

The former (B) comprises a switch used to signal the need for expansion. The "SWITCH CapEx Decision" compares both loss of load and capacity margin indicators against thresholds. They both need to be exceeded for the switch to turn on, representing the reluctance of the utility operator, the PPC, to act as a matter of urgency on demand spikes that tourism might cause in any annual peak season. It also reflects the serial way in which the PPC deals with the multiple power plant requests it has from the islands. Unless a request is persistent (expressed by continuous failures of the two indicators in the model), signifying a confirmed trend, the PPC will not prioritise. The switch is formulated as:

```
IF LOLP_last_year>LOLP_OBJECTIVE
   AND cap_mrgn_annual<CAP_MARGIN_OBJ
       THEN 1 ELSE 0
```

The method by which load loss "LOLP_last_year" and the annual capacity margin "cap_mrgn_annual" are calculated will be exposed in the following. For now, when this expression has the value 1, it triggers the "CapEx Addition" auxiliary, expressed as:

```
IF SWITCH_CapEx_Decision=1
   THEN (peak_forcst-confirmed_future_capacity)/(1-CAP_MARGIN_OBJ) ELSE 0
```

This is effectively the expansion proposal "capex proposal" in section (A) of the stock and flow diagram. The peak forecast "peak_frcst" is a 10 year trend extrapolated 10 years into the future, according to PPC's practice. The "confirmed_future_capacity" sums the installed capacity at the time and any already approved expansion from a previous period.

The loss of load is elaborated further as it feeds into two auxiliaries. The set up for LOLP estimation in essence records each time there is a mismatch of demand and supply within a simulation year of twelve months. This comparison occurs for every DT of the simulation time, i.e. 1/8 (or 0.125). Since a month is simulated in 8 steps according to the DT value, then a year is simulated in 12*8 = 96 steps. Dividing the number of total failures in a year over the total steps in a year a simple and practical LOLP figure is possible to be extracted. The structure of the LOLP estimation itself is not explained further since the inflow and outflow rates are operating as switches of sampling and have no physical meaning. The phase diagram in Figure 61 below shows the ensuing value and utility in the model and will be discussed shortly.

Since there is no source suggesting a LOLP threshold, one needs to be constructed. The tourist season in the islands lasts for roughly two months in the summer and is responsible for two- to five-fold increases in demand. It will be assumed that no more than one occasion of loss of load per week during that period should occur according to Nikos Boulaxis of RAE (Boulaxis 2007). A week was established as the typical stay of a visitor. Since that period is by far the busiest of the year, the LOLP goal of that season will determine that of the whole year.

If the season lasts in total 61 days and the aim is to allow no more than one failure per week, then there are 9 occasions of loss of load allowed in a year (61 days over 7 days a week times 1 failure per week), i.e. 9/365 results in a target LOLP of 0.025.

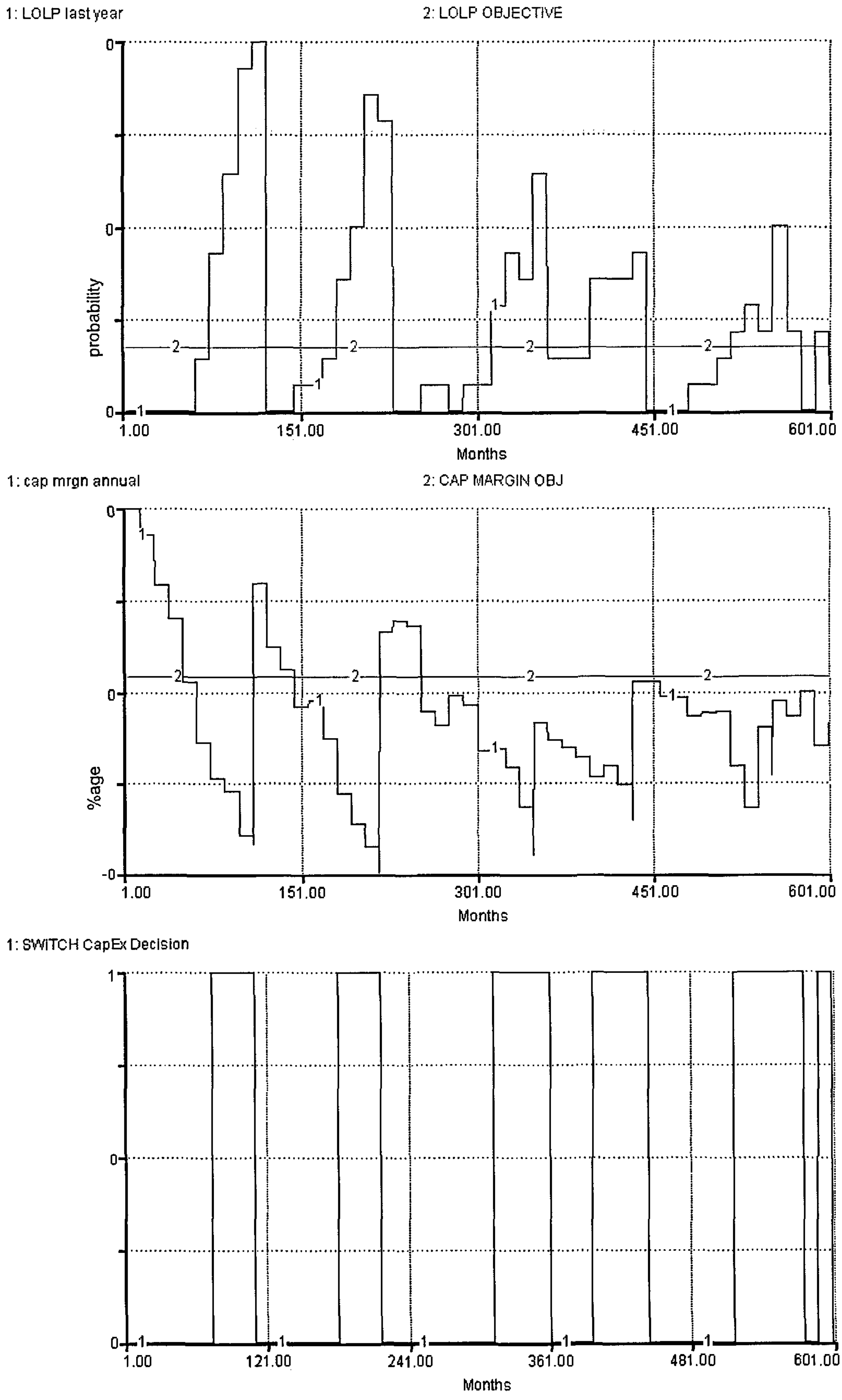


Figure 61: Phase diagram for LOLP & Capacity Margin

The top graph in the phase diagram shows the evaluated LOLP along with its objective (0.025) and it is a failure when it is above that line. The middle graph does the same for the system's capacity margin which on the contrary underperforms when it is below the line threshold of 20%. The bottom graph is the switch when both conditions fail.

This formulation is effective in that the operator does not respond as soon as the capacity margin threshold is crossed, thus making the expansion policy hyperactive. In such a volatile impulsive system like the one on the Greek islands, it would cause many more frequent investments that would make power even more costly than it already is. On the contrary, the proposed formulation confirms an urgency to invest by looking also at the shedding probability.

In a similar manner, the utility does not invest just on data regarding the peak. Instead, it confirms it is not a random effect by looking at the evolution of the capacity margin too. The power of System Dynamics is evident in such situations, where behavioural patterns of a system can be incorporated easily along techno-economic algorithms and formulations. Figure 62 demonstrates the extreme cases above.

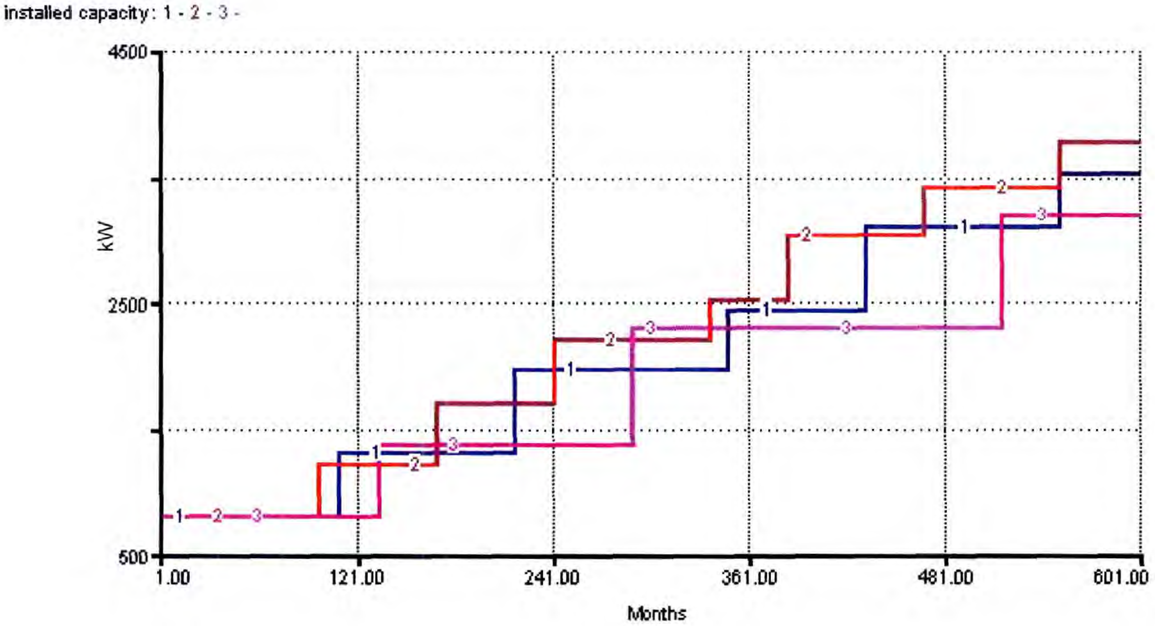


Figure 62: Testing the capacity expansion switch

Line 1 is the case where both indicators operate. Line 2 represents an over-sensitive system operator (LOLP criterion disabled) adding more capacity sooner. Line 3 is acting only on shedding events (capacity margin threshold disabled) which are limited to the occasional demand peaks of a few weeks in a year, thus making fewer and exaggerated investments. In that case, as the reader may deduce, the load factor is immediately affected (diminished) right after an addition, while allowing the margin to shrink dangerously before an addition.

Returning to the main capacity expansion circuit, area (A) of Figure 60, the following phase diagram, Figure 63, illustrates the decision making of the entire utility component.

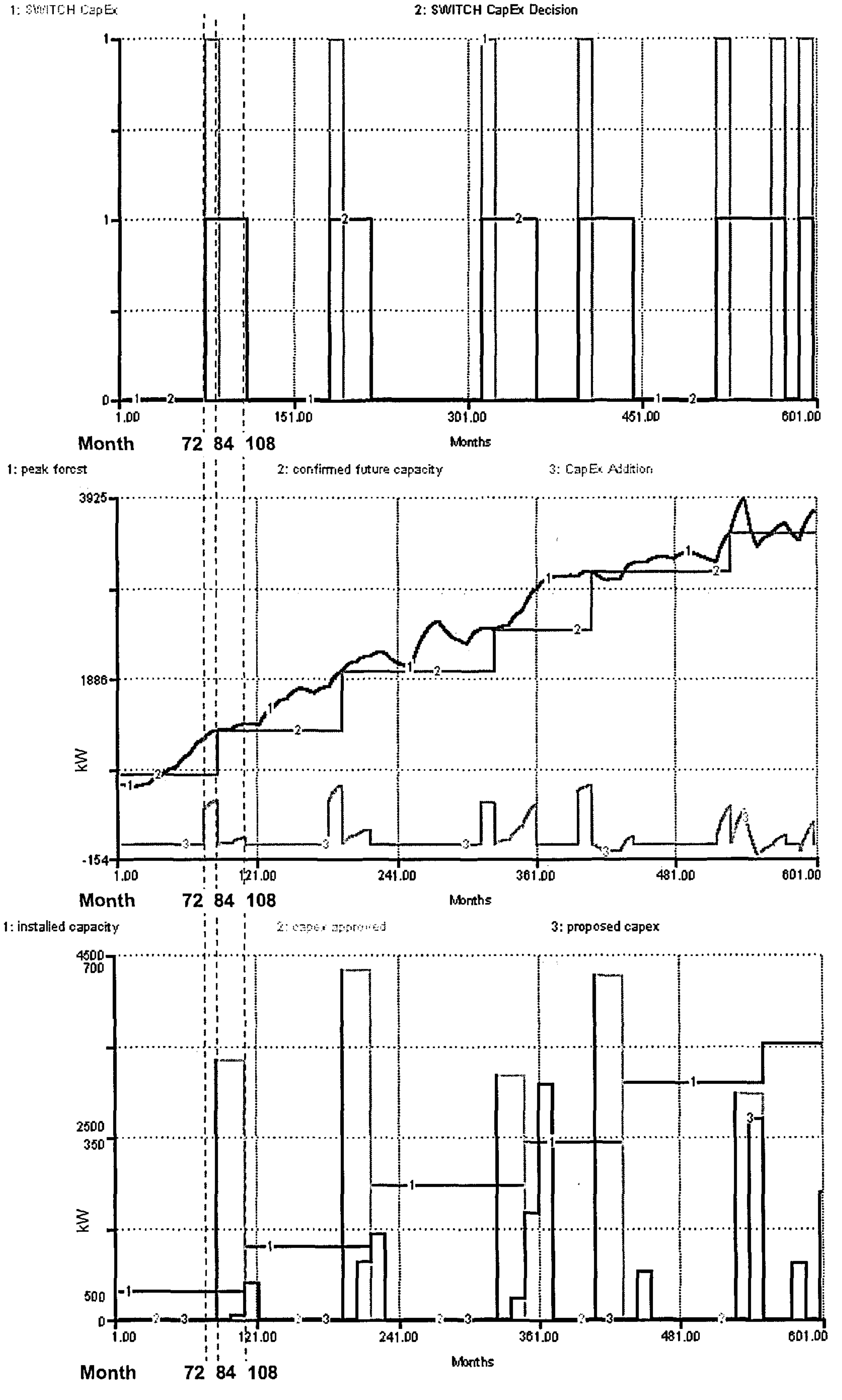


Figure 63: Phase diagram of capacity addition

Reference lines are drawn across the three graphs to help follow the events of the first ten years. As soon as both the capacity margin and the loss probability thresholds are passed, the "SWITCH CapEx Decision" is switched on and "CapEx Addition" in the middle graph begins to register the difference between the peak forecast and future confirmed installed capacity, while the system confirms the request is valid and persistent over the next twelve months. Once this is true, the addition calculated passes to the proposed capacity stock "proposed capex".

In the example above, "SWITCH CapEx_Decision" turns on in month 72 and the proposed capacity reaches 498 kW in month 84. At this point, one more check takes place between the stocks "proposed capex" and "capex approved" in Figure 60, represented by "SWITCH CapEx" at the top graph of the phase diagram above. It effectively turns the flow between the two stocks on and off. That switch typically checks that LOLP still fails and it also stays shut if the previous investment was less than 3 years ago. This period equals the total time it takes when a proposal is successful from recommendation and commissioning to delivery.

Once the check above is completed and passed, the proposed capacity flows into the approved expansion stock, commissioned and delivered 2 years later as the installed capacity in month 108 of Line 1 in the bottom graph, i.e. total of 3 years after a possible expansion need was first put forward. The bottom graph of the phase diagram illustrates these final steps as it also plots installed capacity. Requests that are not fulfilled are discarded after a year from the proposed expansion stock which thus has two outflows in Figure 60. Discarded proposals are illustrated in Figure 64, shown as blocks (Line 2) of 12 month duration, which equals the request confirmation period mentioned earlier. The spikes of Line 2 are the materialised investments whose height after 3 years becomes the expansion step of the installed capacity in Line 1.

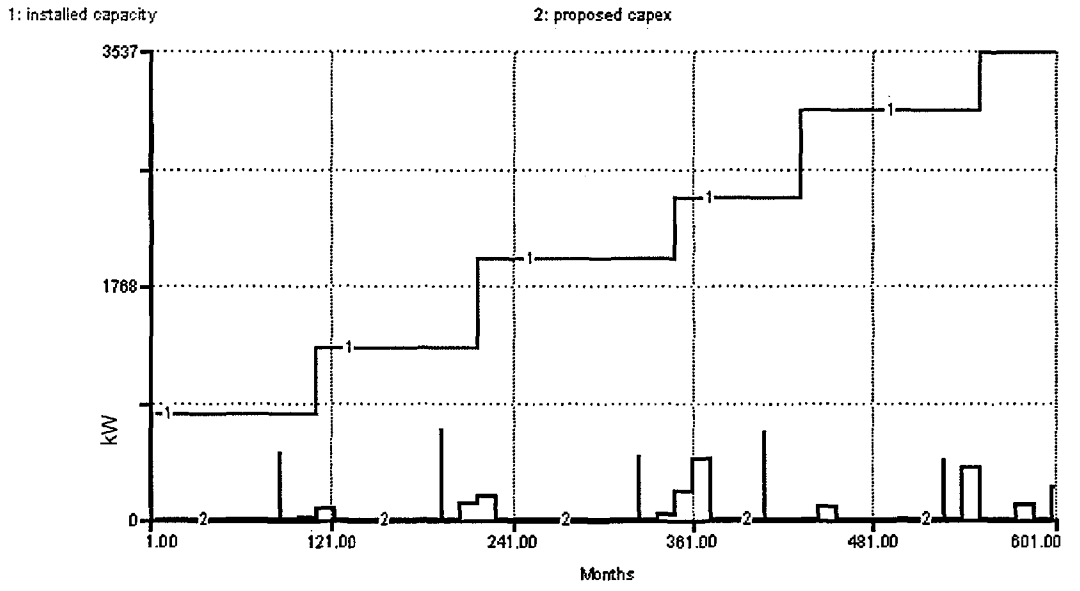


Figure 64: Installed capacity against proposed expansion

Calibration condition (c) of section 6.3.3 is fulfilled by the configuration of the demand and supply sub-model, as illustrated in Figure 65, where the smoothed instantaneous load factor is plotted. The smoothing function averages a variable over 12 months (in this case) to bring out the trend in cases when the output is randomly fluctuating. It stays within the 25-35% zone as wished.

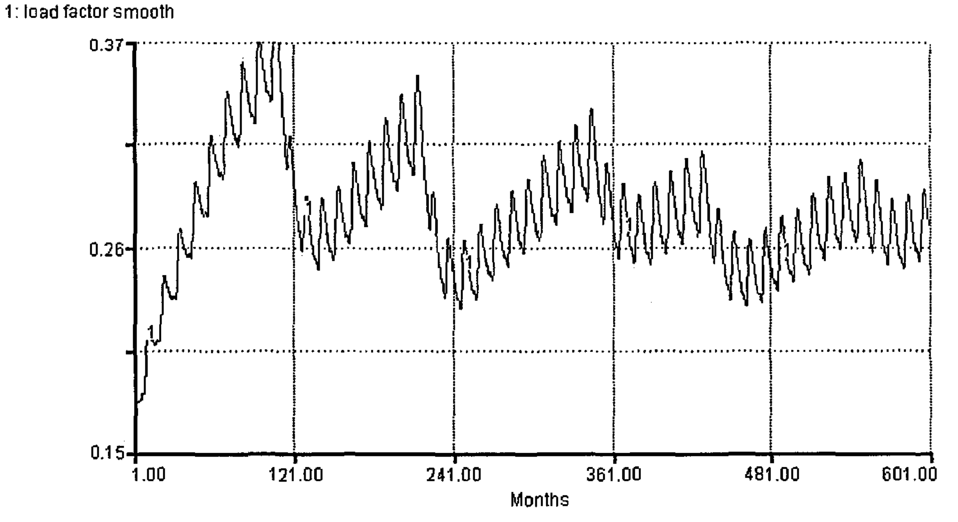


Figure 65: The load factor of the sub-model

6.3.3.3 THE FINANCES: COST OF POWER AND RESULTS

As the demand interacts with the supply, capital is spent on capacity additions, fuel is consumed to meet demand as well as maintenance and these elements plus overheads are all contributing to the cost of the kWh. The losses of the PPC in servicing the electrification of the islands was the initiating observation that led to this thesis. There is limited available data on the cost structure, apart from what was presented at the beginning of Section 6.3.3. In order to study the evolution of the costs, sales and ensuing financial performance of the simulated island over time, a loading pattern needs to be built from scratch. In addition two calibration criteria involve costs: the relevant share of fuel, O&M, overheads and capital costs, as well as the specific consumption of the system.

It is important to have an engine fuel consumption configuration that differentiates among different loads. However, the consumption curve of different engine ratings varies. An early effort to adopt the technical details of engines produced by a specific manufacturer was not very satisfactory as the handful of ratings available by each manufacturer was only a fragmented representation of the variety of the capacity added by the real system, as well as the model. After researching on the internet, a US generator and power equipment trader[20] was able to provide a list of consumption at ¼, ½, ¾ and full load, at ratings ranging from 20 to 2250 kW, from which appropriate curves for each loading tier and rating were constructed. These are summarily presented in Figure 66 (from 200 to 2250 kW).

[20] Diesel Service & Supply Inc. (http://www.dieselserviceandsupply.com/) [contacted June 2008]

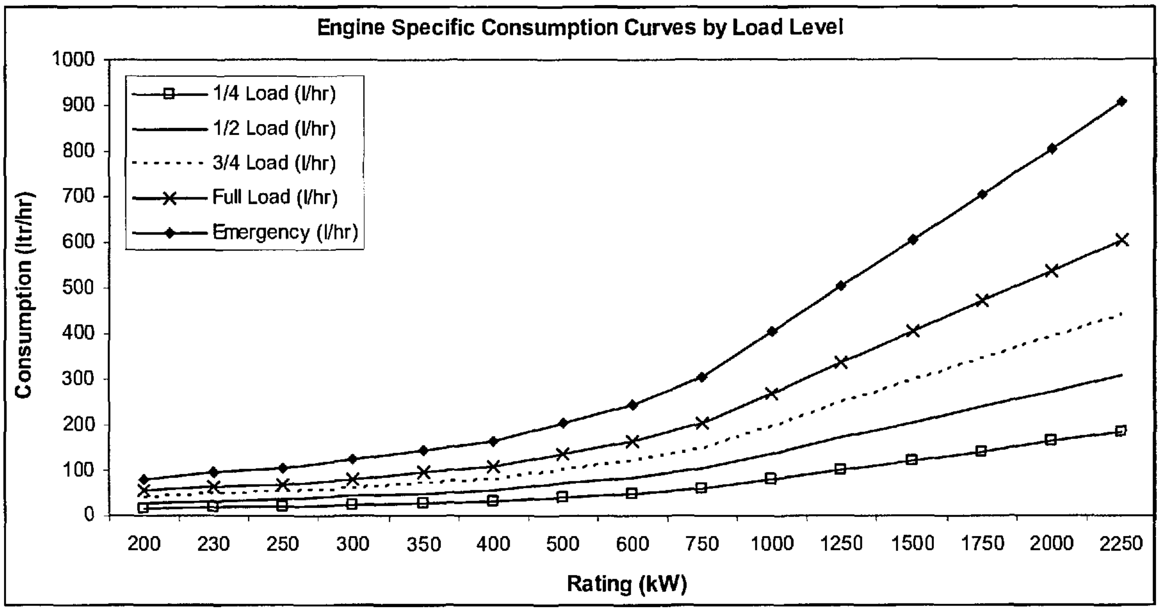


Figure 66: Specific consumption curves for generators

The curves were then applied to the total installed capacity, as optimisation of the loading is beyond the scope of this thesis. Furthermore, neither the literature nor discussions with PPC employees suggested that there is a top-down universal policy on scheduling. The dominance of diesel and heavy fuel oil, the diversity of engine sizes and frequent break-downs due to age do not allow for a comprehensive or effective strategy. Thus, the simulation configuration devised operates on the aggregate installed capacity.

The theoretical consumption at each load tier is monitored in parallel according to the peak at each DT of simulation, as shown at the top half of Figure 67. The extreme right "Engine Load 1 inf" is the emergency rating curve devised by the author and adapted from the cost of hiring in generators, as reported by RAE in Section 3.2.5.

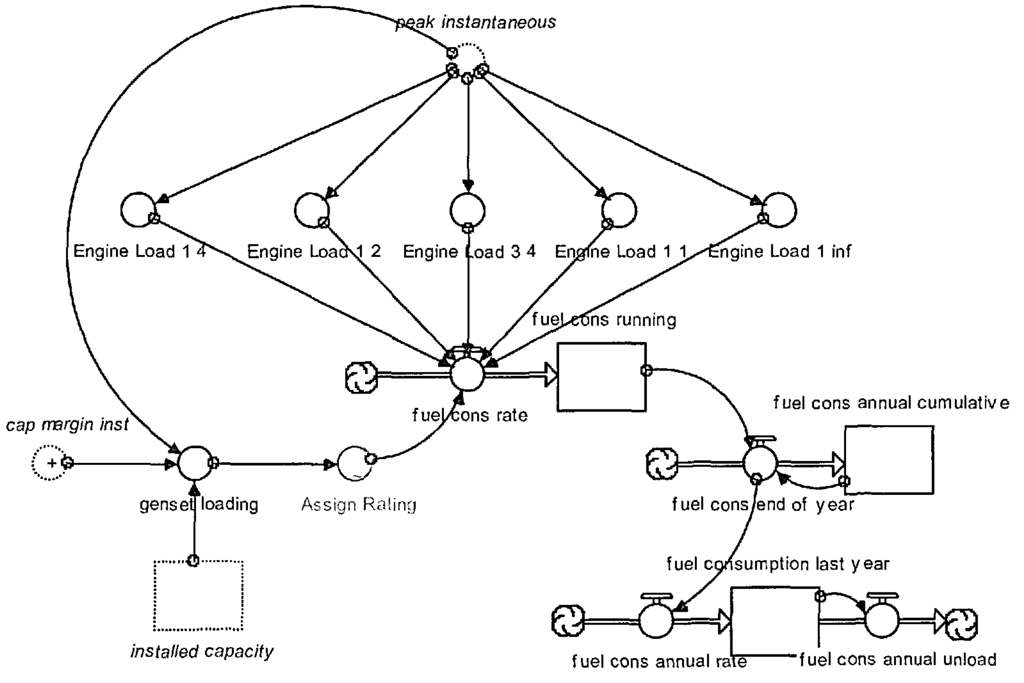


Figure 67: The fuel consumption simulation

The auxiliary "peak instantaneous" at the top also feeds into a converter that determines the load percentage of the plant, named "genset loading". According to that, the appropriate engine load is assigned and the corresponding consumption curve is allowed to feed into the stock "fuel consumption running". At the same time, one additional stock monitors the fuel consumption throughout the year and another registers the final annual quantity of fuel consumed at the bottom left of the graph.

For the remaining cost components the detailed study by Stathis Tselepis of the main national laboratory for energy research, the Centre for Renewable Energy Sources (CRES) in Athens, is used (Tselepis 2001). Tselepis calculated the curves per kWh consumed for the overheads, O&M and capital costs summarised in Figure 68. These were incorporated in the model. A sample strip of the final results of the completed financial performance component is provided in Figure 69.

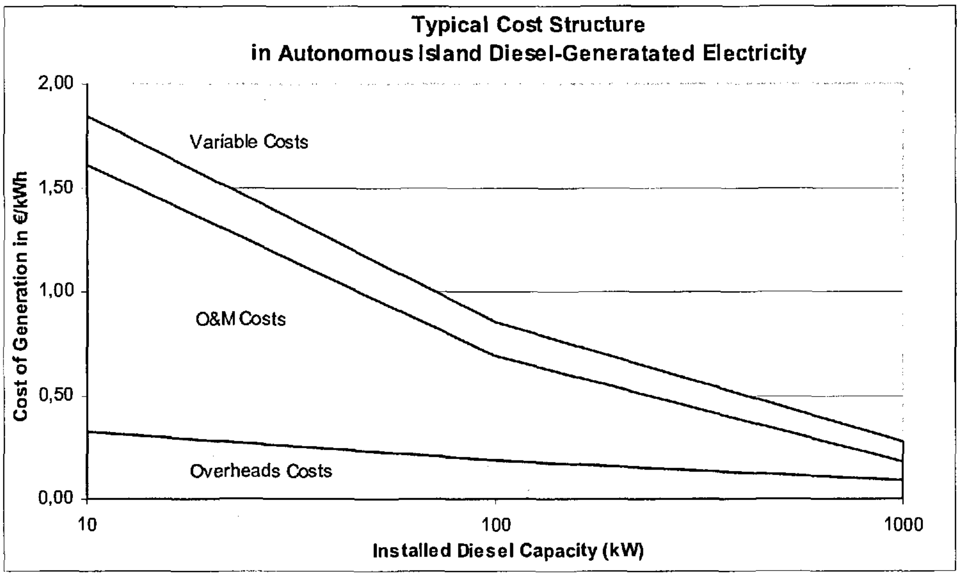


Figure 68: Island power plant cost curves (Tselepis 2001)

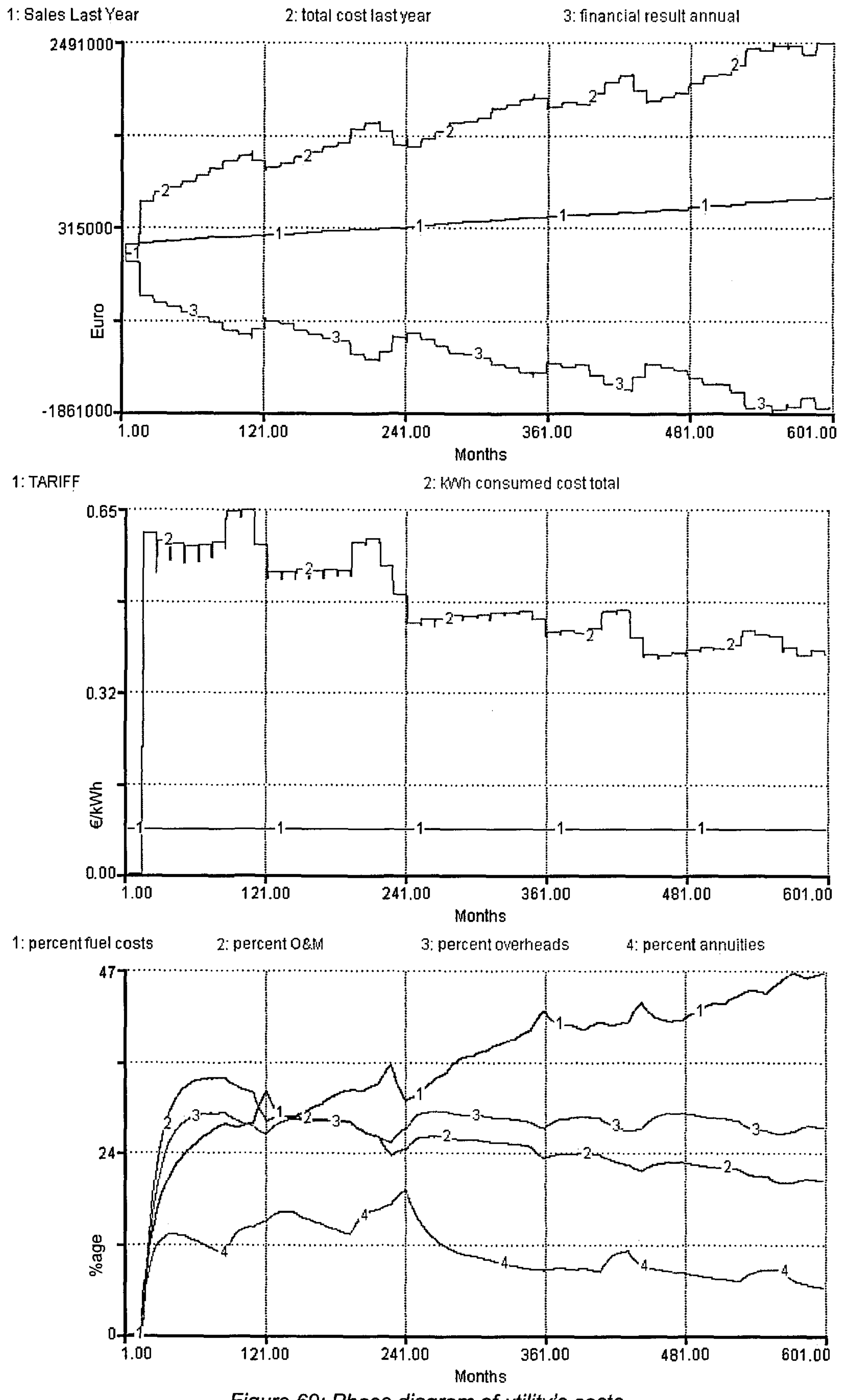


Figure 69: Phase diagram of utility's costs

The top graph plots the total cost of power consumed, the sales and the resulting annual result. The cost of power multiplies the final figure of cost per kWh by summing the various cost components with the kWh generated to service the demand, including the stand-by (the 20% capacity margin). The sales are the power consumed multiplied by 0.08 €/kWh, i.e. the basic tariff. The price of fuel used is included in Figure 70. These two values are determined in relevant terms. Their 2005 values are taken, then the tariff is kept constant while the fuel price is adjusted backwards by correlation and inflation estimations found in the literature (Christodoulakis & Kalyvitis 1997;Donatos & Mergos 1989;IEA 2006).

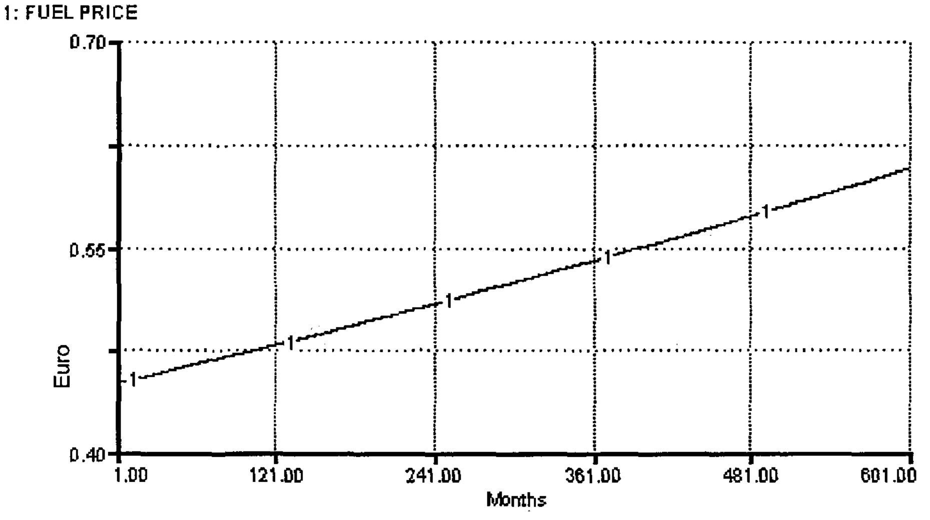


Figure 70: Price of fuel

The middle graph in Figure 69 shows the detail of the basic tariff (Line 1) against the kWh cost of the power generated (Line 2). The latter varies from 0.40 to 0.65 €/kWh. Finally, the bottom graph checks that the relevant share of the cost components is similar to that expected from Figure 50. Indeed, the fuel cost occupies a larger part of the expenses when the system is small and reaches about 40-50% as it grows. Thus, calibration condition (d) is fulfilled.

Finally, calibration condition (e) regarding the specific consumption of the system is also achieved and is illustrated in Figure 71.

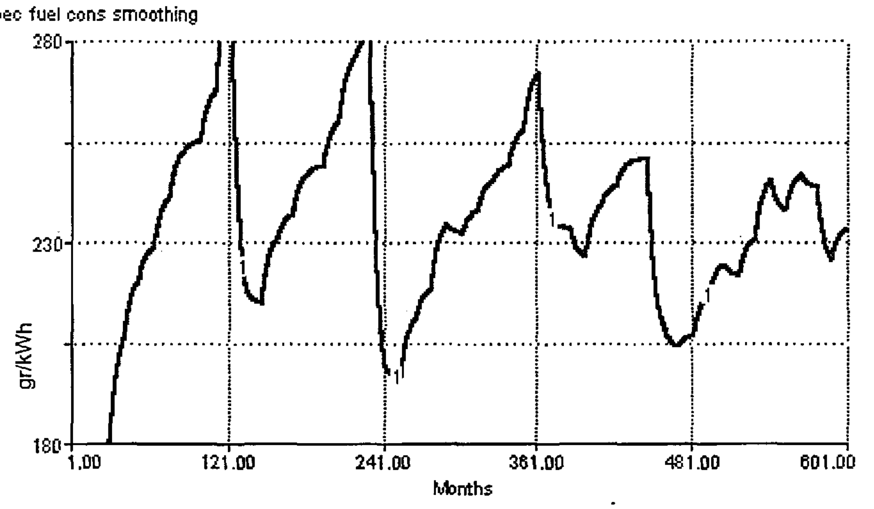


Figure 71: The specific consumption of the simulated island's APS

Compared to Figure 51, the specific consumption of the simulation is within the price range accepted and also shows the trend towards a lower number as the system grows.

6.3.3.4 CONCLUDING REMARK

An operational model simulating the observed modes of behaviour of the Greek islands over time was successfully constructed. It captures the main dynamics and interactions of the demand and supply sides. Techno-economic algorithms as well as decision-making were incorporated in a single model to simulate the expected evolution of the energy system of an assumed average island of the Aegean Sea, as it grows from a small to a medium towards a medium-large power system. The assumptions of the bottom-up profiles that disaggregated household from tourism demand, as well as the cost break-down, worked satisfactorily and achieved all five calibration points set out in Section 6.3.3.

6.3.4 THE TECHNOLOGY DIFFUSION SUBMODEL

The sub-model simulating the diffusion of technology is developed by elaborating on the literature on the tourism sector and the experience from the solar water heater market. The literature sources on diffusion and learning on which the author drew are summarised in Appendix B. This component of the simulation model is an experimental proposition. It is not based on current practices in the Greek islands in the way that the previous sub-model is, and thus a series of assumptions are developed and adopted. Since there are no calibration points as in the case of the demand-supply component, a range of tests of validity and robustness are devised according to Sterman's recommendations to assess the undertaking (Sterman 2000).

It was decided early on that the thesis should demonstrate its approach on space cooling in the Greek islands and the need arose to introduce a regional competitiveness index. The choice is justified by the World Trade Organisation's (WTO) statement that "a key element in leisure travel demand is the degree of comfort (or discomfort) to be experienced at the traveller's destination" (WTO & Todd 2003). It is mentioned that comfort is harder to maintain at air temperatures exceeding 31°C, that is the norm in the Greek islands during the peak summer season. This chapter assumes that the 'comfort factor' constitutes a major attractiveness of Mediterranean destinations, assuming that they compete on similar levels of scenery, cultural heritage, bathing facilities and cuisine. Thus, while air-conditioning is recognised as a main culprit contributing to extreme demand peaks in the islands it does indeed link conceptually and practically to the competitiveness of an island economy via comfort.

6.3.4.1 THE COMPETITION HABITAT OF THE ISLANDS

In the simulation, a regional competition indicator on cooling comfort coverage affects the rate of adoption between the two A/C equipment variants. Among other things the success of technology diffusion includes keeping as close as possible to a regional, i.e. Mediterranean, average of cooling service coverage. To be applicable it assumes all other factors affecting destination attractiveness are held constant.

The WTO has reported that there is a mass movement of people with the intrinsic purpose of travelling to visit a sunny seaside destination (WTO & Todd 2003). For 2002, a total of 133 million arrivals were registered to the northern coast of the Mediterranean and the Caribbean. Out of the figure quoted above, 116 million arrivals concern flows from Northern Europe to the Mediterranean's South European coast and islands alone. This is clearly the market the Greek islands are competing in: population flows where the weather is evidently of paramount importance as the destinations' cultural & natural heritage.

Visitor travel exhibits a 3% growth rate per annum and its market worth was US$70 in 2000, projected to rise to US$300 by 2050 (WTO & Todd 2003). Thus, the Mediterranean basin's boundaries can be rightly adopted as defining the competitive market area. Being also an area of homogeneous climatic characteristics enhances the validity of a regional competition indicator. That is to say:

The similar temperature profile and seasonality of the tourism wave indicate an equally similar visitor expectation and cooling comfort demand in the region. The attractiveness of Mediterranean destinations balances along complementary elements of hospitality, climate, culture, gastronomy and natural beauty, thus one can reasonably safely assume all other factors held constant across that economic habitat when comparing performance on cooling comfort.

6.3.4.2 SERVICE BENCHMARKING & COOLING CAPACITY

A standard reporting framework for air-conditioning consumption in tourism does not seem to exist in the international literature yet (WTO 2002;WTO 2003;WTO & Todd 2003). Official and comprehensive statistics on the consumption of electricity for air-conditioning on the Greek islands do not exist either. As a matter of fact, there was an effort in the 1980s to measure energy consumption and use patterns in the islands. The programme reached only the residential sector and was abandoned as early as 1988, with limited output available (Mamounis & Dimoudi 2005). To overcome the lack of statistics, in the previous section the demand profiles were built from scratch. Each visiting tourist is 'credited' with a peak demand made up of typical electricity consuming activities for the duration of her/his stay. The estimate did not, however, include the air-conditioning load, which is developed in this section.

It should be noted that research papers do report electricity consumption figures per guest or square metre for hotels. This is not, however, sufficient for the thesis as it requires a figure that includes all the activities of a visitor during their stay, as well as being broken down so that air-conditioning can be singled out during the simulation. European hotels and resorts are quoted at 25 kWh/guest/day, while Balearic hotels were found to be as low as 12.37 kWh/guest/day (Fortuny et al.). A study of Croatian resorts showed that they required a cooling capacity per square metre of 33 W/m^2. However this assumed buildings designed according to principles of passive architecture, preventing direct solar insolation through windows, and better than standard thermal characteristics of building material (Zanki & Galaso 2003). A study of hotels across Europe found that hotels in Lisbon and Rome need 44-48 W/ m^2 (Mateus & Oliveira 2009).

The average Greek hotel consumption is quoted at 273 kWh/m^2 per year but this includes winter hotels and considers all energy carriers including liquid fuels for heating (Karagiorgas, Tsoutsos, Drosou, Pouffary, Pagano, Lara, & Melim Mendes 2006). In another study, however, the cooling load alone is quoted at 125 kWh/ m^2 for hotels built before the1980s (Daskalaki & Balaras 2004). Specifically for cooling, though, in the climatic zones of the Aegean islands the figures quoted are 145-150 kWh/m^2 per year (Mamounis & Dimoudi 2005). An average monthly cooling load across a range of commercial accommodation types in the island of Chios studied by Mamounis was 13-14 kWh/m^2. As these figures are very diverse and need to make sense for the Greek islands and the simulation model specifically, a bottom up profile of the A/C load is constructed.

The air-conditioning load of a person comprises two parts: a) the sensible heat load, i.e. removing heat to reduce temperature, and b) the latent load that has to do with the dehumidification necessary when hot air is removed from an enclosed space. Each person generates 75W of sensible heat and 60W of latent load in a sedentary occupation (Stephenson 1968). In order to confirm that figure as the per person cooling load suitable for the Mediterranean, papers from France (Cron, Inard, & Belarbi 2003), Italy (Gugliermetti, Santarpia, & Bisegna 2001) and Turkey (Górbóz 2001) were consulted. The warmer climate suggests that the latent load is higher. Thus an aggregate of 200W/person is assumed and hence the cooling load is about 700 BTU/person, i.e. the heat generated by a human and needed to be removed.

Based on the government hotel building and operation guidelines and specifications (FEK 2009), it is assumed that each tourist's activities require a built, potentially space-cooled, area of $25m^2$ as the visitor moves around in the island receiving services including in service areas, auxiliary spaces, storage etc (Cataropoulos 2008). A 6,500 BTU A/C unit is suggested, making broad assumptions on the number of windows, orientation of the building and insulation, among other parameters[21]. The Energy Efficiency Rating (EER) of an A/C unit is its BTU rating over its wattage. The higher that number is the more efficient the unit. Assuming an EER of 8, the equipment capacity necessary is approximately 800 W/person. A higher efficiency unit will have a higher EER, i.e. a EER 10 unit will require 650 W/person – 20% decrease in required installed capacity per person. On the contrary, an EER 6 unit requires roughly 1000 W/person for the same load.

To evaluate a regional average, the coverage of service should also be considered. It will be assumed that in the average case there is 50% coverage, based on touristically developed destinations in the Mediterranean where there co-exist small sized hotels of 100 beds and larger complexes offering package holidays concluded (Ali, Al-Mashaqbah, Mashal, & Mohsen 2008;Mamounis & Dimoudi 2005;Onut & Soner 2006).

[21] http://www.purityplanet.com/air-conditioner-sizing.aspx & http://personal.cityu.edu.hk/~bsapplec/cooling.htm [Accessed 15/08/2004]

BTU/person ÷ average_EER_of_equipment_installed * (coverage%/100)

In this example: 7,000BTU/p ÷ EER8 * 0.5

Therefore, the average installed capacity of air-conditioning per tourist for the given cooling load comes to slightly over 400 W/person. The figure of 400 W/person will be the regional Mediterranean competition average towards which the island needs to keep as closely as possible in order to be comparable, in terms of cooling comfort, to other destinations in the region. The configuration actually compares well with the W/m^2 figures quoted earlier.

According to the web statistics of the European Council for an Energy Efficient Economy[22] (ECEEE), the cooling hours were found to be 1.5 to 2 times more in Mediterranean countries than the European average. All sectors were found to require cooling above 500 hours/year in all sectors (commercial, domestic, office, hotels). For the study, the average of the weighted averages of all sectors in Spain, Greece, Portugal and Italy will be adopted – i.e. 1,023 cooling hours per year.

6.3.4.3 THE SIMULATION MODEL & ITS SFD

To summarise, the methodological approach to capture the correlation among tourism arrivals, cooling service coverage, equipment substitution, and destination competitiveness is based on two major assumptions[23]:

- There is an expected regional, i.e. Mediterranean, cooling comfort average to visitors (measured in BTU) generating a cooling wattage installed capacity per visitor per area occupied, depending on the efficiency of the equipment. The model assumes that to attract visitors all competing destinations must be as close to that average as possible.

- The air-conditioning load can be met by two variants of cooling equipment averaging at distinct values of rating and efficiency. These are assumed to be a conventional electric A/C unit opposed to a hybrid solar absorption chiller; the former being more power consuming than the latter, albeit cheaper to buy. The latter has overall more desirable characteristics and the purchase/installation price is the only deterrent to

[22] http://www.eceee.org [Accessed 03/02/2008]

[23] The assumptions are built with a single visitor (tourist) as the base unit of the model metrics. That has been decided to keep in line with WTO practices that define a visitor "as a particular type of individual consumption unit, who is distinguished from other individuals by the fact that he/she is outside his/her usual environment and travels or visits a place for a purpose other than the 'exercise of an activity remunerated from within the place visited'" (WTO 2004).

potential adopters of the technology.

Figure 72 presents the stock-and-flow diagram of the diffusion model. What is not shown in the diagram is the technology-learning loop. This is a separate module that is not shown here for space economy: the module receives data from the two-adopter pools, runs a learning algorithm based on the number of installations of each equipment variant, which affects the cost, and then returns this to the cost ratio.

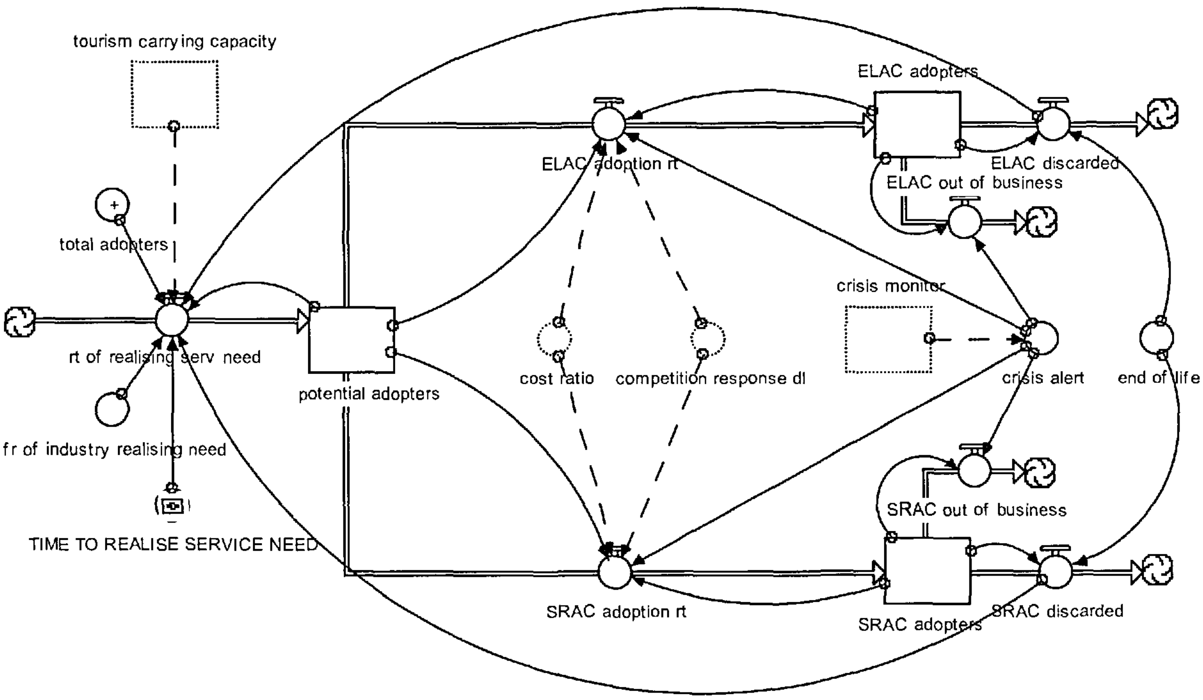


Figure 72: Diffusion with seasonal tourism and two adopter stocks

The seasonal tourist population, as in the demand-supply sub-model before, has a ramp and random function combined to generate a fluctuating, seasonal and growing tourist wave. The outcome is shown again in Figure 73 where in Line 1 are the tourists arriving at any time, given the seasonal pattern, while Line 2 registers the peak of arrivals each year, effectively the hosting carrying capacity of the island. Line 2 represents the stock at the top-left in Figure 72 and logs successive peaks of visitors during the simulation when there is a net increase. If this year's visitors are less than last year's then the Line 2 remains straight. If however, there are more visitors this year, there is a step increase to accommodate for that demand.

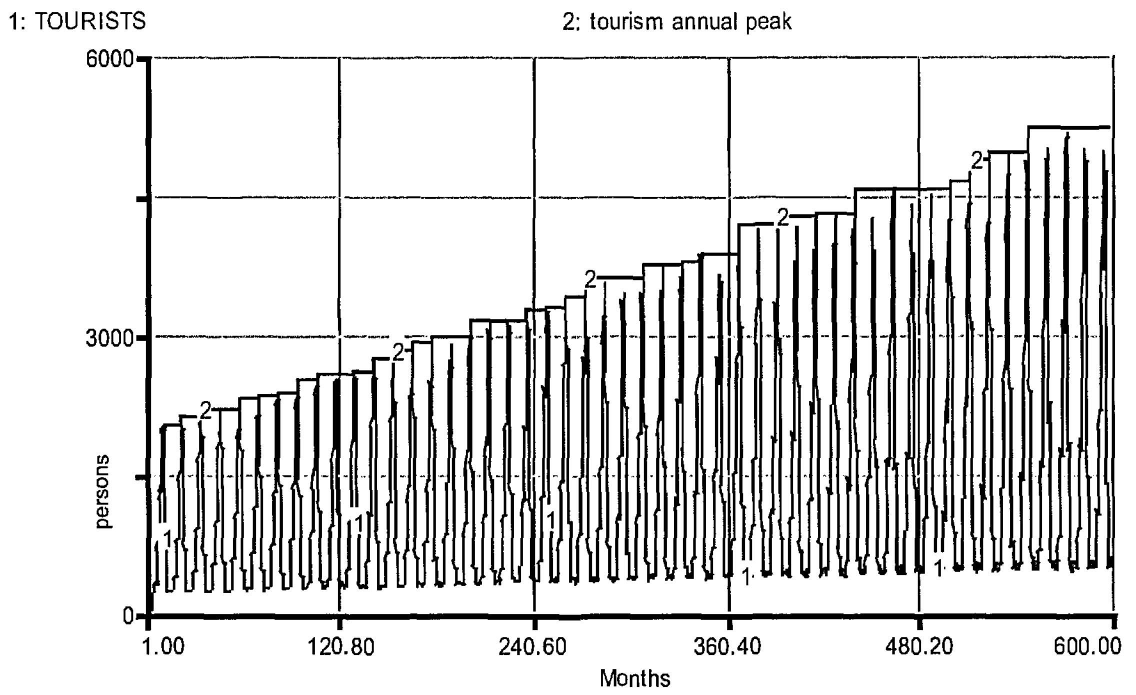


Figure 73: The seasonal tourist wave

6.3.4.4 THE VARIANTS AND THE ADOPTER STOCKS

The two variants in the adopter stocks of Figure 72 are ELAC (ELectric Air-Conditioning) and a sort of SRAC (SolaR Assisted Air-Conditioning). Their efficiencies are relatively defined as $SRACeff=\alpha*ELACeff$ where $0<\alpha<1$, i.e. the former technology is more electrically efficient than the latter by a factor of α which can be a constant or a variable. According to the analysis of the technologies in Chapter 1 there is no solar cooling technology that clearly leads in the market (Garcia Casals 2006;Mateus & Oliveira 2009). In a nutshell, although the physical procedures involved are well known and demonstration projects installed, there is still significant R&D to be performed as there is uncertainty on the cost-effectiveness of sizing, configuration and installations of such systems.

Thus the thesis avoids singling out any particular technological set-up and rather works on the conceptual level where thermally driven heat pump based systems are a fraction less power consuming than electrically driven systems. As Mateus explains (Mateus & Oliveira 2009), although thermally driven systems spend less electricity their coefficient of performance (COP) is much lower (from 0.6 to 1.2 for double absorption compared to 3 for electrically driven ones); therefore the systems are cheaper to run but more expensive to build, as larger installations are required to meet the same load. Sensitivity runs will be included in the testing of the model in the next chapter, to grasp the effect of this fraction on the intervention's effectiveness.

Back to Figure 72, there are three evident stocks and one concealed stock in the diagram that share the carrying capacity at any moment. These are the stocks of the "potential adopters", the "ELAC adopters" and the "SRAC adopters". The resulting figure, when subtracting the sum of the three stocks from the hosting carrying capacity of the island, is the concealed stock of visitors who will not experience any space-cooling service during their stay. The mechanism by which the carrying capacity expands is not explicitly modelled here, as it is of no immediate effect to the modelling exercise and the research question. It can be assumed to be a forecasting of some sort that allows the commercial sector to absorb any hosting demands and then maintain that level.

6.3.4.5 THE COST COMPARISON

The cost ratio (C_{OLD}/C_{NEW}) in Figure 72 consists of the price paid for the installation per unit of marginal installation and the running cost discounted over five years, which has been found to be an expected comparison timeframe for energy technologies in the islands, based on payback observations during the critical review of the literature. The cost is compared over five years despite the benefits over the lifetime of the products, to represent consumers' attitude to short term benefits and to ensure the observed preference towards older and established variants (Mateus & Oliveira 2009;Mulder, de Groot, & Hofkes 2003). Mulder's paper specifically justifies the prevalence and preference towards older vintages of a technology that is fading out much more slowly than a new vintage is being adopted both by the industry and users.

In Figure 72 the cost ratio does parametrically affect the flows of population to the adopter pools of the model. A fraction of the commercial agents servicing the carrying capacity of the island are aware of the proposed, or improved variant, and are willing to install it if conditions are right ("fraction of industry realising need" in Figure 72). These agents consequently control a share of the carrying capacity that ends up in the "potential adopters" pool.

There is great difficulty coming up with cost figures for a proper cost comparison of conventional electrically driven to solar driven systems, as there is a variety of non standard demonstration installations based on a range of technologies and techniques. Furthermore, these are installed in climates ranging from the Mediterranean and California to Northern Europe. An additional difficulty is that cost figures are quoted in currency over area, or cooling load provided, installed capacity or even referring to the costs of specific components only, making it thus difficult to compare them (CRES 2005;Karagiorgas, Kouretzi, Kodokalou, & Lamaris 2007;Mamounis & Dimoudi 2005;Mateus & Oliveira 2009;Tam & Gielen 2007;Zanki & Galaso 2003).

To overcome this, as it is critical for the learning to have cost components of capital and running costs separately, relative terms are adopted from Mateus' study (Mateus & Oliveira 2009). He estimates the capital cost of an integrated solar cooling system (including electric back-up) to be four times higher than a conventional electric one. According to Karagiorgas' paper summarising European research on the penetration of RES in the hotels of Southern Europe (Karagiorgas, Tsoutsos, Drosou, Pouffary, Pagano, Lara, & Melim Mendes 2006), the cost of solar including installation for Greek hotels would be about €4,300 for the BTU per visitor load, as calculated earlier for this thesis. Thus, the electric cost is deduced by dividing this figure by four, i.e. €1,075 per visitor receiving cooling.

For the running cost of the electric option, the author returns to the bottom up approach. One more line is added in Table 12 of 6.3.3.1 (energy profile of consumers), coloured in grey in Table 13 below. The resulting consumption per visitor is multiplied by the electricity tariff and the seasonality co-efficient over the period of five years. The SRAC's cost is obtained as a fraction α referred to in the previous paragraph 6.3.4.4. The equipment cost is added to these figures to come up with the desired total cost comparison over five years.

Table 13: Visitor energy use profile including A/C

Description of service	Number of appliances	Rating (W)	Consumption each for 1hr (kWh)	Service use details	Monthly Consumption (kWh)
Lighting	4	100	0.1	8hrs pd (1 bulb pp per commercial place visited)	97.33
Hot water [50oC for 10lit]	1	2000	0.33	9 hrs per day by thermostat	90.34
Dining (refr'n) [131lit]	0.5	90	0.5	24hrs operation. Everyday	7.60
Air-Conditioning	1	800	0.8	5 hours each in hotel, shops, services	365
Cleaning services	0.5	2800	1.3	Laundry: 2hrs/week	5.65
(laundry+dishwasher)	0.5	3200	1.3	Dishwasher: 2hrs/day	39.54
				TOTAL	605

6.3.4.6 THE COMPETITION INDICATOR

But do all potential adopters eventually install one of the two variants based just on relative costs? That exactly is the purpose of the loop that compares the quality of service to the regional average. A commercial accommodation owner might wish to upgrade his services to customers but will not do so if the standard is acceptable for the type of destination and clientele the island appeals to. Furthermore, the model has that "fraction of industry realising need" variable that is meant to leave out smaller family-run accommodation owners who only provide basic services, bed and bathroom, as well as marginal shops.

When the local cooling capacity per tourist is above the regional average, it is suggested that it makes the basket of services provided by the island marginally costlier than competing destinations. Whereas when it is below that figure then the quality is not up to standard. The competition indicator is based on the amount of service required, i.e. cooling capacity installed in BTU per person per area quota. There could be a reduction in power consumption simply by degrading service quality but that is not deemed a desirable policy or sensible commercial practice. On the contrary, the success would be to maintain the service standard by reducing the power input required for it. For each tourist to receive that service there is an installed capacity to generate the cooling load required. Introducing a new power-saving technology would allow the energy expenditure to drop while maintaining or even increasing service coverage.

6.3.4.7 THE LEARNING LOOP

There is still no experience (or learning) curve available from which to deduct a progress ratio for solar cooling, as it is yet an infant technology; not standardised and mass installed. However, learning occurs in the manufacture and assembly of various components of a technology as well as its installation, use and marketing (IEA 2000;Kaldellis, Kavadias, & Spyropoulos 2005;Neij 1997;Tam & Gielen 2007). There is adequate historical data for the Greek solar water heater market which can reasonably be assumed to include such learning. Figure 74 presents the effort to come up with the progress ratio over the course of 23 years, which is of the order of 9%, i.e. at each doubling of installations the price drops by 9%. Appendix B includes a summary of learning and diffusion theory. Nevertheless, the manufacture of solar water heaters is almost entirely dependant on simple components that can be sourced and assembled locally. Solar cooling, on the other hand, associates to international material science, chemistry and mechanical engineering (for the thermal pumps) and thus can be assumed to be closer to solar PV, which has been shown to have a progress ratio of almost 20%, mainly due to development in solar cells, wafers and production techniques (IEA 2000;JRC 2007;Tam & Gielen 2007).

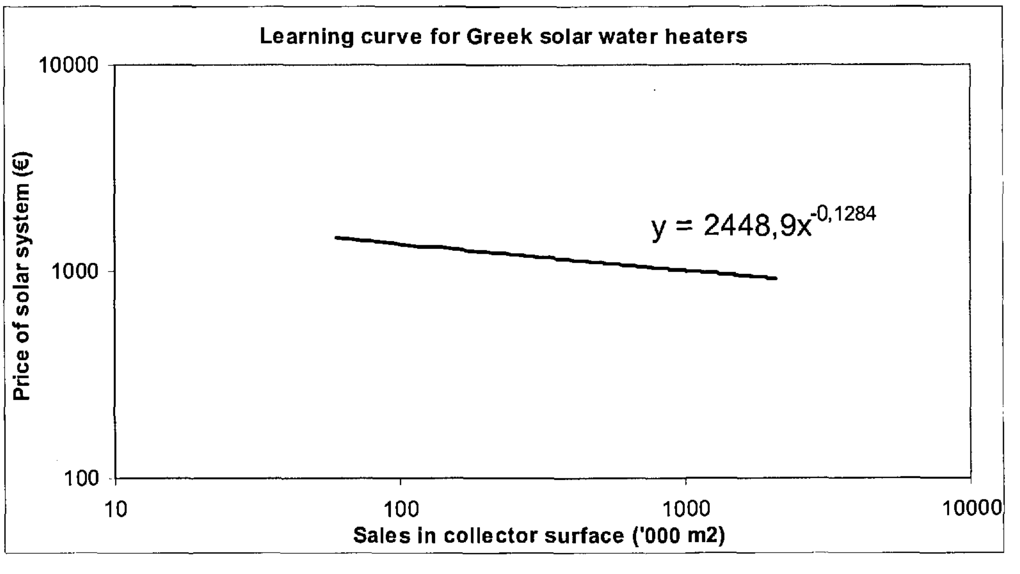


Figure 74: Evaluating the learning of the Greek DSWH market
(adapted from (Kaldellis, Kavadias, & Spyropoulos 2005;Sidiras & Koukios 2005))

Further research on this thesis could include looking into details at the learning of the various components of solar cooling. However, for the moment and the purpose of the research it is here assumed that a progress ratio of 15% can reasonably represent both the local and international learning that should contribute to solar cooling technology learning. This can be also justified by air-conditioners that have been found to have a progress ratio of 15% in the USA (1980-1998) and 10-17% in Japan (no study period provided) (Tam & Gielen 2007)

6.3.4.8 DEMONSTRATION OF THE MODEL'S OUTPUT

This paragraph aims to familiarise the reader with the model's output and parameters, through a simplified run. Each year a number of visitors arrive on the island while facilities expand to accommodate that demand. However, for illustration purposes the following assumptions are held for the model in Figure 72:

- "Tourists" have a steady flow of 2,000 throughout the year without any seasonal peaks.
- The "fraction of industry realising need" is set to 1 signifying all commercial premises are to be space-cooled if the competition & prices permit.
- The cost ratio C_{OLD}/C_{NEW} is set at 0.20, defining the relevant flow from potential adopters to either of the variant stocks in a constant manner.
- The consumption of SRAC is half that of ELAC, i.e. α=0.5.
- The learning rate in the background is not affecting the system since the cost ratio is stable. The system thus adjusts on competitiveness performance alone.

The phase diagram of Figure 75 presents a series of model parameters. At the start of the simulation, the competition indicator has maximum value in graph (75.C) since there are no units at all to provide the cooling service; thus the competitive imperative to install is high. On the top graph (75.A), the arrival of tourists (Line 1) exerts system pressure and eventually the consumption per tourist overshoots the regional average, illustrated on graph (75.B)/Line 1. Once there is the need to install, ELAC adoption grows faster since the price favours it on graph (75.A)/Line 2. By the 5th year of the simulation (60 months), there are 751 tourists in ELAC and 312 in SRAC. Also, there are 875 people in the "potential adopters" pool that cannot yet enjoy the service despite their hosts having realised the benefits of the installation, since the latter are yet to install. The three numbers together total 1,938 people.

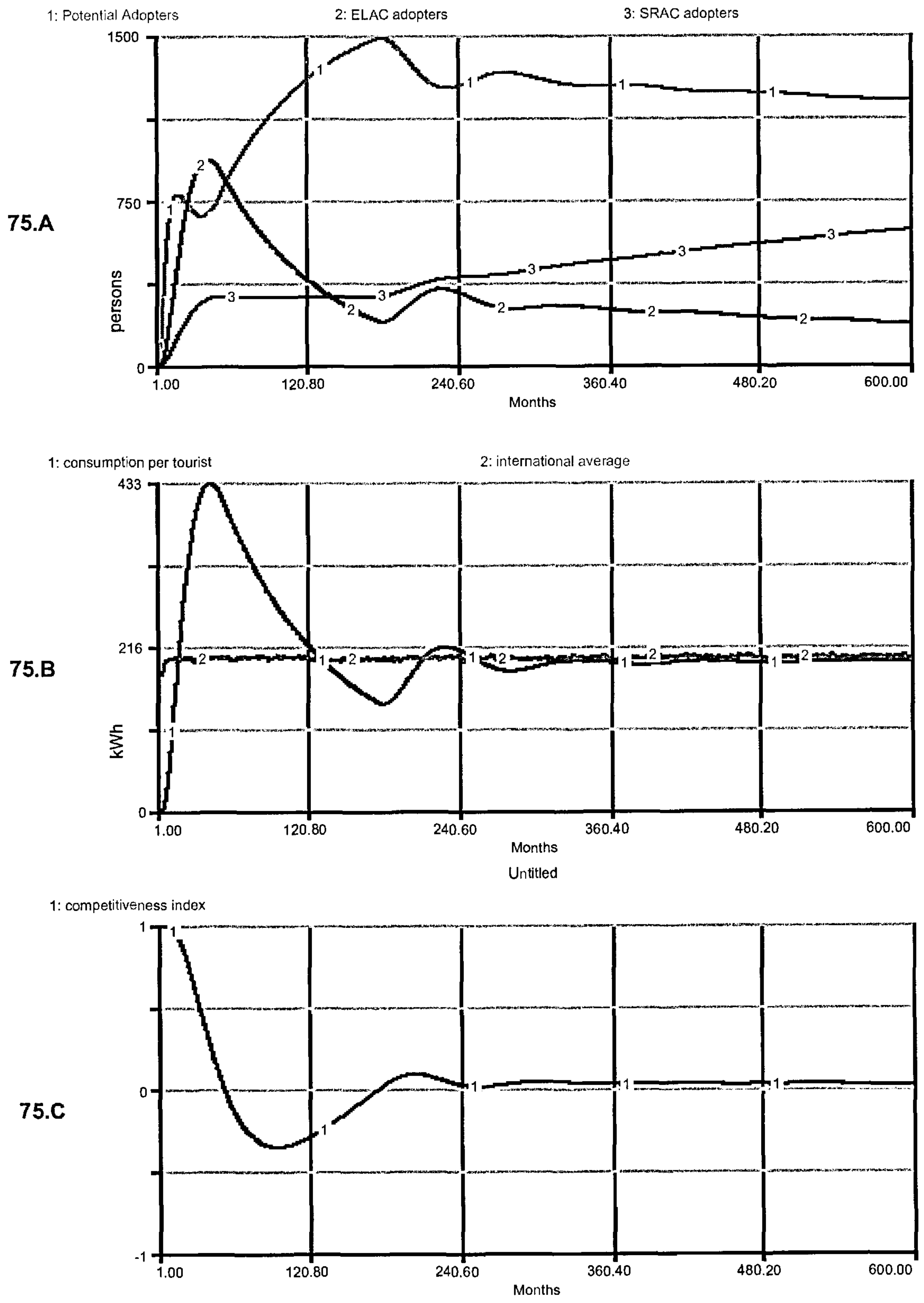


Figure 75: Test run of diffusion

By year 10 (month 120 in the simulation graphs), these three numbers changed to 388, 312 and 1,300 respectively. The sum now is 2,000, i.e. as much as the carrying capacity. That is the effect of delays in the system, such as the "time to realise need" auxiliary function that defines the delay the tourist industry service providers need to make up their minds on the usefulness of the service, and the 'adoption delay' in the model, that represents the time it takes for commercial adopters to actually purchase the equipment once they have justified its superiority.

There are a number of qualitative observations to be made. Once the system overshoots the international average (75.B) in its momentum to live up to the expectations, there is a similarly steep decline in a goal seeking type of behaviour that would be expected from such a system. In the uphill period both adopter pools grow rapidly until roughly month 48, 4 years into the simulation. The system then has to decrease its consumption. The only outflow from the consuming stocks of the adopters occurs in ELAC and is due to the equipment reaching the end of its life and being discarded. There is no replacement as it can be deduced from the flat curve of SRAC (Line 3) in (75.A) for quite some time, just more people flowing out of ELAC that is steadily reducing.

The curve in (75.C) confirms this through the competition comparison. Around the 4th year, the indicator becomes negative, ceasing any flow to the two stocks. Qualitatively, this reads as follows: Commercial agents, even though realising the need and having moved the share of carrying capacity they command to the "potential adopters" stock, do not feel any pressure from competition since a falsely sensed alignment to the average presides over. Similarly, those that did discard their equipment do not believe there is a need to replace it immediately; thus the released tourists return to the "potential adopters" and stay there until the drivers for adoption are ripe again. Policy-makers can easily misinterpret this situation as equilibrium since it is statistically observable, despite the Greek government not gathering the specific data at present.

Back to graph (75.B), consumption continues to decrease as more equipment is taken out of the system and consequently the system now undershoots the regional average. It takes time for the competition indicator to rise again due to sampling and reporting delays in its estimation. It takes about four years from the first time the local cooling capacity is found to lie below the average until the indicator gains a positive value (75.C) that effectively allows adoption to resume (75.A – app. 180 months). This delay has accumulated in what can be referred to as pressure to adopt in the system, therefore the slope increases again, albeit of lesser magnitude, in ELAC and SRAC adoption. That draws people heavily out of the potential adopters' pool. The oscillations caused by the delays in the system ultimately die out and the system reaches equilibrium with the competition indicator settling close to the average with a healthy replacement rate for SRAC (75.A).

6.3.4.9 TESTING THE SUB-MODEL'S BEHAVIOUR

This section runs a number of scenarios to validate the structural logic and assess the behavioural sturdiness of the model. The aim here is not to produce conclusive runs, since this is just a sub-model in the overall research but to assess the usefulness of the multi-disciplinary diffusion sub-model and its success in dealing with the required specifications. The testing is performed under two categories adopted from Sterman (Sterman 2000)[24]:

- Validity – aiming to ensure the model produces logical behaviours
- Robustness – aiming to confirm it can adjust to possible changes of conditions

Each section of the test runs draws policy making hints for decision makers.

Figure 76 is the sector diagram of the sub-model, showing its conceptual components. For robustness in extreme events, a function that allows closure of commercial premises in prolonged periods of arrivals being less that the carrying capacity has been added. That is the only case when the carrying capacity is allowed to reduce. At the same time, the efficient variant is experiencing learning effects, leading to reductions in price as installations grow (assuming an 82% learning rate). A 'promotion scheme' can be seen that can be designed to provide a single programme of installations over a period of time or a series of annual installations during the course of many years.

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[24] The reader might also wish to look up the following important references by Forrester (Forrester & Senge 1980) summarise by the sentence "the model builder accumulates confidence that a model behaves plausibly and generates problem symptom or modes of behaviour seen in the real system" and which Sterman adopts summarised as well as Barlas (Barlas 1996) on the significance of structured-oriented behaviour tests.

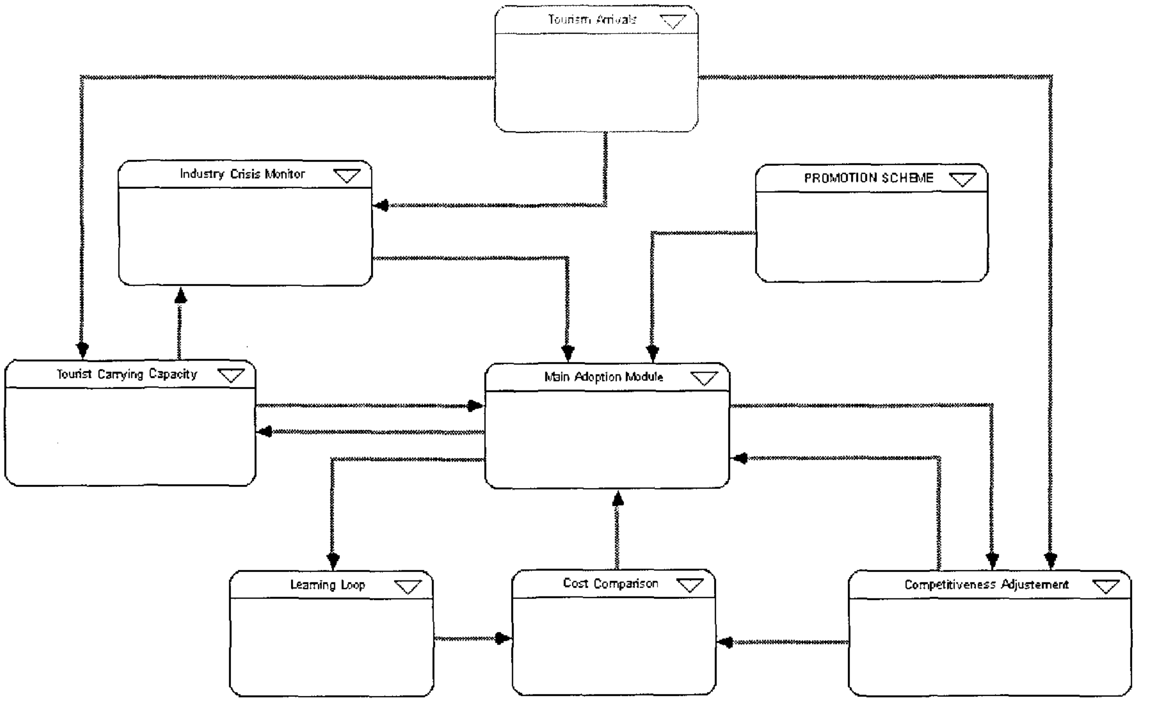

Figure 76: Sector diagram of the diffusion model

VALIDITY: Testing structural behaviour

Information delays & system control

There is a significant amount of time from the time a survey is taking place until the statistics are published and eventually reach decision makers in the private or public sectors. In the diffusion model, the existence of a regional average of cooling capacity per visitor is assumed to require three years (or touristic seasons) from the time it is collected and subsequently processed, checked and published until it reaches the island's commercial sector through national tourism institutions and media. The main consequence of delays found in case studies from the System Dynamics literature, is the creation of oscillations in the system (Forrester 1961;Sterman 2000). This behaviour is met in the model, as can be seen in Figure 77 (sensitivity type graphs, i.e. one graph depicts a single parameter on separate test inputs).

Line 1 in both graphs represents the case where the comparison of the local to the regional capacity performance is done almost in real time on a monthly basis. It is noticeable that the system is very well controlled. On the other hand, Line 2 represents the three-business seasons delay where the momentum gathered is not properly adapted when the goal is eventually reached and it overshoots the regional average around which Line 1 evolves. The bottom graph of Figure 77 sketches the total adopters, i.e. the market, and indicates a market with booms and busts for Line 2. A downhill curve signifies a stall in purchases as equipment reaching the end of serviceable life exits the adopters stock and there is no replenishment.

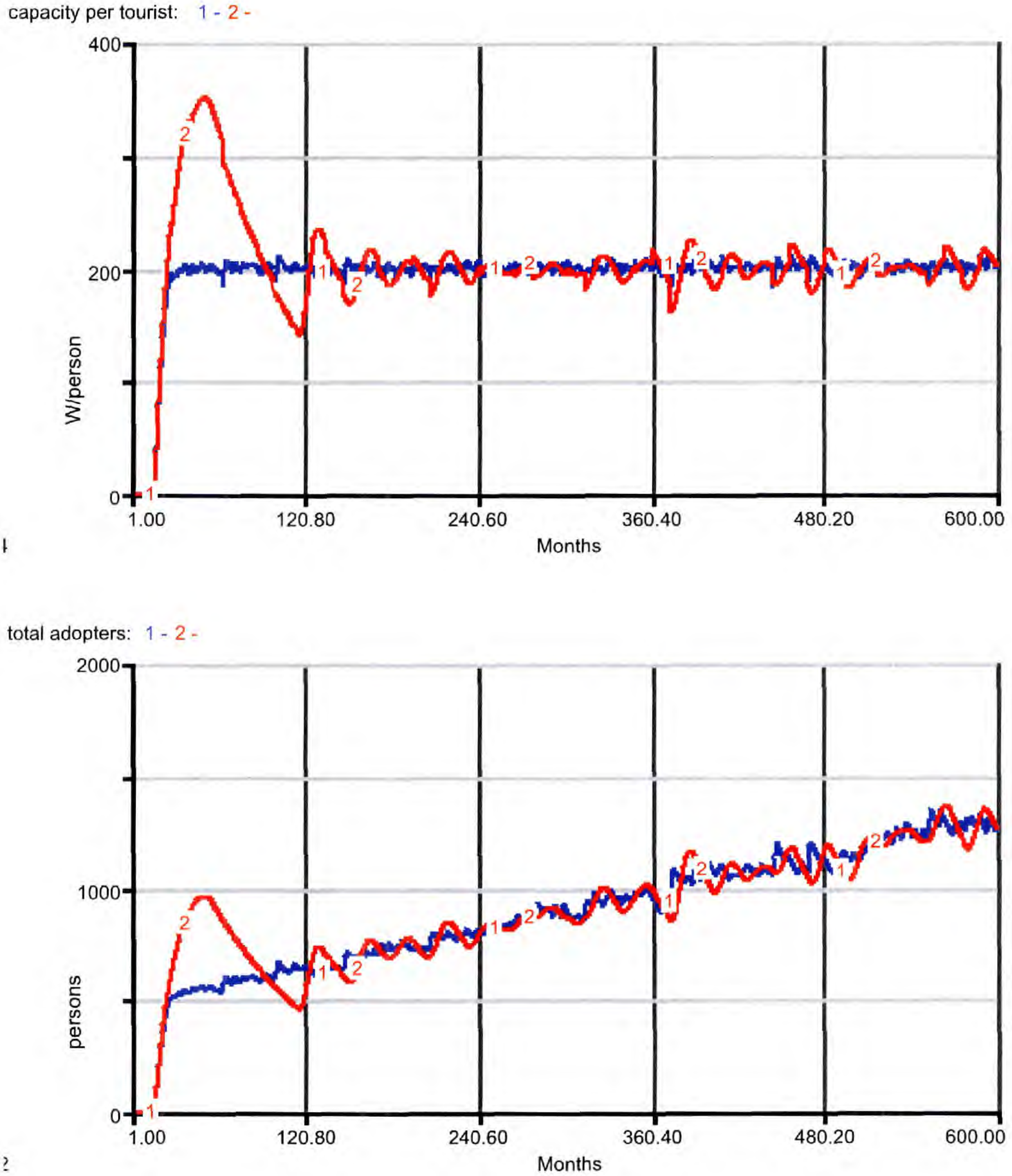

Figure 77: The oscillations due to information delay

In the real world, great variations between business cycles will deteriorate efforts of policy makers to establish an efficient and controllable market. An objective of the policy makers should therefore be to reduce information delays in critical positions of the system and be as close to the ideal behaviour of Line 1.

The time to respond & oscillations

Once the information reaches the commercial operators of an island, there are more delays to be faced in their reaction to the news. In the model the reflex gain has been formulated to vary depending on the extent of the deviation from the regional average. The lines 1-4 in Figure 78 (sensitivity graph) represent test runs of an increasing minimum reaction time threshold – from 1 to 36 months (Line 1: 1 months, Line 2: 12 months, Line 3: 24 months & Line 4: 36 months). The impacts are easily observed despite the effect dying out in all cases as the gap narrows and adjustments become marginal.

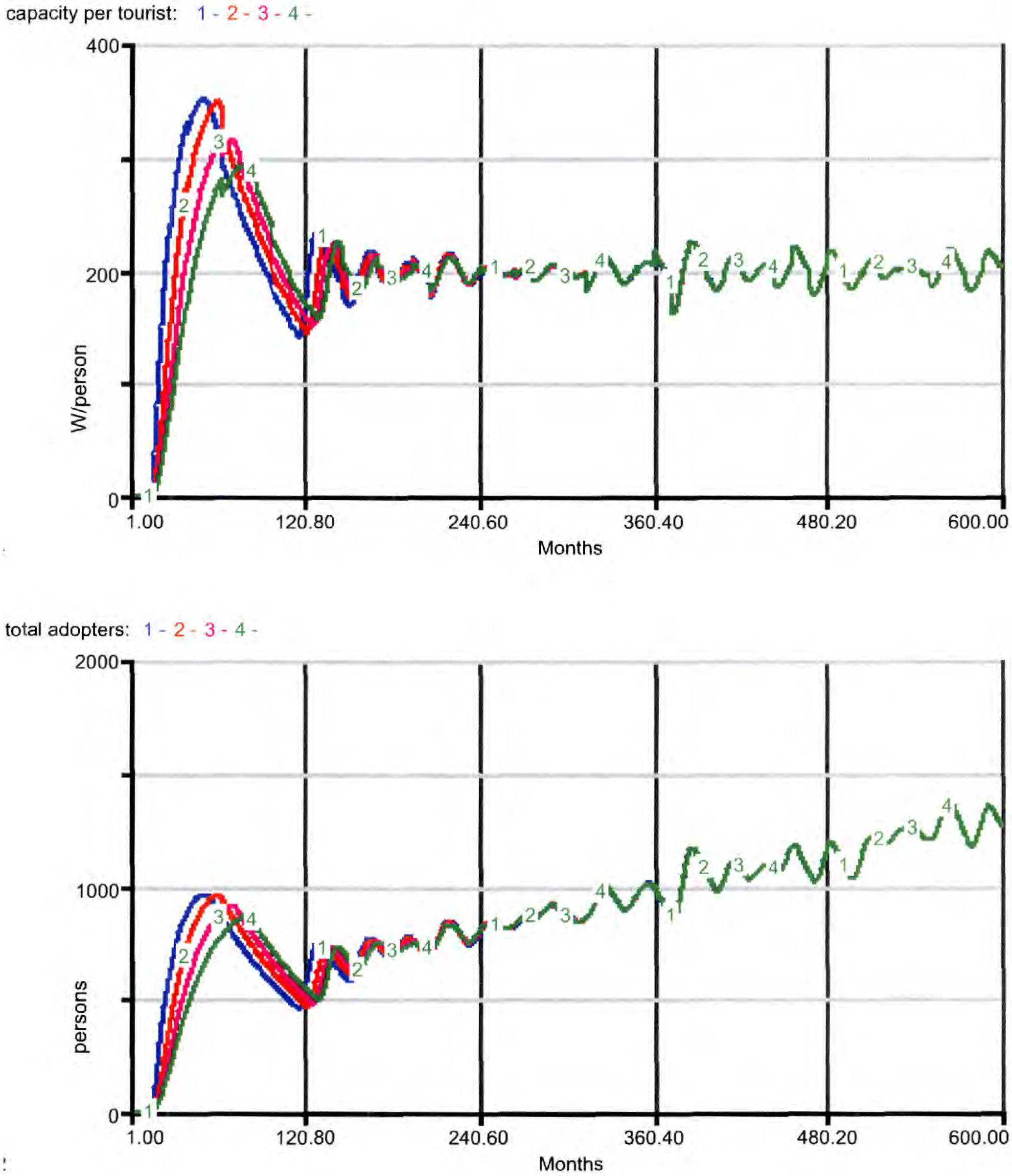

Figure 78: The impacts of operators' reaction

In real life Line 4 reveals a sector that is very restrained and cautious in adopting a new technology. On the contrary, Line 1 would represent a risk-taking group of commercial operators.

Despite the apparent ability to control the oscillations as in the previous case, the access of policy makers to this parameter is limited. The perceptions of risk in economic sectors are highly subjective and peer behaviour can only be changed through years of stable policy aiming to influence those perceptions. The final model will adopt the one-month response time that characterises risk-taking agents and competitive economies such as those of the Greek islands.

Diffusion & replacement of equipment

Graph (79.A) of Figure 79 illustrates the dynamics of replacement between the two equipment variants in Line 3 and Line 4. Initially, there is only the early power-consuming variant (Line 3). At some point around the course of the 7th year a scheme is introduced that sees the installation of 200 efficient units. The size of the scheme is such that it causes the cost of the new equipment over five years (purchase and operation) to drop below that of the conventional technology, as observed in graph (79.B). As soon as installations commence, SRAC is the favourable choice, and therefore we see its rapid growth (79.A/Line 4) and the parallel decline of the ELAC stock.

What is the impact on the system, however? Graph (79.C – sensitivity) compares the scenario with (Line 2) and without (Line 1) the introduction of the efficient variant. The number of total adopters, i.e. visitors who enjoy the cooling service, has increased dramatically in the former case. The improvement in coverage is achieved in line with the competition requirement of the regional cooling capacity per person (200W), as can be confirmed in graph (79.D - sensitivity) between the two scenarios (see heading 6.3.4.2).

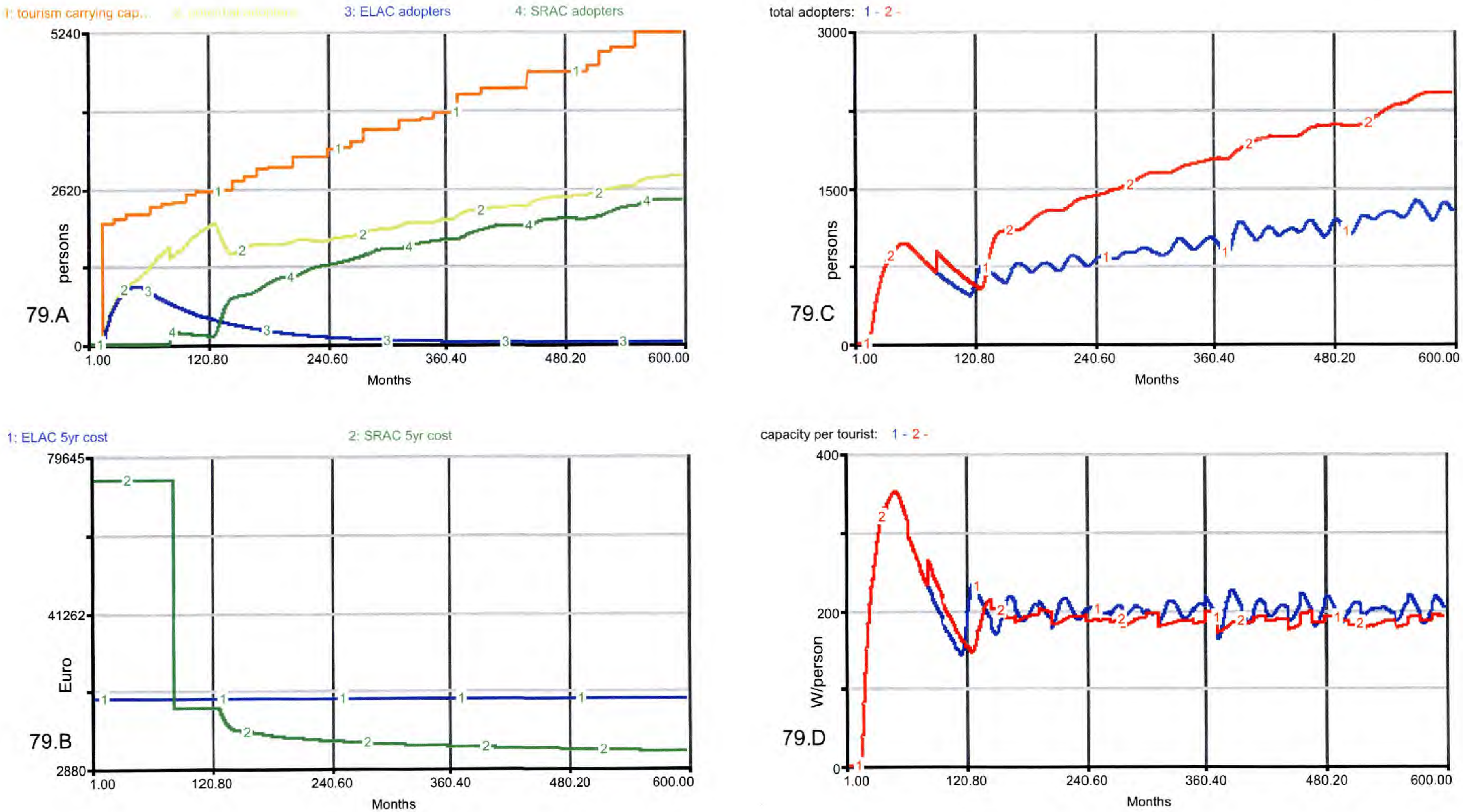

Figure 79: Observing the competition of equipment

Unit rating and service coverage

The simulation runs in the previous paragraph assumed the new equipment needed half the wattage rating to provide the required cooling load. Figure 80 (80.A) examines the sensitivity of service coverage for a range of SRAC ratings – namely ¼, ½ and ¾ of the ELAC capacity. A quick look reveals that the relationship is not linear; the impacts are disproportional to the rating step (Line 1 for ¼, Line 2 for ½ and Line 3 for ¾).

Taking a closer look of the last run at the ¾ rating in graph (80.B), it is revealed that the SRAC support scheme in the 7th year failed to establish the market (Line 4 does not pick up after the intervention). The reason can be found in graph (80.C) where the five year cost of the SRAC for this rating is still higher that that of the ELAC units, even after the financed installations.

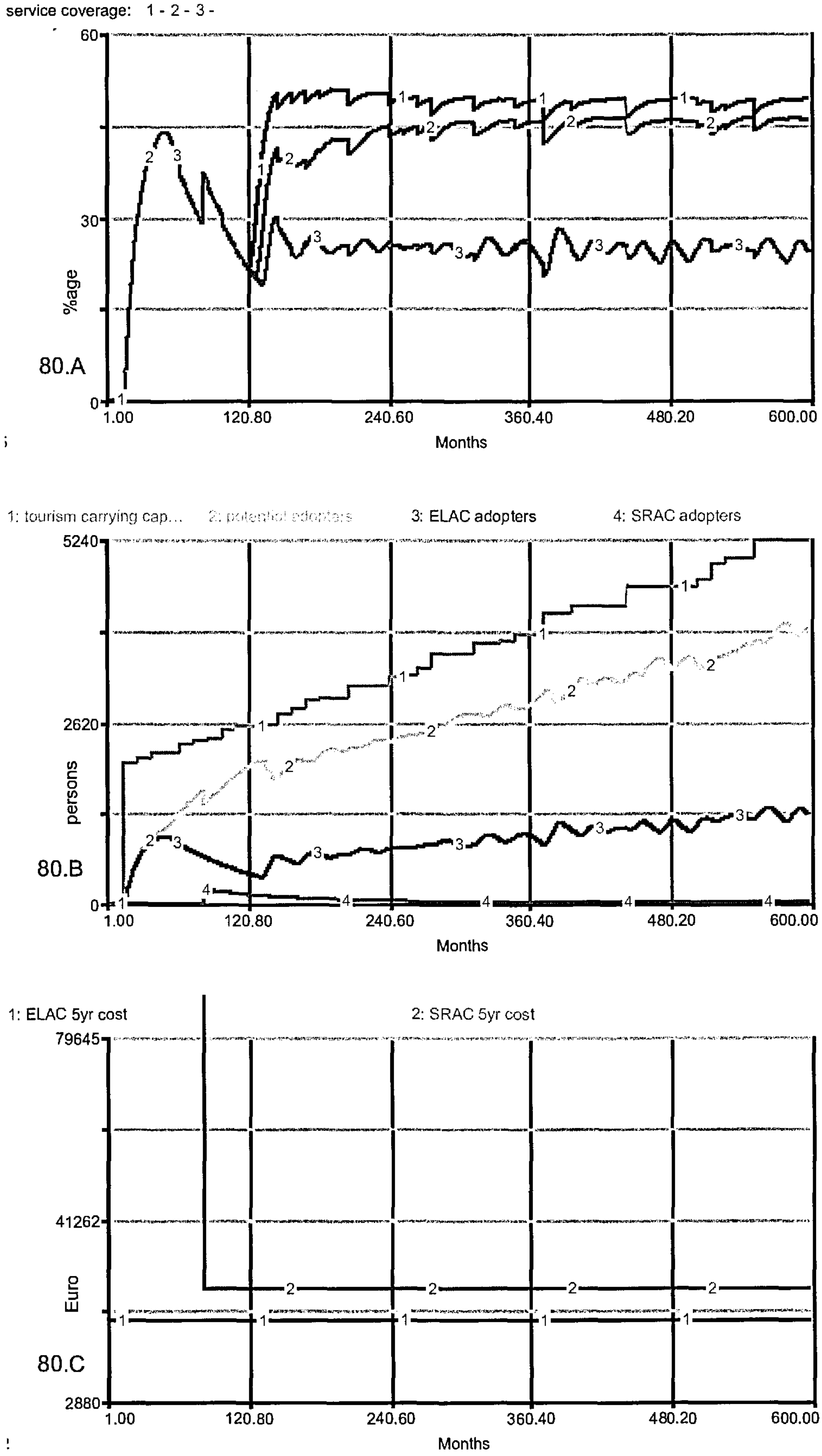

Figure 80: Assessing the sensitivity of efficiency gain

ROBUSTNESS: Testing response to extreme events

Keeping up with improved competition

So far it has been assumed that the regional competition average has been fluctuating randomly between a given set of values. This simulation run explores the situation of a major and abrupt service upgrade in competing destinations, expressed as a step improvement in the average regional capacity per tourist. The left hand-side column of graphs in Figure 81 [(81.A) and (81.B)] explore the sensitivity of the level of competitors' service upgrade – scheduled for month 120) to the capacity per tourist and the total adopters of the island system under examination. The larger the step of improvement in competing destinations (ascending from lines 1 to 4) the longer it takes for the local tourist sector to respond, indicating there is a period when the system re-adjusts the relevant shares of ELAC and SRAC stocks to face improved competition. Line 1 is the reference case at 200W per person.

The right hand-side graphs [(81.C) and (81.D)] look into the impacts of the timing of the step improvement of competitors' performance. The timing of the step decrease is not showing any unexpected behaviour. The regional average is accepting the same service upgrade each time at 100 months interval for each line from 1 to 5, Line 1 being the reference case again. The response is immediate and after few cycles the relevant values balance around their new reference state. In both cases, it is observed that the system adjusts its competitiveness by reducing the number of total adopters of the service. In the real world, that would reduce the coverage of the service and may alter the island's attractiveness. This is a valid danger for a tourist destination that has not been upgrading its services in line with the competition. Policy-makers being pro-active on their strategies can alleviate such situations and assist the local economy to be flexible and agile.

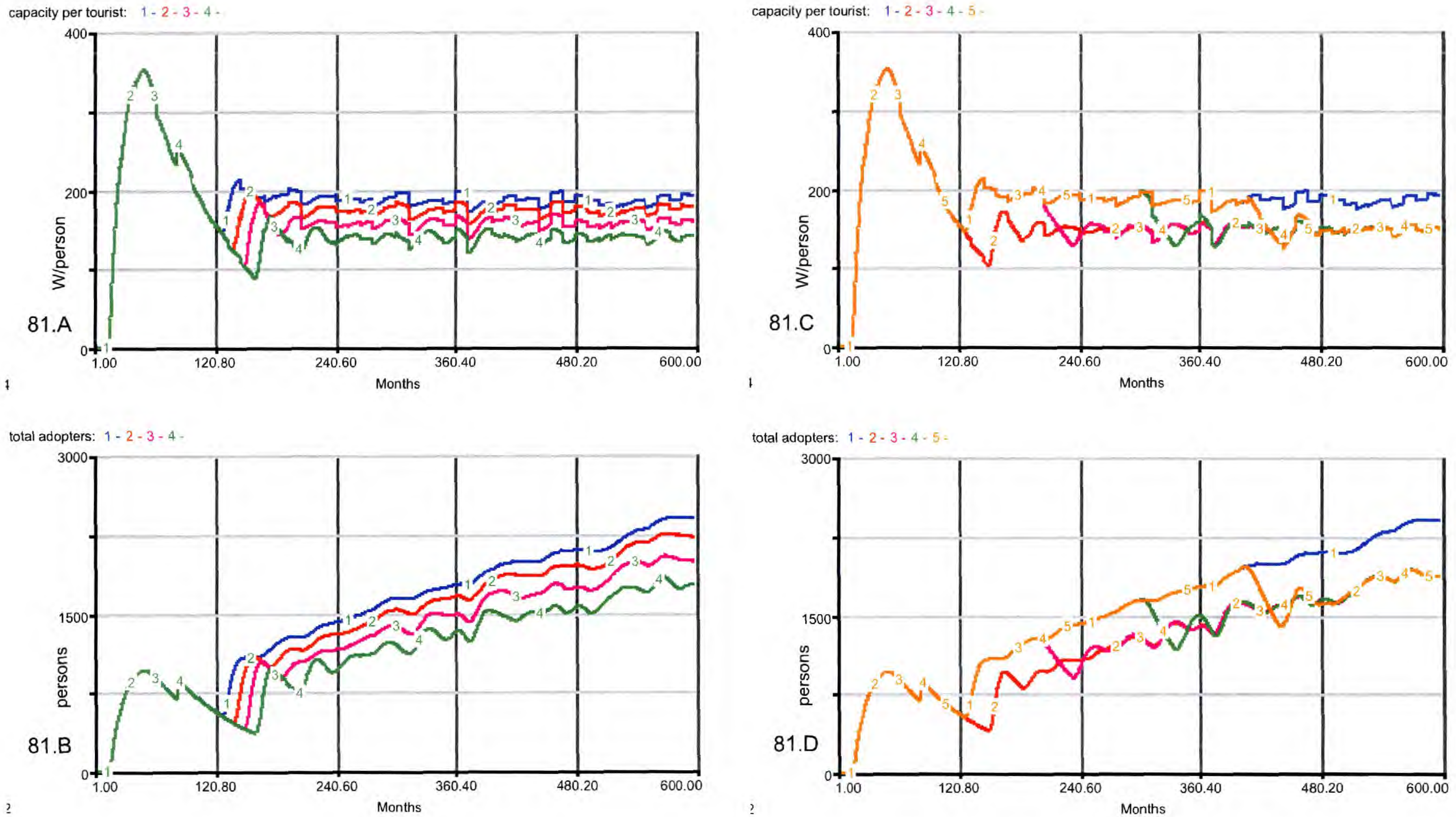

Figure 81: Exploring a changing competitive environment

Industry crisis: Facing reduction in arrivals

The tourism industry is quite volatile (WTO 2003;WTO 2004). Despite the 2004 Olympic Games in Greece, the tourism industry had a very bad year overall due to bad press coverage about expectations of the preparedness of the country to host the Games prior to the event, the threat of terrorism and the inflation impacts of the Euro zone (Ktenas 2004). The model has been designed to confront prolonged periods of tourism crisis by allowing the exit of commercial establishments from the market, thus reducing the available cooling capacity for the tourist population.

Starting from the top left corner of Figure 82 a sudden crisis occurs in the tenth year (120 months) of the simulation. Arrivals are kept low for a period of fifteen years, after which a new era of touristic popularity begins, as portrayed in graph (82.A). The occasion of an industry crisis is the only situation when the model allows the carrying capacity to scale down, as in graph (82.B/Line 1). The delay observed until the carrying capacity reduces, in month 180, is due to an internal loop that first needs to confirm that the crisis is a persistent phenomenon. Similarly, the relevant stocks of the potential adopters and ELAC/SRAC adopters adapt to the new market conditions.

As expected, keeping the same facilities for a much smaller tourism population initially makes the local capacity per tourist availability soar, as Line 2 indicates in graph (82.C) – Line 1 being the reference case. The system responds and eventually stabilises around the regional values (82.C & 82.D), albeit after a long period of abrupt adjustments. The corrective actions of the model return the system to its previous competitive state.

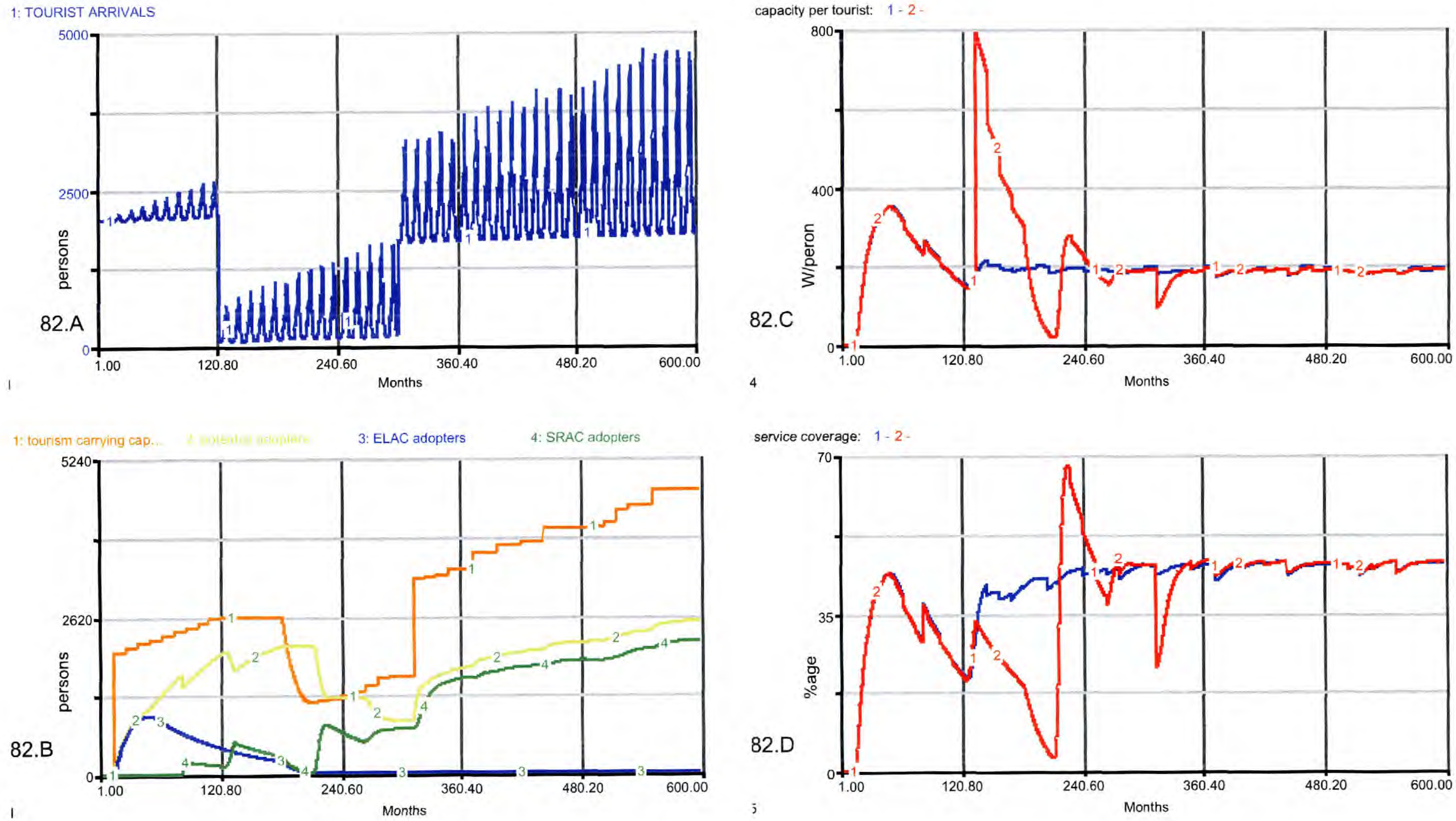

Figure 82: Confronting a prolonged industry crisis

6.3.4.10 INTRODUCING POLICY & DECISION-MAKING

In the next chapter, a range of scenarios is developed and tested using the entire simulation structure built so far. Here is a demonstration of the sort of questions the model can be asked to test and involves the diffusion sub-model specifically. What is the best promotion strategy for new equipment? How do policy-makers know which alternative scheme will work? The sub-model gives the ability to design a promotional policy and dynamically study such issues. The demands of a programme can be observed through the graphs in Figure 84. Despite attempting the introduction of the new equipment in graph (84.B), as denoted by Line 4, there is practically no impact compared to the reference case represented in graph (84.A). The technology fails to break into the market, as the cost effects are not significant enough to establish the viability of the new equipment variant, although the planned installations are set to 25% of the dominant variant at the time. However, raising the installations to roughly 28% puts the appropriate learning effects in motion and the new technology has a startling development, as described graphically in (84.C).

The final graph (84.D) depicts an alternative policy design. Instead of a single large-scale demonstration scheme, the policy-makers decide on an annual small-scale installation scheme as low as 6% of the installed variant in the first year. The consideration behind this is the smaller budget required and a fractional approach that would allow closer monitoring of the procedure. The choice between the two and a number of other potential schemes will depend on conditions of available funds, institutional organisation and commitment, and the financial profile of the commercial actors involved.

The choice will also depend on the rapidness of substitution desired, as demonstrated in the sensitivity graph of Figure 83, where lines 1 to 4 represent each of the cases from (84.A) to (84.D) above comparing their service coverage. Line 1 is the reference case of (84.A) and Line 2 is (84.B) in the previous. Line 3 and Line 4 correspond to graphs (84.C) and (84.D) respectively. Although these two balance at similar percentages of coverage, their path is different due to the modular approach of the latter. This shows that a possible saving in funds for the modular scheme has to be balanced against the time taken to achieve the result.

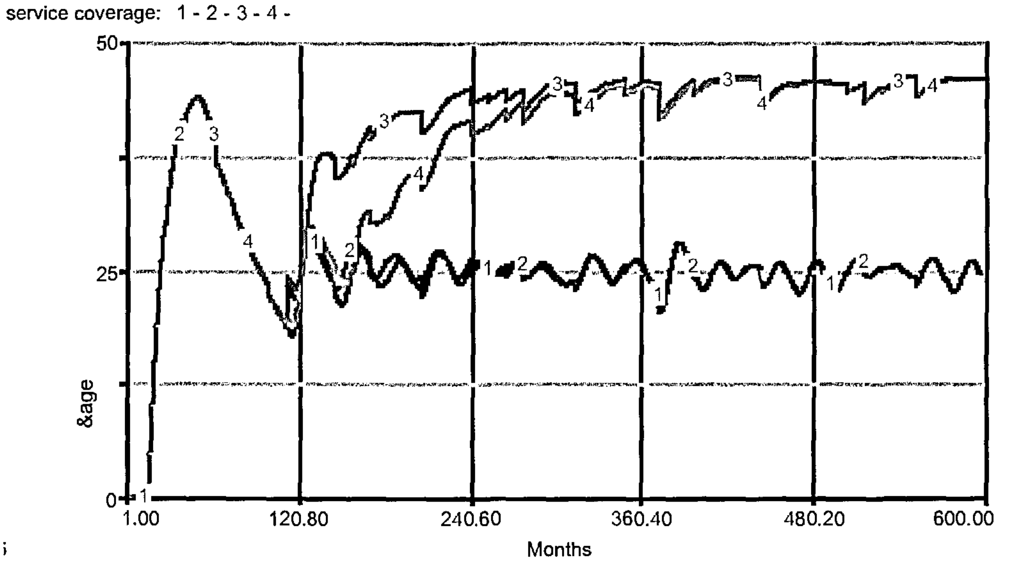

Figure 83: Sensitivity of system response to promotional schemes

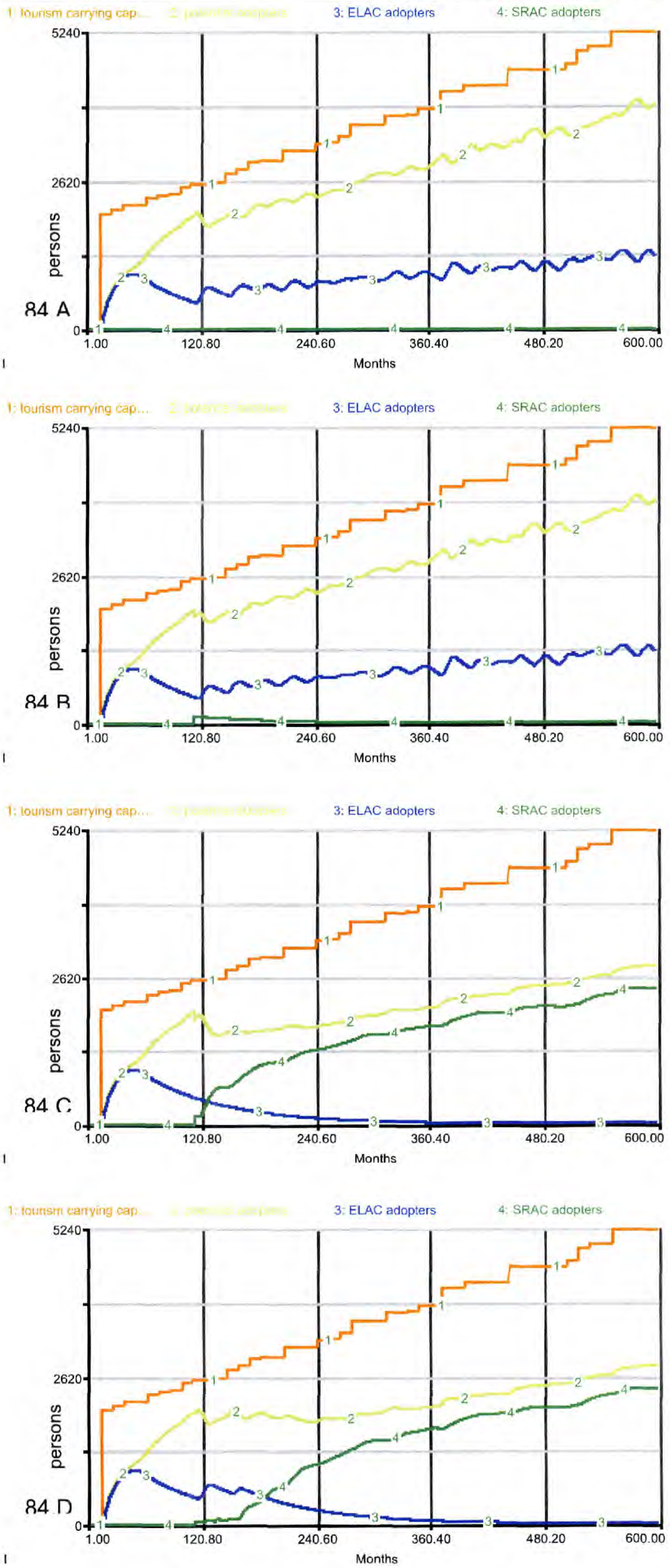

Figure 84: Assessing promotion plans

6.4 CONCLUDING REMARKS

The chapter hopefully presented the model building exercise in comprehensive terms. Initially, the dynamic hypotheses and associated variables were laid out in the fashion of a CLD. It was followed by detailed exposure of the actual model itself, broken down into two sub-models with plenty of test runs, explanatory comments and constant references to the literature research and empirical information. For the demand-supply segment, calibration was achieved by matching outputs to five real world observations. The innovative technology diffusion component proposed the introduction of competitiveness of destination, cost comparison of variants and learning in the dynamics of equipment adoption. It thus achieved the capability to allow concurrent study of the power system, both in terms of energy policy making as well as the broader economy, the characteristics of which directly affect how the operator acts and spends funds.

A meticulous bottom up methodology was preferred, as in many cases data was lacking due to the pioneering approach and questions posed to the power issues of the Greek islands as well as to develop a convincing narrative of how the island communities and their power systems have evolved through the use of what was termed the 'average island'. As the diffusion component represented a scenario not yet present in the islands or indeed studied similarly before, there were no calibration points and instead a series of tests were conducted to ensure the validity and robustness of the proposed structure.

As a final remark, the modelling exercise provided significant insights into system behaviour at each stage of its development. It demonstrated how decision making in the real world that may divert from standard theory can be accommodated through a series of soft variables and switches representing actions and the thinking of agents. This was particularly evident in the capacity expansion loop. It was possible to represent and construct a decision making process that incorporated weaknesses of the real world that are part of the problem, by either introducing delays or magnifying problematic behaviour elsewhere. In the case of the diffusion component, it was possible to dynamically involve not only the adopters/visitors but also the owners of the carrying capacity (the bulk of the commercial agents owning hotels, restaurants, shops etc.) and regional competition under one simulating framework.

In the following chapter, the complete model built will be run under a series of scenarios, in an effort to explore potential pathways to a solution to the pathological situation that the autonomous islands of the Aegean Sea are faced with.

7 POLICY DESIGN AND EVALUATION

Having built, calibrated and tested the model and its components, this chapter uses it to obtain insights into in the application of technology diffusion strategies consistent with the objectives of the research. Opportunities, pitfalls, synergies and bottlenecks are identified with reference to the real world and suggestions for policy-making in particular are made. The elaboration is conducted in the style of the thesis so far: the aim is to illustrate the findings as clearly as possible by the use of comparative graphs. In addition to the juxtaposed sample scenarios, selected what-if tests are run to discover further policy points of interest for the problem at hand. The evaluation is summarised at the end of the chapter before proceeding to the final stages of the thesis.

Structure of Chapter:

7.1 INTRODUCTION
7.2 SCENARIOS & STRATEGY APPRAISAL
7.2.1 Assumptions & Specifications
7.2.2 Comparison of Diffusion Schemes
7.2.3 The Impact on the Cost of SRAC
7.2.4 The Impact on Competitiveness
7.2.5 The Impact on Tourism and Utility Finances
7.2.6 The Impact on Savings and BEP
7.2.7 The Impact on Utility Operation and Expansion
7.3 WHAT-IF TESTS AND INSIGHTS
7.3.1 Tariff Level
7.3.2 Competition Catching Up
7.3.3 Economic Recession
7.4 CONCLUSIONS

7.1 INTRODUCTION

Sterman suggests that all models are effectively incomplete since they represent both a simplification of the world and the decisions of agents with cognitive limitations, the sum of which is described as *bounded rationality*, a concept first developed by the Nobel Prize winning economist, Herbert Simon.;(Sterman 2000); i.e. the cognitive capabilities of humans are overwhelmed by the complexity of the systems they are called to manage. An aspect of the value of a mathematical model may lie in telling a compelling story that provides insights that challenge the perspective stakeholders have on the issue at hand, confirming, rejecting, altering or expanding them. Any solution suggested by a model is not itself a panacea and not necessarily valid in a given situation, since a number of assumptions are made and study boundaries established, while longer time frames add to uncertainty. Moreover, any solution's application is left to rules of thumb of the real world and the mental and management capacities of agents, all of which introduce a certain degree of uncertainty and randomness. Also, conflict of interest and/or misalignment of objectives in groups may act counter-intuitively to a solution. As such, the author recognises the limitations of the modelling exercise so far and with that precaution in mind aims to expose as many of the insights his simulations have to offer in the following.

To achieve immediate comparison between the policy interventions, the model developed is cloned and both versions run in parallel; the original with the set up to be tested, while the clone always shows the assumed BAU case. The key variables are synchronised, in case other scenarios need to be tested in order to maintain consistency. Monetary comparisons should not be looked at their nominal but rather their relative values. For this reason, the effectiveness of interventions is discussed in broader terms, focussing on the structure of the model and what it reflects for the real system and its stakeholders. As this chapter uses the model for the appraisal of policy design, net present values of the associated costs and benefits are discounted at the time of intervention; this is mostly relevant when testing various equipment diffusion options.

7.2 SCENARIOS & STRATEGY APPRAISAL

7.2.1 ASSUMPTIONS & SPECIFICATIONS

The setting in which the scenarios are designed and tested is one where the policy-makers need to determine how to structure a financial support scheme for the diffusion of a new solar assisted A/C variant. This variant is on the one hand prohibitively expensive for commercial adoption at the time but on the other hand has a much lower electricity consumption that could curb peak demand growth. At the same time, its cost (that includes learning on use and installation, as well as on the technological components) is expected to have a favourable progress ratio. In order to avoid too much analytical complexity, the support is assumed to come in the form of a direct subsidy

The roll out can be deployed in any punctuation wished; segmented over the years or in a single blow. The expected saving, here taken at the end of the simulation, is expected to pay for the diffusion scheme. The net present value of the cost of the schemes and the expected savings are evaluated and the total years from start to the Break Even Point (BPE) registered at the end of each simulation run. At the same time, the competitiveness of the island needs to be maintained and it is also observed.

Three scenarios are chosen for juxtaposition, all introduced shortly before the 10th year into the simulation. By that time the system has stabilised as in Figure 85 and is in line with the regional average (top graph). Line 2 represents the clone as denoted by the BAU suffix that will later show the deviation from the tested scenarios (in Line 1); for the moment there is no scenario tested so both lines coincide. Line 3 shows the regional average around which the island has to balance to be keep competitive (as far as space cooling is concerned under the assumptions and limitations in Section 6.3.4.6).

The service coverage is fluctuating about the 50% average derived in the previous chapter as a result of keeping up to the competition above (middle graph, 50% line not shown). Line 2 again is the BAU case as before.

The fluctuations are the due to the intermittent and seasonal arrivals of visitors which have an impact on the carrying capacity found sketched in Line 5 of the bottom graph in Figure 85. Subsequently, the carrying capacity affects the potential adopters (defined previously as a percentage of the carrying capacity) in Line 1 of the bottom graph again. As the potential adopter stock interacts with the dynamics of adoption and regional competition, the fluctuation tends to get amplified (i.e. the parameters affecting adoption are phased in) and carried on inevitably to the ELAC stock in Line 3 of the same graph. The ELAC stock also fluctuates as equipment becomes obsolete at the end of its life and is candidate for replacement through the potential adopters stock again. Constantly adapting to the situation in each month of the simulation creates the over and under shooting observed in the top two graphs.

The scenarios examined are:

1) Twenty units installed every year (referred to as Sc.20/12)

2) One hundred and twenty units every three years (referred to as Sc.120/36)

3) Two hundred units in a single year (referred to as Sc.200/0)

The first two are run until the commercialisation is achieved, while the third is a one off. The initial cost of the SRAC unit per adopter is €3,200 compared to €800 for the ELAC while the five year equipment and running cost of the former is €3,920 compared to €2,240 for the latter representing the great saving in electricity expenditure (the increase is disproportional, 22.5% for SRAC compared to 180% for ELAC). The SRAC requires half the installed capacity (400W) to provide the same cooling load as the incumbent ELAC unit (800W); a modelling decision explained in the previous chapter.

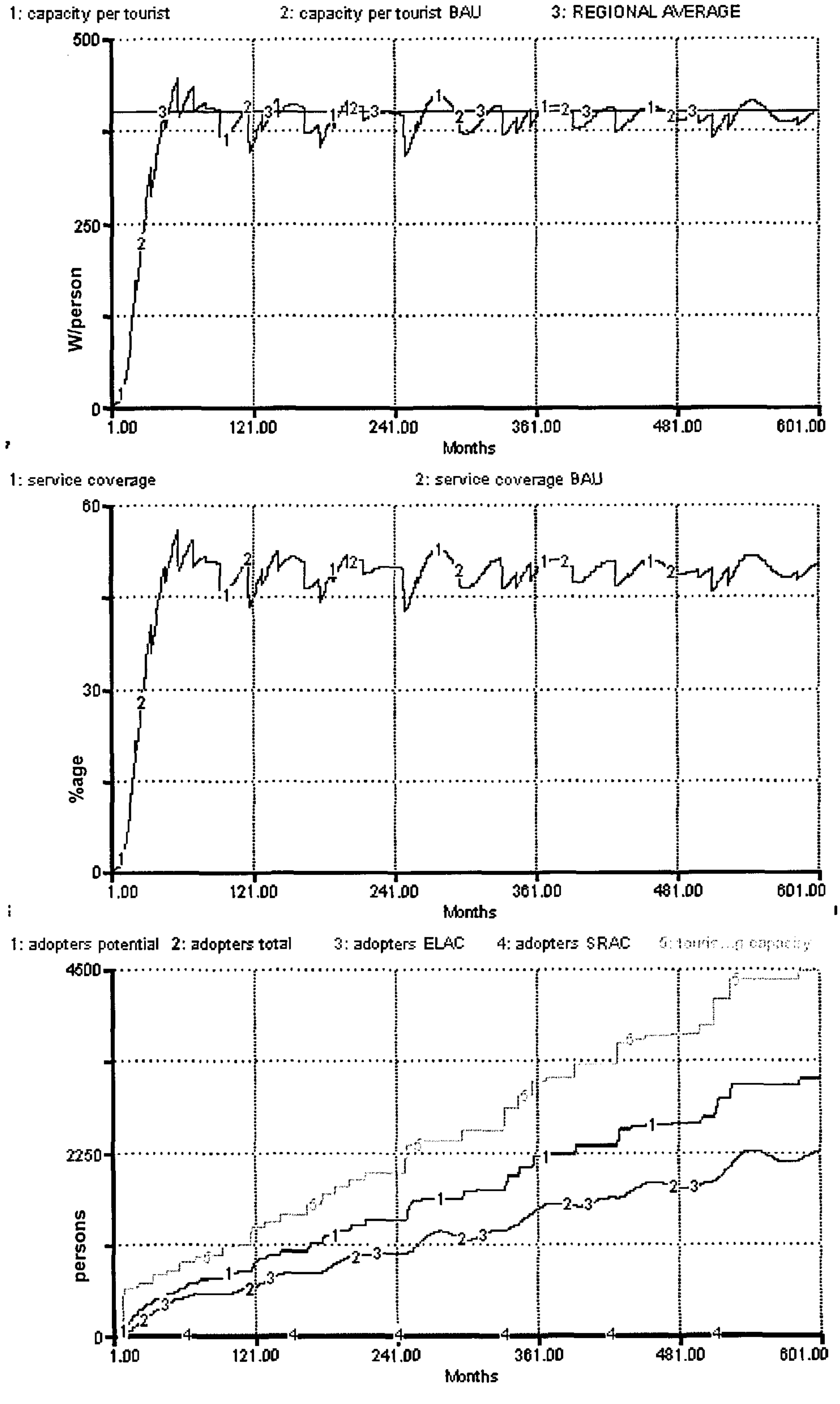

Figure 85: The island in competitive balance

7.2.2 COMPARISON OF DIFFUSION SCHEMES

From top to bottom the system diffusion graphs of Figure 86 present each of the scenarios in the order of Section 7.2.1. Line 4 represents the SRAC adopters.

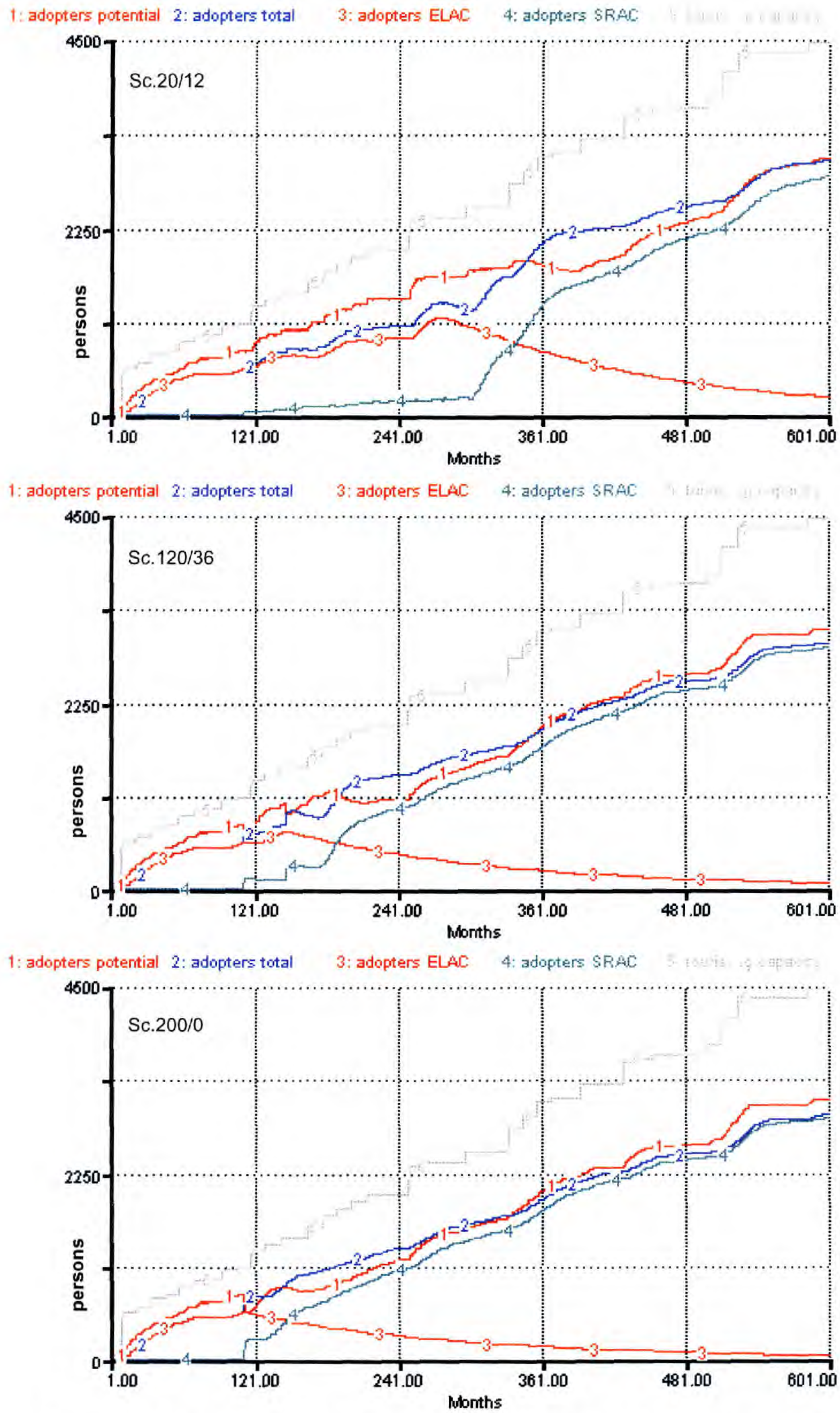

Figure 86: Comparing the adoption graphs of the three diffusion scenarios

In Sc.20/12 the programme runs for quite a few years before the technology finally commercialises and takes off. In Sc.120/36 (middle graph) one can notice the two steps required for the wished result. At the bottom graph of Sc.200/0 a one-off scheme of greater ambitions achieves the same result.

It can be noticed in the last two scenarios that Line 4 of SRAC adoption plateaus before take-off or the next support wave. What does it represent?

7.2.3 THE IMPACT ON THE COST OF SRAC

System behaviour is best portrayed in the Sc.120/36 graph, the middle one in Figure 88 overleaf. After the first wave of support, the 5-year cost of SRAC does not drop enough to compete with the ELAC variant. Thus, no more installations are taking place and the learning is decaying which is signified by the rising cost curve observed. Then, the second instalment of support comes; the cost drops below the 5-year cost of ELAC but the SRAC does not catch on for roughly another two years with the risk of depleting learning, jeopardising cost competitiveness and the diffusion potential as it approaches the ELAC cost.

There are two possible reasons for the delay of the diffusion to commence. One relates to the inherent delays in the system which dampen rapid changes in conditions. The other proves to be simply coincidence, or in other words, reality! Looking back at Sc.120/36 in Figure 86 after the second support instalment, adoption in general is low. Apparently, uptake seems to have stalled altogether and furthermore the total adopters in Line 2 seem to be dropping.

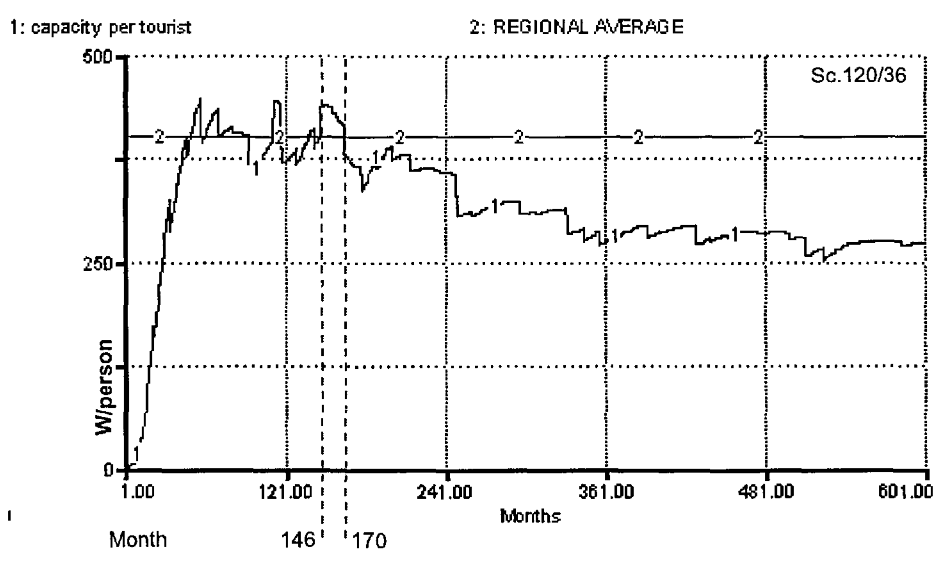

Figure 87: Capacity per tourist for Sc.120-36

Indeed, looking at the island performance against competition in Figure 87 between months 146 and 170 when the inertia is observed (the period between the dotted lines), the local economy has overshot the regional average. Therefore, no more installations are taking place since the aim is over-achieved. As has been argued in the test runs of the previous chapter, not only is the incentive missing but overshooting the average might actually mean it makes the services basket to visitors marginally more expensive, hence the definitive response of declining adopter stocks.

To prove the randomness of the effect which brought a risk to the success of the intervention, Sc.120/36 is shifted 20 months ahead, i.e. commencing in month 130 instead of 110. The result can be seen in the phase diagram of Figure 89.

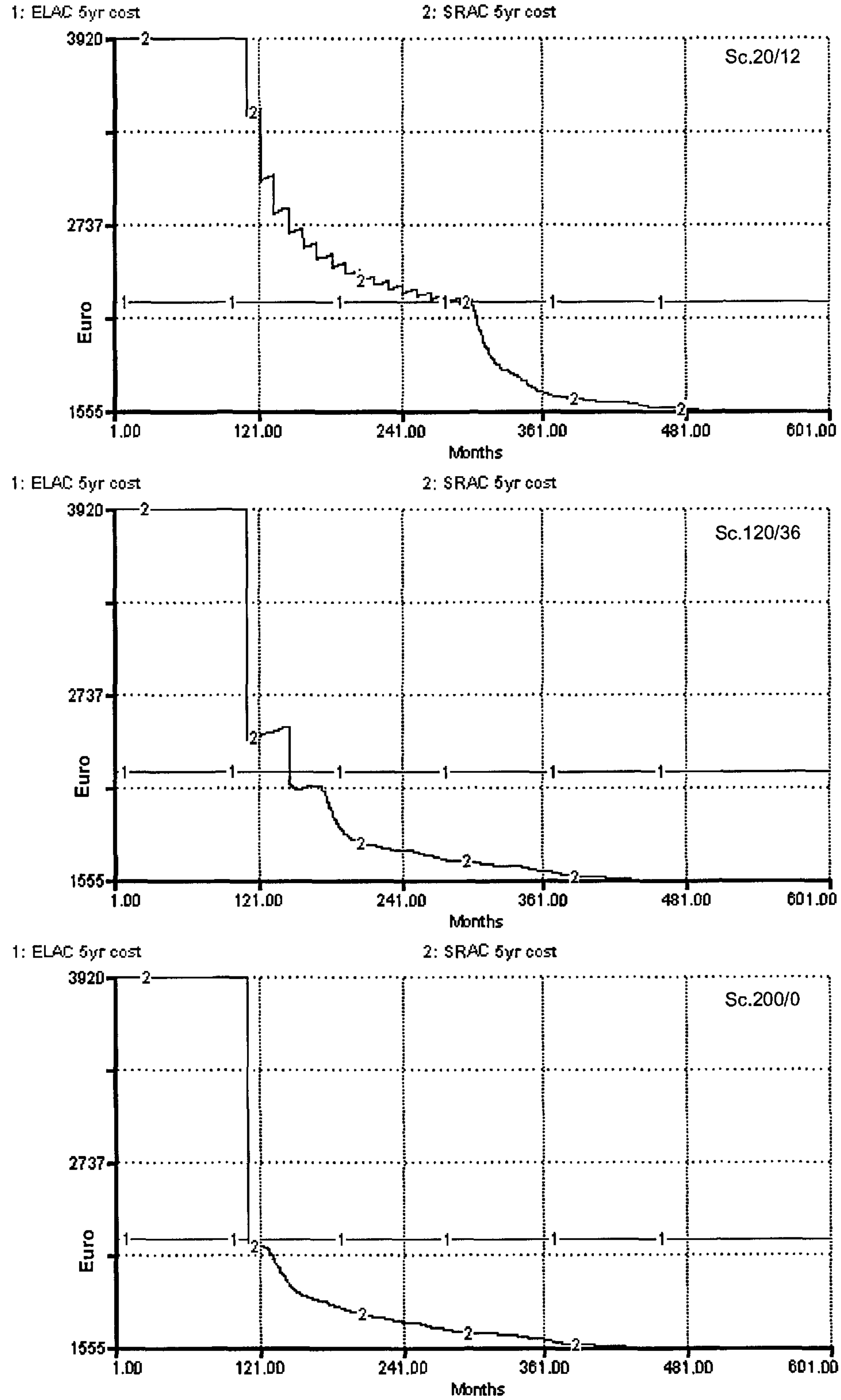

Figure 88: The effect of diffusion on the 5yr cost of equipment

Postponing the start of the support scheme by 20 months, eliminates the risk associated with the previous period of competitiveness overshoot and SRAC picks up immediately after the second batch of support and as soon as its 5-year cost drops below that of ELAC.

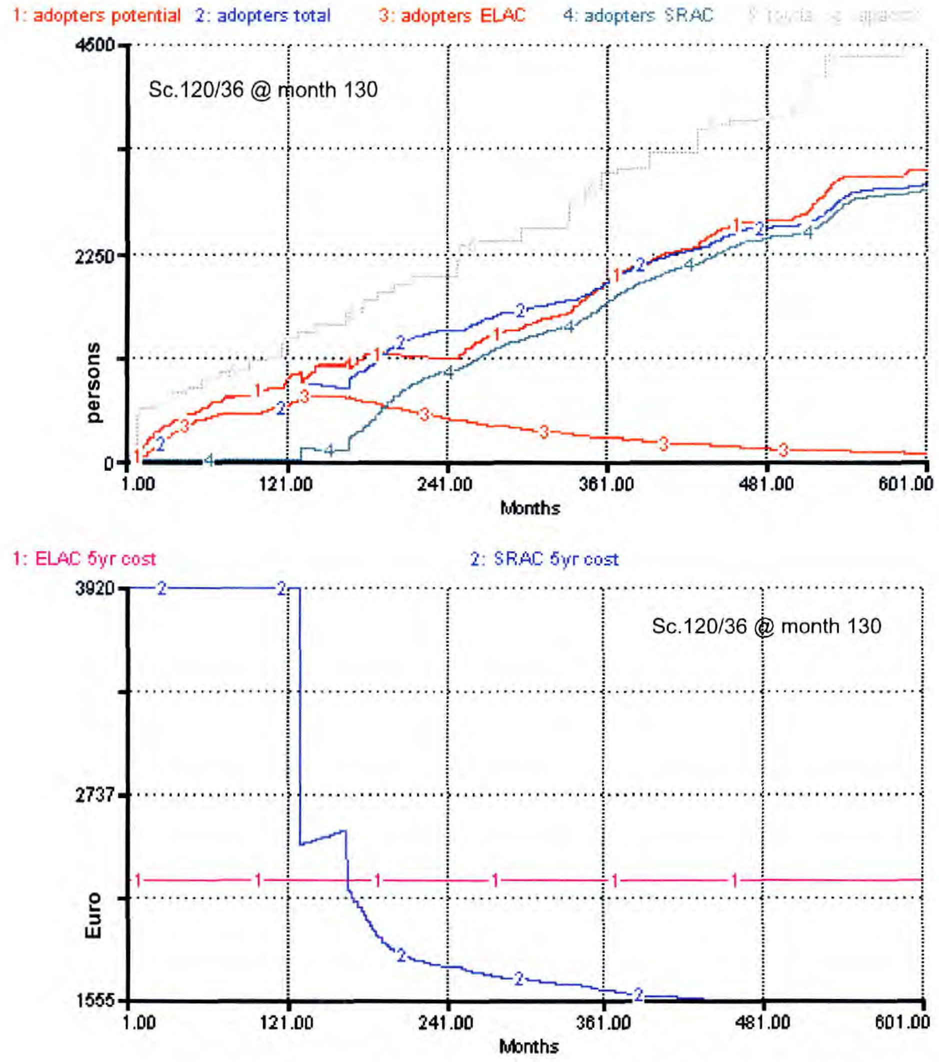

Figure 89: The diffusion postponed to month 130 for Sc.120/36

As a matter of fact, the rescheduling of the subsidised installations cuts down the time needed from the end of the programme to the break even point (BEP) by 8 months – from 58 to 50 months. Before getting into such metrics though, attention is drawn back to Figure 87 and the perpetual undershooting of the regional average after the commercialisation of the SRAC unit. The effect is examined in the following section.

7.2.4 THE IMPACT ON COMPETITIVENESS

The common sense developed in this simulation model suggests that when the local capacity per visitor is below the regional average, the competitiveness of the island as a destination is marginally diminished. To mitigate this, a range of switches and converters make sure potential adopters move from their stock to either the ELAC or the SRAC stock, depending on conditions of costs and learning, causing a rise in the A/C capacity per adopter.

Any movement of that index though should be cross examined with the coverage of the service. A rise in the capacity per visitor could be also observed using more inefficient equipment, which means covering fewer people with more power while trying to keep close to the regional average, not a desirable situation. In the case of Figure 87 above, there is a different story though.

The capacity per visitor drops but it does not trigger mitigative action because the uptake of the more efficient variant, especially after commercialisation, actually achieves more with less. The actual total number of adopters grows significantly higher than the BAU case, as Figure 90 illustrates.

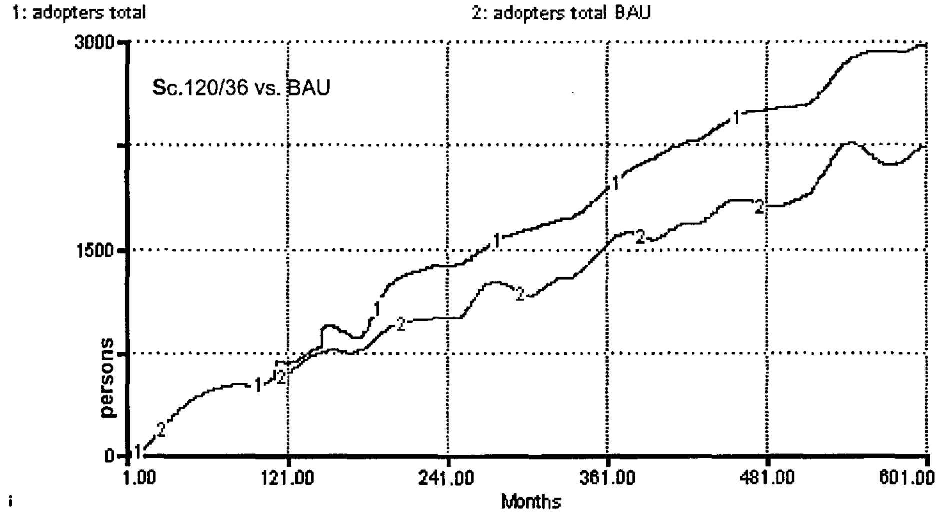

Figure 90: Total adopters Sc.120/36 vs. BAU

This is the effect of a virtuous cycle of efficiency that was predicted in Causal Loop Diagram of Figure 48 in Chapter 1. As the efficiency uptake grows, the capacity per visitor, which is a weighted average of visitors on ELAC and SRAC, drops. This triggers a competitive gap that drives more potential adopters to either of the two A/C stocks. As this happens, the system becomes ever more efficient as SRAC commercialises and is the dominant option. As a result the island can afford to expand the service to all potential adopters and still spending less per visitor compared to the BAU case (Figure 91).

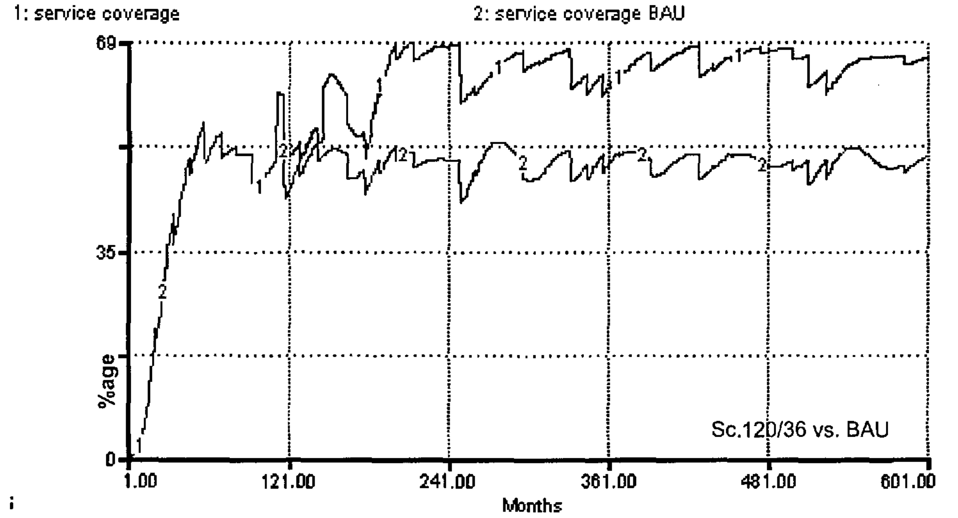

Figure 91: Service coverage Sc.120/36 vs. BAU

There is a key insight to be revealed here. In the analysis so far it was assumed that the regional average, the competition, stayed constant at 400 W/person, i.e. it has not advanced technologically (nor degraded in quality for that matter). What the simulated island did is exactly the opposite, to innovate. And it paid off by expanding the service to more of its visitors at the same or even lower cost of cooling. The impact of such a strategy during arrivals recession will be examined later on too.

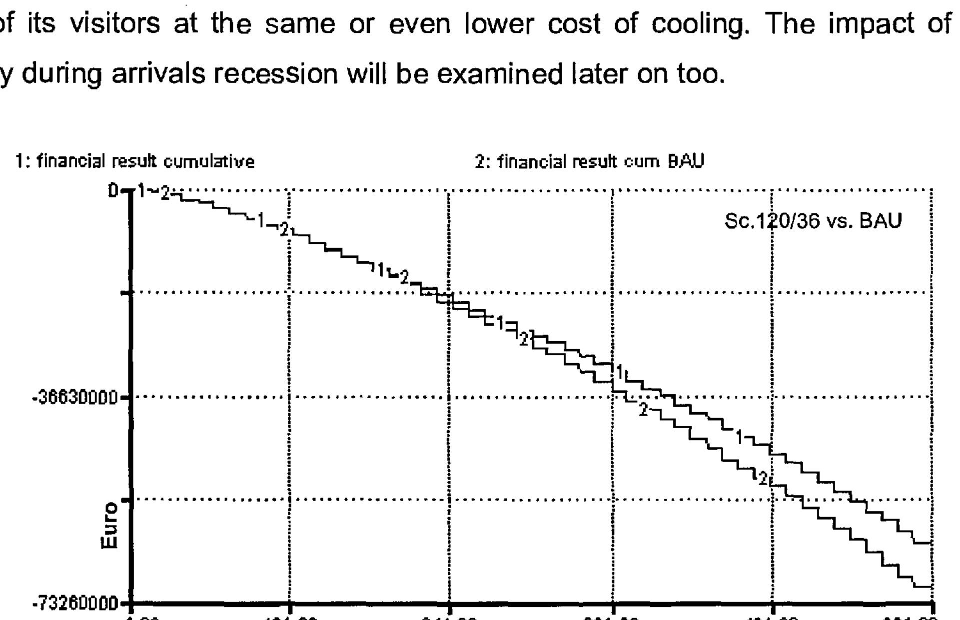

Figure 92: Financial result of utility 120/36 vs. BAU

At the same time, the utility itself improves its finances (Figure 92 in terms of running accumulation year on year, not discounted to any basis year). Still, as it stands in the Aegean islands, it is loss reduction rather than increased profits that the utility can achieve. Nonetheless, this saving could be passed to consumers who would still need to be heavily subsidised for their power as Figure 93 attests. The marginal cost of kWh consumed remains well above the average electricity tariff of €0.08.

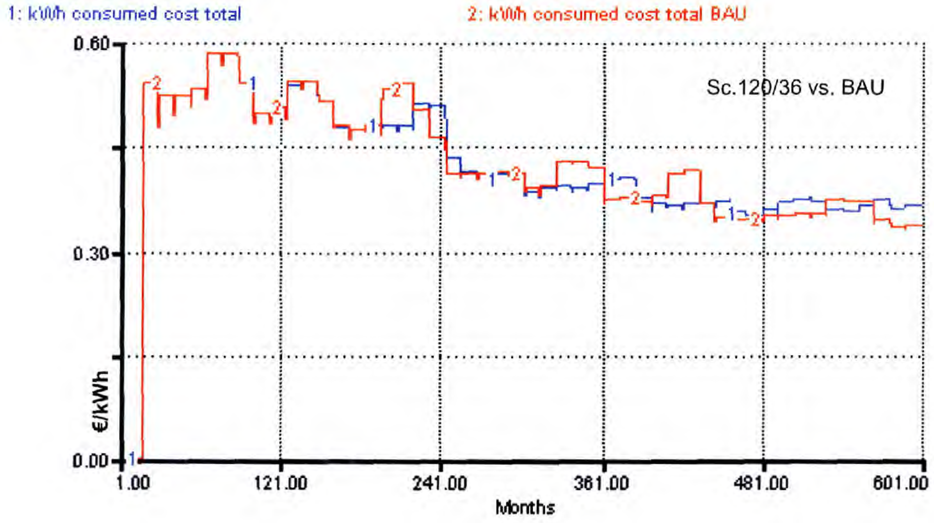

Figure 93: Total cost of kWh consumed 120/36 vs. BAU

The graph cannot convey much about the savings achieved though. These will be studied in detail soon after the next section on the effect of the demand side intervention on the tourism industry and most importantly the utility's financial performance.

7.2.5 THE IMPACT ON TOURISM AND UTILITY FINANCES

Continuing the view into the positive impacts of intervention, the potential benefits to the tourism industry are briefly looked into although a fully fledged CBA is not the aim of the thesis. It rather assists in keeping within the context and in constant reference to reality and pragmatic issues.

The top graph of Figure 94 compares the average monthly consumption of electricity per tourist between the BAU and Sc.120/36 as an example. At month 241, roughly eleven years after the scheme's introduction (eight after completion), the saving to the industry due to the drop of the average electricity consumption is estimated at about €70,000[25]. This is about €12 per visitor a month or £3 per visitor a week. It seems like a small amount but if a one-week package holiday to the island is to cost a random €50 less per visitor per week than offered by a comparable competing destination, the electricity saving would represent 6% of that discount. For a family of four on a two-week package,

[25] The difference between BAU and Sc.120/36 is 128kWh at month 241, tourism peak arrivals for that year are 6,042 which sums to a saving of 733,400 kWh or €70,000 in bills.

the total saving would be a significant €400 of which 6% is already sizeable enough considering it is only concerning power efficiency of the A/C service in the basket of services holiday-makers are receiving. Further elaboration into pricing strategy for tourism is far from the thesis immediate aims.

However, while the industry is becoming more competitive, less consumption means fewer sales for the PPC, a possible fear of policy-makers in introducing energy efficiency. And it might be. However, the specific socio-economic conditions where such measures are applied should be considered.

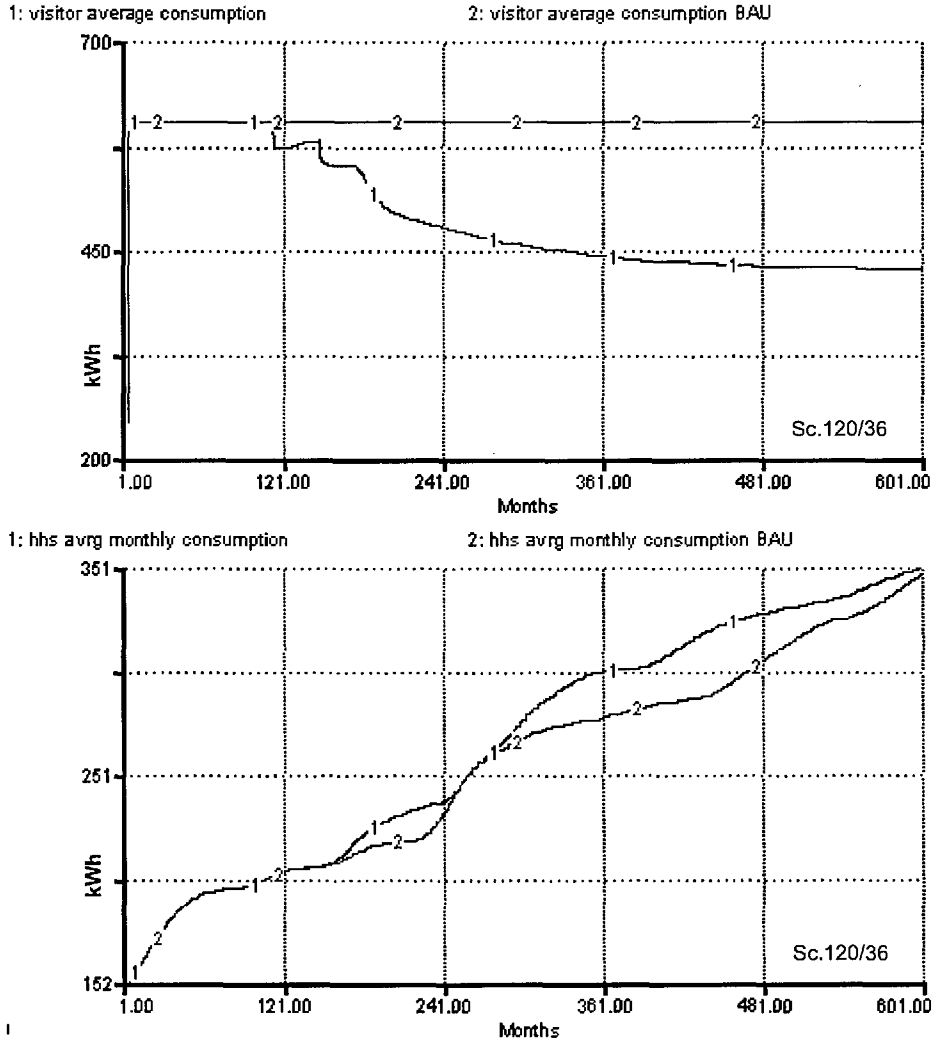

Figure 94: Visitor & household average monthly consumption Sc.120/36 vs. BAU

For example, the nature of households' power consumption behaviour, as well as the population and income dynamics described already for the simulated island, actually causes a rise in the monthly consumption (top graph of Figure 94) when DSM schemes to the commercial sector are introduced. Still, the effect of efficiency is definite as in the top graph of Figure 95. In the same graph, indeed sales drop (middle graph) but costs even more so (bottom graph).

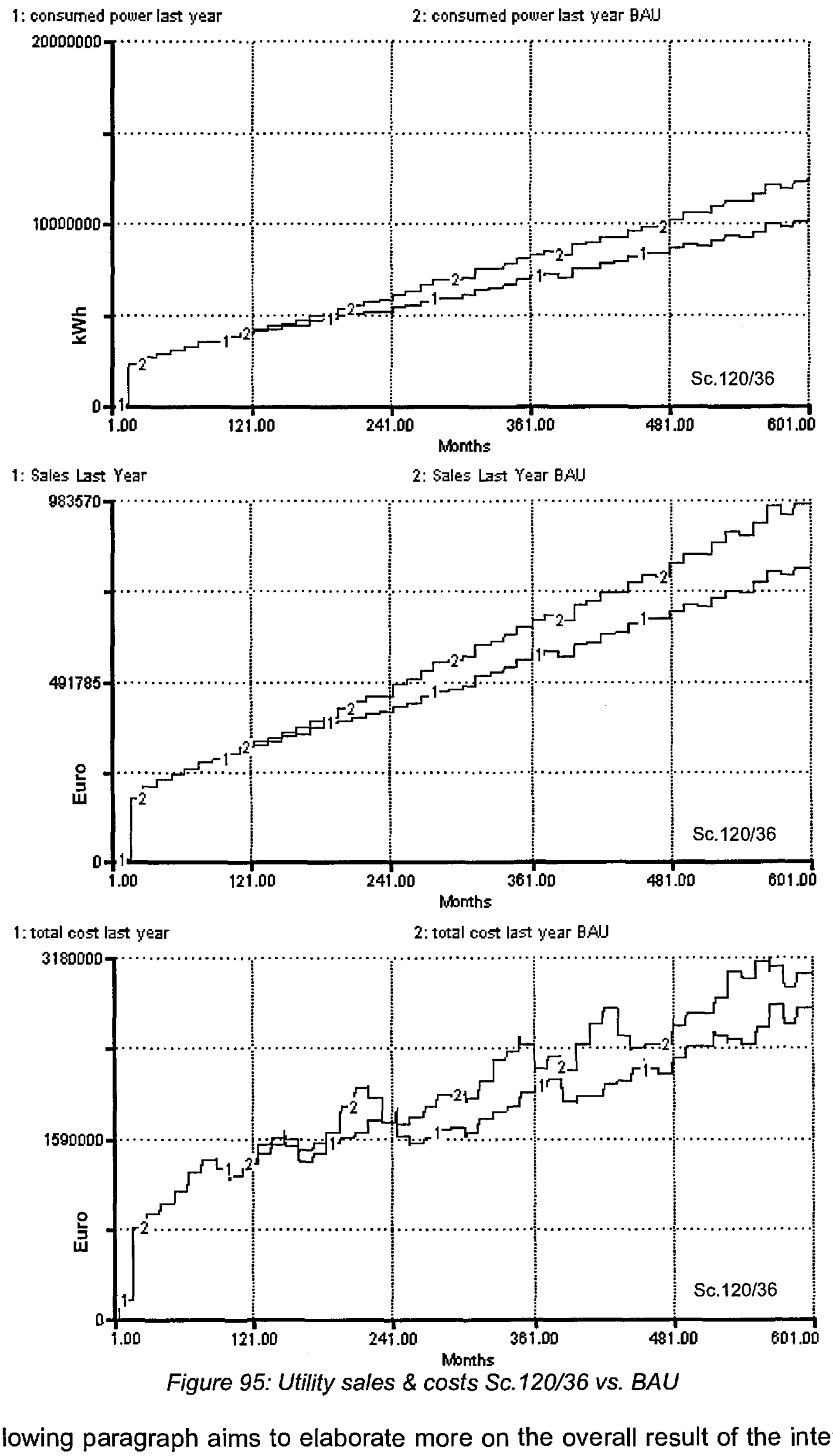

Figure 95: Utility sales & costs Sc.120/36 vs. BAU

The following paragraph aims to elaborate more on the overall result of the intervention on savings, the cost of the diffusion options and a crude financial appraisal.

7.2.6 THE IMPACT ON SAVINGS AND BEP

A comparison of the annual savings from BAU across the three scenarios should provide more insight into diffusion policy making, as in Figure 96 below.

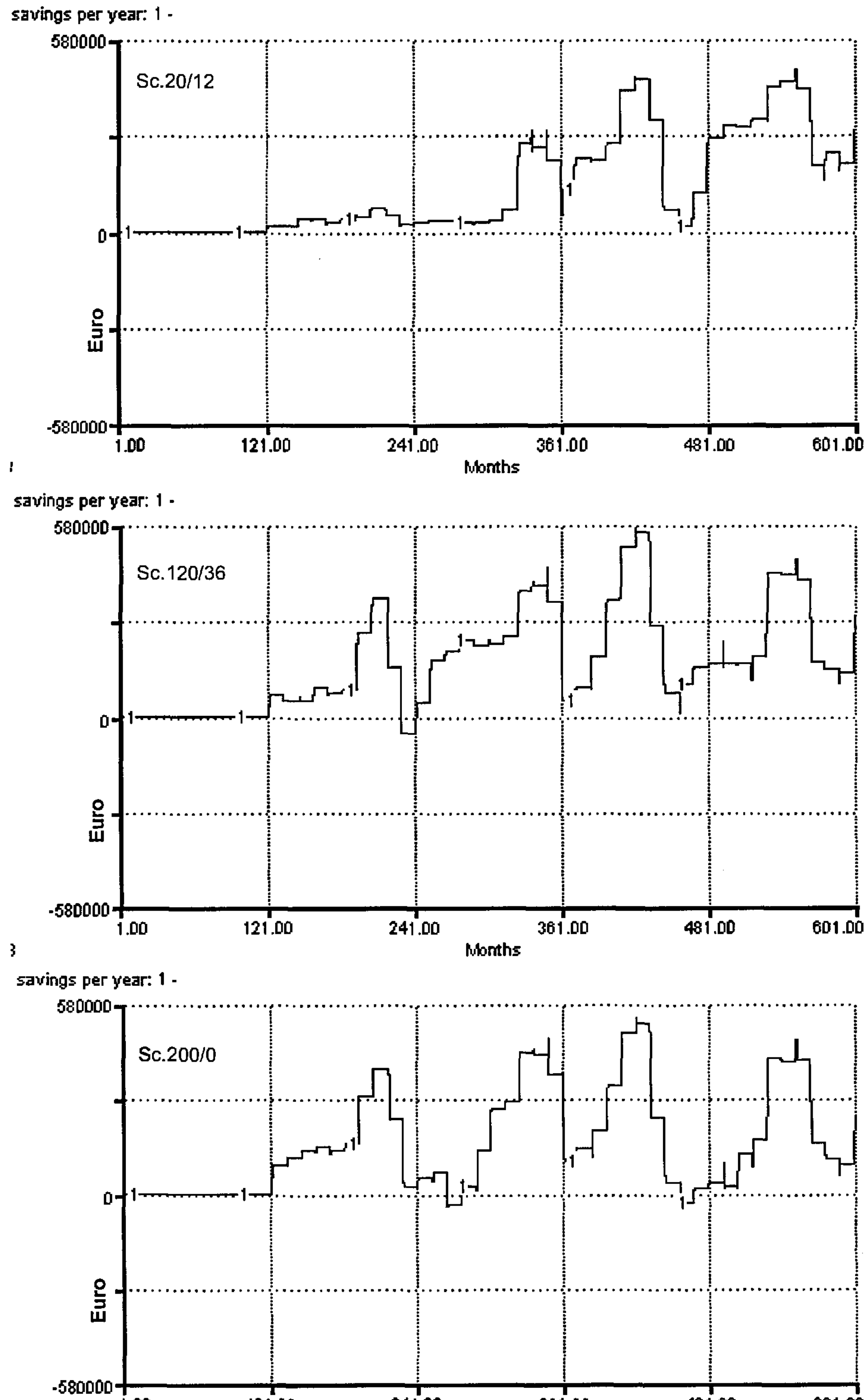

Figure 96: Comparison of annual savings across the three scenarios

An immediate observation is that the savings are punctuated. That must have to do with the nature of visitor arrivals and random events, as already explained. Annual arrivals of tourists are also pretty unreliable and subject to exogenous fluctuations in the simulations as in real life. A slight change might be the defining moment between the programme succeeding or not. The value of the approach in this thesis is exactly in that it is not an optimisation exercise whose result would inevitably be arbitrary under this light of uncertainly. Rather it is a strategic overview of key variables in a setting approaching realistic uncertainty and erratic behaviour as much as possible. More like mapping rather than driving; going through unknown lands a map is crucial before setting off, simulating the ride is of even greater assistance.

What can be also noticed in Figure 96 is that on many occasions, savings are small, even occasionally going to the negative side compared to BAU. Nevertheless, there are significant savings for the duration of the simulation in all scenarios, the least roughly €6,600,000 for Sc.20/12, €7,200,000 for Sc.200/0 and nearly €8,000,000 for Sc.120/36 (in end-of-simulation undiscounted terms). It is not as straightforward to simply choose the scenario saving the most.

The financial requirements should include the cost of money in the layout and horizon of a support scheme. Does the policy maker have the funding for a major costly scheme that will produce results straight away (which is on many occasions the requirement of the ruling political party near elections) or is a long campaign that is manageable financially but also digestible in institutional capacity terms preferable? Although this last dilemma is beyond the aims of this particular thesis, similar questions are critical in designing a diffusion campaign and are conceptually within the broader area of the research.

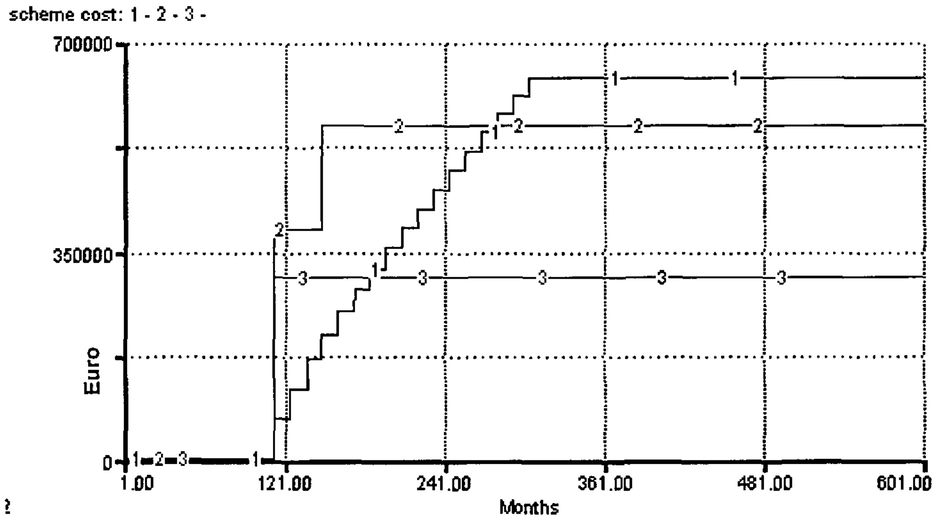

Figure 97: Comparison of the cost of scheme considering the cost of money

Table 14: The scheme's NPV cost under the three scenarios

	Scheme's NPV Cost
Scenario 20/12	€ 274,192
Scenario 120/36	€ 330,443
Scenario 200/0	€ 303,689

The effect of the value of money is shown in Figure 97 above, which compares the cost of the three schemes (Line 1, Sc.20/12; Line 2 Sc.120/36; Line 3, Sc.200/0). At the top, Sc.20/12 seems the most expensive and as it also provides the least savings then it would be expected that it is rejected. Sc.200/0 on the other hand seems by far the most promising as it also provided the second best savings after Sc.120/36, which here does not perform that well. The funds should be available at the start of each programme, thus the final cost of each scheme is discounted at the risk-free rate of 5%[26] to month 110, the start of all three scenarios, which has the result shown in Table 14.

A different story! Sc.200/0 remains the same since it rolls-out in a single step while Sc.120/36 drops significantly, as it requires two steps totalling a duration of 6 years until

[26] Based on the average of 3-year and 30-year Greek Government's bond yields issued by the bank of Greece at http://www.bankofgreece.gr [Accessed 20/06/2009]

the SRAC market matures. The surprise comes from Sc.20/12 that is at current prices lower than the other two options. So, despite the original common sense, it proves a much harder decision. In addition to the non-measurable benefits of a gradual roll-out, the funds for Sc.20/12 are deployed gradually and can perhaps be used in a hedging strategy. However, this is again beyond the scope of this thesis and it would require elaboration with tools such as Real Options to evaluate each scenario.

For example, how would one value the option of terminating the programme in Sc.20/12 in case of radically altered circumstances at different stages of its deployment? Still, these are the sort of insights and issues the methodology does raise while keeping a firm cross-disciplinary reference to the local economy and its competitiveness, the utility's benefit and assisting an innovative energy efficient technology to break through.

The time it takes from the completion of the programme to the BEP for Sc.20/12 is three years compared to five for the other two scenarios. The total duration of the former though is 16 years.

This simulation model illustrates the mechanics by which a switch to efficiency can be engineered and its benefits, direct or collateral. It challenges perceptions of planning and has shown so far that a shift to an efficient paradigm is possible within reasonable timeframes. Decisiveness, boldness and consistency seem to be key aspects of the decisions a policy maker needs to take. The search for the diffusion scheme most likely to succeed then needs to iterate a number of scenarios and adopt a specialised appraisal tools. First, a shared vision is critical. A tool such as the one presented in this thesis, can also accommodate the involvement of stakeholders.

More conclusions are to be drawn at the end of the chapter. The physical and operational components of the utility are studied next.

7.2.7 THE IMPACT ON UTILITY OPERATION AND EXPANSION

The most likely set of graphs to look into where and how the savings for the utility occur is that of installed capacity. The obvious effect of the intervention in all cases is less installed capacity compared to BAU in the graphs of Figure 99. The figure includes the annualised growth of peak power demand and consumption in each option's graph.

There are two more observations to be made, though. Firstly, fewer expansions are needed; in all three scenarios one can count five instead of the six expansions under BAU. In addition, perhaps equally importantly, in all cases the added capacity is found to occur in smaller steps than BAU after the schemes begin indicating a better managed system. The second observation, as a consequence of the previous, is the delay in installing capacity.

Thus a better managed system perhaps points to improved running costs, whereas investment deferral affects capital costs. A better managed system is characterised from the interaction of LOLP and the Capacity Margin that determine the switches and heuristics that decide on capacity additions. However, their graphs cannot be easily studied to observe the improvement. On the contrary, the load factor of the system under BAU and Sc.120/36, for example, can provide a glimpse of the positive impact of the intervention on the management of the utility, as in Figure 98.

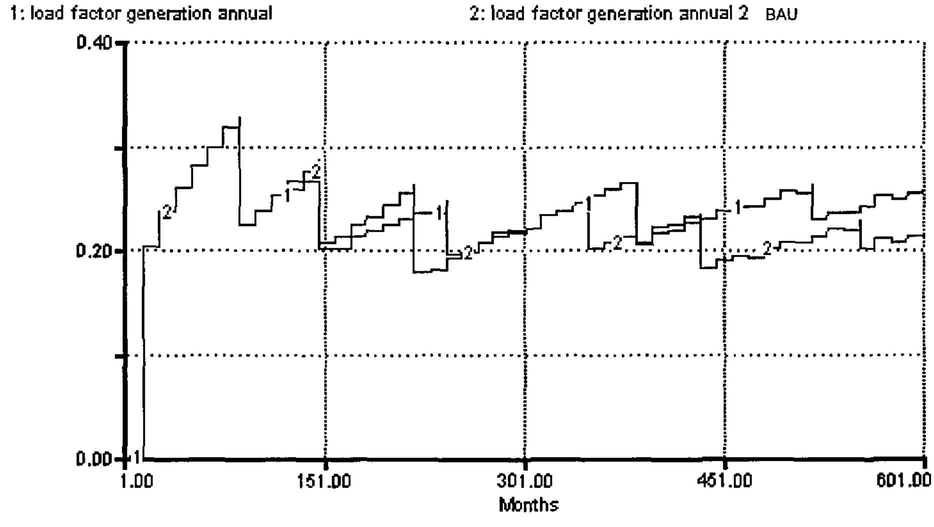

Figure 98: The Load Factor Sc.120/36 vs. BAU

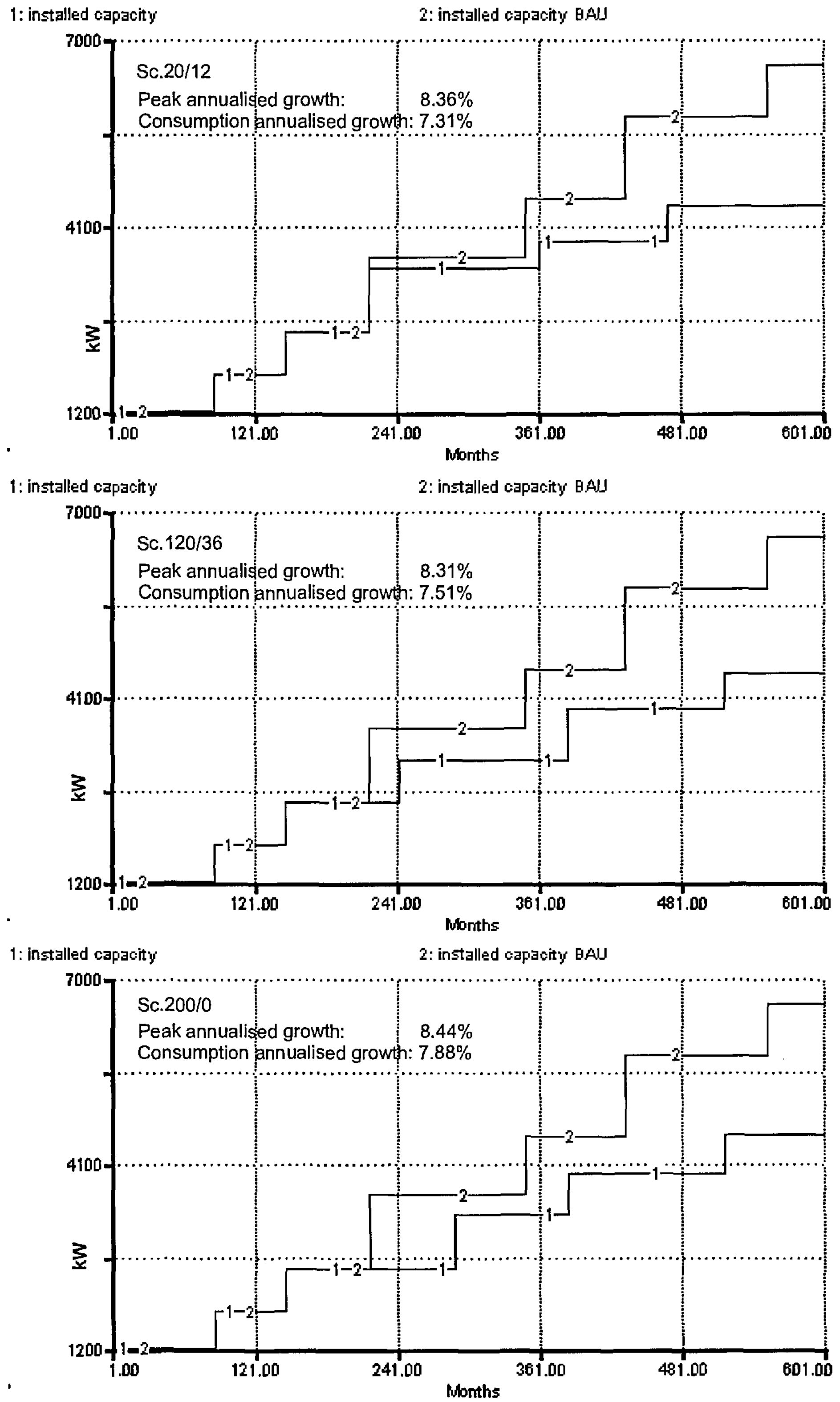

Figure 99: Installed capacity of options vs. BAU

Regarding the annualised growth of peak and consumption of Figure 99, the insight is that the policy makers need to carefully establish how the consumers in their system interact. A customised bottom-up approach, especially when talking of remote or easily definable communities, markets or economy sectors, as in this case, is highly recommended. During the model's design it was suggested by bibliographical and statistical research that household demand should be linked to availability of power in the island. This conceptual assumption, as well as its mathematical design in the simulation, might be less or more complicated than reality. Once this is understood, it is then up to the aptitude of the modeller and the availability of data to incorporate it in the best representative structure to generate the real observed behaviour.

Figure 100 illustrates the previous insight by comparing the growth of the average household consumption from BAU in Line 1 to an ascending fashion from Sc.20/12 to Sc.120/36 and Sc.200/0 (Lines 2-4). The fact that the latter is launched in one go makes the system immediately efficient and savings accrue almost instantaneously. That also means power savings and thus availability of spare capacity for as long as the system becomes ever more efficient[27], which the households take advantage of.

As long as the households have the capacity to do so, it can be said it actually marginally improves the load factor. A policy maker in the case of the rapid uptake in the tertiary sector of Sc. 200/0 should consider introducing the efficient A/C to households. At perhaps round about month 361, as on the one hand A/C is within the electricity comfort sought in their consumption increase and equipment ownership but not least, on the other hand, to ride on the extremely fast learning on efficiency that occurs in the island. That is the spiral of efficiency that unless simulated, policy makers cannot afford to test otherwise.

[27] By replacement of ELAC units and the deployment of SRAC anew once it is commercialised and space cooling is still in demand.

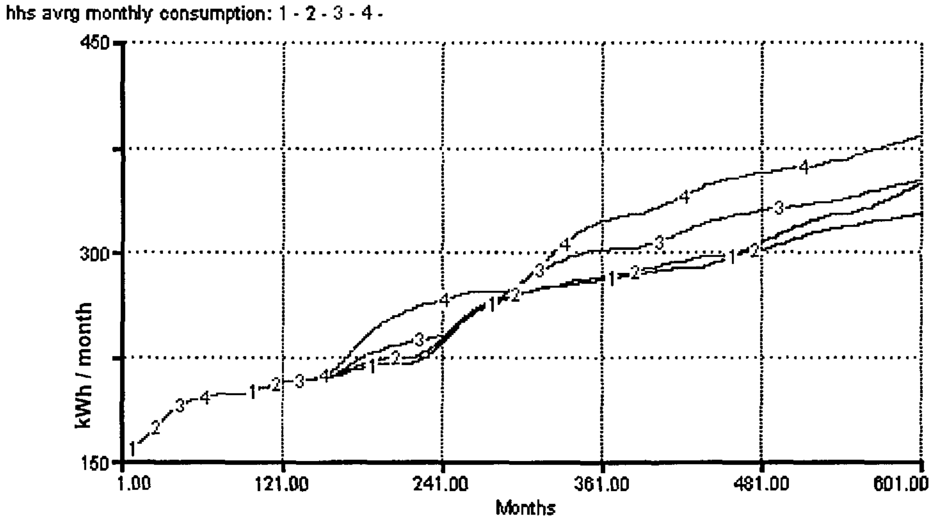

Figure 100: Household average monthly consumption across BAU & schemes

The relevant percentages of the cost components of the utility do not change significantly, as in the example of Figure 101 illustrating Sc.120/36. It is similar to the other two scenarios not presented here for economy of space. This outcome is foreseeable as the nature of the system does not change, i.e. the arrival of visitors maintains the same seasonality and overall numbers across the scenarios while the A/C load is after all only a fragment of the total consumption (albeit a major contributor to its peaks). To have a radical shift in the split of cost components, perhaps expanding the touristic season might pull the trick and could be studied separately using the simulation model built here.

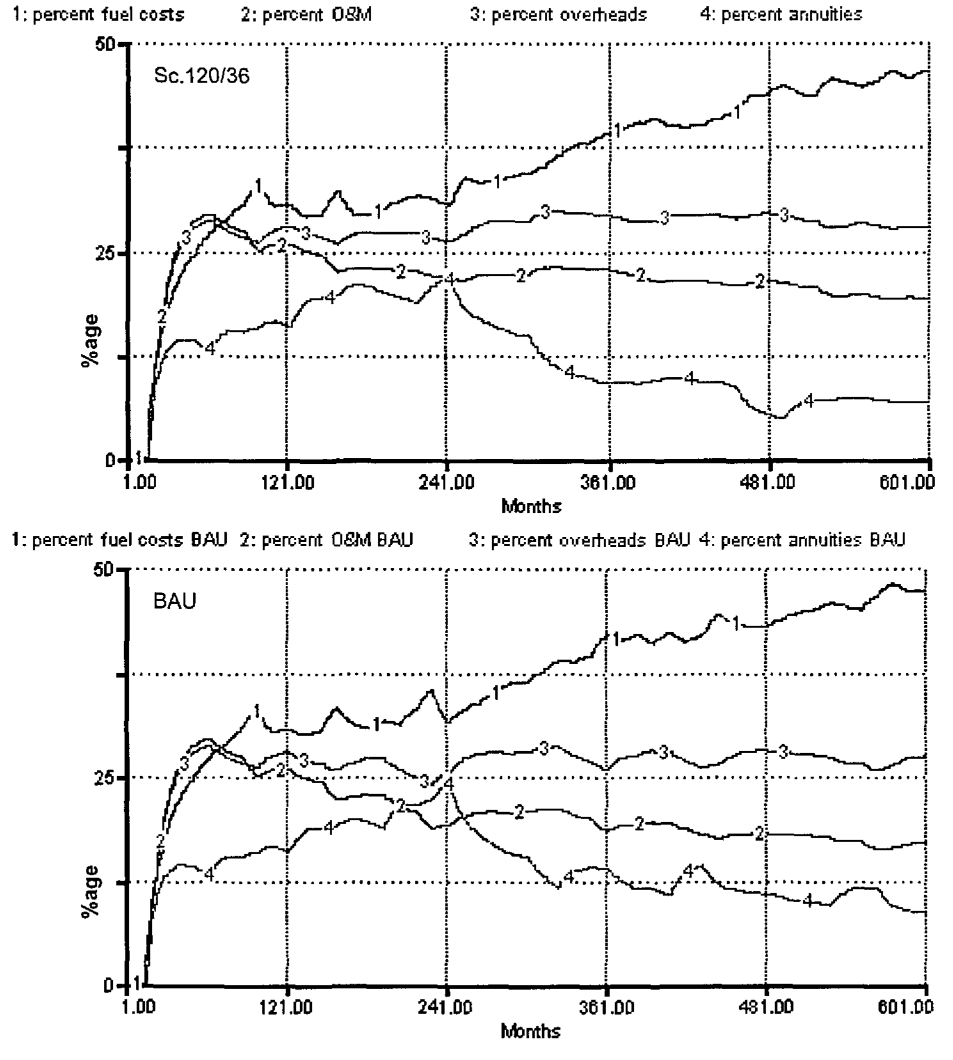

Figure 101: Share of cost components Sc.120/36 vs. BAU

As expected, fuel maintains its dominant share of costs in Figure 101, while there is a noticeable drop in annuities since fewer investments of lesser capacity less frequently are needed when a promotion scheme is successfully introduced. Operation and maintenance share of costs also seem to drop more sharply under the diffusion scenario while overheads seem to fluctuate more. To inspect these figures better, the actual costs over time are included in Figure 102.

The savings are clear in the cases of fuel, overheads and annuities. The effect on O&M is also clear, albeit not as distinguishable. The O&M costs reflect the actual struggle with the seasonal wave of visitors, which remains the same in all scenarios. Dealing with the seasonality peaks of tourism is of equal importance to the power systems of the islands as dealing with their power peaks.

Last but not least, for comparison purposes and completeness, Figure 103 juxtaposes the evolution of power peak demand and generation for BAU in Line 1 and then Sc.20/12, Sc. 120/36 and Sc.200/0 in ascending order from Line1-4.

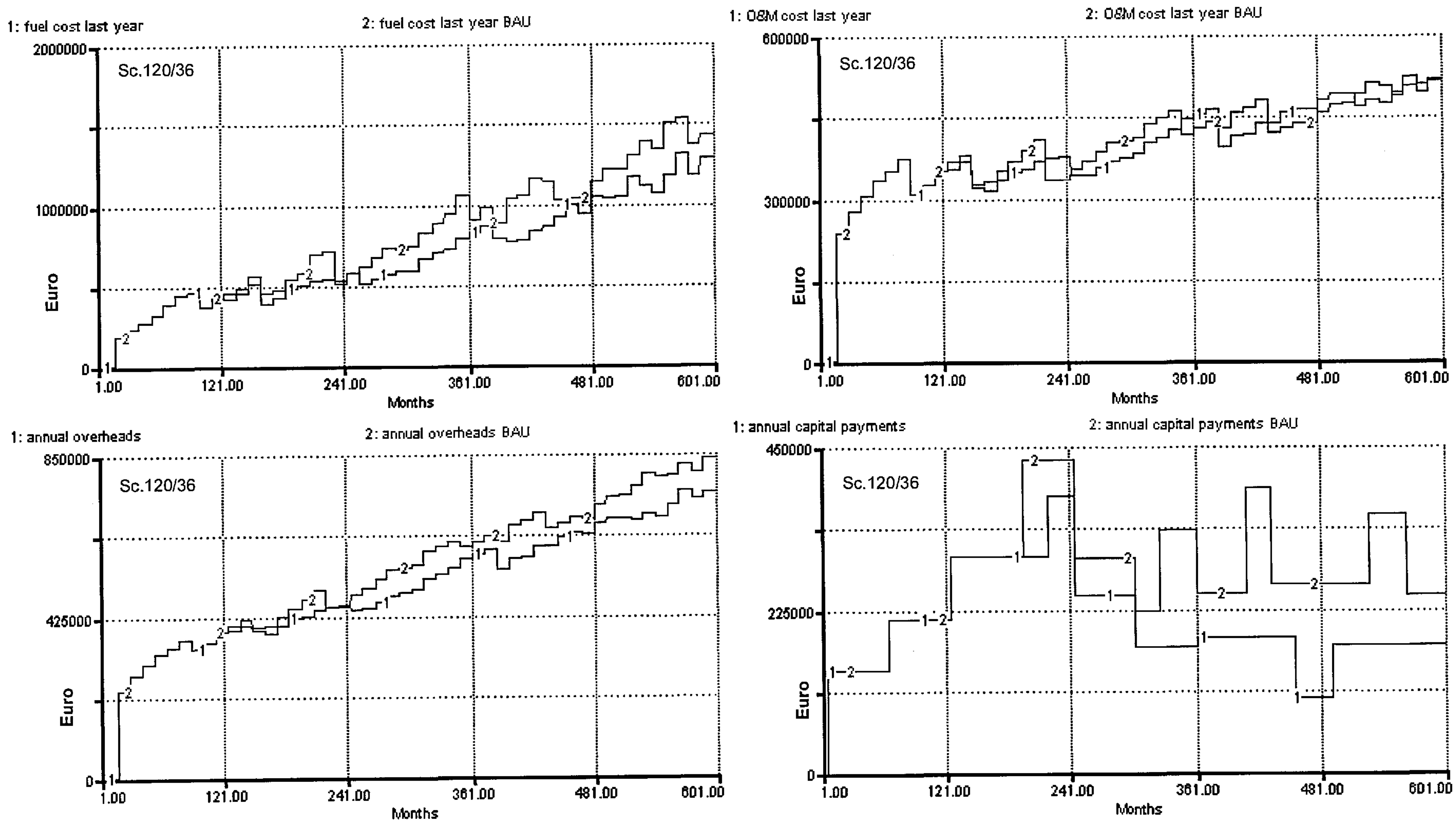

Figure 102: Cost components of Sc.120/36 vs. BAU

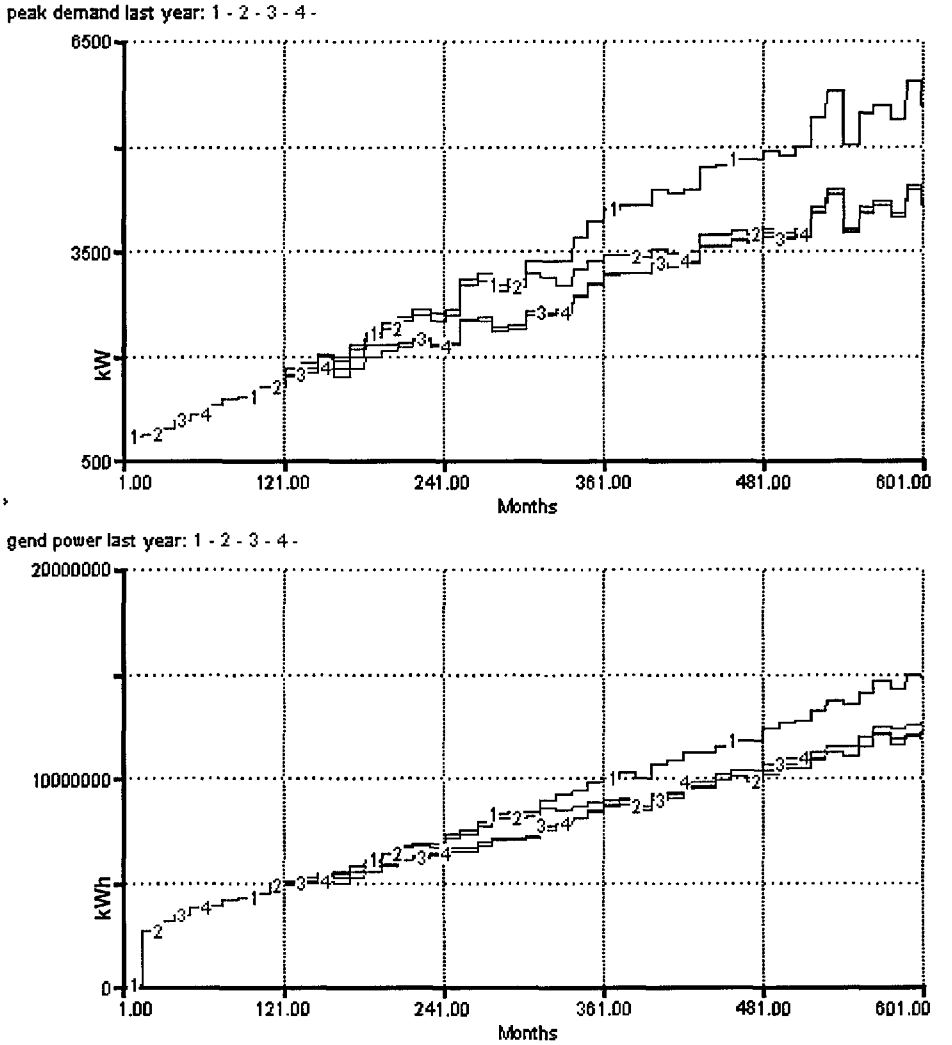

Figure 103: Comparison of peak power demand and generation across BAU & schemes

7.3 WHAT-IF TESTS AND INSIGHTS

7.3.1 TARIFF LEVEL

Looking back at the Sc.20/12 in Figure 88, the diffusion strategy succeeds when the 5-year cost (including the purchase and five year running costs) of SRAC drops below that of ELAC. Looking at the cost evolution of the unit itself though (Figure 104), SRAC only reaches ELAC's price towards the very end of the simulation. It is the tariff rate then that determines its competitiveness even if components of learning should deteriorate as the technology assumingly reaches maturity. At any point after the dotted line indicating the end of the support scheme SRAC is a commercial technology for the Greek islands and other markets where a five year break even point compared to the established technology is acceptable.

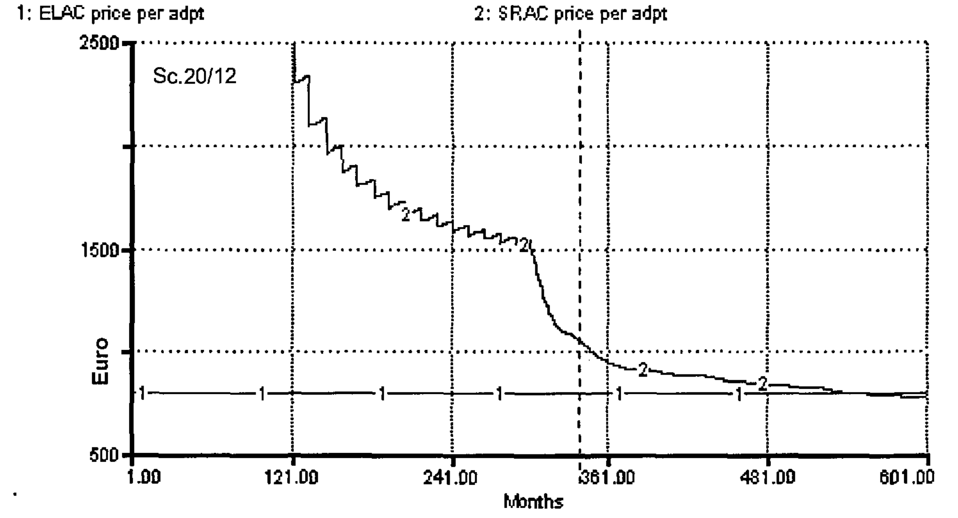

Figure 104: The equipment purchase cost of ELAC and SRAC

Tariff restructuring is a sensitive issue in Greece and the Greek islands in particular, as already explained in early chapters, along with the fact that the Greek power rate is among the lowest in Europe. It theoretically is a valid option for energy policy, albeit applying full costs would be disastrous socially and politically (looking back at kWh cost in Figure 93). However, a reasonable rise in tariff that could have a great impact on the diffusion could be considered.

Figure 105 provides the comparison of raising the tariff by €0.01 (which still is a 12.5% increase) for the Sc.20/12. Line 1 represents the normal case and Line 2 the impact of the new rate. In the top graph the benefit is obvious as commercialisation kicks in and rises faster (from 16 to 10 years while end-of-scheme to BEP increased from 3 to 4 years). Consequently, the support scheme costs less and provides greater savings.

The insight was expected although very dramatic. It is unlikely any government could only raise the rate in the islands or any particular economic group there. Such an option could be another study altogether, looking at how a strategy could be devised where the expected benefits are distributed visibly and clearly among the stakeholders. Still, however, the issue of efficiency which is the major question here, would not be addressed. It is important to keep the effect of tariff rates in mind though as a beneficial stimulus to efficient equipment increase might come from a national renegotiation of the cost of power.

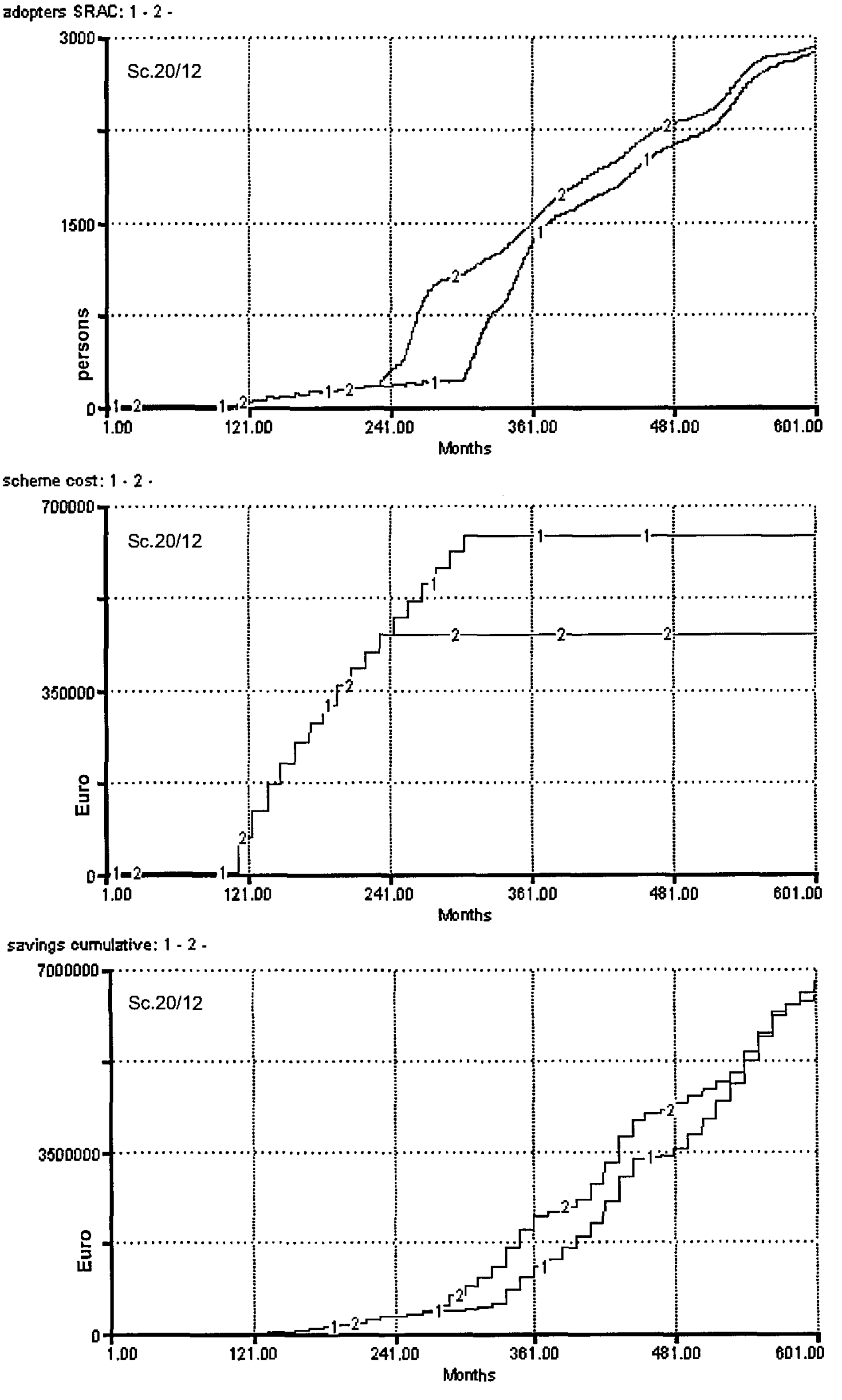

Figure 105: What if the tariff increased

7.3.2 COMPETITION CATCHING UP

What if in the midst of rolling a diffusion scheme out the competition catches up and actually outperforms the simulated island? Sc.20/12 is chosen for the illustration as it has the longest duration on which to test this possibility. Here, the regional average suddenly becomes twice as efficient.

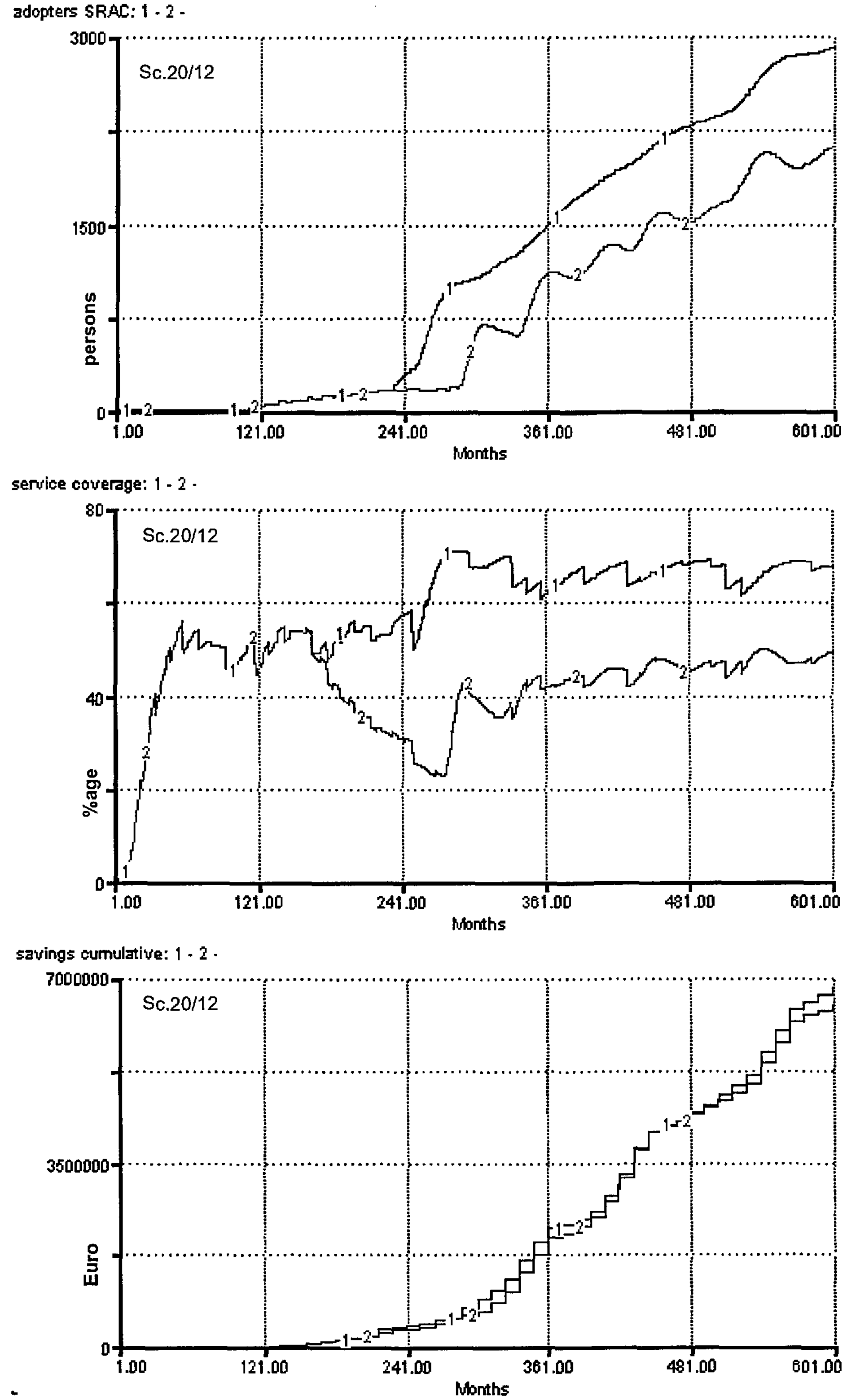

Figure 106: What if the competition caught up before commercialisation Sc. 20/12

To begin with the scheme takes longer to reach its goal, as at the top of Figure 106-Line 2, compared to the expected roll out of the scheme in Line 1. SRAC adoption is more erratic and not as high, since the improved competition (less installed W/person for the same cooling load) drives the system to reduce overall ownership, i.e. coverage.

However, after a sharp drop service coverage manages to leap back to a level that is the norm for the BAU scenario: fluctuating around 50%.

Coverage can be observed in the middle graph of Figure 106 in Line 2. Line 1 shows where the capacity for the coverage rebound is coming from: the trouble free progress of the support scheme that would have reached almost 70% of the potential adopters. The bottom graph confirms that there is no significant toll taken on the expected savings of the roll out under increased competition. The lesson to be learnt is that it might be actually the best option to keep on pressing with the policy even if it costs more in the short to mid term.

Nevertheless, the choice of scheme a policy maker made and committed to (see Lock-in in Appendix B) does make a difference. One can quickly compare the same scenario for Sc.120/36 in Figure 107, where in assistance to the simulated island the competition improvement is introduced soon after commercialisation was achieved.

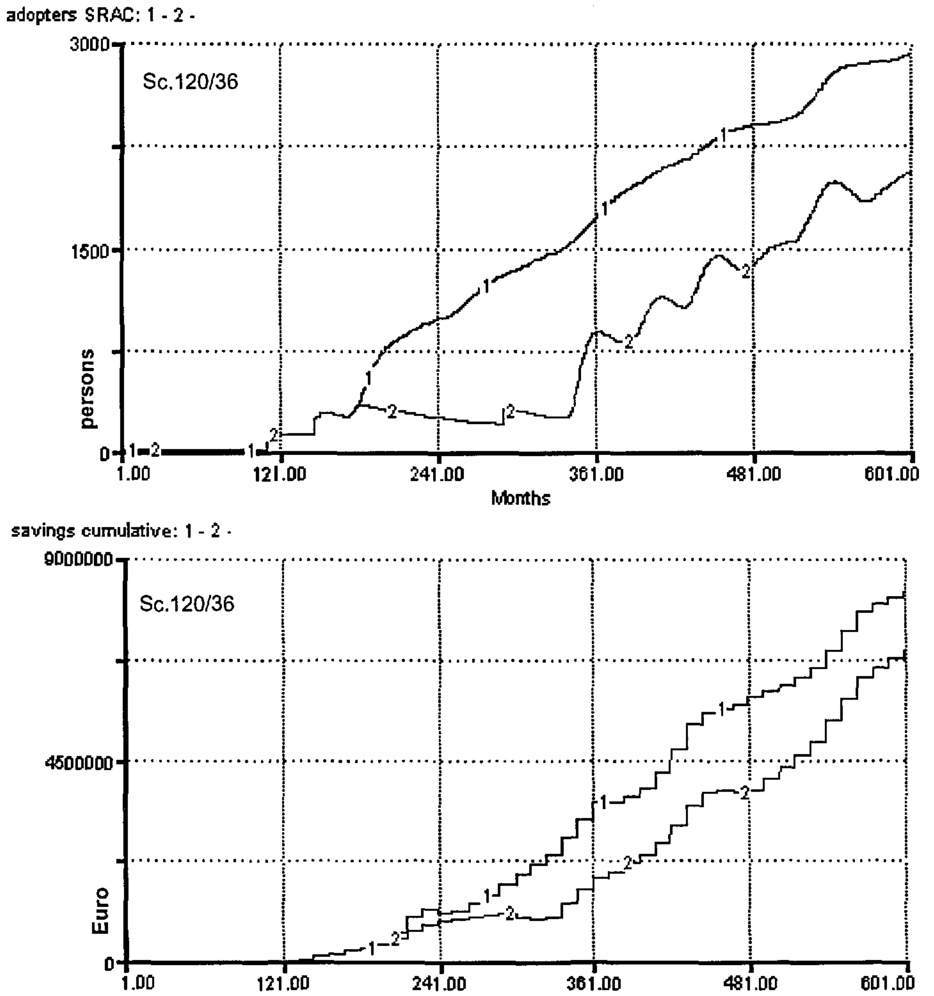

Figure 107: What if the competition caught up before commercialisation Sc.120/36

The impact is dramatic. SRAC adoption needs an additional 10 years to break into the market (from 3 to 13), its cost rises by 30% (not shown) and the delay takes 8% off potential savings. Savings do occur nevertheless and the lesson here is that policy makers need even harder stomachs as they are called not only to press ahead with a designed strategy but more than triple it in time and beef up its budget by a third. If that decision needs to be taken (even worse when one has to convince the treasury as well) just when it seemed the programme was successful, this insight is vital. It shows that money will not be necessarily wasted, however, it should be assessed in detail.

7.3.3 ECONOMIC RECESSION

Natural disasters happen in the nip of time and their impact is immediate to the region and/or people affected. So are acts of terrorism. Epidemics can be equally devastating but alter perceptions and trends in a more profound way. In addition to a global or regional economic recession *per se* (as the banking crisis at the time of writing), any of the above situations and many more could cause a slump in tourism arrivals to the Greek islands.

Suppose that a recession is introduced in the form of a sudden drop in arrivals in month 170 which lasts for ten years, during which the arrivals gradually rise, as in Figure 108. The crisis is so hard though that even the carrying capacity is affected (Line 1 below), i.e. infrastructure on the island is diminishing, possibly manifest in permanent closure of commercial establishments and hotels.

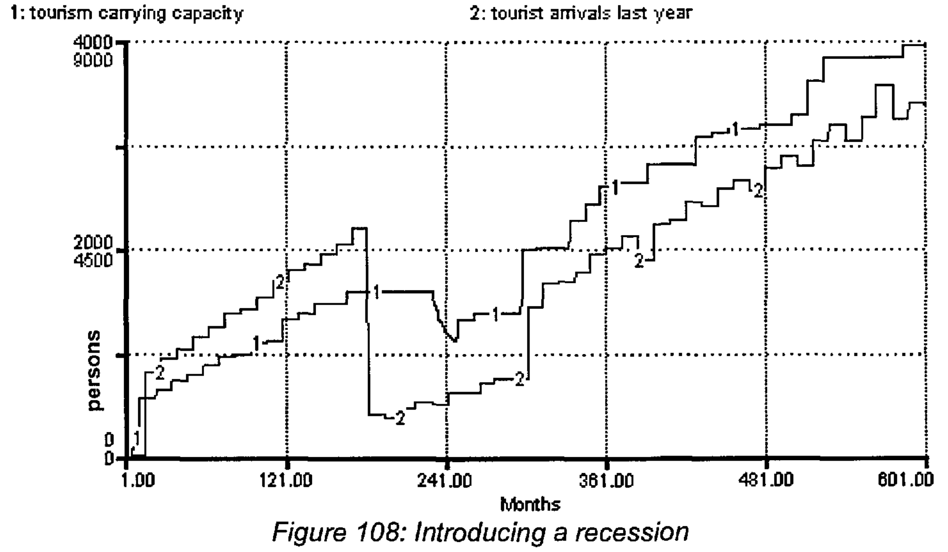

Figure 108: Introducing a recession

Would a support programme still have any influence in the power sector in such occasions? What would that be? Would it pay off? These questions are addressed comparing the three sample support schemes in years of recession to the no-intervention case under two conditions: the intervention commencing shortly before and shortly after the crisis.

For the long-winded Sc.20/12 portrayed in Figure 109, Line 1 in both graphs represents the no-intervention under recession case, Line 2 intervention at month 150 and Line 3 at month 190 after the start of the crisis. The impact on installed capacity is negligible. However, a degree of savings does occur in both situations, more so apparently when the scheme had been introduced before the economic conditions turned around. Indeed, in that case the programme lasts 21 years until commercialisation, 5 years longer than under no major recession, and pays for itself within 2.5 years after that. When the support scheme is introduced during the crisis, it does run for 19 years but does not succeed in covering its costs within the simulation horizon.

What if a more rapid, albeit more expensive, deployment is tried?

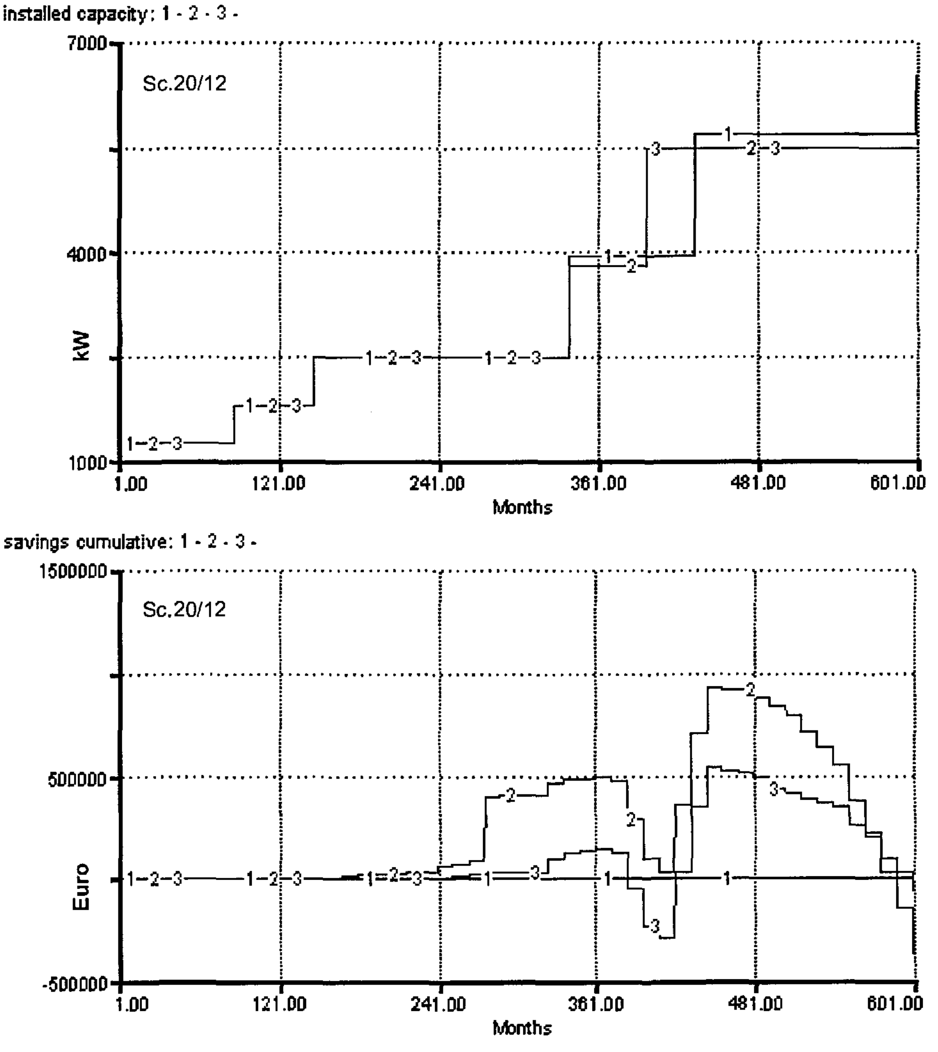

Figure 109: What if a recession occurs, Sc.20/12

Figure 110 examines Sc.120/36 where indeed the potential benefit can be clearly noticed in installed capacity while the savings seem significantly higher than for Sc.20/12 (the Lines correspond to the same situations as before). The great difference is the scheme's duration in this case compared to the no-recession deployment for Sc.120/36. If such a support scheme were introduced before the crisis hit, due to proper reading of the signs or simply luck, it would need 12 years for the technology to reach commercialisation; up from 3 years under stable economic conditions. From then on it only needs a year to pay itself back.

When introduced after the recession has kicked in, although the deployment reduces to 9 years, it needs another 9.5 years to BPE. A total of 18.5 years compared to 13 years, if the policy-maker can be pro-active.

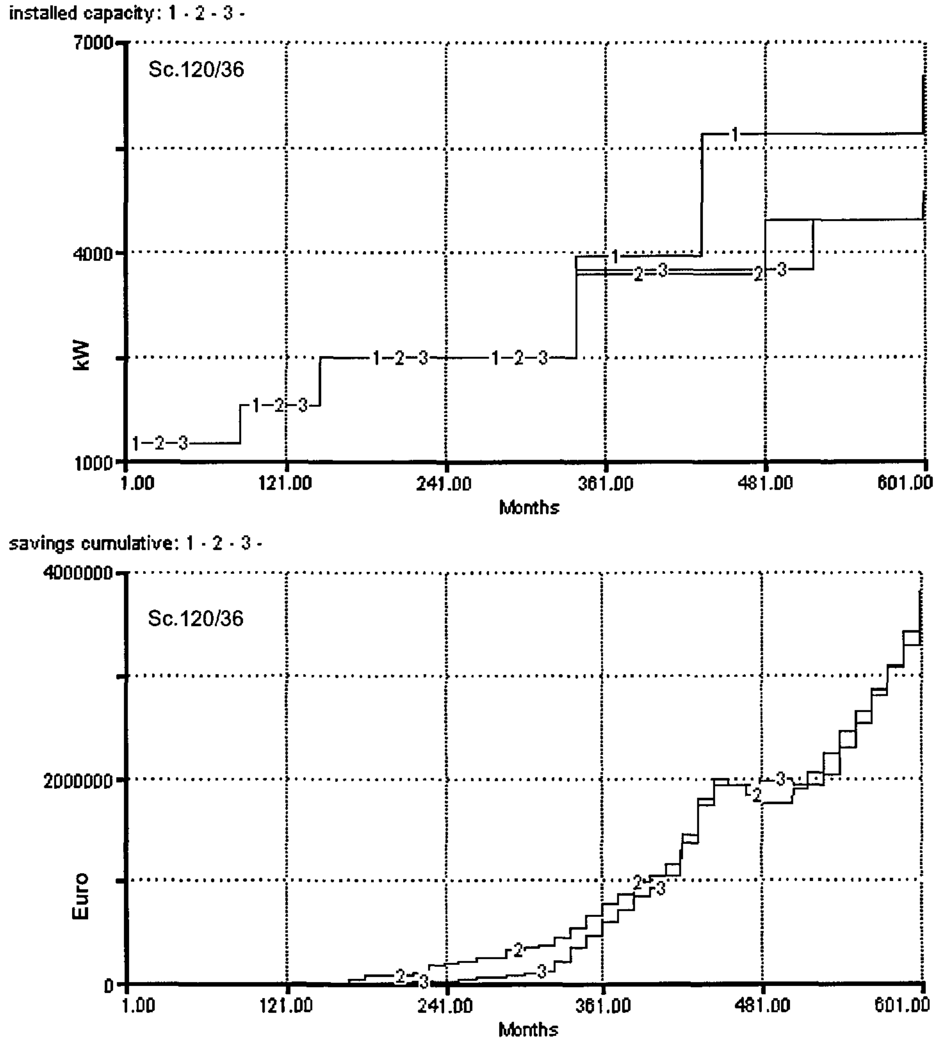

Figure 110: What if a recession occurs, Sc.120/36

One can assume then that an even more rapid response, like that of Sc.200/0 would produce even better results and provide better control. The model categorically alleges the opposite in Figure 111.

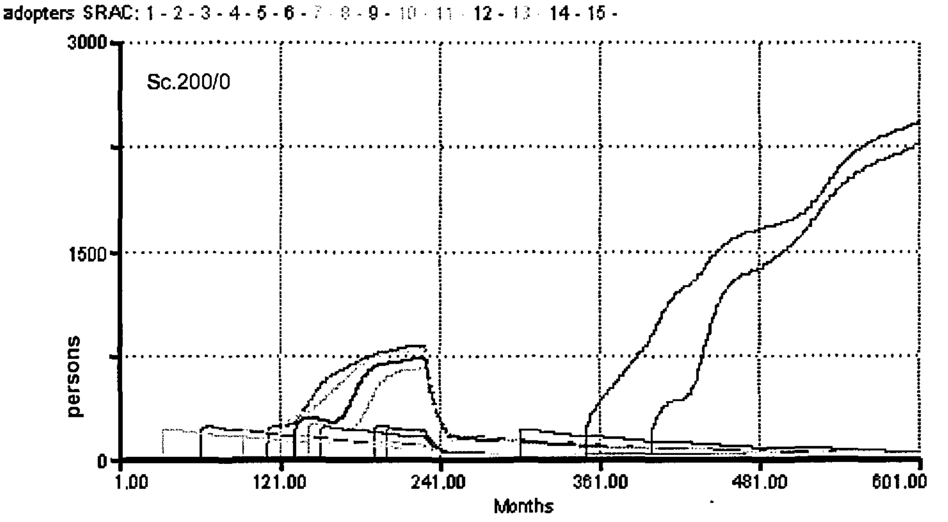

Figure 111: What if recession occurs, Sc.200/0

As a matter of simulation fact, the scheme totally fails to produce any result at any point of introduction unless well after the recession, once the system has stabilised under its new conditions. The diffusion does not pick up less than three years after the recession. On the other hand, when tried to introduce earlier in the simulation expecting to build some defence in the system, the dynamics of adoption were not favourable to support the diffusion.

Other than testing to acquire insights into the behaviour schemes generate under an economic downturn and the power of simulation to look into a variety of strategies, no best option can be adopted as crises do not usually come knocking. Even if they do, it might take a policy agent long to react. If policy making can read the signs well, there might be better chances of success acting pre-emptively (comparison between Sc.20/12 and Sc.120/36 above). Indeed, once a recession has set in, efficiency can still alleviate the burden of power provision in the islands and other regions under similar settings. Being overzealous, however, does not pay at all and the model showed a response counterintuitive to the common sense expected after the two first scenarios were tested above.

Perhaps the greatest difficulty to the policy makers in such situations is how to make a case for more spending when a crisis is imminent or ongoing. Under proper design and evaluation it stands good chances of paying back in the future, nonetheless, in longer horizons.

7.4 CONCLUSIONS

Three sample support schemes to diffuse the energy saving A/C were chosen. Their comparative impacts on the system were studied, as well as their performance against the established business as usual situation. Many insights were expected and confirmed while the simulation revealed more that on occasions was counter-intuitive to expected model behaviour or apparent common sense. The simulation demonstrated that the understanding of complex dynamics, feedbacks and delays is crucial when designing a strategy for energy efficiency. It also firmly supported the belief of this thesis in a wider and inter-sectoral approach to energy policy that could be highly customised with the assistance of System Dynamics modelling.

Across the scenarios the island's competitiveness was protected while the benefits to both the consumer and the utility in particular were evaluated. The modelling showed that no scenario can ever be absolutely 'safe', since even under stable economic conditions a number of random variables can critically alter the end result. If one considers that reality has many more data to evaluate and act upon, then the capabilities of a modeller and the availability of data is of paramount importance to the validity of the simulation. Thus, in the Discussion and Conclusions chapter, further research will be suggested to strengthen the model, clues to much of which were uncovered in this chapter.

The objective is not to choose the 'best' scenario which proved heavily dependent on the aims and resources of the policy-maker. Under different circumstances different schemes will work. More so in that the schemes will not work in isolation but under a greater strategy whose critical factors the simulation can help to identify. In this case, how to reinvigorate the solar water heater manufacturers and introduce them to the technology in order to achieve the PR envisaged could be part of it.

Thus, on occasions, the commentary on the simulation outcomes led to wider discussions on sustainability seemingly flying off at a tangent to the thesis' topic. However, no energy efficiency measures can be discussed in isolation, more so when a niche market with potential global impacts is in the epicentre of the research. The author deemed it necessary to expand on the occasion, at times simply acknowledging the link and at times providing an extra figure or line in an existing graph to elaborate further if adding to the completeness of the analysis.

The learning and shared vision the simulation provided, did also have to do with unexpected occasions. It is unthinkable not to take advantage of a simulation in order to explore the navigation of changes of circumstances. For example, in order to generate arguments for policy-makers to lobby for marginal cost pricing of electricity. Policy-makers themselves must have an idea of the impacts the performance of the economy sector(s) predominantly driving their power system have in general and on their diffusion scheme. A policy maker should consider uncertainty and extreme events in securing the financial viability of an intervention. To that extent, this chapter proposed Real Options as a potential tool to further appraise the long-winded Sc.12/20.

Each variable in the simulation of this thesis could be tested. Here, however, those with the greatest demonstration potential were chosen. Others would replicate similar insights from another perspective. Various rates of PR would generate different reactions. In that case, an appropriate set of new scenarios would be chosen and tested, leading to similar kinds of observations.

A few more words need to be said on the progress ratio. The model adopted a similar PR under all schemes examined, which was assumed to include both local/national and international learning. The local element of learning can most likely ensue in the short and longer term, since it is associated to local entrepreneurship, marketing, technical and institutional capacities. The case of the solar water heater market showed this in its 30 or so years of existence. The international element though may be associated with advances in the manufacturing know-how of patented technological components, proprietary scientific R&D and exotic materials. Unless the local market develops more or less along with international progress, a doubling of capacity in Greece will not absorb the entire PR assumed or have an impact itself.

Although tempted, the author did not experiment with various SRAC setting and prices either. Again, the observations would be similar. Unless there is a specific variant one wants to try, the insights remain valid under a range of SRAC ratings. New scenarios would have to be worked out and tested in search of specific inquiries.

The best way to reveal more of the potential of the simulation model built would probably be hands-on involvement. Although a large scale demonstration and evaluation of its training potential was not in the initial objectives of the thesis, a small exercise was undertaken. A simple interface was designed that allows access to selected data for the user, while a few variables are made available to manipulation and a single policy objective dictated. Details of the role-playing simulator and comments by participants can be found in Appendix A

8 CONCLUSIONS, STRENGTHS AND LIMITATIONS AND FURTHER RESEARCH

This chapter begins by a brief reminder of the research objectives and context. It then summarises a set of key findings stemming from the methodological approach, the modelling exercise itself, the results and their meaning for the real system and policy-making. The section is followed by an attempt to take a critical stance towards the entirety of the task undertaken in the broader context of energy policy where possible. This leads to the identification of potential extensions to the thesis, alternative applications of the simulation model and suggested topics leading to further research altogether. The aim is to summarise the knowledge gained, the insights achieved, the novelty of the research and future potential study to strengthen its assumptions and uses.

Structure of Chapter:

8.1 OUTLINE OF THE RESEARCH AIMS AND CONTEXT

8.2 SUMMARY OF THE ISSUES AND APPROACH

8.3 DISCUSSION OF MAJOR FINDINGS & CONCLUSIONS

8.4 CRITIQUE OF RESEARCH DONE

8.5 FURTHER RESEARCH

8.1 OUTLINE OF THE RESEARCH AIMS AND CONTEXT

The research had two main aims (Section 1.2.1):

- Build a simulation model that captures the dynamics of the islands' energy systems and portrays the behaviour of stakeholders and its impacts by integrating sectors and concepts not conventionally considered part of utility management, thereby expanding the role of energy policy making in the islands.

- Explore the potential & critical parameters in the uptake of innovative demand-side technologies to assess whether and how these could provide a better service to consumers and improve the financial performance of the small island utilities without impeding the local economy.

And four key objectives set out in Section 1.2.2 (p.17).

The research questions of Section 1.5 are repeated here with a brief comment on how they have been addressed.

1. Are there ways to reduce the costs of energy services in islands without hindering the local economy, while continuing to satisfy the current energy service needs of the people and manage their evolution?

   To provide a meaningful thesis, the author decided to identify a specific intervention point. The thesis meticulously analysed the Greek islands singling out space cooling as such a point and resulting in a number of observations on the background dynamics interrelating the costs of power, the local economy and stakeholder objectives (Section 3.2 and Chapter 4). These observations and additional assumptions were tested in the simulation model (Chapter 6) where it has been shown that it is possible to concurrently improve the finances of the utility, allow the growth of the local economy and not place any restrictions on the energy use (Sections 6.3.3, 6.3.4.8, 6.3.4.9 and Chapter 7).

2. Could the interests and objectives of consumers, local business, government planners and the utility operator towards sustained community growth be balanced through the introduction of innovative demand side management and technologies?

   The demand-side intervention envisaged addressed possible concerns of major stakeholders identified by means of a potential self-financed "spiral" of energy efficiency (Section 7.2). Special attention was given to bring out the benefits accruing to each stakeholder group during the model building exercise (Chapter 6). No restrictions were put on the household although it is suggested that many DSM measures should be examined in the sector. Visitors on the other hand who mostly spent energy indirectly by services they receive (e.g. shopping in air-conditioned shops or dining, renting vehicles etc.) do, according to the model, receive the same service as similar destinations in the region provide (defined in Sections 6.3.4.1 and 6.3.4.2).

The commercial actors in the tourism business are able to extend the service coverage, in terms of space cooling as discussed in the thesis, or use the savings achieved to reduce their cost; in both cases increasing the islands competitiveness (*ditto*). Finally, the utility can reschedule their investment plan and save costly peak power while the central government is secure, under conditions, to receive the funds of efficient equipment diffusion back (Section 7.2.6).

However, the specific design of such an intervention would always be based on assumptions of system behaviour and it would be susceptible to random events. The thesis discussed critical parameters that could negatively affect diffusion (Section 6.3.4.9) and also studied the model's behaviour to extreme events in What-if scenarios (Section 7.3).

3. What are the critical parameters in technology commercialisation in the Greek islands and what are the interactions with existing perceptions of social policy and local economic structures?

Concisely, one should consider the local merits (national and island-specific) and comparative advantages in a customised approach to DSM; an approach advocated in this thesis (Section 7.4). For example, the high level of entrepreneurship needs to be fostered by sketching images of a commercial market or a trade. To this extent this thesis monitored arrivals and the size of adopters along with a comparison to competing destination (Section 6.3.3). Since Social Obligations for the tariff are in place, the merit of power efficiency needs to be portrayed as increased competitiveness or profitability.

Learning effects were not studied in as great detail as originally expected but according to the detailed overview of the domestic solar water heater market, there is a great potential of repeatability, synergies and spill-over learning

(Chapter 5). Nevertheless, the simulation model has integrated a learning component in its structure assumingly incorporating all learning (national, international and local) which is a critical parameter in the diffusion of efficient equipment in the islands (Section 6.3.4.7 and 7.2.3). The study of its leverage in niche markets in the islands is suggested for further research in Section 8.4.

Next, the findings of the research are being comparatively and critically discussed with references to the real situation in the islands and the relevance to policy making.

8.2 DISCUSSION OF MAJOR FINDINGS AND CONCLUSIONS

A thorough investigation of the energy situation in the Greek unconnected islands was performed and culminated in the design and execution of a simulation model customised around the research aims of the thesis. The literature suggested that a great many studies are devoted to the supply of electricity, whereas a key issue is that of demand management, of energy services and not simply the provision of more power. The critical literature review showed that, whether it is wind power, solar PV or hybrid systems, the economic structure of the Greek islands and the blanket social policies of the State – with no consideration for the actual wealth of each island – have created a vicious cycle of power expectations and supply dependence that is admittedly financially unsustainable. Demand side intervention has been ignored and there has been no concerted and comprehensive DSM programme in either the islands or the rest of Greece, for that matter. Occasionally, researchers have looked into the technicalities of energy conservation in buildings and reported expected benefits to owners/users, with significant findings, albeit their studies did not include appraisal of possible policy pathways (e.g. asking how to provide incentives) or did not relate their findings to utility finances.

One of the initial modelling decisions was to model the tourism industry separately from the household sector. That required a series of assumptions such as how the two interact and their energy use profiles which had to be built from scratch since that sort of segregated data does not presently exist. The ensuing structure followed from the literature review, which showed that intervention priority should be given to the tertiary sector and furthermore that space-cooling would be the most significant service to focus on. Once the model had been assembled, the calibration tests carried out reproduced the average behaviour observed in the islands. In addition, a key behavioural characteristic of households was assumed and tested successfully; that of a parasitic behaviour towards excess off-season power capacity. That collateral insight itself might prove an argument to specifically target household appliance labelling campaigns to the islands and to provide incentives to replace older equipment.

Other gaps identified in the critical review of the literature were a predominantly top-down approach, lack of simulation of stakeholder behaviour, a focus on the symptoms and not the causes, wide application of optimisation techniques and a neglect of non-linearity. Most notably, discussion of energy policy-making in the islands tended to assume factors that directly affect it, such as forecasts of future demand, to be exogenous, although they in turn depend on tourism arrival trends. Similarly, issues of information flow, accumulation (of information or perceptions) and related delays were at best implied or qualitatively mentioned. Correlation might have been stated but causality was not being explored.

The thesis did manage to incorporate such softer elements into a socio-economic model that portrayed the behaviour of economic actors, their perceptions and rules-of-thumb in decision-making, along with representations of techno-economic power sector formulations in the more classic sense (i.e. loss of load, capacity addition, load factor, peak forecast, specific fuel consumption etc.) representing the utility operator.

As set out in its aims, the thesis pragmatically addressed the current issues in the Greek islands and explored how to reduce the utility's financial losses without compromising the local economy. A main insight is that demand-side intervention not only can reduce the costs of power both to the Public Power Corporation and consumers alike, but that it also can create a virtuous "spiral" of efficiency if learning dynamics are concurrently considered and supported in the choice of technology to be introduced.

There could be many ways to ensure this. The thesis suggested that a 5-year purchase and operation cost was an appropriate horizon for the comparison of the two competing variants of space cooling. From then on, a sample choice of three scenarios was studied and a range of significant observations reported. One of them related to the persistence of an efficiency programme even when economic conditions change. The extreme conditions though have to be tested for the right choice of a scheme and it is suggested that policy-makers might use a tool like the one suggested here to decide what dangers to hedge against or watch out for (by constructing specialised indices, for example).

A critical component of the approach and a novelty of the simulation was the parallel monitoring of the simulated island's competitiveness as a touristic destination, on which the coverage of space-cooling and the average rating of A/C equipment have an impact when compared to the regional average. Thus, a strategic viewpoint for the policy-maker was achieved that expanded beyond the energy system to the overall economic entity that it supports and that consequently affects the energy system's development. The thesis also showed that through the use of System Dynamics, the viewpoint and vision of the future can be shared in a common language with other stakeholders.

To examine the policy of intervention, the author had to search for critical success factors and variables for the envisaged niche market. The Greek DSWHS market received further analysis because as it has been a success story in the country, acknowledged worldwide. Technologically, as well as in terms of deployment and marketing, it is quite similar to the proposed introduction of solar assisted air-conditioning. For example, both use solar energy, had to compete with established electric variants, and needed local entrepreneurship and as well as manufacturing and assembly. Thus, the State can draw lessons from past experience, while the model itself used an adapted progress ratio from the solar water heaters sector incorporated in its learning loop.

A variety of tests to assess the validity and robustness of the model were carried out successfully. Useful insights with respect to system delays were reported and in many instances 'common sense' assumptions were broadened. For example, information about the level of competition seems to play an important role in the magnitude of the response of the services sector, which as a result can eventually cause over-investment in capacity to the utility by amplifying signals of power needs. Also, better-devised capacity margins and loss of load thresholds can reduce pressure on capacity expansion across the Aegean Sea islands, effectively undermining the self-fulfilling prophecy of exponential growth that is currently driving the island power systems. Other assumptions were confirmed, however, such as the benefits of innovation that made the island more competitive (in terms of service coverage), actually a leader, as soon as a diffusion scheme managed to launch the technology commercially.

The thesis has a major contemporary value not only because it examines the continuing issues in the autonomous islands but also because it addresses the current concerns of national energy policy. As the summer approached and A/C use once again is expected to threaten the power system, the government announced on June 10 2009 a replacement programme of older A/C units with modern inverter units; mainly targeting the broader Athens region (Attica). The budget is €15 million and the aim was to replace 50,000 units, which was achieved within the first two weeks of the roll-out. Consumers are subsidised by 35% of the cost of the inverter A/C, up to a maximum of €500. Apparently, the scheme achieved 65,000 replacements as of June 25 2009[28]. Nevertheless, this figure only represents approximately 16% of the estimated old variant units (400,000) reported in the same newspaper article.

The efficacy of these measures will be shown later in the summer of 2009 as the temperature rises although it is in general a step in the right direction overall. Unfortunately though, it seems the measure's main motivation is not efficiency but is the support of the market to confront the impacts of the global liquidity squeeze. Its impact will stop as soon as the money pump is turned off, therefore, and there will be no long-term benefits to the market, since no local capacity is supported apart from the cash flows of large electric good retailers. Although not accurate enough for reasons mentioned later here, the simulation suggests that a roughly €1,000,000 scheme of the sort suggested in the thesis could put an island in an irreversible orbit of space cooling efficiency, while at the same time potentially helping to build an international champion industry in solar air-conditioning in the country.

To conclude, focussing on the Greek unconnected islands and their specific socio-economic characteristics, the thesis contributes to debate in contemporary energy policy, while the novelty of the research stands both in addressing the energy problem of the islands through the construction and testing of a dynamic non-linear behavioural simulation model and in the educational/training value that the methodological approach and the ensuing model can have. The latter's potential has been briefly studied by means of the role-playing simulator and left to, hopefully, subsequent extensions to this thesis. Before proceeding to further research though, it is important to elaborate further on the main strengths and weaknesses of the work.

8.3 CRITIQUE OF RESEARCH DONE

Despite modelling a potentially successful intervention in space cooling for the tertiary sector, financial losses in the islands remain, albeit reduced. Savings from efficient A/C equipment could be quite possibly overshadowed by the spread of other electricity-based services currently on the islands (or as rapidly introduced as A/C) or simply by the continued growth of hotels and households themselves. As an example of the former, desalination employing power demanding reverse osmosis is promoted as the solution

[28] Reported by Antiope Schina on 26/06/2009 in the financial daily Kerdos: www.kerdos.gr/default.aspx?id=1038952&nt=103 [Accessed: 28/06/2008]

for islands with no natural aquifers and any other island where currently summer water demand is covered by tanker ships from Piraeus, the port in the vicinity of Athens, nautical miles away from most islands[29].

Indeed, a proper DSM programme and an electricity efficiency plan would need to look at all power consuming services and their evolution in time. Recognising the limitations of breadth and horizon, the thesis provides a new framework under which to consider energy policy decision-making in a localised and customisable way, calling for an intra-sectoral and multi-actor review of a situation in the design of an intervention. A tool expanding from this thesis could be used, for example, to evaluate the strategy, options, risks and success pathways, along with the inclusion of stakeholders' objectives and concerns.

In studying the intervention technology a specific solar A/C unit was not tested. Rather, power ratings and related costs were assembled from a variety of literature and the internet. This was mainly due to the lack of a standardised product, even if it was to be a prototype of some sort, on which to base costs and consumption ratings. Although the key behavioural characteristics of the system were captured, if the need arises for such a use, the equipment related elements of the model have been designed so that they can be adapted accordingly.

The simulation of a single 'real' island was not attempted, as it was deemed there would be unnecessary attention given to the behaviour of a specific energy system when the collective 'average' behaviour and common trends in causal interaction were the objects of the study. The calibration points for the main demand/supply sub-model were made up of average figures from the selected group of islands. In the Further Research section, the application of the simulation model on a single existing island is suggested as a topic of further study.

More time could have been devoted to the impact of learning and niche markets in the islands. Nonetheless, the related theory, included here as an Appendix B, was studied to an appropriate depth for the aims of the thesis. However, the author feels more insights into particular areas could have been drawn from the simulation. More complicated structures could test and challenge the concepts and theory of technological progress and innovation. Similarly, the learning dynamics could be further

[29] On June 12 2009, the Minister of Mercantile Marine, The Aegean and Island Policy, Mr Anastassis Papaligouras, and fourteen local island authorities signed a Programming Memorandum for the installation of integrated desalination plants by twelve plus three year tender contracts with the private sector. Reported in financial daily Naftemporiki on 12/06/2009: www.naftemporiki.gr/news/static/09/06/12/1676211.htm.

disaggregated in specialised "learning-by-" components and discussed further, allowing parallel learning loops representing various aspects of international, national and local progress to be assessed and studied.

The model has achieved the representation of the demand, generation, fuel consumption and marginal cost profiles typically found in the Greek unconnected islands. During the break-down of the dynamic behaviour, the author suggested that the loops responsible for the vicious cycles of rising demand could be turned to virtuous cycles of ever-increasing efficiency. This hypothesis held true and test runs indicated key elements of success to address in a real world situation, such as adopters' perceptions of payback and the perception of competitiveness urgency affecting the willingness to adopt.

Such insights can be invaluable to policy-makers, even if their impact is mainly a broadened understanding of energy issues and is not translated into specific actions. On a practical note, during the building and testing of the model, notions of marketing and dissipation of information or monitoring of key economic developments sprang up at various points in the analysis. Thus, the success of an intervention might call for a press campaign or the manipulation of word of mouth mechanisms. That was the case in domestic solar water heaters, for example, especially during the 1980s, in parallel with an effectual financial support programme. The modelling suggests that it should not be left to chance and the far-sightedness of people that happen to be in a key position at the time, but rather designed endogenously from the beginning.

These sort of dynamics were incorporated in the model in the form of delays in information flow or decisions. For example, the time to update regional competition indices and consequently the potential adopters' time to decide and act (or not act) upon those perceptions. Manipulation of such variables can make the difference in borderline situations, possibly costing less than an expansion of the support scheme itself. Finally, the model's financial appraisal tool worked satisfactorily; however, it allowed only a specific type of support to be tested, i.e. direct subsidy. A wider range of instruments could be investigated in future applications.

8.4 FURTHER RESEARCH

As mentioned earlier, a more detailed study of the learning rates of the technologies could be very beneficial and allow more flexibility in the planning of diffusion schemes and the control of market growth. The diffusion dynamics themselves could be augmented by the introduction of more complicated dissipation of information and marketing loops.

The cost comparison that drives the relevant flow to either ELAC or SRAC is abrupt, acting as a switch when the cost comparison is favourable for the SRAC. It could be rebuilt to incorporate the innovator type of adopters who, according to theory (see Appendix B), are willing to pay a premium to be pioneers even when the price does not compare favourably. Thus, substitution could be smoothed out and possibly studied better.

The simulation model raised a number of issues and held many assumptions that could form the basis of an extensive survey of energy use in the islands. That would include the visitors, the residents, the commercial operators and the utility alike. The analysis of the results could possibly hold a thesis itself; however, significant additional elements to the formulation of the thesis' modelling structure could be made if there were better data and thus achieve an even more convincing model that is less based on literature. Perhaps, such a survey focussed on a single island could also accommodate the historical calibration lacking as mentioned in the previous section.

Proper bottom-up disaggregation of household and tourism demand based on collected survey data would be invaluable. The impact of arrivals on income growth and consequently household electricity consumption is missing further clarification in this thesis. Also, the link between the competitiveness of a destination due to cooling comfort and arrivals needs to be elaborated to a greater degree, e.g. researching its elasticity. From such field research perhaps the simulation could expand to general electric comfort competitiveness. In turn, that might lead to greater efficiency measures covering a wider range of activities and services.

Perhaps, that extension could then spill over to the water shortage issue that is qualitatively very similar to the electricity problem and the discussion then becomes one of the overall sustainability of the touristic product and the ecological appeal of Greece, in terms of the rising trend of eco- and agri-tourism.

More complicated support schemes could also be introduced in the simulation. In case a specific technology needed to be supported, the model would then be used to perform tests and assess detailed rebate schemes, soft loans, tax credits or indeed combinations on those, depending on the sophistication the modeller would be able to add to the original structure and the requirements of policy.

Finally, further elaboration of the training potential of the simulation model should be explored. Various concepts of energy policy making can be focussed on working out ways and presentation sequences to bring them out, such as planning routines, investment appraisal, choice between RES and DSM, to name a few. Also, collective behaviour lessons through role playing, such as those demonstrated by the popular System Theory role-playing games Fishbanks (tragedy of the commons) or the Beer Game (boom and bust cycles) could be explored[30], expanding from the draft tested here (Appendix A). For example, groups of participants could each manage an island, competing against each other for visitors by lowering their energy costs. They would be given identical options of investment in diesel generators, wind power and efficient demand-side equipment.

The choices of each group would not only give them a unique power mix and cost but in the background affect dynamics that would only be later revealed to the participants. For example, the progress ratio and economies of scale when they collectively invest in efficiency will cause the price of a technology to drop. Or, the price of fuel that will increase if they collectively or a major group of them goes for the safe diesel generators option through some sort of environmental tax due to more pollution in the Archipelago. At the debriefing at the end of such a session, analysis and insights would be given to the collective behaviour and perhaps the factors behind the best and worst performing groups.

If negotiating skills and deeper utility economics were part of the curriculum of such a game, then at some point in time, the participant groups could be given the chance to interconnect their power systems through some sort of central government subsidy. They would thus need to financially appraise the best submerged cable link they could afford.

[30] These are both computer simulated role-playing games. Fishbanks was developed by Dennis Meadows at the Laboratory for Interactive Learning of the Institute for Policy and Social Science Research, at Hood House - UNH, Durham in the USA. Participants experience the "tragedy of the commons", and the way human nature focuses on the short term, and in so doing, can destroy resources critical for long term survival. At the beginning of the game, each fishing company has equal amounts of money and fishing ships. Each company has the same operating costs and technology. At the start of every simulated year, the teams make decisions about buying or selling ships, whether to fish or not, and where to fish. The object of the game for each company is to maximize profits. The Beer Game was developed at MIT in the 1960's to clarify the advantages of taking an integrated approach to managing the supply chain; it particularly demonstrates the value of sharing information across the various supply chain components. The purpose of the game is to meet customer demand for cases of beer, through a multi-stage supply chain with minimal expenditure on back orders and inventory. Players look to one another within their supply chain frantically trying to figure out where things are going wrong. Players wonder whether someone in their team did not understand the game or assume customer demand is following a very erratic pattern as mounting backlogs and/or massive inventories accumulate, in what is termed the *bullwhip effect.*

In conclusion, the research has managed to address a problem of the real world through a valid and coherent methodology and the construction and testing of a working simulation model. It contributed insights into to the policy issue itself and discussed it in the wider field of energy policy. The main findings and strengths were identified and key limitations have been followed by proposals for further research.

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APPENDIX A: THE ROLE-PLAYING SIMULATOR

Structure of Appendix:

A.1 Introduction

A.2 Experimental Tests of the Simulator

A.3 Summary of Participants' Observations on the Simulator Experiment & the Process

A.4 Conclusion and Prospects

A.1 INTRODUCTION

The simulation model of the thesis was adapted to include a simple interface for the purpose of testing its potential as an interactive learning tool. There are two potential sets of users are envisaged.

On the one hand, the thesis has advocated a new framework for energy policy in the islands and criticised the methodologies and perceptions that underlie the current practices. As such, the first aim of the interactive simulator is to help agents of policy making in Greece to be interactively led to deduce for themselves the nature of the dead-ends to which the management paradigm of the past 30-40 years has been taking island utilities. At the same time, it aims to provide them with new insights into:

- The diffusion of technology, its impacts on the power systems of the islands through time and the methodology for identifying and assessing intervention opportunities (such as space cooling in the tourism sector, as suggested in the thesis)

- The use of technological progress and learning curves to plan diffusion schemes that are financially sustainable as well as balancing social and private benefits, with the aim of ensuring win-win interventions.

- The understanding of interactions and feedbacks between the power system and the local economy, as well as the potential to devise energy policy more closely knitted to the islands' needs.

- The drivers of energy consumption and potential intervention points on the demand side, in addition to the simulated scenario of space cooling in tourism.

On the other hand, as a second aim, the role-playing simulator can introduce students of energy policy, through a hands-on exercise, to the concepts of learning rates, technology diffusion and demand-side management, as well as issues related to tariff structure, marginal costs and capacity planning. It can be all the more exciting if it is revealed that the solutions and insights that they come up with could have an impact on a real system, i.e. that of the Greek islands on which the model is based while the application and value of model-based education is elaborated by Graham, Morecroft, Senge and Sterman through the concept of 'microworlds' (Graham et al. 1992).

A.2 EXPERIMENTAL TESTS OF THE SIMULATOR

The draft simulator is at present designed as a one-to-one exercise and requires the presence of a skilled facilitator with knowledge of the model's background dynamics and the policy issues and practices. After an initial outline of the exercise, the participant is given a sheet of paper explaining the setting, the plot and the roles.

Three students of the MSc in Environmental Technology and a PhD candidate of the Centre of Environmental Policy at Imperial College London volunteered to participate in the experiment. We will refer to them as A, B, C and D. Their names are available upon request. In the experiment, once a participant has read the explanatory sheet, as in Box 1A, they are presented with the simulation screen on Figure A1, which is paused at year 20 (that is month 240 out of 600, which is the end of the simulation, i.e. 50 years in total).

In this screen, they are shown the statistics in the introduction sheet and are familiarised with the graphs and how they should be read. Reminded of their aim and shown where the scheme parameters are (top right hand side), their attention is eventually drawn to the graph at the bottom right hand side corner. It sketches the visitor carrying capacity of the island, as well as the number of adopters/receivers of the ELectric Air-Conditioning (ELAC) service up to that year. The figures at year 20 (month 240) are 1,211 and 528 respectively and a brief introduction about the diffusion of technology is given at this stage, aiming to guide them on the likely size of their first trial scheme.

THE SETTINGS AND OBJECTIVE

Through a Public Private Partnership (PPP) for electrifying a complex of small remote islands in your country, you, as a private investor, have installed and are operating a power plant in one of the islands.

The availability of power has had a significant and unanticipated effect on the number of leisure visitors to the island. As a result, a tourism industry has actually sprouted. By the 20th year you were forced to undertake a second major capacity expansion; as a result, the plant is now 3.5 larger than when you started (shown on computer screen).

The tourism is very seasonal (80% of arrivals in July and August) and is positively correlates with the power peaks. The peak has been growing at an average 9% annually, whereas consumption has only grown at 4% per year (now forecast to rise to 23% and 10% annually within 30 years at current rates respectively). The peak season also keeps your load factor very low, as the winter demand of your permanent residents is much lower. Your business plan is up in the air and you are losing money.

Your total costs have reached €0.50/kWh, of which the government subsidises you with €0.15/kWh (these are the annuitised costs in your business plan). Still, the authorities have set the tariff at €0.08/kWh and you are committed to maintain this by Social Obligation Agreements.

The government did not respond to your effort to persuade them to relax those obligations and let you raise the tariff. They are only willing to subsidise a demand-side management (DSM) programme. You have called in a research group which reported that due to regional competition the tourism sector in the island has been rapidly installing cheap space cooling technology that is very inefficient. It is identified as the single major contributor to the extreme system peaks in the system, both at present and for the future.

You are now sitting with one of the government policy makers (the Facilitator) negotiating on the layout options for the subsidised diffusion scheme for SolaR-assisted Air-Conditioning (SRAC) units. The government's condition is a Break Even Point (BEP) within a maximum of 15 years, yours is to achieve the greatest savings possible by the end of the simulation.

Definition: the BPE is the point in time where the Net Present Value (NPV) of the cost of the scheme equals the NPV of the savings achieved.

You have three options to test on the simulator, from which you will choose the best option.

Trial	Scheme			Savings NPV (€)	Scheme Cost NPV (€)	BEP (years)
	Size	Frequency	Duration			
1.						
2.						
3.						

Box A1: The plot of the game and its objectives

As an example, Figure A2 shows participant D's scheme of 150 units every 2 years for a duration of 10 years. The simulation screen now shows the impact of the intervention in graphs I and II (Line 2 is the BAU case, as indicated in the top of each graph). Here are a few words said about peak-power saving, demand-side management and the cost value of money brought about by not only reducing the total installed capacity but also deferring additions to the future. Graph II is the year on year financial savings which are shown cumulatively and in net present values for each year of the simulation[31] in graph III. Finally, graph IV shows how the diffusion and replacement of equipment has developed. In this case, a successful market in SRAC was established once the scheme was completed (Line 3). However, no break-even point was achieved within the requirements of the government or indeed the simulation horizon, as the relevant display in the bottom left hand side corner reveals.

Participants A & B went for a first scheme of 100 units (maximum 200 allowed) annually over 5 years. Participant C, on the other hand, had a much more cautious approach of installing 50 units annually over 20 years.

Before the next trial, the participant is talked through diffusion dynamics and the replacement of equipment. The cost comparison between the two variants and the existence of a learning rate for the new technology is introduced and briefly explained if the participant is not familiar with the concept.

If the objective of the BEP has not been achieved or is above expectations then the displays of the NPV of savings and the scheme's cost are examined in the bottom left hand side corner. Through a quick calculation and perhaps revealing the cost of the SRAC unit, the participant tries another scheme. For example, Participant D was asked to elaborate on why he chose to deploy 750 units given the information he had on the carrying capacity and the installed electric units. Similar discussions were undertaken with all participants and, depending on the topics brought up, relevant elements of the model and of energy policy were revealed and elaborated upon.

Participant D, after absorbing the information from the simulator and discussion, realised he needed to reduce the scheme's cost. Consequently, decided to do that both in size

[31] As present, the author refers to year 20 in the simulation, the scheme's introduction year.

and the time horizon of the layout, and on his second run tested 100 units annually over 5 years (instead of 150 units every 2 years for period of 10 years before). Graphs I-III of Figure A3 representing this new scheme tried are comparative so Line 1 is the BAU; i.e. no SRAC is introduced. The savings achieved are similar to the first trial (not shown here but available to the participant) but still no BEP was achieved within the simulation horizon. The participants at this stage (since even if they have achieved a good result, still do not know whether it is the best) are given some more detail about the behaviour of the island's economy and the simulation. Graph I in Figure A3 introduces the dynamics of the island's regional competition to attract visitors. As in the thesis, it assumes power installed per cooling comfort unit as a metric of competitiveness, the average of which is the dotted vertical line. For an explanation about regional competitiveness and its implications, please refer to Sections 6.3.4.1, 6.3.4.6 and 7.2.4.

The introduction of the SRAC makes the island more efficient, i.e. more competitive, allowing it, if necessary, to expand its service coverage, as seen in the testing of the model in the main body of the thesis (Sections 6.3.4.9 and 7.2.4). However, the fluctuations reveal the dependence on the competition threshold, as well as the stock of potential adopters and the comparison of the cost of the available equipment. On the former, the participant is asked to look more closely at graph IV and to discuss substitution and the factors that influence the dynamics of diffusion, such as word of mouth, marketing, service life, technical capacity and other elements for the successful growth of a market from niche to mainstream. On the latter, the comparison of costs on graph III is given where the participant can see at which point the SRAC cost breaks even to that of ELAC; an effect of the working of the learning curve. A point is also made here about the fact that the cost is of purchase *and* operation, not only on the purchase price of the equipment (the graph of purchase cost alone is shown to the participant separately and actually depicts SRAC purchase price never reaching that of ELAC). A short discussion is stimulated, on tariffs and the importance of consumer payback and other choice criteria.

Staying on the same graph, the participant is then asked to think about what the continuation of the line of SRAC cost below the break even point of the equipment costs represents. It is eventually explained that the further down the line goes from the cost of ELAC, the more unnecessarily expensive their scheme is, since it has already achieved a competitive cost comparison (assuming that the consumers of that society find the 5-year cost comparison acceptable for adoption, as the thesis suggested for the Greek islands). In a case like Figure A3, the participant would be asked to think of a way to shift SRAC's curve upwards. However, this cannot only be achieved with fewer units. Graph II is used to assist the participant to reflect on time-phasing as well as size.

It shows the paths of SRAC adoption between the two runs (Line 1 is BAU). Their attention is drawn to what seems to be an upper limit to adoption. It is explained through the use of an additional line revealed in Figure A4, graph IV, Line 5 after the third trial. That line represents the potential adopters indicating owners of tourism related establishments who perceive the necessity of space cooling and wait for the right incentives to install (either ELAC or SRAC). Following from the previous suggestion to shift the SRAC cost curve upwards, it is now suggested that they might also ask themselves how quickly could the market get on that threshold. It seems the sooner the better, as it means SRAC becomes commercial sooner and more benefit from increased adoption accrues to the system. However, participant A, who tried a more aggressive policy after these observations, was surprised to find out that he was back at point zero. His scheme was too much too soon, requiring him to put up lots of money ahead of any savings that consequently did not cover his costs by the end of the simulation.

By this point, participants know they have to trade and balance time against money by considering the cost comparison of the equipment and the learning effects, and worrying about the randomness of their customers' response to tourism competitiveness, as well as the limits to market growth. For example, participant A could possibly succeed with an aggressive policy if the threshold of potential adopters could be raised. However, this is not an option given but it is discussed. It would probably mean making space cooling (of any sort) a requirement to licensing commercial establishments in the islands through an initiative to attract higher income visitors who seek greater comfort, for example. However, this sort of elaboration lies beyond the aims of the thesis and the game at this stage.

Sparing any more detail in the exact reaction of each participant, they all eventually achieved the government's objective and varying degrees of their own objective as private investors, set out in the beginning. Various topics for discussion were raised during the game, depending on the participants' interests, background and simulation performance. Figure A4 shows all three trials by participant D. A few of the participants" reported insights and observations are summarised next.

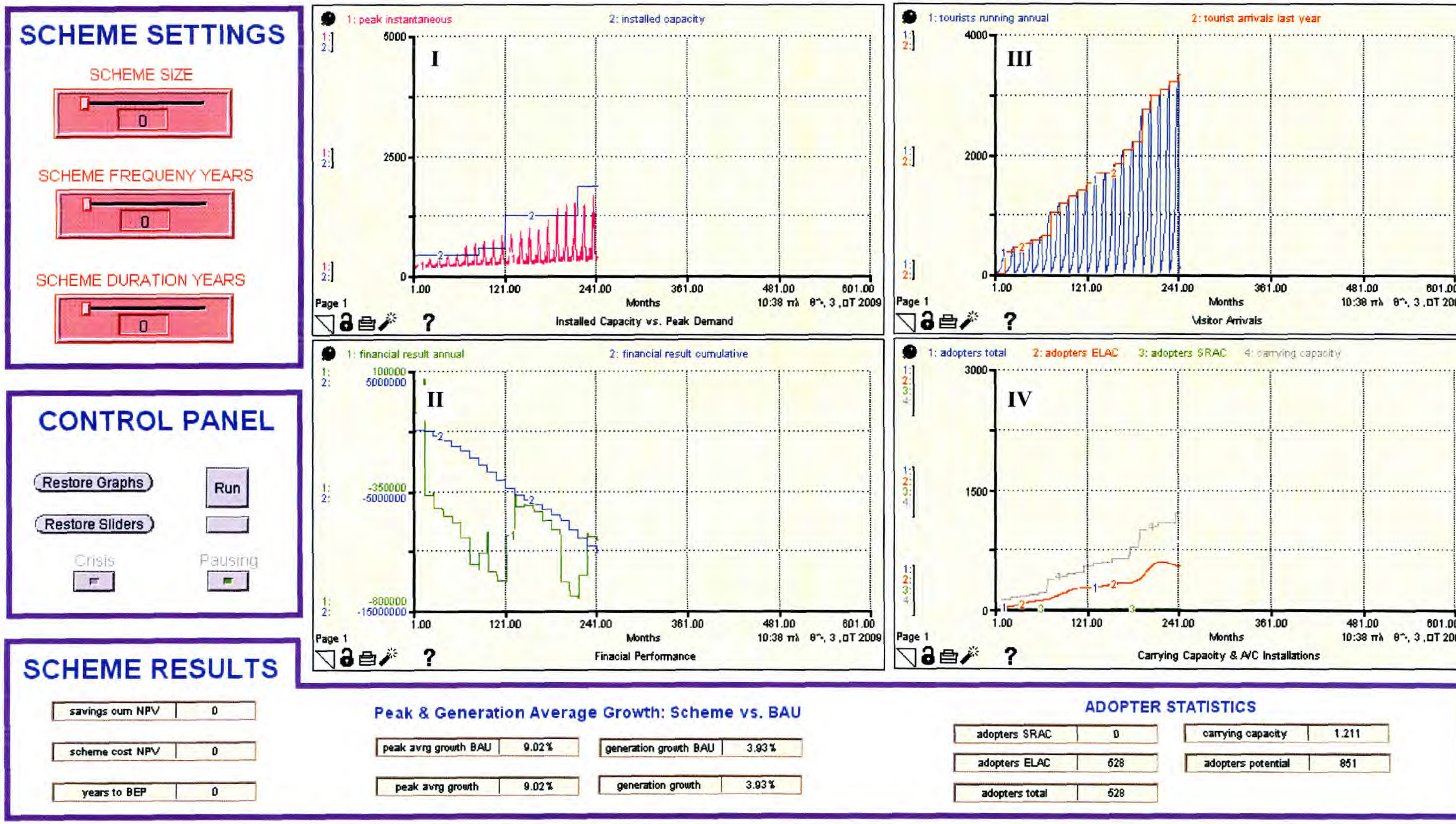

Figure A1: Screenshot at 20 years into the simulation

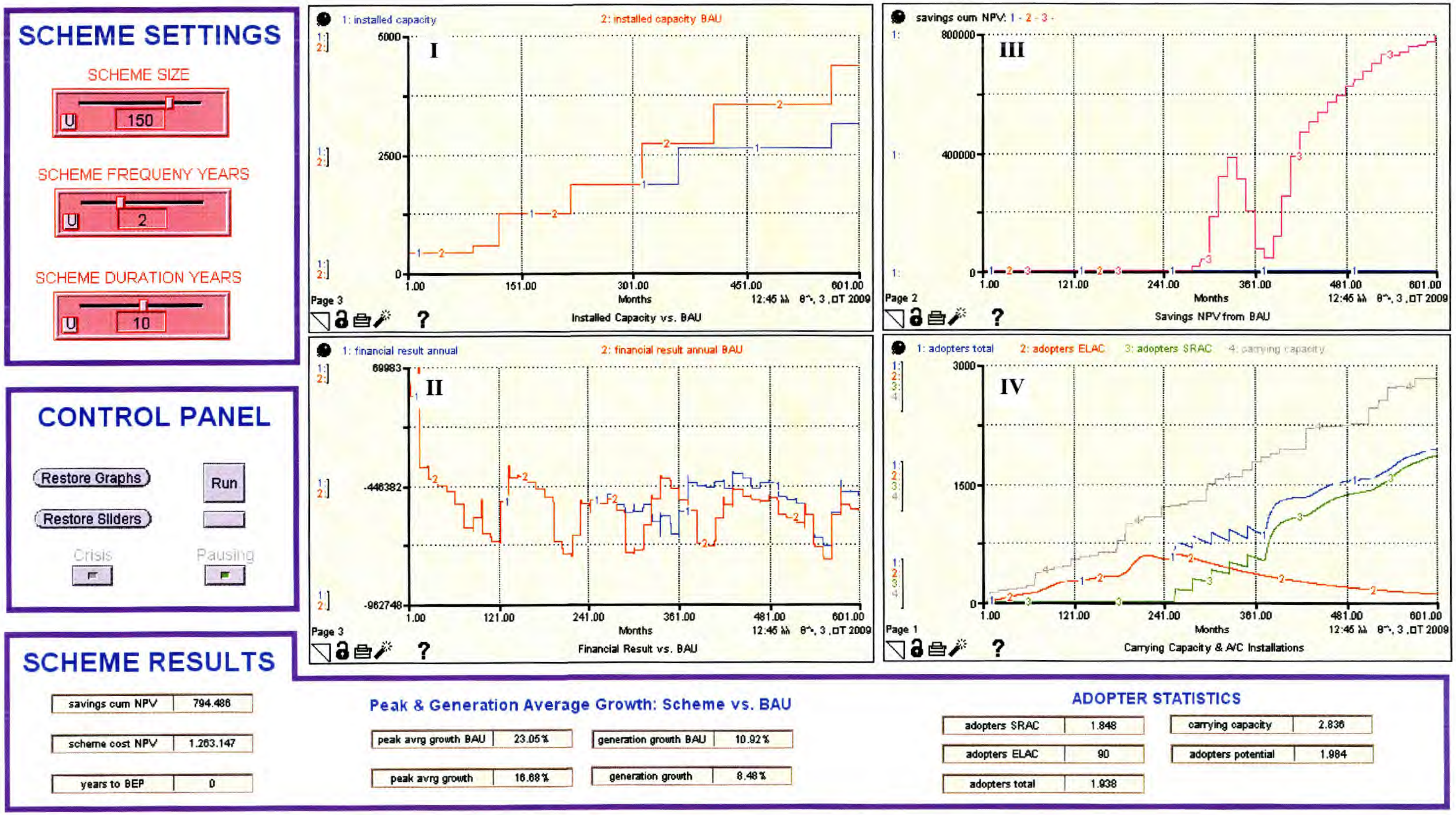

Figure A2: Screenshot of participant's D's 1st scheme trial

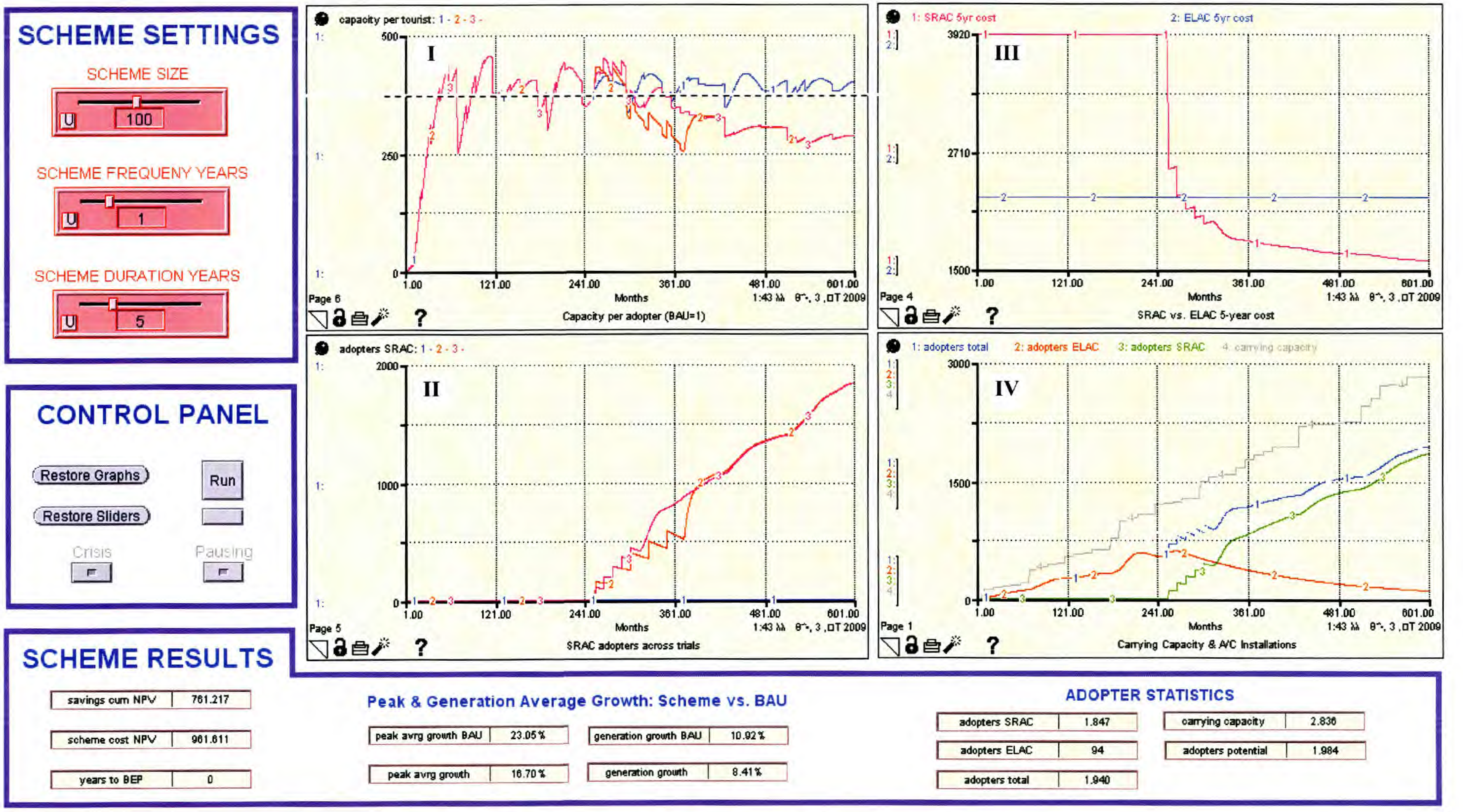

Figure A3: Screenshot of participant D's 2nd scheme trial

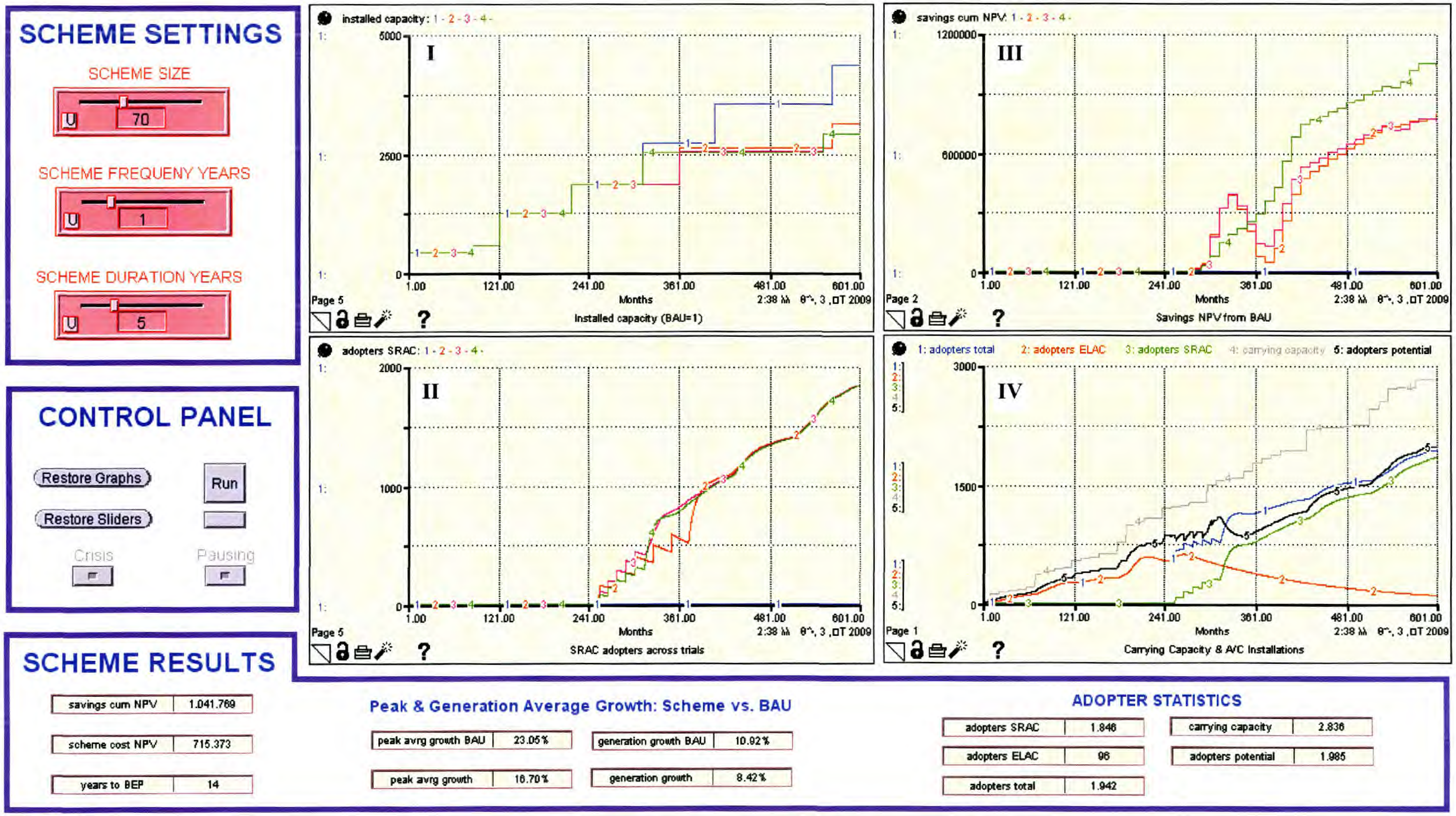

Figure A4: Screenshot of participant's D's 3rd scheme trial

A.3 SUMMARY OF PARTICIPANTS' OBSERVATIONS ON THE SIMULATOR EXPERIMENT AND THE PROCESS

Participant A suggested the use of fewer graphs and a display to show the savings and cost of the scheme, both of which were adopted in the screenshots shown here. He is a student of the Global Environmental Change and Policy Option of the MSc in Environmental technology, and was mostly struck by the fact that there were social obligations that did not allow him to play with the pricing policy of tariffs. Learning curves and technological progress needed to be discussed in detail as concepts, as well as their impacts on energy policy making. He inquired into the fluctuations in the NPV of savings and the dynamics of destination competitiveness and the adoption decision in the model, as well as in the context of the real economy of the Greek islands, was explained. He was given 5 trials in total as it was necessary to find the right balance between his perception of the time value of money and the effects of learning. In his case, it was critical to delve more deeply into the graphs of regional competition and the reason behind the convergence of the lines from trial to trial. The potential adopters' stock, as explained before, was put forward to him.

Participant B, on the other hand, is a student on the Energy Policy Option of the MSc and consequently the facilitator was able to release more background dynamics of the model. He admitted that his main perception that was challenged was the concept of economies of scale. He thought more units sooner would reduce the costs and thus enhance faster adoption of SRAC but it proved catastrophic, with a very expensive scheme as the bulk of funds were needed in the near future for the investment. Another significant learning point reported was the realisation of wasted funding once the cost of SRAC lies below that of ELAC, and that one should use market forces where appropriate and not subsidise more than needed. This is a challenge itself, as not only it is difficult to know and harder still to predict that point but one should have already chosen the technology that: On the one hand has the greatest impact on the power system but on the other hand also has a significant learning potential that can actually be influenced by the volume of installations of the envisaged DSM programme.

Participant C was also an Energy Policy Option student and took what she considered a safe approach of a long 20 year deployment of 50 units annually. It produced a very expensive programme and actually it was on the contrary a great gamble. In total that scheme meant 1,000 units when she had no indication in year 20 that the carrying capacity or potential adopters would develop to that extent. At year 20 the total adopters are the ELAC adopters (530) and the carrying capacity is 1,211. She put a lot of emphasis on the expectations of growth which, interestingly, is not very different from how the PPC seems to plan their capacity when it comes to additions of power. Thus, in the second trial, she went for 1,000 again but as an annual scheme of 100 units over 10 years. That also shows how to some people early perceptions of a system can guide their subsequent decisions. The facilitator then exposed all the elements that had to be balanced and considered and focussed her only on what seemed to be mainly affecting the system; namely the time value of money in the balance of cost and benefit, the comparison of costs through learning reductions and the adoption threshold. The third trial was the best of all of the participants and to the knowledge of the facilitator so far: 50 units annually for 5 years.

Finally, as noted, Participant D, the PhD candidate in energy policy, started with an awkward scheme of 150 units every two years within 10 years, effectively a 5 step deployment. A mixture of aggressive behaviour to start with but turning to a cautious approach for the remainder of the simulation. The approach achieved cost below that of ELAC within the first couple of steps and all subsequent additions just added to the cost of the scheme, basically a waste of resources and thus achieved no results. Eventually, through the processes exposed in the previous iteration, his attention was focussed on reducing the cost of the installation at current values. In the debriefing he mentioned that it was also an insight for him to realise that economies of scale do not always mean faster results and he appreciated the understanding he received of the various levels of costs and benefits involved in the Greek islands. Another point of interest he raised was the interplay between the local economy and the demand and the growth of the power system (installed capacity) as well as the inability to intervene in the tariff structure which, from his own research, he knows is a sensitive issue for consumers. He thus recognised the value of the DSM approach attempted in the islands.

For all participants, after a successful scenario is reached, the facilitator supposedly runs that scheme as if in real time. However, this time an arrivals crisis occurs (e.g. spread of a health epidemic reducing travelling dramatically for a decade) and the adverse effect on the previously successful scheme is noticed; the market for the efficient variant does not even pick up any more. The facilitator, however, commercialises the technology again by expanding the scheme, effectively making it more expensive and beyond the original exercise objectives. The question posed and discussed then is whether a policy-maker should push ahead expecting a gradual return to the previous levels of the economy or abort the programme altogether, which means losing all the money spent and jeopardising the knowledge gathered up to that point too.

The issue is left open-ended and the participant is called to comment on his experience of the simulator.

A.4 CONCUSIONS & PROSPECTS

At this early stage the expectation was to assess the potential of developing the concept of a simulator further. The interface was clear enough to the participants and had all the necessary background information handy enough to assist the facilitator to quickly provide information on the working of the game to the participants. Many issues were raised during the trials and importantly they could all be discussed within the context of the thesis and the Greek islands. Useful feedback was received, which will enable the simulator interface, the facilitation and the documentation to be enhanced for future applications.

With respect to future directions, one long-term objective would be to allow groups of individuals to play concurrently, affecting collectively the cost of SRAC through the learning curve of the technology as well as compete on tourism among them, depending on how well they perform on space cooling. More is discussed in the Further Research section of the Conclusions to the thesis. Returning to the potential target groups mentioned in the beginning of the appendix, the simulator might have to be developed separately for energy-policy makers such as regulators and students. The former should be focussed more on the practical implications and feedbacks of the island power systems perhaps revealing more on the financial performance and cost of power, whereas the latter group would benefit from learning and experimenting with energy-policy options like mostly presented in this first trial.

APPENDIX B: LEARNING, DIFFUSION AND NICHE MARKETS

This appendix summarises knowledge on technological progress, diffusion of technology, learning curves and niche market development. It mainly adopts the theory developed by the IEA in Paris and draws heavily on two of their publications on experience curves for energy technology policy and market creation for energy technologies. Topics are discussed in relevance to the Greek islands and the simulation model built.

Structure of Appendix:

B.1 Experience, Learning and Technical Progress
B.1.1 Introduction & Theory
B.1.2 Options for the Islands
B.1.3 The Learning Organisation
B.2 Deployment, Diffusion & Learning Investments
B.2.1 End-Use Technologies & Deployment Dynamics
B.2.2 Diffusion & Speed Variables
B.2.3 Evaluating Necessary Investment
B.3 Markets, Niches and Energy Technologies
B.3.1 Market Development Policy
B.3.2 Niche markets
B.3.3 Disruptions & Structural Change
B.3.4 Technology Lock-In & Path Dependence
B.4 Concluding Remarks

B.1 Experience, Learning and Technical Progress

B.1.1 Introduction & Theory

Experience gains can be achieved at various stages in the path of a technology from the laboratory to the market. Manufacturers, retailers, installers and even end-users of a technology can realise efficiency improvements in their procedures, deal with problems more effectively or, maximise their profits or utility by other personal initiatives. Thus there are many branches of learning in a product chain, such as learning-by-doing, learning-by-using, learning-by-producing, and similarly anything that suggests a series of incremental advances in the way a process, or part of it, is performed (see

Box 10 for a generic example). The most common performance measure is the price of the product or process under examination. The experience curve provides a simple and quantitative relationship between price and cumulative production or use of a technology, and is most suited for long-range strategy rather than short-term operations and decision-making (IEA 2003). There is little evidence on the theoretical explanation for the form of the curve or the value of the learning rates despite overwhelming empirical support for its existence[32].

Box 10: The basic theory of experience curves

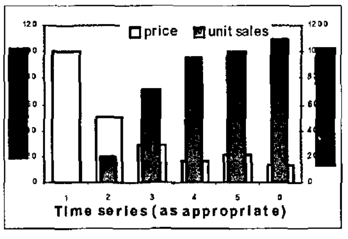

Fig. A

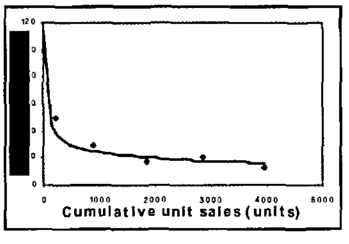

Fig. B

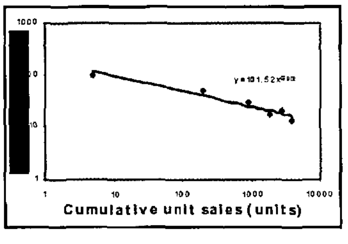

Fig. C

The data usually comes in the form of Fig. A; historical price and sales figures. Although exemplifying a relationship between volume and price, it cannot be described adequately to allow comparisons of learning within an industry or across a range of products/services. The graph following in Fig. B plots the price of the unit under consideration (e.g. wind turbine) against the cumulative unit sales. The asymptotic relationship observed can be further treated by sketching it on a log-log scale and drawing a power function trend line through (Fig. C). This line is commonly referred to as the *'experience curve'* and it allows comparison across industries and products. It is mathematically described as:

$$\text{Price at year } t = P_0 * X^{-E} \qquad \text{Eq. 1}$$

Where,

P_0 is a constant equal to the price at one unit of cumulative production or sales,

X is cumulative production or sales in year t and,

E is the experience parameter, which characterises the inclination of the curve.

An increase by a fixed percentage of the cumulative production anywhere across the line, gives a consistent percentage reduction in price determined by the slope of the line. Commonly, comparisons are made doubling the cumulative volume; the corresponding change in price is the *'progress ratio (PR)'*. The PR can be derived from the experience parameter as follows:

$$PR = [P_0 * (2X)^{-E}] / [P_0 * X^{-E}] = 2^{-E} \qquad \text{Eq. 2}$$

For Fig. C, E equals to 0.029, thus PR is 82%. The *'learning rate (LR)'* is simply (100 – progress ration), i.e. 18% in the example.

That is, for any doubling of cumulative production, the price is 82% of the previous value, or reduced by 18%. The PR/LR are the same for any part of a simple experience curve. This suggests a new technology taken to the market for the first time learns faster than older ones with the same PR. This can be examined better in Fig. B where the same absolute increase in cumulative production will have more dramatic effect at the beginning of a technology's deployment than later on.

Adapted from: (IEA 2000)

[32] In addition to the IEA's 2003 publication on learning curves, classic sources include: Boston Consulting Group (BCG) (1968) *Perspectives on experience*, Boston Consulting Group Inc., Stockholm, Mansfield, E. (1961) *Technical Change and the Rate of imitation*, Econometrica, 61, pp.741-766, Davies S.W. (1979) *The diffusion of process innovations*, Cambridge University Press, Cambridge, and Abell, D.F., Hammond, J.S. (1979) *Cost dynamics: scale and experience effects*, Strategic Planning: Problems and Analytical Approaches, Prentice-Hall, Englewood Cliffs, NJ.

The experience effects in stable markets or mature technologies are hardly noticeable even with significant increases in volume of production. In such cases, structural changes in the market or technological innovations may be able to alter this (discussed further in Section B.3.3 *Disruptions & Structural Change*). In other cases, a component of a technology may be learning faster from market experience, but with the impact on product price still remaining miniscule. Such is the case with wind, where the experience curve for the total process of generating electricity (incl. siting, power management, use of hybrids) is steeper than for producing wind turbines, which relies on technical components most of which have reached maturity[33].

B.1.2 Options for the Islands

Following the textbook distinctions of technical progress (see Box 11 overleaf) there are a few points to be made in the context of the thesis. Having distilled the thesis down to isolated medium to medium-large islands and the exploration of consumer energy equipment (Section 1.4), the concept of improvements in production becomes vague. Island communities will typically be receivers (buyers) of an international technology, e.g. solar heat pumps, which will most certainly not be produced locally. Their effect on technology price will thus be infinitesimal and there cannot be such a notion of learning-by-producing even at a national level to start with. However:

- The demand technology, originally assumed to be imported and subsidised, can demonstrate local learning-by-installing and/or learning-by-retailing dynamics, therefore showing profit opportunities for other importers and installers of similar technology. Perhaps there might be a spillover effect, driving entrepreneurs to other energy-saving or environmentally benign equipment to provide the end-user with services currently fulfilled by electricity.
- The profit margins or market size may rise by such a level that economies of scale kick in and national manufacturers of DSWHS, or other players, invest in industrial manufacturing capacity of the new technology affecting costs of the particular service equipment in the region.

[33] Refer to Neij, L. (1999) *Cost dynamics of wind power*, Energy, Vol.24 (5), p.375-389, for the full analysis.

Box 11: Classical Distinctions of Technical Progress

First Distinction

Process Developments are associated with the introduction of new processes or techniques, typically embodied in new capital equipment used in production.

Product Developments are involved with changes in the nature of products offered for sale. Such developments, if successful, typically enhance economic welfare.

Second Distinction

The *Invention Phase* comprises of the initial stage in product or process development. May involve basic research into new scientific principles on top of development towards a particular commercial application.

The *Innovation Phase* follows when the invention is further refined and developed for commercial launch. In this stage, technical development is combined with marketing and entrepreneurial expertise.

The *Diffusion Phase* is when other firms, or actors, are convinced of the commercial opportunities of the new technology and adopt or imitate the product.

Adapted from: (Clarke 1985)

The invention phase, mainly involving R&D, is riddled with uncertainties; its output albeit having the characteristics of a public good, does not spread that risk over all members of the community and there is increased margin for free-riding on the expense of actors carrying on costly research. Therefore, individual firms and even government are reluctant to commit to such strategy due to the risk involved. Greece being in the very last position of R&D spending in the EU (IEA 2002;IEA 2006), this phase is rendered a non-option for the problem under examination. For the same reason, the innovation phase is rendered out of context since in addition to the above requires the existence of a sturdy market structure built on competitive principles, which by nature islands distort[34].

Conclusively, the focus is on products that are on the brink of breaking into the market or in their diffusion phase of development elsewhere, i.e. abroad. The thesis considers such technologies available for import and installation initially through a direct subsidy strategy that aims to bring about the niche market properties of the island economies. As far as the first distinction in Box 11 is concerned, a *process improvement*, assuming electricity is the 'product', shall be any intervention on the supply side of the power system, whereas a *product improvement* is an action or equipment that delivers the energy service (e.g. heating) by less or no electricity on the consumers premises.

B.1.3 The Learning Organisation

Barriers beyond technical competence and cost can also significantly hinder market expansion and are critical as they do not directly relate to cost or performance of the

[34] The incentives to invent and/or invest in new technology and the links to market structure and competition as theory and in the case of Greek islands are discussed in greater detail in Section B.3.4 *Technology Lock-In & Path Dependence.*

technology itself. Therefore, these lie further than the influence of a manufacturer-assembler. Such barriers relate to the flow of information, standardisation, and transaction efficiency to name a few. As a new technology is deployed, potential returns and newly discovered needs to adapt to can lead to changes in the perception of market actors regarding the technology, which in turn can affect the commercial performance of the product and, effectively, the structures of the market itself (Barreto & Kemp 2008;Sterman 2000). This dynamic interaction reveals the opportunity for consumers, intermediaries and government to learn and it is commonly referred to as *organisational learning*; the organisation being the market itself rather than a single institution or firm as in the case of technology learning (Sterman 2000).

An example of the latter would typically be technology deployment programmes targeting the supply-side actors of the energy system (*technology push*), while restructuring the market on competitiveness grounds and challenging the division between the suppliers and consumers is an organisational learning opportunity (*market pull*). In the case of the Greek islands, organisational learning is driven by the need to deal with the great financial loss of power generation and involve all stakeholders towards a new paradigm of energy management as well as the competitiveness of tourism. An example of a policy that can achieve both types of learning are procurement programmes where developers, customers and intermediaries come together along the chain that leads from determining specifications of the equipment to its production, delivery and use.

B.2 Deployment, Diffusion & Learning Investments

B.2.1 End-Use Technologies & Deployment Dynamics

As mentioned earlier the experience curve provides an empirical tool that links the growth of cumulative sales or production to the market price or total costs of production. Which pair of indicators is plotted is application and objective specific – i.e. a market vs. an industrial analysis. Under stable market conditions, i.e. stable return on equity for producers, the cost and price curves should appear as parallel lines, that is having the same progress ratio. Physical effects and government-induced policies to a market can persistently or momentarily favour the introduction of new technologies; such is the case of niche markets described in detail in Section B.3.2 *Niche markets* with particular reference to the islands.

The experience curve is basically the result of a backward loop from an indicator of output to the process that transforms inputs to products on the shelf. Inputs can vary from raw material to sales force to advertising budget, and is commonly expressed in monetary value. The output of all transformations of input is then a physical quantity and, consequently, the experience curve is a measure of performance of the system (€/kW, USD/m^2 etc.) (IEA 2000). Schematically, borrowing from basic cybernetics notation:

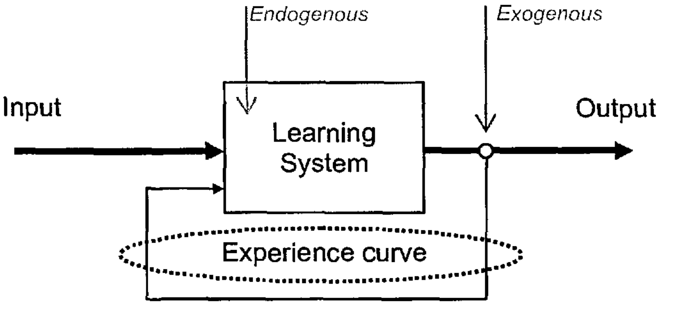

Figure 112: Basic model of learning

The learning system itself is an intricate set of structures and cause-and-effect relationships. Increased learning, i.e. better efficiency, can be achieved with endogenous and exogenous interventions as shown in Figure 112 above. Policies to increase R&D spending would affect the system endogenously (a push effect), while incentives for extended application or use of the output would feed the external signal back to the system, including a possible delay, providing a pull effect.

The state of development of the technology under consideration, the market in which it will first be launched, the availability of support funds and the urgency of intervention, i.e. a long-term strategic technology diversification by the State or an abrupt environmental need to change consumption patterns, will determine the accessible basket of commercialisation policies. As it will be seen later in detail, policies can target R&D directly or, some early demonstration project could capture the real benefits of the new technology and confirm the low technical risk to operators aiming to draw more to the pool of potential adopters. In cases where a barrier in the market has been identified, such as lack of information, a measure is to introduce consumers to the choice through information dissemination, highlighting potential benefits but not obstructing existing options from fair competition unless their social costs clearly outweigh their benefits. In cases where the objective might be to create adoption leaders in a system that will eventually challenge and hopefully alter the current mindset of technology choice, extensive deployment programmes might be the option which also feed back to the learning system that provides the technology generating economies of scale. Section B.3.1 *Market Development Policy* establishes a framework and theoretical background for classifying intervention alternatives.

All the aforementioned possibilities aim to assist market development for the chosen technology. The thesis is concerned with energy technologies that are at the mature end of their development, when these are ready for niche application at small autonomous markets where consumers are the early commercial adopters. Thus, policy-makers may need to 'pick' the winning technologies that closely match the needs of the community under consideration and seek to incite learning on components such as assembly (which may eventually grow to manufacturing), marketing, installing, utilisation and perhaps maintenance (after-sale). Such an extended learning requires deeper understanding of the learning process itself. A hypothetical configuration is presented in Figure 113 below (IEA 2003).

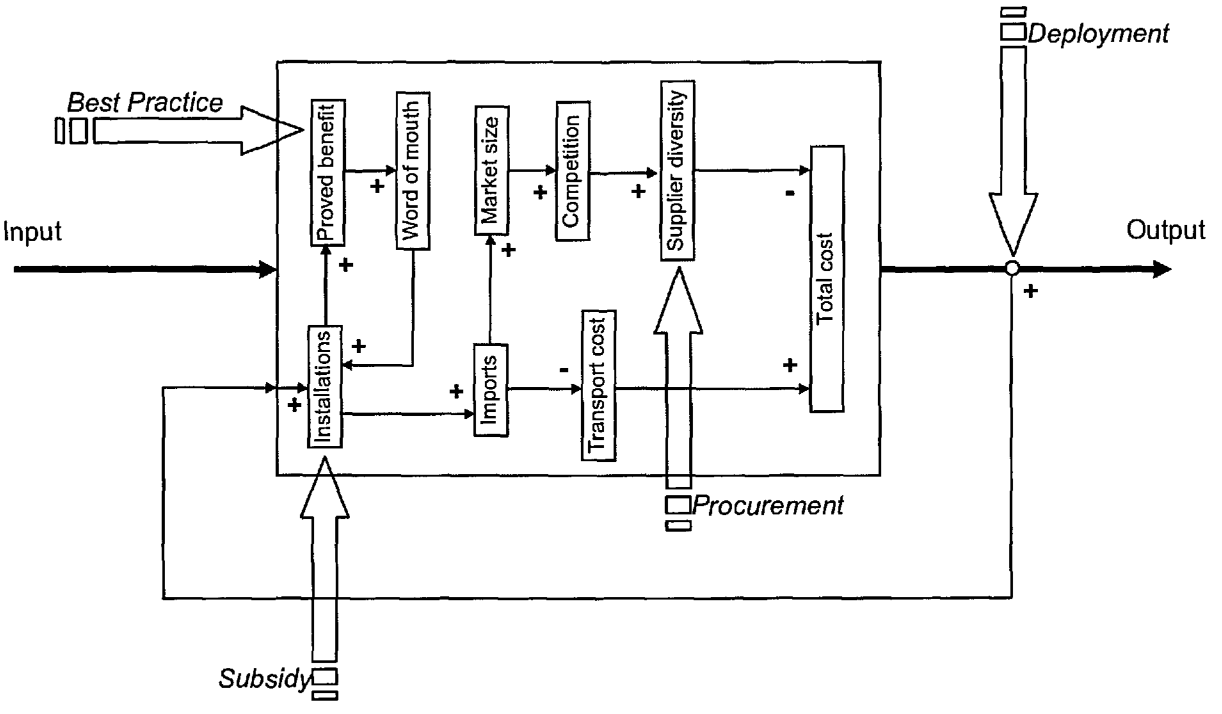

Figure 113: The influence of public policy to technology learning

The figure above presents a possible structure of the learning process with signs of causality indicated on its parts (+/-). Actual installations increase the net stock awareness of the benefits in the community that in turn amplifies positive word of mouth dynamics and lead to more installations *per se*. More installations means more orders of the imported end-use technology which is then assumed to have two repercussions. On one hand, it establishes scales of economy as far as the costs of transport are concerned and reduces the related cost per unit – therefore, the negative impact sign – which then pass on to the total per unit cost (here the "+" sign indicates that the previous impact causality is retained, i.e. a decrease is carried through). On the other hand, more imports mean a greater market size and therefore more competitors are attracted into the new market. Presumably, those private actors partner with more efficient technology suppliers or take on local assembly of equipment to capture a greater share of the growing market by providing a more cost-efficient product.

Few indicative possibilities of public policy in support of the new end-use technology are also drawn in Figure 113 by the oblong transparent arrows. The deployment measure is external to the learning system and aims to drive the number of actual installations up. This can be achieved by labelling of all equipment, building codes or direct taxes to inefficient technologies. All three remaining public policy initiatives are endogenous and demonstrate that an impact on costs does not necessarily need be targeted explicitly at costs.

A *Best Practice* programme aims at reaching the buyers of equipment at key decision points and disseminate information of energy-efficiency through publications, workshops, decision tools and partnership networks. It is a measure mainly aimed combating the barrier of information lag. A *Subsidy* on the other hand is an aggressive policy when the expected net physical benefit of new installations justifies diversion of public funds to the purchase itself, or when in urgency to accumulate experience or pursuit economic, environmental or other leverage. It might not sustain a shift if not accompanied by complimentary policies such as technical R&D to assimilate the interaction with the market.

Finally, competitive *Procurement* processes, e.g. buyers associations, can be used to encourage equipment suppliers to develop and market technologies according to specifications by the policy initiative. The option is considered a 'market transformation' intervention where the target is the whole chain of innovation and commercialisation, including R&D, manufacturers, suppliers, retailers, installers and the users themselves. It is an especially useful tool when energy is a small component of the total cost of an appliance's usage or the consumer is much more interested in other aspects of the equipment rather than energy efficiency but still its widespread adoption creates energy related problems.

Finally, Figure 113 previously, intrinsically demonstrated there can be compound learning processes where a single learning system is broken down to a number of sub-system experience curves. The depth will depend on the level of detail the analysis needs to reach and the data available. For example, the wind power market can be bundled together in measuring a common output, or broken down to manufacturers of wind turbines and producers of wind power as illustrated below (Archer & Jacobson 2005;IEA 2003).

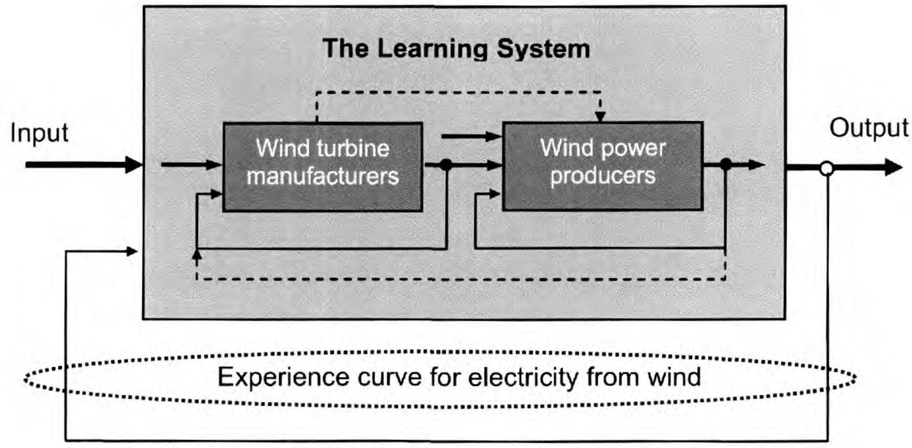

Figure 114: An example of a compound learning system

B.2.2 Diffusion & Speed Variables

There are cases where the break-even point with the conventional technology might lie quite far in the future and require momentous capacity expansion. However, the diffusion of a technology is a gradual transition that can be assisted by recognising the critical variables subject to the boundaries of the policy objectives (e.g. geographical, market or social) and focussing on influencing them (Papineau 2006). A new technology, or technique, benefits the pioneering users providing a competitive advantage, adding prestige or reducing costs. Eventually, other users are convinced of the merits and substitution takes place until the new becomes the norm. By that stage a particular industry, a group of consumer and indeed the society as a whole is assumed to have gained in the short-term; that is despite possible uncertain trade-offs, e.g. between cost effectiveness and environmental protection (IEA 2003). The speed of diffusion varies significantly for different technologies and user groups. However, the primary concern is what factors (incl. market structure) influence the speed at which diffusion takes place and whether these can be manipulated for sustainable community growth.

Box 12: A simple approach to diffusion curves

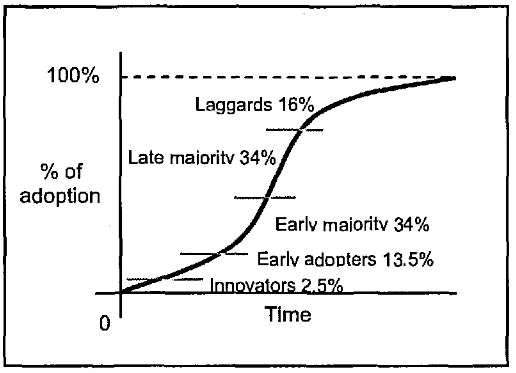

Fig. D

Edwin Mansfield has looked at the diffusion of 12 techniques in four industries in the USA. The positively (i.e. successful innovations) sloped S-shaped curves he came up with have been widely used in the study of innovation (IEA 2003). Fig. D presents a typical distribution of adopters. Imitation proceeds very slowly among enthusiasts and risk-takers at first; eventually getting up to speed as the technology proves itself. Mansfield in his firm adoption analysis devised the ratio:

$$\lambda_{ij}(t) = \frac{m_{ij}(t+1) - m_{ij}(t)}{n_{ij} - m_{ij}(t)} \quad \text{Eq. 3}$$

Considering the *j* -th innovation of the *i* -th industry, and letting n_{ij} be the total number of potential adopters while $m_{ij}(t)$ is the number of actual adopters at time *t*, and $m_{ij}(t+1)$ the number of adopters at $t+1$. Then, Mansfield assumed λ_{ij} as a function of the proportion of adopters at *t*, $m_{ij}(t) / n_{ij}$, the profitability of installation, π_{ij}, the size of the investment for the installation, S_{ij}, and other unspecified variables.

$$\lambda_{ij}(t) = f_i\left[{m_{ij}(t)}/{n_{ij}}, \pi_{ij}, S_{ij}, \ldots\right] \quad \text{Eq. 4}$$

By a series of mathematical manipulations and assumptions, such as treating $m_{ij}(t)$ and time as continuous elements, Mansfield ended up with:

$$m_{ij}(t) = n_{ij}\left\{1 + \exp\left[-\left(l_{ij} + \phi_{ij}t\right)\right]\right\}^{-1} \quad \text{Eq. 5}$$

Where, l_{ij} is a constant of integration, and φ_{ij} depends linearly on the variables of Eq. 4, excl. $m_{ij}(t) / n_{ij}$. This equation of a symmetrical S-shaped curve is frequently used in biology and the social sciences. It is called the *logistic curve* and is used extensively in models of epidemics, spread of ideas etc. In addition, the shape and position of the curve in Eq. 5 depends only on one parameter, φ_{ij}, which determines the rate of imitation and is a linear function of π_{ij} and S_{ij} if one confines all other variables to noise, z_{ij}, i.e.:

$$\phi_{ij} = \alpha_{i1} + \alpha_{i2}\pi_{ij} + \alpha_{i3}S_{ij} + z_{ij} \quad \text{Eq. 6}$$

Adapted from: (Clarke 1985) & (IEA 2003)

The work of Edwin Mansfield in the 50s and 60s is seminal to the matter (Clarke 1985) and a quick summary of his approach can be found in Box 12 above. According to Mansfield, the more the firms that have adopted, the more information and experience has gathered; therefore the non-participating firms view it less risky. The profitability of the innovation balances the willingness of the potential adopter to take on the uncertainties involved. On the contrary, the larger the investment required, the greater the subjective risk. Eventually, Mansfield has included fuzzy variables, such as the reluctance to scrap durable but old equipment; market growth & structure considerations albeit with ambiguous impacts on diffusion and; subjective insights such as the expectation that developments in communications and investment appraisal techniques can accelerate diffusion.

B.2.3 Evaluating Necessary Investment

Deployment support aims to assist producers and users to gain experience, consequently reducing the associated prices. Experience curves can be at hand when asking the key questions of how much support to provide, when a technology breaks the competitiveness barrier and how much government budgets should cover for. Deployment generally aims at inducing or increasing the rates of diffusion. Thus, one is past the strictly technical R&D phases to where markets are progressively taking the upper hand. For a technology to compete against the incumbent method of delivering a service, its price has to be brought down to a comparative level.

An experience curve provides a systematic methodology to describe historical price development and can be used to estimate the investment necessary to make a technology competitive. However, it cannot forecast when this will happen. This depends on the deployment rate, which is influenced by deployment policies of the policy-makers. Learning investment is an indicator of the monetary value of learning efforts in order to bring technology price to the break-even point (with respect to the current conventional technology). It is defined as the additional costs necessary to be invested by the market for the new technology to reach a cumulative output where the price is comparable to the price of the same service from technologies that the market presently considers cost-effective (IEA 2000). A generic example of the methodological approach is given in Box 13.

Box 13: Estimating learning investment

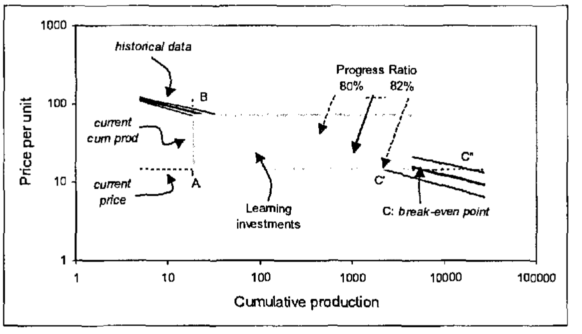

Fig. E

Starting off from historical data that provides the progress ratio (Fig. E), the trend line is extrapolated until it hits the price that the incumbent component, technology or service is supplied for; i.e. the new technology has broken even and is competitive (point C).

In this generic example, to reach C one needs a cumulative production of nearly 5,400 units. Consequently, the area of the triangle defined by the points A, B and C represents the additional cost of becoming competitive or else, the *'learning investment (LR)'*.

The shaded area sums to (say, € for the sake of the example) €170,500; which is a substantial investment given that about €60,000 have been spent to get to point B. The uncertainties are significant and to illustrate the point, the ±2% experience curves are also drawn resulting in two new potential break-even points – C' and C". Those points suggest a wide gap of 2,000 and 17,000 of cumulative production, i.e. €70,000 and €550,000 of learning investment respectively. It is expected those uncertainties are progressively resolved as more experience accumulates.

Adapted from: (IEA 2000)

The challenge is to put forward policies that can mobilise resources on the market to commit to the learning investments, especially, in the diffusion stage of technological progress when the technical answer is there but one has to find ingenious commercial coupling or appropriate niche applications. Such mechanisms can be feed-in laws, a carbon tax, or consumer demonstration. Ultimately, the government or commercial market actor has to be convinced that costs will be eventually recovered. In the case of the former, this might involve avoided social costs, such as the impact of climate change to human health and the economy, while the latter will have to see either strategic benefit or satisfactory and secure future return. Effectively, this has a lot to do with the amount of risk institutions or private actors are willing to take.

The general rule is that if the new technology, process or service appears valuable and marketable, government intervention can set off substantial commercial deployment programmes. Private sector learning investments are then expected to provide an increasing share of the resources for technology improvements. In the case of the islands under examination, the thesis assumes that the policy-makers are capable of picking winning technologies whose initial development stages have been performed elsewhere (abroad) and formulate such policies and market structures to allow commercial diffusion within their territory initially by imported product. There are three benefits to be claimed for this approach listed below with the relevant assumptions:

1. Avoiding the initial public R&D cost and risk associate with developing new technology from scratch. The policy-makers know well the needs of island

communities and are able to pick the appropriate technologies developed elsewhere that fit.

2. The focus being energy-saving equipment (Section 3.4), the import and successful diffusion of such a technology is expected to decrease the size of public spending on island power generation, reduce the cost of electricity to consumers or increase the competitiveness of the local economy.

3. Greece is the leading country in passive solar energy use in the EU with 20% of the households using solar-water heaters (IEA 2002) and maintains an exporting industry (see Chapter 5). A synergy of past subsidy, industrial growth, entrepreneurship and appropriateness of technology have attributed to that. A similar development might be possible to replicate for the chosen new demand-side energy-saving technologies.

B.3 Markets, Niches and Energy Technologies

B.3.1 Market Development Policy

Market development policy, consumer behaviour and patterns of energy demand strongly depend on social and commercial constructs such as traditions, culture, politics and economic structures that prevail in the geographical area (state or region) where it is applied (Raven 2007). The analytical framework for looking into policy design for market development looks into three perspectives; R&D and Deployment, Market Barriers, and Market Transformations. It has been extensively used by the International Energy Agency (IEA) in conducting comparisons among a range of case studies and it is further explain in Box 14 below. In brief, 'the strength of the research, development and deployment perspective is its vision of the future; the market transformation perspective encourages sensitivity to the practical aspects of crafting policies to get results; and the market barrier perspective leads to policies that work efficiently and generate net value' (IEA 2003).

Box 14: The three-perspective analysis of market development policy

The development of a successful market policy draws extensively from empirical knowledge in a variety of countries and a multitude of programmes involving a range of stakeholders, technologies and policy tools available. Building towards a comprehensive understanding of experience and a distinction of generic and transferable lessons learnt a market development process is viewed from three perspectives, often overlapping but each with a distinct set of tools to provide an insight to market mechanics.

R&D+Deployment: Focuses on the nature of innovation and learning. Deals with interactions among R&D and market development, esp. cost and performance of new technology. Early 'learning-by-doing' is central in this perspective by extended use. Government stimulates early deployment to incentivise industry R&D. Orientated towards the future and gradual societal change in adapting to new technology.

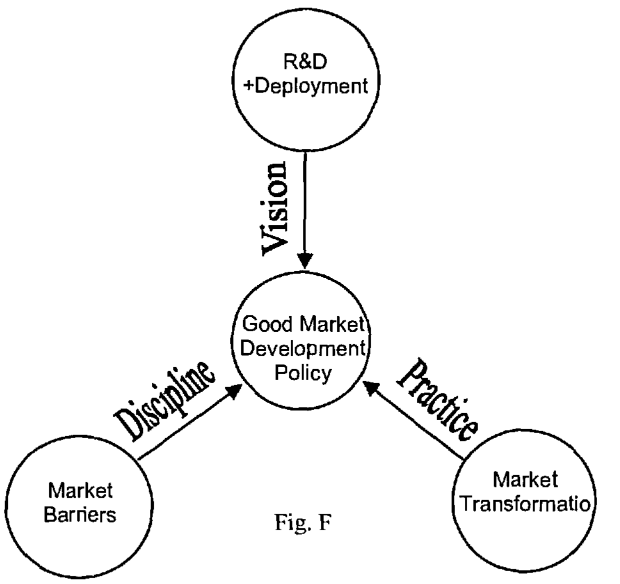

Fig. F

Market Barriers: Investigates the adoption of new technology as a market process. Interested in the frameworks in which investors and consumers make decisions, e.g. institutions and economy structure. Looks to remove obstacles that decelerate the market expansion rate. Uses tools of economic analysis with emphasis on understanding the barriers and describing the legitimate role of government in reducing them.

Market Transformation: Concerned primarily with actions to build markets in practical terms. The focus is behaviour and role of market actors, how their attitudes guide decisions, and how these attitudes can be influenced. A major difference with the *Market Barriers* perspective is that broad strategic choices on technologies and markets to be looked at are necessary early in the development of this perspective.

Adapted from: (IEA 2003)

R&D+DEPLOYMENT

Deployment programmes provide the market with commercialisation prospects and are commonly technology-led and government-run. There can be an immediate *physical effect* on the production and/or use of energy, i.e. same service for less consumption, higher reliability, revenues for investor etc. Nevertheless, such effects maybe temporal to the duration of the programme since there is no link drawn between deployment programmes and private decisions to invest in the market learning process (IEA 2003). It has been assumed there is inadequate R&D infrastructure to absorb the potential experience gathered, the *learning effect*, thus the R&D+D perspective of market development policy is rendered extraneous in the case of the Greek islands.

MARKET BARRIERS

The market barriers perspective has its foundation in market economics and deals with phenomena of market inertia. The role of government in markets, according to the market economy doctrines, can only be justified when a market failure occurs; i.e. when resource allocation is distorted or inefficient. It also assumes that the intervention itself is efficient; leaving all marginally better off or at least no-one worst off. Still, the recognition of barriers does not necessarily constitute a market failure. Three considerations of legitimising government intervention with respect to new energy technology can be recognised:

1. Most instances of typical market failure involve externalities, when the cost or benefit of an economic transaction is not fully included in the price paid for the product exchanged. An example of a negative externality in the islands is the subsidy provided to the retail tariff of electricity. Hotels and other tertiary installations to serve visitors are found to be the main culprits of demand surges in the summer still there is no premium on the power they consume to reimburse the costs of capacity expansion and the spinning reserve required to service them. The standard way to adjust market prices to internalise a negative externality is to levy taxes that will force actors to take account of external costs to the markets. This is assumed politically sensitive to apply to the islands being economically sensitive regions albeit the aggregate GDP figures are pretty close to the mainland indicating some islands must be doing really well above the national average.

2. Nevertheless, governments are reluctant to take such extreme measures of internalising such costs due to the risks involved. Governments can then argue that direct support for markets, that would have flourished have the externalities on conventional products and services been accounted for, is legitimised. This is known as the second-best argument. The question in this case is how to reach consensus on the choice of new technology to be supported. In the Greek islands this has been achieved easily in the past by a synergy of factors on the supply side. Falling international wind turbine prices and a favourable wind regime has initiated the first wave of installations of the technology. The experience gained by construction companies involved in the 1980s and continuing technology advances has provided an overwhelming response to special incentives, such as feed-in tariffs, provided for wind power in the mid-1990s. An overwhelming amount of applications for wind parks flooded the

Regulatory Authority for Energy (RAE) since the market opened up in 2001 (Lampaditou 2009). The learning has been so large possibly due to a lower perceived risk since municipalities, local authorities, and other island initiatives were significant bidders in the process. Nonetheless, this is a strictly supply-side approach and does little to address the extreme demand growth in the islands.

3. A final argument to be raised in order to justify government intervention refers to the dynamic nature of market barriers and the need for disruptive intervention. Having discussed the mechanics of learning, the government might provide funding to a particular industry to develop knowledge that can be shared, i.e. not proprietary or commercial. Such policy is seeking to take advantage of positive externalities taking on the risk of under-investment in non-proprietary knowledge. Of most relevance to the islands however, is the stochastic behaviour of consumers and their preferences. There is a basic feedback at play where consumers are no longer assumed to have a set of well-defined and constant preferences but their choices and preferences are influenced by product differentiation and other marketing strategies of suppliers. Intervention on this front can have a sustainable impact as it aims at changing paradigms of consumption. It can overlap with the Market Transformation perspective examined next.

MARKET TRANSFORMATION

The market barrier perspective previously has been formulated under theories requiring delineating roles of government and decision makers in the market as prescribed by neoclassical economics. The fundamental example of differentiated underlying assumptions between the barriers and transformation approach is that the former assumes consumer preferences given and rational, thus less likely to focus on, whereas the latter looks exactly into influencing private decisions. The role the policy-maker is called to play in market transformation is that of a commercial competitive actor albeit the objective is not private profit but increased social welfare.

According to the IEA (IEA 2003), a central principle of market transformation is to understand well the buyer-specific characteristics of the technologies being promoted and the relevant market structures in which these compete. Appropriate measures should then dampen the negative characteristics (i.e. high installation costs, lack of experience) and highlight the positive attributes (i.e. increased efficiency, cleanliness, low running costs). Consequently, there is no generic approach to effective market transformation and location specific analysis is necessary having established the physical and institutional boundaries. Market transformation is about engineering a substantial change in the basket of services offered and the behaviour of all actors and supply chains involved, i.e. a green certificate programme would require specially trained auditors and new marketing of innovative or modified products. The perspective also requires bold strategic choices to be made early with respect to elements such as focus, objective, target user group, critical needs to be looked at, level of acceptable risk etc.

The idea of market transformation is in the early stages of development with respect to the other two perspectives. The guidelines suggested by the IEA (IEA 2003) is that 'when approaching markets in which there is an unexploited potential for net benefit to society', i.e. cost-effective energy saving equipment that has not yet kicked in due to market structures and stakeholders behaviour, 'the focus should be very specifically on ways to make the desirable energy-related attributes of the products involved more attractive to the suppliers and buyers'...'while at the same time disturbing normal market processes as little as possible'. It is held that niche markets can have a vital role in providing a less risky and better-controlled environment to initiate market transformation and build up technology experience before scaling up. It is held in this thesis that the Greek islands provide this environment at least for the national interests, and in this context, the following section provides an introduction to the workings of niche markets development.

B.3.2 Niche markets

Technologies compete for learning investments (Section B.3.4 *Technology Lock-In & Path Dependence*) in an international context. However, there is a trade-off between flexibility, technical risk and the global outreach a particular technical solution can have. A wide portfolio of potential technologies to reduce energy consumption which all compete for the same international finance opportunities and generic markets might hinder their commercialisation opportunities and never get into the market maturity phase. It is important to understand the limitations of global analysis and get involved in practical applications in the small scale where local flexibility, diversification of the supply chain, relative weight of local needs, and the ability of taking up technology risk provide early hands-on learning possibilities for candidate technology. 'The management of flexibility and technology risk thus requires local autonomy for decisions on deployment, which is in conflict with the concerted action necessary to achieve maximum effect from learning investments' (IEA 2000). Thus, the thesis, focusing on very particular niche island applications, hopes to balance experience gathered on a global scale in the development of energy-efficient equipment and their application, with seeking coherent locally adapted deployment strategy informed by learning phenomena.

Niche market development is a particular market transformation strategy to which the Greek islands present an ideal test bed. The new technology is by nature given competition protection from the wider market. At the same time real interactions with users are built while trial and error experience amasses. Institutional and technical adaptation is another side effect of the niche market as a commercialisation tool. In addition, islands due to the closeness of the community provide a very immediate interaction among stakeholders.

It is however extremely important in such enclosed economic habitats to deal with the risk brought upon the society by potential lock-in to the wrong technology. The principle is to have as a close fit as possible between the technology being launched and the expectations of the market and stakeholders. According to the IEA (IEA 2003), the niche should take full advantage of the merits of the new technology, concentrate on a limited number of applications and work initially in small geographical areas. The thesis focuses on medium to medium-large islands in the Aegean Archipelago and is mostly concerned with dampening the impact of energy use in the tourism sector. However, the island economies have already been locked-in choices, technologies and a rationale of electricity use which has to be re-evaluated and adjusted.

As examined in Section B.2.3 *Evaluating Necessary Investment*, there can be significant investments necessary in learning how to compete with incumbent technologies. A central question is how to share the amount between the private investors and government in an optimal path to accelerate learning and achieve competitive technology costs. Niche markets can be stepping-stones towards large volume commercial markets attracting private investors and developers to imitate potential success. However, the author reckons that there is an immediate actual social impact, especially in the case of remote island locations, that innovative technologies can at the same time provide solutions to real community problems and benefit individuals even if the dynamics of an extended market do not converge. Assuming that there is a thorough investigation of the demand for energy services of marginal communities, appropriate alternative technologies can then be picked on the basis of their technical competence to provide the same service. These could take the form of user-level cost-benefit small-scale analysis of a number of candidate appliances. Dynamic implications of learning and diffusion can then determine the spread and popularity as well as the savings to the power system operator and the cost reductions on technology components such as procurement, retailing, marketing, installing etc.

In the context of remote islands, close consideration of the energy needs and the investigation of internationally existing energy-efficient technologies to deal with those can lower technical and institutional risk. Gradually, early, time-consuming application specific adaptations will evolve to more generic configurations of the technology as the market achieves to take off showing real value to the end-users and the utility operator. The weakness of picking the most likely winning technology to introduce can be overcome by the use of wider Cost-Benefit Analysis of the available options in a top-down long-term sustainability approach for the whole archipelago. The next step then is to choose the deployment programmes and rules of engagement of the different stakeholders. However, one should be careful of biases towards the benefits of current technologies and technology lock-out dynamics further discussed in Section B.3.4 *Technology Lock-In & Path Dependence*. This latter point is particularly true for the Greek islands where, as already seen, the cost of providing power has spiralled out of control but is still stranded by a strong social policy and an entrenched supply-side-intensive common sense which pushes the system to the perceived 'safe option' of thermal plant additions.

Eventually, the thesis is drawn to an outer limit of its reach. It shall be concerned with new demand-side appliances in the islands as long as, or as far as, this proves to:

a) Provide a net benefit to the costs of running the island power system (positive externalities) and,

b) Achieve cost reductions or increase competitiveness of the local economy. Subsequently, spillover dynamics to continental Greece or firm competition strategy will not be dealt with unless if necessary exogenous variables.

Box 15: Developing the niche market of a challenger technology

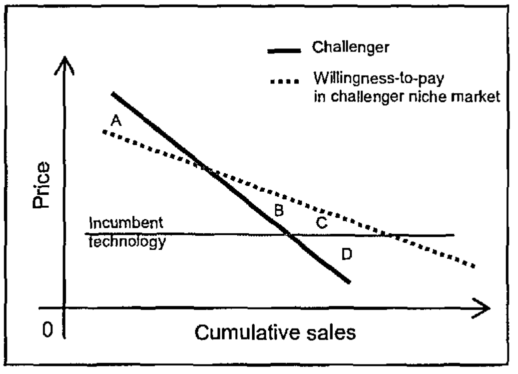

Fig. G

The cost of the challenger technology is initially higher than the willingness-to-pay of consumers in order to have the needed services fulfilled by the new technology. In that situation, marked 'A' in Fig. G, a government subsidy might be necessary to support the innovative energy service equipment providing the difference. As demand on the upper end of the niche is fulfilled, the WTP falls indicating lower income members of the community are eventually entering the niche. At the same time however, learning effects and word of mouth dynamics lead the price of providing the technology down assuming a point where it reaches below the WTP of potential buyers (region 'B').

In that situation public financial support can be phased out or diverted to indirect support measures such as labelling schemes and education campaigns. At this point, learning is assumed to lie mainly at the retailer or manufacturer of the technology and there are two directions. The product can still be marketed at the premium niche market according to the WTP of consumers given that it provides unique and competitive characteristics justifying the extra in the sales price (region 'C') or, launch a low-price version to compete directly with the incumbent technology perhaps with further institutional support until the incumbent is forced out in the case that the social net benefit expected is high enough for the policy maker to justify sustained support; i.e. in the case of extremely high costs of power generation or pollution.

Adapted from: (IEA 2003)

Potential buyers in niche markets may be willing to pay extra, or take up the associated risks, for energy services by a disrupting technology provided that the challenging technology offers characteristics that appeal anew to the consumers. Such qualities can be for example lower running costs, modularity, better reliability or compatibility with available equipment. Box 15 describes how can successful niche markets speed up the commercialisation of technologies, the role of government subsidy and potential benefits to private commercial suppliers. The IEA suggests that niche markets are highly recommended when energy efficiency improvements are spread over a large number of small individual decision-makers (consumers) despite the aggregate being significant (IEA 2003). In such cases, the mass market (e.g. solar space cooling or energy efficient lighting) is highly fragmented and there is the need for joint learning and experimentation with alternatives, an opportunity offered by small and individualised markets with identifiable inefficiencies similar to the Greek autonomous islands and their power consumption patterns. Deployment of challenger technologies in niche markets has a much rapid deployment impact.

B.3.3 *Disruptions & Structural Change*

The simple model of the learning system p in B.2.1 *End-Use Technologies & Deployment Dynamics* assumes a steadily declining learning curve. How would a shift in the current technology paradigm look like? What are the dynamics involved in the introduction of a new and more efficient variant of an end-use technology into the system or a major breakthrough in the methods to produce a technology? How do price and cost come into the analysis of learning effects? The IEA (IEA 2000) identifies two main discontinuities in learning; the *technology structural change* associated with disruptive improvements in the production process or technical aspects of a technology and, the *market structural change* which is brought about by conditions of market structure and players' strategy.

TECHNOLOGY STRUCTURAL CHANGE

Such discontinuities are identified in the cost curve of a technology and suggest a radical change in the content of the development process, e.g. much faster assembly, better heat resistant material. The change looks like a step shift, or discontinuity, firing a learning signal in the experience curve of costs. The currently employed variant A of a technology (Figure 115) is used until the point where a technological innovation draws investors and/or buyers to realise the benefits of variant B. The two variants are assumed similar, therefore during the transition, variant B can accumulate the experience learned from deploying variant A. This is happening rapidly until the market sets variant B as the new standard and stabilises on a new overall more efficient situation. There is a danger that a technology structural change is masked by changes in the market since experience curves are commonly based on prices rather than costs. This is elaborated further in the following.

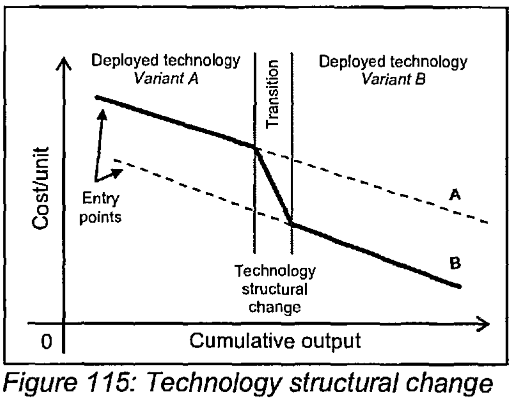

Figure 115: Technology structural change

MARKET STRUCTURAL CHANGE

Cost data is usually unavailable and policy makers have to rely on market prices to measure the experience effect. As already mentioned in Section B.2.1, under stable market conditions, the price to cost ratio is fixed and the two respective curves appear parallel. However, the price curves can also reflect sales and pricing strategies of market suppliers, bargaining power and consumers' reaction. Those entrenched relationships may alter the signal of cost reductions passed to the price of a product. In Figure 116 the cycle of a viable technology is broken down to four stages. A supplier (e.g. producer or retailer) initially sets prices below cost to enter the market in the development phase of its commercialisation. Assuming learning effects and economies of scale, costs fall below the going market price and the leader has the chance to maintain a higher price reflecting the short-term costs of new entrants thus redeeming their initial layout. Eventually, the new market learns as a whole and led to an unsustainable situation where the gap between price and cost becomes ever larger. The Shakeout phase abruptly set the market back to balance with a similar PR to the cost curve.

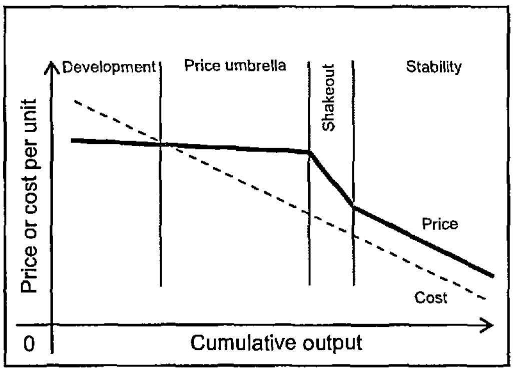

Figure 116: Market structural change

The two discontinuities are two distinct phenomena and any observation on the price curve can provide no conclusion for the cost curve. However, the average price progress ratio over one cycle could provide some insight in the cost progress ratio.

B.3.4 Technology Lock-In & Path Dependence

This section draws from Sterman's handbook of System Dynamics (Sterman 2000) according to whom 'path dependence is a pattern of behaviour of any system where the state and nature of its initial conditions along with random events during its evolution determines its eventual stable state'. In such systems small, random effects early in their history characterise the ultimate equilibrium when all end states are equally possible in the outset. Path-dependent systems are dominated by positive feedback processes, i.e. reinforcing loops. In the context of technology promotion, a successful market implementation programme initiates a positive price-growth cycle. As the market expands it provides learning and reduces prices, thus supporting further growth that further reduce prices and so on until the system reaches equilibrium, e.g. market saturation or technical limits. This process is known as technology *lock-in*. Box 16 below goes further into the explanation of path dependent systems.

Box 16: Path dependence and a first-order system

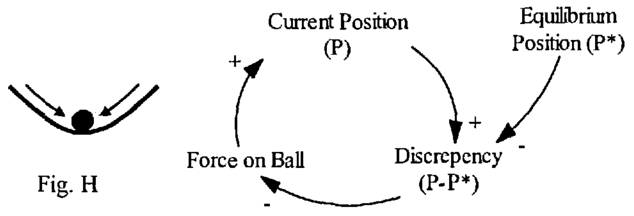

Fig. H

Fig. H represents a locally stable equilibrium. The system is governed by negative feedback: the greater the displacement of the ball from the equilibrium position, the greater the forces pulling it back to the centre. Any perturbation within the bowl has no effect on the final equilibrium of the system. The causal loop diagram (CLD) on the left shows that the greater the new position P is away from P*, the weaker the forces driving the ball out, thus the closer it is drawn to the initial position.

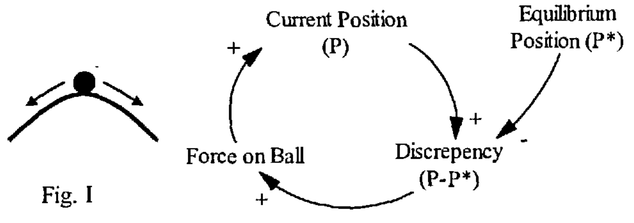

Fig. I

Fig. I on the other hand represents a locally unstable equilibrium governed by positive feedback. A slight disturbance of the equilibrium sets the system off balance. The greater the displacement, the greater the forces down the slope pushing away from the initial position. The initial perturbation determines the path taken and even the ultimate destination; the system is path dependent. The CLD says that the greater the discrepancy, the greater the force on the ball drawing it away from equilibrium; the further is P.

Source: (Sterman 2000)

Equally possible is the converse result, technology *lock-out*, when the technology cannot enter the market because its high price restricts it from obtaining additional learning investment to overcome the cost and other market barriers that would make it more attractive to consumers. Despite the great benefits of lock-in to the objectives of policy-makers and the chance to provide new energy technology options by exploiting the learning effect, e.g. through niche markets, there are considerable risks too. In brief according to these are (IEA 2003;Raven 2007;Sterman 2000):

1. Wrong assessment of the technology to promote or the policies sought may lock it out of the market permanently even if the environmental, efficiency or other technical benefits are proved or improved.

2. The expected benefits of lock-in may not materialise as they depend on continuous monitoring and support since the recently commercialised technology will be competing in a wider market with all strategic and market interests at play.

3. It might prove very difficult to get out of a lock-in situation in the case the conditions of the market or the objectives of policy change. The costs involved

will be that of changing the system and in addition those accruing from having locked out other options. For example, the natural gas has locked in at the expense of renewable energies. Despite gas technology being praised over recent years on its environmental efficiency and performance, it might prove the wrong choice on proof that dealing with climate change requires more carbon reductions.

The ability of the market to choose the winning technologies can reduce the risks of lock-out and bring about the benefits of lock-in. However, since markets are not ideal in the sense that they do not reflect all the costs of present and future externalities, market mechanisms and other policies introduced by government are expected to spread learning opportunities equally. There are cases where environmental protection imperatives legitimise further policy intervention in the market, such as introducing carbon taxes to raise the break-even point of carbon intensive power generation (IEA 2003).

Nevertheless, the underlying condition is that learning opportunities in the market and related investments are a scarce resource. Apart from competition among a variety of technologies in the market, environmentally friendly technologies do compete among themselves for development opportunities in the global as well as local environment (already discussed in Section B.3.2 *Niche markets*). Policy decisions must lie on the assessment of the future markets, the site-specific socio-economic conditions and objectives, as well the value of the technological choice on the energy system in a much broader context. Consequently, it might be necessary to define two curves when contemplating an island niche market technology development policy; an exogenous international experience curve related to the manufacturing the new energy service technology, and an endogenous local experience curve measuring the effectiveness of marketing, installation and use of the equipment.

The prevalence of positive, reinforcing, feedback in the economy is widely accepted and backed by empirical evidence (Sterman 2000) and it provides an equal possibility of lock-in to inferior technologies. However, an inferior technology that won the battle for market share might later on with improvements overcome the initial deficiencies. A more subtle issue that may not require any change in the technology itself is the stochastic nature of people's tastes and choices. Consumer's preferences are not static and habituation occurs in all levels of perception. It follows from this that the behaviour of consumers towards a technology should not be considered given or their current state of choice fixed and finalised. In effect captive customers, i.e. adopters of some energy equipment, are a stock which is in dynamic exchange with the pool of potential adopters of all candidate technologies bi-directionally, i.e. they can switch at any moment the conditions are right. The special case of the islands allows links of market transformation in the energy sector to be drawn with the broader economy due to the limited commercial exchanges and size of the economy.

B.4 Concluding Remarks

This final section collects the most relevant points of the appendix that have an impact on the design of the model and in general the positions held in this thesis. They are presented in bullet point format as adopted assumptions with an explanatory comment were necessary.

- Due to the low R&D spending in the country, the lack of appropriate research infrastructure and a sturdy market structure in the islands, the invention phase in Greece is not considered part of the technology's development (see B.1.2). Thus, the focus is on products that have been developed elsewhere and are ready for niche applications.

- The solar air-conditioning technology to be adopted is assumed an imported good to begin with. Learning on importation, marketing, installation and use will ensue first. Given the right support from the State this could lead to a local assembly or even manufacturing base by providing incentives firstly to the local DSWHS industry (Chapter 5).

- It is assumed that solar air-conditioning is a 'winner' technology picked by policy-makers following the analysis of the impact of space cooling in the power systems of the islands (Sections 3.2.2 and 3.2.4) and the fact that there are already commercial demonstration projects of variants of the technique in Europe and Greece (Section 5.3).

- The approach in this thesis is one of transformation not of barriers; i.e. it assumes that consumer preferences should be focussed on and can be influenced. The IEA recommends location specific analysis for a successful transformation intervention, an approach adopted in the thesis.

- It was reported that the IEA also suggests (Paragraph B.3.1) that when an unexlpoited net benefit to society exists, the focus should be make energy-related attributes of a product more desirable to consumers. The thesis tries to achieve this by having competitiveness as well as equipment cost factors affecting the adoption.

- The principle to avoid technological lock-in to the wrong technology in close knitted and small communities as those of the islands is to have as close a fit as possible between the technology launched and the needs of the community (Paragraph B.3.2). The simulation model achieves this by monitoring visitor arrivals and the feedbacks that exist between those, the equipment's spread, relevant cost of technologies and the competitiveness regional average.
- At least two technology learning curves should be considered for the islands, the international and the local. However, these are aggregated in this simulation model leaving disaggregation to further research (Section 8.4).