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Aggregating Energy Supply and Demand

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ABSTRACT: Energy usage in general, and electricity usage in particular, are major concerns internationally due to the increased cost of providing energy supplies and the environmental impacts of electricity generation using carbon-based fuels. If a “systems” approach is taken to understanding energy issues then both supply and demand need to be considered holistically. This paper examines two research projects in the energy area with IT tools as key deliverables, one examining supply issues and the other studying demand side issues. The supply side project used hard engineering methods to build the models and software, while the demand side project used a social science approach. While the projects are distinct, there was an overlap in personnel. Comparing the knowledge extraction, model building, implementation and interface issues of these two deliverables identifies both interesting contrasts and commonalities.

1 INTRODUCTION

There has been significant research and development within the construction industry on minimising energy usage in individual buildings, with the use of “smart” technology and sustainable energy generation. In parallel with this, power engineering researchers and distributors have been analysing and building “smart” grids. There have also been programs at the national and state levels to promote the use of sustainable energy systems. A key problem is that optimising the energy generation and use at the individual consumer (building) level is often not an optimal solution for the energy distribution system as a whole.

This paper describes the current outcomes of two related research projects that are underway at QUT in partnership with Ergon Energy. Ergon Energy distributes electricity to approximately 700,000 customers spread over 1.7 million km² of the state of Queensland, Australia.

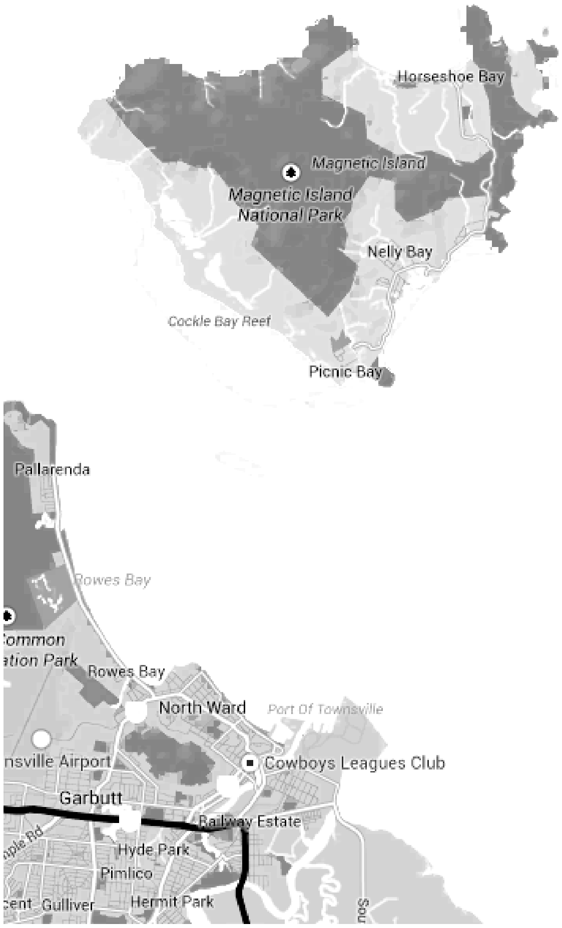


Figure 1. Townsville and Magnetic Island

The two projects explore two complementary areas of electricity supply, one covering the design and optimisation of the physical infrastructure and the other project examining demand side management. Different approaches to knowledge extraction, model building, software implementation and user interfaces were used for each project due to differences in the available data and algorithms. Hence the product and process models used for each project are different, but they share much of the input data required to produce valid results for each system.

We consider three major stakeholder groups, the state government, the electrical distributor and the customers. The state government sets the terms under which electricity is supplied. In Queensland this means equality in pricing across the state. This means that customers in Brisbane pay the same rate for electricity as in Birdsville, 1500 km to the west. The government also specifies a high level of reliability, 99.5%, which implies that there should be one level of redundancy at all locations in the distribution system. The state government also introduced very attractive buy-back tariffs to encourage residential customers to invest in photo-voltaic panels. This program was so successful that the scheme was revised to reduce the buy-back tariff to a level nearer the standard supply rate.

The customers connected to the main grid in Queensland are spread over 13° latitude (15.5°S – 28.5°S) and 13.5° longitude (139.5°E – 153°E). The climatic zones over this region vary from zones with hot, humid summers and warm winters to warm temperate climates which often experience sub-zero temperatures in winter. Consequently there are both cooling and heating driven zones within Queensland.

A major cause for concern has been the growth in peak demand for electricity across Queensland. This has been mainly caused by increasing use of refrigerated air conditioners by residential customers during hot weather.

In most public systems electricity is generated at a power station using some kind of fuel. The power is then sent over the transmission system at high voltage over long distances to the distribution grid. Within the distribution grid the voltage is reduced in stages through a series of substations and transformers until it reaches the customers' premises at the supply voltage.

The introduction of small scale renewable energy systems to distribution grids that were not initially designed for power input at these locations can lead to instability in the distribution grid. Depending on the configuration of the grid, instabilities occur between

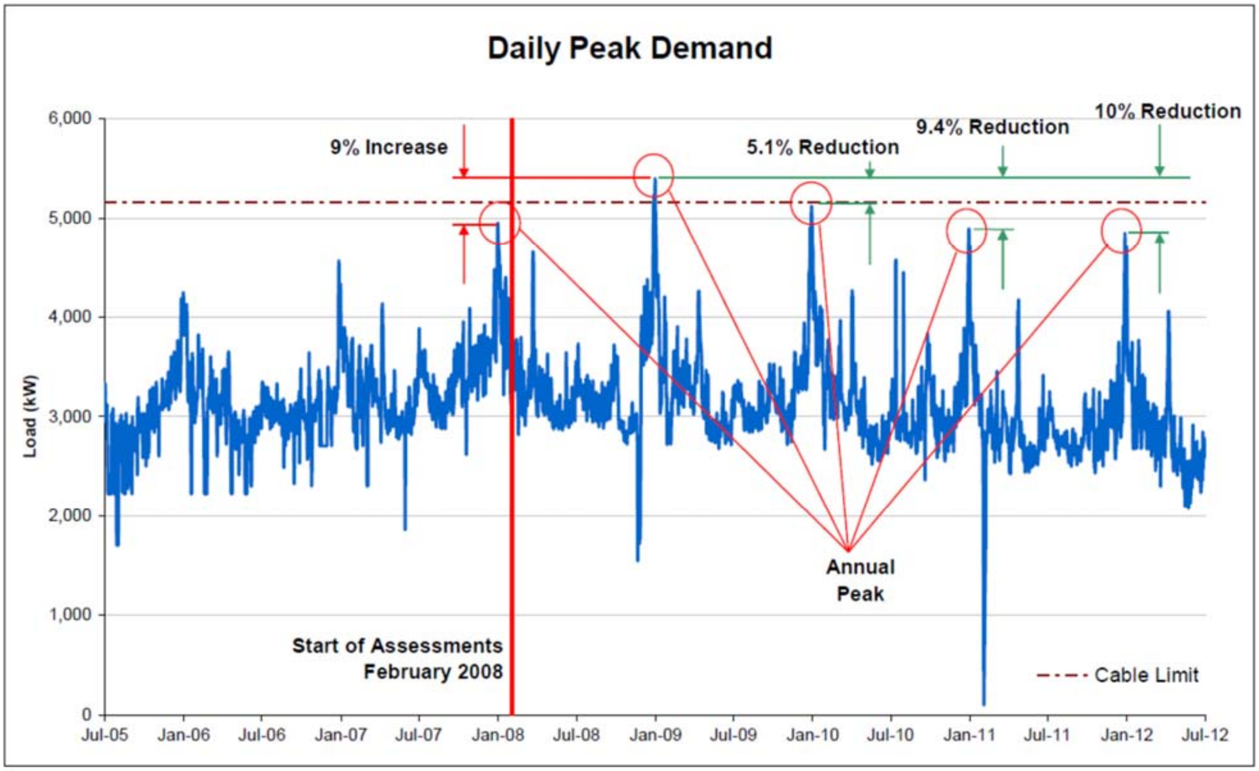


Figure 2: Daily peak electricity demand at Magnetic Island (Townsville Solar City Project 2012)

10% and 20% penetration of renewables. Since this is below the targets for renewable energy penetration for many countries in the 2020 time frame distribution grids need to be adapted to manage this level of renewable energy contribution. Two other drivers are the potential introduction of electric vehicles at a large scale and the possibility of consumers going “off grid” as the price of solar panels and battery storage decrease over the next few years.

The city of Townsville will be used as the case study. This is located on the East coast of Australia at latitude 19° S. Hence it is well within the tropics. The Renewables project concentrated on distribution substations in areas around Castle Hlll (Lower outline in Figure 1) and the central business district. Magnetic Island is located 8 km North of Townsville. It is mainly residential, self contained and needed an additional undersea cable if projections of load growth made in 2008 were to be met. The Townsville Solar Cities project was established to address the issue of load growth on the island. By June 2013 over 80% of the residences on Magnetic Island had been subject to residential energy assessments. Changes to energy efficient light bulbs and showerheads, cash-back vouchers to encourage upgrades to energy efficient appliances, reflective roof paint and the removal of old inefficient appliances all contributed to reductions in energy use. Figure 2 shows the measured reduction in energy use, with peak demand in 2011 lower than peak demand at the commencement of the project in 2008.

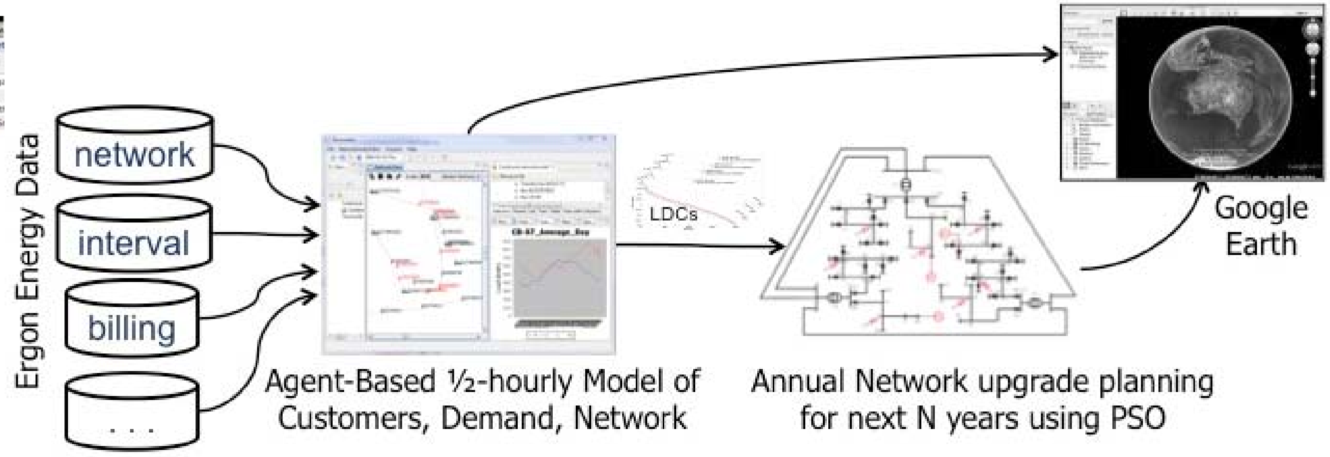


Figure 3. Renewables software architecture

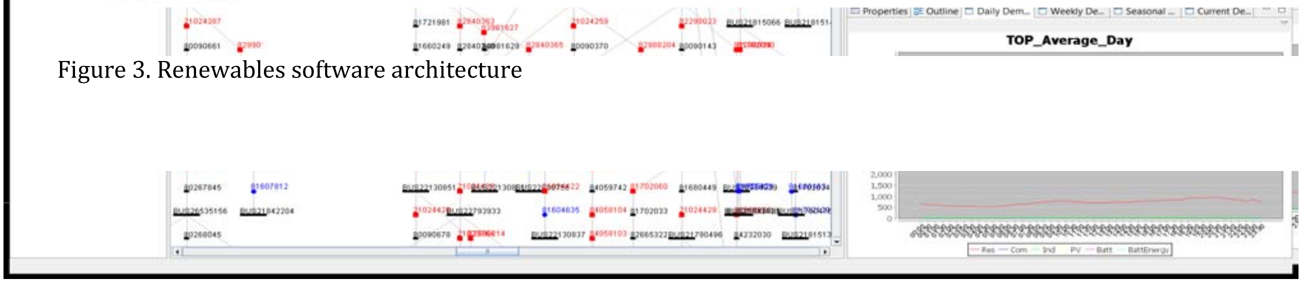


Figure 4. Network topology and graph output

2 RENEWABLES ON THE GRID PROJECT

The aim of the “Renewables on the Grid” (Renewables) project was to develop an agent-based model that would support the analysis of the electrical distribution system serviced by Ergon Energy. This meant that the physical components of the distribution system and the performance of the system needed to be modeled. This was in contrast to other agent-based models that had been developed up until this time which modeled energy markets and treated the transmission/distribution system as a “copper plate” where energy could be added and removed at any location.

The major goals were to understand the impact of renewable energy technologies on the reliability of the electricity distribution system, to understand how to maintain system reliability, and to support optimisation of the design of upgrades to the grid from a cost perspective. The model defines objects that represent the key components of the electrical distribution system, ranging from large step-down substations at the

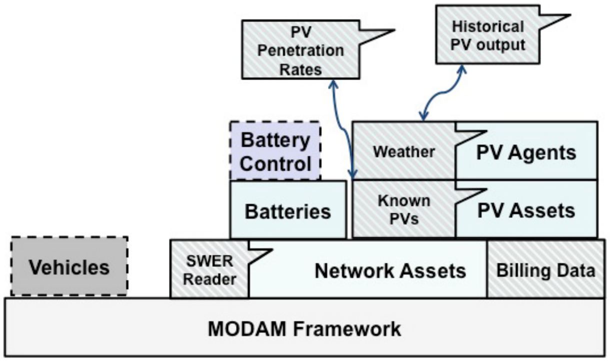


Figure 5. Modular architecture

end of transmission lines down to individual customers and the renewable energy systems within an individual premise. The use of batteries for energy storage and capacitance to maintain phase was also included as the price of batteries became more economic during the project. The potential impact of electric vehicles, their potential to contribute to peak load and also possible use a backup storage were also explored.

Currently customers are divided into residential, commercial and industrial. Due to privacy requirements data on residential customers is de-identified, although for the areas covered in this paper it is known what proportion of customers have swimming pools, air conditioners and photo-voltaic (P-V) panels.

Ergon Energy, as the energy distributor, is subject to numerous, sometimes contradictory, demands. Firstly, Ergon must maintain the existing physical network infrastructure and plan to meet future growth in demand. Given a 5 year planning horizon for network changes and the requirement, enforced through penalties, for 99.5% reliability, Ergon need to make engineering decisions with a conservative outlook. The major counteracting pressure is the need to keep the unit price at a publicly acceptable level. The 5 year planning horizon also makes rapid response to policy changes difficult. For example, five year capital investment plans were in place before the announcement of substantial subsidies for the installation of photo-voltaic panels. The reduction of net demand then lead to accusations that the transmission and distribution network organizations were “gold plating” the network infrastructure.

The Renewables project has developed two separate software modules that exchange data through file-based exchange (Figure 3). The first component is a detailed simulation tool that reads network topology, interval energy usage data and billing data from Ergon Energy databases. After analyzing the datasets this module produces analyses of customer usage, demand and network performance at 30 minute intervals. This data is then fed into the second module which develops network upgrade plans at 1, 2, 3, 4, 5, 10 and 20 year intervals. The annual outputs for years one to five match the Ergon Energy planning horizon, with the 10 and 20 year analyses providing a longer term context that is likely to be overtaken by a range of variable parameters. The results can then be viewed in Google Earth. A user can iterate back and forth between the two modules to gradually refine proposals.

The user can interact directly with the network topology by selecting individual nodes at whichever location and level in the network structure is appropriate. Graphs can then be displayed interactively over selected time sequences (Figure 4).

Approximately 700,000 agents are created in the agent-based module when performing a single run of the standard electricity distribution network for Townsville, while smaller areas, such as a single sub-

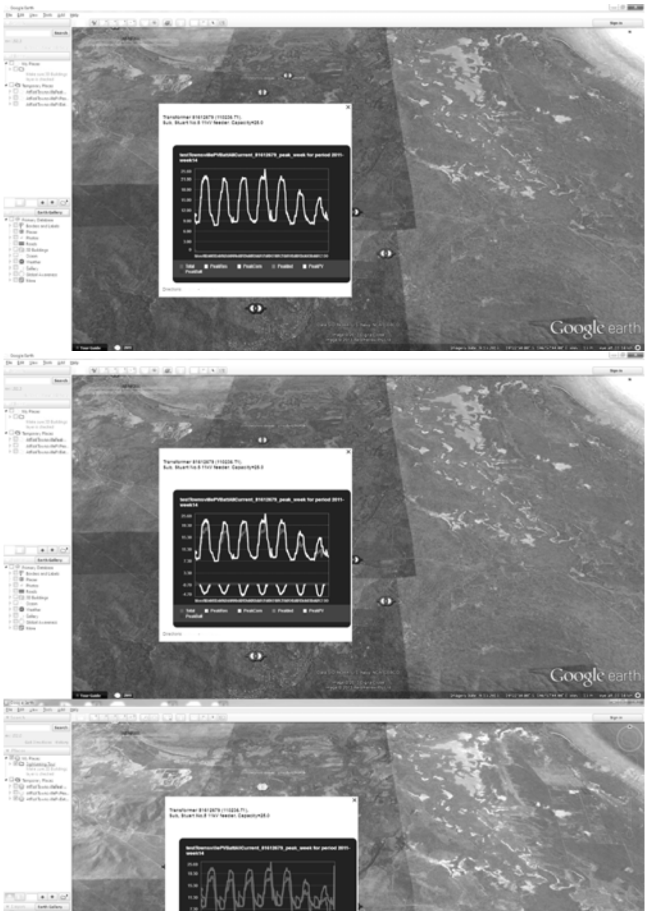


Figure 6. Three options for upgrades using color to identify overloaded transformers

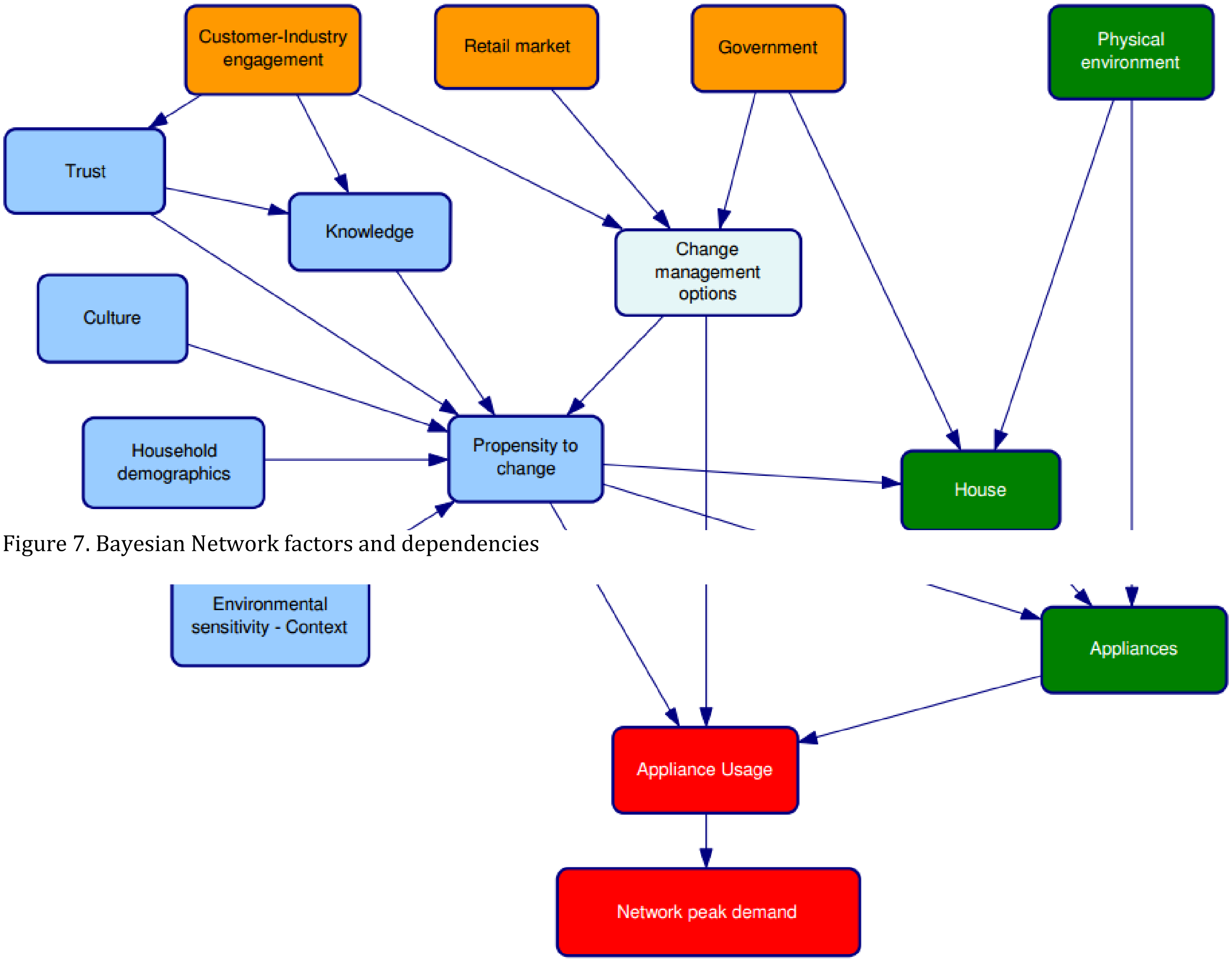


Figure 7. Bayesian Network factors and dependencies

urb take 10 – 20 minutes. Since scalability has a significant impact on execution time the base system was modified to support modularity within the agent population. In Figure 5 the electric vehicles and battery control modules have been added to the system while the PV penetration rate and historical PV output modules have been removed.

Multiple options can be compared (Figure 6).

The "product" model within the renewables project contains the three different types of electrical loads – resistive, inductive and capacitive (Blume, 2007), the physical components of the electrical distribution system – substations, buses, cables, etc, and three types of customer – residential, industrial and commercial. These are modeled within the agent-based module (Macal & North 2005; Macal & North, 2006). The software modules as a whole also implement the design process used within Ergon Energy – load growth prediction, development of network re-configuration and assessment through load flow analysis. Network configurations are generated through the use of particle swarm optimization (De Valle *et al,* 2008) within a second software module.

3 DEMAND SIDE MANAGEMENT PROJECT

In contrast to the Renewables project, the Demand Side Management (DSM) project is qualitative in its approach. This recognizes that any attempt to modify user behavior must influence the socio-technical system of which it is part (Lovell 2005).

In the knowledge elicitation stage a total of 40 participants from Magnetic Island were interviewed on the their experience of the Solar Cities project and the ongoing adaptations of their families to electricity use. Thematic analysis was used to identify the patterns or themes relevant to their life and behaviour.

A Bayesian Network was used to model the concepts, the dependencies between the concepts and the probabilities that are estimated to govern the dependencies (Korb and Nicholson 2010). The graphical representation of the derived network is shown in Figure 7. The factors can be divided into five groups – market factors (customer-industry engagement, retail market, government), physical factors (physical environment, house, appliances), change management options, social factors (trust, knowledge, culture, household demographics, environmental sensitivity, propensity to change) and outputs (appliance usage, network peak demand). The heavy influence of social factors should be noted. If the customer does not trust the energy provider, or just does not want to change then there is little that can be done.

The results of a run of the Bayesian Network are shown in Figure 8. The cumulative impact of the selected interventions is shown. A key message is that the various change options are not independent. If one option is removed then the total impact needs to be recalculated. It is not feasible to "cherry pick" a particular choice and just rely on that choice.

Some complex statistics lie underneath this simple interface. There are 14 different residential segment profiles grouped into three consumption levels (Figure 9). This allows detailed demographic information at a particular location to be described.

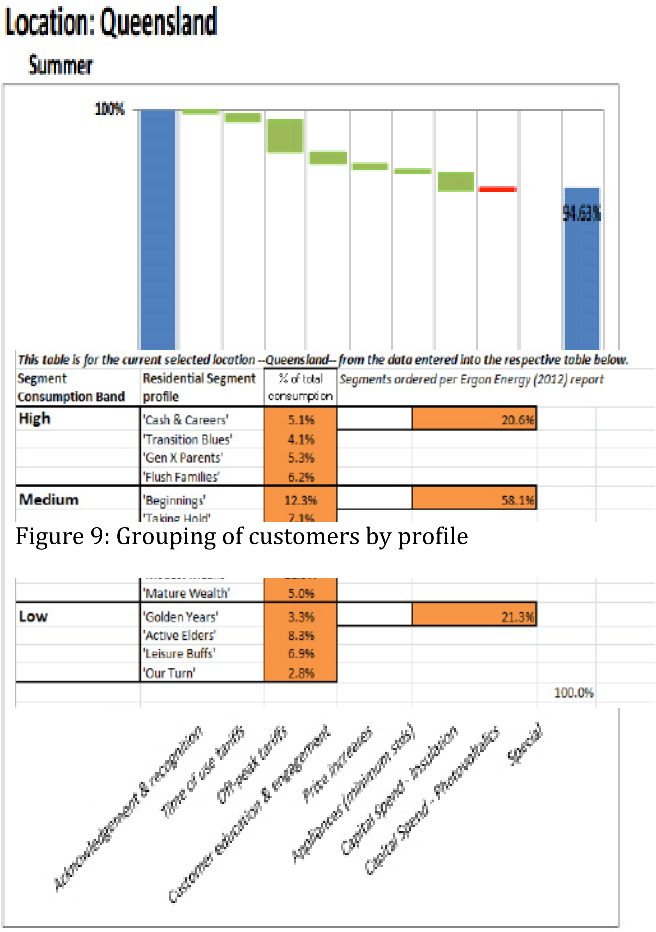
The expected impact of particular interventions at various locations is also modeled, for the state of Queensland as a whole, for Toowoomba (heating driven climate) and Townsville and Mackay (cooling driven climates). The range of locations can be extended easily.

Conditional probabilities for the "propensity to change" node are also accessible, as are appliance usage estimates.

The model underlying the Bayesian Network and the decision making can be divided into the physical aspects (the residence, appliances, external environment), stakeholders (customers, government, retailers, suppliers), options for change and the factors influencing change. The linkages between each of the model components are expressed as probabilities of change between related components. Changes to any component will then flow through the linkages, forcing a recalculation of the results.

4 COMPARISON

While these two projects are addressing problems that are opposite sides of the same coin – supply and demand of electricity – they are substantially different in concepts and algorithms.



This table is for the current selected location --Queensland-- from the data entered into the respective table below.

Segment Consumption Band	Residential Segment profile	% of total consumption	*Segments ordered per Ergon Energy (2012) report*	
High	'Cash & Careers'	5.1%		20.6%
	'Transition Blues'	4.1%		
	'Gen X Parents'	5.3%		
	'Flush Families'	6.2%		
Medium	'Beginnings'	12.3%		58.1%
	'Taking Hold'	7.1%		
	[illegible]	[illegible]		
	'Mature Wealth'	5.0%		
Low	'Golden Years'	3.3%		21.3%
	'Active Elders'	8.3%		
	'Leisure Buffs'	6.9%		
	'Our Turn'	2.8%		
				100.0%

Figure 9: Grouping of customers by profile

The Renewables project is a typical "engineering" problem, with a well defined object model of "things of concern" and well understood algorithms for calculating the interactions and flows within the system. The major issues with this project are that the problem domain expands combinatorially, lack of access to high quality input data, the difficulty of predicting demand in the future and the large number of potential, near optimal solutions.

On the other hand, the DSM project has a weakly defined object model since this is built from people's opinions and the interactions between the concepts are fairly subjective.

5 FUTURE WORK

The individual software tools within these two projects can be incrementally refined through providing improved input data, optimizing the software code to improve run times and improving the user interfaces to allow better analysis of the detailed results of analysis.

However, the major potential improvement will be to interface the two projects so that the supply side and the demand side can interact automatically. This would allow the government and the distribution/retail arms to trade off upgrades to the physical infrastructure of the grid versus incentives for demand reduction. A funding submission has be prepared to support this amalgamation of the software for the two projects but the results of the funding round have not yet been advised.

Figure 8. Ranking of DSM interventions

6 CONCLUSIONS

These software tools have potential application to cities elsewhere in the world as utilities tackle the issues of energy cost, reliability, security and sustainability, within the context of energy consumers making individual choices on the energy consumption, generation and usage patterns.

While they have been developed for locations that have different climates to much of Europe and North America they could be readily adapted to more widespread use given access to the requisite local data.

7 ACKNOWLEDGEMENTS

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- University of Duisburg-Essen - Professor Christoph Webber’s team
- TU Dortmund University - Professor Christian Rehtanz’ team
- RWTH Aachen University - Professor Antonello Monti’s team

A large number of Ergon Energy employees have also contributed to the Renewables project over the 4 years that it has run.

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