Continuity Model for Energy System Sustainability

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Executive Summary

What is a sustainable technology? Can something be 10% more sustainable? What is sustainable growth? By sustainable, do we really mean, we don't want to change? If we were to define sustainability as an engineering design criteria or a performance parameter, what would the numbers mean? This paper explores the first steps to functional deployment of the criteria of sustainability for a regional energy system using a novel continuity model.

At the University of Canterbury, the Advanced Energy and Material Systems Group (AEMS) is dedicated to research into the planning and development processes for development of the next generation energy system. The standard engineering systems design approach, together with advanced modelling techniques is employed in a revolutionary methodology to determine an "energy system framework" that could meet society's needs within the limits of available sustainable resources. This field of study is called Strategic Analysis of Complex Energy and Environmental Systems (SACEES).

The SACEES approach has been developed from original research describing human activity, energy consumption, and the environmental impacts as a feedback control system, which operates within a geographical, cultural, and economic context. In this paper, the theory is described, and used to demonstrate that the first step toward a sustainable energy system is to design a system that meets the given requirements of the regional society within the constraints of geography and environment. The theory of energy continuity is several hundred years old (the First Law of Thermodynamics). However, the continuity model developed for the SACEES programme requires that:

1. at least one possible manifestation of a fully sustainable energy system for a specific region must be defined;
2. the nature and functionality of the resource-constrained, sustainable energy system must be communicated to the community in non-technical terms; and
3. feedback of service availability and environmental impacts must be related directly to immediate, daily activities of individuals and businesses.

A SACEES study must be done for a specific region, and for a specific community requirement. The study requires compilation of renewable energy availability data and energy conversion technology characterisation, together with cultural requirements of the society for a high quality of life. In this paper we will present the example of a SACEES study done for the city of Christchurch, concerning the winter home heating problem. The continuity model of a sustainable system was developed, specifying that wood energy in the form of forced-air pellet stoves could provide the service required to all residents of the city within the waste wood supply limits for the area. Direct feedback mechanisms were also proposed which would drive the change to the sustainable system.

Introduction

Sustainable Growth

In its physical dimensions the economy is an open subsystem of the earth ecosystem, which is finite, non-growing, and materially closed. As the economic subsystem grows it incorporates an ever greater proportion of the total ecosystem into itself and must reach a limit at 100 percent, if not before. Therefore its growth is not sustainable. The term "sustainable growth" when applied to the economy is a bad oxymoron.[1]

Economists will complain that growth in GDP is a mixture of quantitative and qualitative increase and therefore not strictly subject to physical laws. They have a point. It is precisely because quantitative and qualitative change are very different that it is best to keep them separate and call them by the different names already provided in the dictionary. To grow means "to increase naturally in size by the addition of material through assimilation or accretion". To develop means "to expand or realise the potentialities of; to bring gradually to a fuller, greater, or better state". When something grows it gets bigger. When something develops it gets different. The earth ecosystem develops (evolves), but does not grow. Its subsystem, the economy, must eventually stop growing, but can continue to develop. The term "sustainable development" therefore makes sense for the economy, but only if it is understood as "development without growth", i.e. qualitative improvement of a physical economic base that is maintained in dynamic stability by a throughput of matter and energy that is within the regenerative and assimilative capacities of the ecosystem. Currently the term "sustainable development" is used as a synonym for the oxymoronic "sustainable growth".

Politically it is very difficult to admit that growth, with its almost religious connotations of ultimate goodness, must be limited. But it is precisely the non-sustainability of growth that gives urgency to the concept of sustainable development. The earth will not tolerate the doubling of even one grain of wheat 64 times, yet in the past two centuries we have developed a culture dependent on exponential growth for its economic stability. Sustainable development is a cultural adaptation made by society as it becomes aware of the emerging necessity of non-growth. Even "green growth" is not sustainable. There is a limit to the population of trees the earth can support, just as there is a limit to the populations of humans and of automobiles. To delude ourselves into believing that growth is still possible and desirable if only we label it "sustainable" or colour it "green" will just delay the inevitable transition and make it more painful.

Limits to Growth

If the economy cannot grow indefinitely then by how much can it grow? Can it grow by enough to give everyone in the world today a standard of per capita resource use equal to that of the average American? The Brundtland Commission calls for the expansion of the world economy by a factor of five to ten.[3] The problem is that even expansion by a factor of four is impossible given that the human economy currently diverts one-quarter of the global energy captured by plants and converted to biomass, Net Primary Product of photosynthesis (NPP).[2] We cannot go beyond 100 percent, and it is unlikely that we will increase NPP since the historical tendency up to now is for economic growth to reduce global photosynthesis. Since land-based ecosystems are the more relevant, and we pre-empt 40 percent of land-based NPP, even the factor of four is an overestimate. Also, reaching 100 percent is unrealistic since we are incapable of bringing under direct human management all the species that make up the ecosystems upon which we depend. Furthermore it is ridiculous to urge the preservation of biodiversity without being willing to halt the economic growth that requires human takeover of places in the sun occupied by other species.[1]

If growth up to the factor of five to ten recommended by the Brundtland Commission is impossible, then what about just sustaining the present scale, i.e. zero net growth? Every day we read about stress-induced feedbacks from the ecosystem to the economy, such as greenhouse build-up, ozone layer depletion, and acid rain, which constitute evidence that even the present scale is unsustainable. How then can people keep on talking about “sustainable growth” when:

1. the present scale of the economy shows clear signs of unsustainability,
2. multiplying that scale by a factor of five to ten as recommended by the Brundtland Commission would move us from unsustainability to imminent collapse, and
3. the concept itself is logically self-contradictory in a finite, non-growing ecosystem?

Sustainable Development

The world is a complex place that changes all the time, and what is sustainable at one time is unlikely to remain so. The quest for sustainability will be continuous and will require vigilance, creativity and continual adaptation.

The concept of an optimal scale of the aggregate economy relative to the ecosystem is totally absent from current macroeconomic theory. The aggregate economy is assumed to grow indefinitely. Microeconomics, which is almost entirely devoted to establishing the optimal scale of each micro-level activity by equating costs and benefits at the margin, has neglected to inquire if there is not also an optimal scale for the aggregate of all micro-level activities. A given scale (population multiplied by per-capita resource use) constitutes a given throughput of resources and thus a given load on the environment, and can consist of many people each consuming little, or fewer people each consuming correspondingly more.

An economy in sustainable development adapts and improves in knowledge, organisation, technical efficiency, and wisdom; it does this without assimilating or accreting, beyond some point, an ever greater percentage of the matter and energy of the ecosystem into itself, but rather stops at a scale at which the remaining ecosystem (the environment) can continue to function and renew itself year after year. The non-growing economy is not static; it is being continually maintained and renewed as is the environment.

Energy System

The energy and environment system is a self-organising system. Self-organising systems exhibit a variety of behaviours, ranging from simple and repetitive to chaotic. Short of chaos there is a regime of behaviour called complexity that is neither simply ordered nor chaotic, but rather a continually shifting interplay between the two.[1] Economies, human societies and living systems are all examples of complex self-organising systems. This insight implies that there are many ways in which viable energy systems might be organised. It also implies that there is no reason, in principle, why the energy system (Figure 1) can't be compatible with

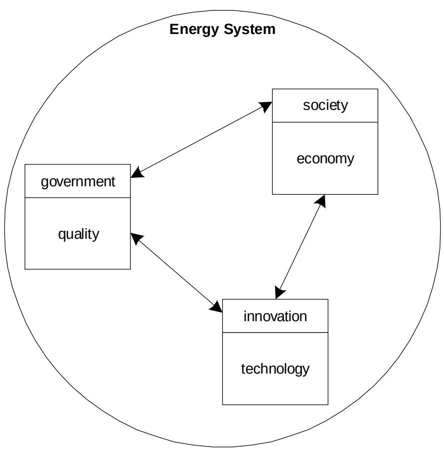

Figure 1 – Energy System

the living environment.

During the twentieth century, a way of looking at complicated systems, including both human-made and living systems, slowly emerged and became known as “systems thinking” or “systems science”.[5] It has been used extensively in engineering as well as for inquiring into the nature of things. The central idea of systems thinking is that new properties, patterns or behaviours can emerge in the system that are not present in its parts separately. Properties of this type are called emergent properties, because they only emerge when the system is fully connected and interacting as a whole.

The energy system includes many soft elements, with many ill-defined boundaries and methods of interaction. Any system of interacting entities gives rise to new kinds of behaviour that are not possible for the individual components alone. This is a central finding of systems theory, that a system can yield a new level of emergent behaviour, so that the whole is greater than the sum of the parts.

In coping with any complex human situation, we must take into account all the relevant factors, not merely a single factor.

Intrinsic to the systems way of thinking is the idea of levels of a system. Emergent properties are present in one level of a system but not in the level below it, the level of its component parts. This leads to the idea that there may be many levels in a system, since the component parts may themselves be formed of smaller parts. At each of these levels there are properties that do not exist at the next level down.

Mode of Operation – Stability

There are times in the development of a complex self-organising system when it becomes poised between alternative possibilities. At those times it may be extremely sensitive to small influences, from within itself or from outside, that determine into which state it develops. Complex systems tend to go through a series of such transitions if they are driven further and further from equilibrium, and the successive states that result tend to be progressively more complex. The alternative possible states into which the system might develop have comparable degrees of complexity, but different arrangements, different patterns in detail.[1]

The character of self-organising systems is determined by the internal relationships between their parts, and by the way those relationships change as the system develops. The crucial relationships involve feedback.

Positive feedback amplifies existing trends. Exponential growth is the key process that initiates self-organisation. Exponential growth results from positive feedback, and it is a powerful process, because through it very small things can eventually grow to be very large.

Feedback can be negative as well as positive. Negative feedback tends to damp out or reduce a trend. Negative feedback tends to stabilise a system, whereas positive feedback is destabilising.

Performance Requirements

The energy and environment system has poorly understood feedback mechanisms with disproportionate lead times, and undefined system performance requirements. The ultimate performance requirement of sustainability has complex interpretations with respect to the energy system, and is therefore not well understood by all participants.

Sustainable Society

What does a contemporary sustainable society look like?

For a sustainable society to develop the long-term compatibility of the economic, social and environmental dimensions of human well-being must be addressed, while acknowledging their possible competition in the short-term. The Organisation for Economic Cooperation and Development (OECD) notes that short-term competition between goals relating to economic, environmental and social dimensions is one of the main causes of the large gap in the implementation of sustainable development policies.[6] The UK government definition of sustainable development, contained in its Sustainable Development Strategy published in May 1999[7], has four objectives:

1. social progress which recognises the needs of everyone,
2. effective protection of the environment,
3. prudent use of natural resources, and
4. maintenance of high and stable levels of economic growth and employment.

Addressing concerns about the implications of sustainable development, sustainable society can be defined in terms of what it need not be:[8]

- Sustainability does not mean no growth.
- A sustainable society need not be technically or culturally primitive.
- A sustainable world would not and could not be a rigid one, with population or production or anything else held pathologically constant.
- A sustainable society would not have to stop using non-renewable resources, but would use them more thoughtfully and efficiently.
- A sustainable society need not be uniform, undemocratic or unchallenging.

This does not just mean conservation, but also working within resource constraints. The single biggest constraint on sustainability is the availability of energy. The vast majority of current energy research regards specific technologies, not the energy system as a whole.

Continuity Model

I use the term continuity model rather than sustainability model for two reasons. First, the term sustainable was quickly co-opted by people who had little conception of what it might mean, or who had no intention of taking more than a few token steps towards sustainability. Second sustainability is not a well-defined concept. The world is a complex place that changes all the time, and what is sustainable at one time is unlikely to remain so. The quest for sustainability will be continuous and will require vigilance, creativity and continual adaptation. Therefore, it is more useful to refer to a continuity model.

Energy System Framework

The continuity model is used to determine a possible future scenario, based on the ultimate performance requirement of sustainability (**Error! Reference source not found.**). It is not merely an engineering model of discrete energy sub-systems, but encompasses all of the soft components and relationships of the greater energy system, including:

- renewable energy availability data,
- energy conversion technology characterisation, and
- cultural requirements of the society for a high quality of life.

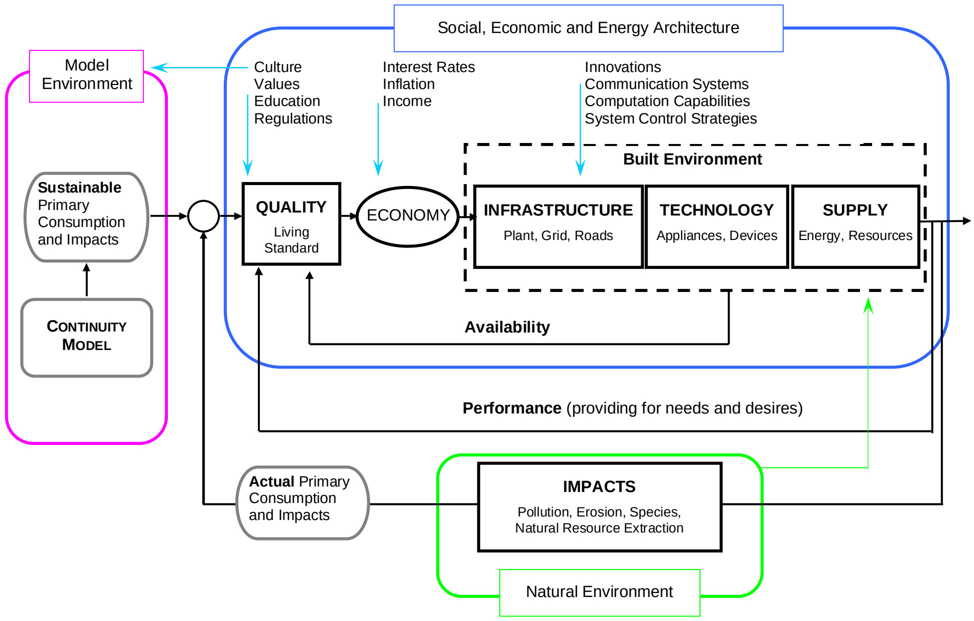

Figure 2. The continuity energy/environment/economy system model showing the role of the continuity model as providing the sustainability reference for the energy system for system design, development, and day-to-day operation.

An idealised, sustainable state of the energy system must be defined, and from this performance objectives (targets) can be developed. The nature of the ideal state must be communicated to the community in such a way that it can be understood. The ideal state is not a steady-state solution, but one which is dynamically stable.

The actual performance of the energy system can be compared with the targets in order to provide consumers with continuous, real-time feedback of availability at the point of use. With these drivers for change, elements of the systems and their relationships will develop in such a way that the overall behaviour of the system will be directed towards a goal.

Communicating the Model – Sim City

The computer game Sim City (and related ones from Maxis, such as Sim Town) is a simulation environment that allows the player to design a city within the constraints of a budget and with consideration for the well-being of the people and environment. Players explore the consequences of their decisions as they observe how the city they planned develops over time.

The game is essentially a finite-element model with a rich graphical mode of presentation. It is this type of graphical presentation that would make an ideal method of communicating the system model, its components, its relationships, and the emergent behaviour. It is difficult or impossible to fully appreciate the dynamics of a system without this type of immersion in the model process.

Application – Home Heating and Health Impacts

A SACEES study must be done for a specific region, and for a specific community requirement. The study requires compilation of renewable energy availability data and energy conversion technology characterisation, together with cultural requirements of the society for a high quality of life. Presented below is an example of a SACEES study done for the city of Christchurch, concerning the winter home heating problem.

The purpose of the study was to develop a five-year scenario using SACEES methodology, based on technical feasibility, sound engineering, and all of the information and analysis resources of the Christchurch City Council (CCC), Environment CANterbury (ECAN), other researchers and interested parties to answer the question, “What else can people do?”.

Overview

Almost all of the information needed to do the analysis was already available from previous studies by the CCC, ECAN, CAE, NIWA, Statistics New Zealand, BRANZ, EECA and others. The nature of the problem and the technical aspects of the solution have been well established through previous work.

Definition of the problem in Christchurch is straightforward:

> *Primarily open fires and secondarily log burners, have high rates of emissions. Those emissions, when concentrated by population density and weather conditions pose a health hazard to the community and a general reduction in quality of life. Cold indoor conditions are not healthy for many, and represent a lower quality of life in general.*

The means to eliminate hazardous winter air pollution is simple:

> *Eliminate open fires and log burners from the city.*

The solution to indoor comfort is well understood:

> *Provide an adequate source of heat energy at high conversion efficiency into a well-insulated living space.*

The analysis in this project was not focused on further defining these aspects of the problem. Our effort has been directed to defining other aspects of the problem, namely a decision analysis of the Christchurch culture, designing a sustainable energy system, and developing an “event map” scenario of how this particular community of people can move from the current situation to the sustainable system. This has turned out to be a very different type of analysis to the previous studies commissioned by ECAN, CCC and other government agencies. We hope that the new results will provide a tool to facilitate the needed improvements in community and household quality of life.

System Definition

The system is defined by the problem that is being addressed. The first task was to define the system for analysis purposes, and acquire data representing the system assets.

It is recognised that burning of agricultural waste in the Canterbury plain can often contribute to the Christchurch air pollution problem. It is recognised that salt spray from the sea can add to the natural particulate loading of the area. It is recognised that winter fog can exacerbate reduced visibility and “smoggy” conditions. It is fully recognised that emissions from vehicles are a major threat to high-quality clean air. None of these contributors are considered part of the system for this analysis. The components of the system for this project are within a 7-kilometre radius of the city centre:

- households which use open coal or wood fires for winter heat
- households which use log burners or coal burners for winter heat

- households which have below standard comfort levels

The data describing this system were taken from ECAN, CCC and statistical resources. Using round figures for simplicity, we base our analysis on 14,000 to 18,000 households that report using open fires for heat on winter days, and 55,000 households which rely on enclosed burners. Many of the homes with open fires also have substandard living conditions, because the open fire doesn't do a good job of providing heat to the living space. Thus, we used a figure of 70,000 additional households that are targeted for improved comfort level.

The energy system is defined according to known domestic resources, and the domestic heating load is defined from the above figures, historical weather patterns, and the cultural practice of heating only a part of the home.

Complex Systems Functional Model for Christchurch

The theory of behaviour of complex systems holds that a regional system can be understood by using the model depicted below (Figure 2). The particular form of this model for the Christchurch heating and related air pollution system was developed.

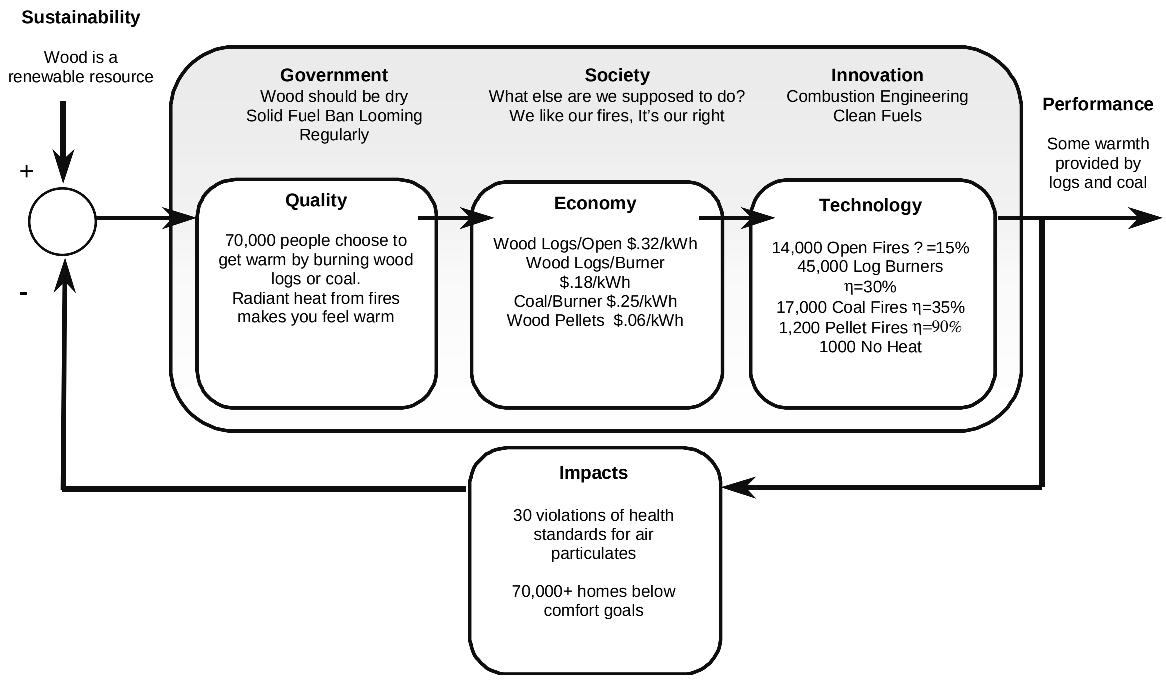

Figure 2 – Regional Energy and Environment Systems Model for Residential Solid Fuel Heating System, Christchurch 2002

Quality

In the autumn, people decide, "I want to be warm this winter.". They call a firewood supplier and get a mixture of the cheaper pine and more expensive hardwoods. This mixed supply lets you start up the fire with faster burning pine, and then use hardwoods for continuous burn. Most coal appears to be purchased in bags at supermarkets. We could not find reliable evidence that a meaningful number of city residents collect their own firewood. Thus, the quality decision, which drives the whole system, is made by people in the autumn, when they choose how they will stay warm.

Finding 1

> *The driver for the current system is people with wood burning appliances choosing to purchase wood to provide the service of staying warm. This decision is made as cooler weather settles in the autumn.*

Government. Government discussions about banning solid fuel burning several years in the future have no impact on this system-controlling decision. Even if a ban on solid fuel burning were to actually be put into law, it would have no impact until the ban actually took effect, and then, only if there was rigorous enforcement and a high penalty for violating the ban. The only effective way to enforce a total solid fuel ban would be to shut down all firewood vendors and outlaw sales of solid fuel. The ineffectiveness of the solid fuel ban approach can be attributed to several factors. Firstly, the people of Christchurch have been conditioned to the looming solid fuel ban never actually happening. The debate about the policy has degenerated to the point where no useful way forward appears possible. At the same time that a new and creative policy to reduce solid fuel burning needs to be developed, we find in ECAN, an unrelenting dedication to the policy. The major force behind the total solid fuel ban appears to be Cr. Neil Cherry. Numerous studies over the last several years have plainly indicated the following facts:

- Winter air pollution levels in Christchurch are causing health impacts.
- Combustion of logs and coal in open fires produces the largest component of the particulate pollution.
- There is a net economic gain in health impacts from immediate elimination of open fires.

These facts don't change the ineffectiveness of the "total solid fuel ban" policy approach. A strategic approach to policy would be aimed at maximising impact for positive change at the point where the decisions of wood and coal burners are made. In the same way that cigarette smokers cannot quit until they admit there is a problem, chimney smokers in Christchurch will not quit until they admit that they are the problem. A possible approach for CCC and ECAN to lead the way forward through policy and action is the subject of the scenario presented in this example.

Present regulation to control the moisture content of wood fuel has an impact on the system, if it is followed, when the fuel is consumed. However, fuel regulation does not impact the decision to use wood, and if anything facilitates it because people assume that their wood is fine to burn because of the regulation.

Sustainability. There is not a pressure for change from the wood as a fuel because it is a sustainable resource and there is no shortage of it. If people perceive that the fuel supply is not secure, they will look for alternatives, because the important thing is meeting their desire to stay warm. This effect can be seen in general reluctance to convert to pellet fires because in the past the supply of pellets has been disrupted.

Impacts. There could be significant pressure for change in this decision from the impacts on the environment and health, except that the interpretation of the impact is not relevant to the decision. There is a disjoint in time because the feedback to the public about the poor air quality is provided only after households have stocked a supply of wood for the winter. The other disjoint is in the relationship between action and performance. People know from first hand experience that they feel warm in front of a fire. It is a rather abstract concept to tell them that the energy efficiency is poor or that it is actually cooling down the rest of the house, because their experience is that the rest of the house is cold anyway. There is a negative impact from the collective activity of wood burning, i.e. pollution. It is psychologically difficult for individuals to change behaviours when they need to make the connection between their immediate actions and a follow-on collective impact.

Society. The Christchurch culture represents a very interesting part of the system dynamic. It can be argued that the actions of about 10% of the population are degrading the quality of life of the entire city. Yet, opinions of people who don't even use solid fuel are often against a solid fuel ban. It seems to make little difference whether a person burns wood or not, everyone dislikes the winter pollution, but everyone thinks an open fire is traditional, pleasant, and people's right. There is a universal concern among citizens about low-income people being cold. There is also a universal opinion that the councils should find a solution. In other words, people don't see that they are actually in control of the problem and thus hold responsibility for individual action to effect a solution.

Innovation. The technology currently exists to provide adequate heating from renewable resources without pollution. Thus new technology innovation will not impact the system. The culture appears to be historically very willing and eager to uptake new technology to improve standard of living and convenience. However, the culture possesses a collective obstinacy when a change is perceived as being forced on individuals by government. The greatest impact from uptake of innovation will come from perception that the new technology provides a superior service, performs better, and is highly desirable. This is basically the strategy used by advertisers to effect change in purchasing patterns.

Economy

In the Christchurch system, people appear to be able to afford the log burners and the wood and coal that they are currently using. They also seem to perceive electricity as terribly expensive. We added up the wood fuel bills for several people in the suburb of Ilam. We calculated the price per kW.h that they are paying for heat from wood. We compared that to their day rate for electricity. None of them had perceived, prior to the calculations, that they were paying more for wood than for electricity. In fact, one person (an intermediate school teacher) kept telling us that the wood heat was "free", despite the fact that her husband had paid $135 per load. In fact, once convinced that per kW.h, wood was more expensive than electricity, the woman still indicated she would choose to use wood rather than pay the power company.

Pressure for change in the decision to use wood seems unlikely to come from economic factors. There is actually a great resistance in the system that can be attributed to the perception of electricity as expensive. Our analysis indicates that there will be a very high resistance to changing to electric heating due to this perception.

We found no evidence that low-income and elderly people represent a large, or even significant, number of homes that rely on open fires. However, there is a very common opinion that banning open fires would disproportionately harm poor and elderly people. Evidence to the contrary will not have a significant impact on the unpopularity of the solid fuel ban.

Our survey indicated that the initial capital cost of a new heating system would pose a large resistance to change. However, our survey of real estate agents showed that the heating system of the home would influence the market potential of a property. They also indicated that the "warmth" and the moisture conditions of a home were second only to location as top priorities for potential home buyers.

Finding 2

> *The largest impact on the number of people changing from wood or coal will come from desire for improved comfort and property values rather than from potential energy cost savings, as wood and coal are presently perceived as affordable.*

Technology

Cold wood from outside the home is stacked in the burner with some newspaper and (hopefully) some kindling. The start-up period for wood and coal fuels alike is usually a very smoky affair. Once the firebox heats up, the fire begins to draw up the chimney, supplying the air for combustion. Heat is actually required to achieve combustion, so as the fire heats up the firebox, the combustion process improves and less of the aromatic hydrocarbons (smoke) escape the flame zone unburned. As the fire is left to burn out overnight, the process can be very smoky if there is any wood fuel left (not coals) when the firebox starts to cool down and draw less effectively. The open fireplace is an engineering marvel of the thirteenth century. It is a vast improvement over its predecessor, the open pit fire in the centre of the room with a hole in the roof for smoke. Benjamin Franklin invented the free-standing "Franklin" log burner in the early eighteenth century. The log burner was another great improvement in heat output and fuel efficiency. Over two decades ago, combustion science and engineering were employed to develop the forced air pellet burner for complete combustion of biomass.

As stated previously, the decision to use wood has already been made long before the heating technology is actually used to make a fire. Building a fire in the grate is a localised decision on a particular day. Government regulations and economy can impact this decision, however, the most important factor for change will be people finding a better, more convenient, high technology way to heat their homes.

Finding 3

> *When people no longer think of open fires as a source of heat, they will cease to use them for that purpose.*

Soft System Assets

The soft system refers to the parts of the system, which are directly affected by individual decisions and choices. Most of the soft system components were touched on above with the analysis of the system. Here we want to emphasise the soft parameters which are most closely related to the primary control element for the system.

Primary Soft System Assets – Shared Values of the Community

The soft system assets for the system are mapped out in Figure 3. Assets identified as having the highest potential impact on changing the heating system are, in many cases, the same factors which are currently causing resistance to the total solid fuel ban. The fact that people care about disadvantaged people who might be cold without a fire makes people resist the solid fuel ban on an ethical basis. This same empathy for other people could possible lead to changes in individual decisions to protect people with vulnerable health from pollution on temperature inversion days. Our analysis indicates that one small change in behaviour can lead to changes in perception, and thus further changes in behaviour.

The CCC and ECAN "Future Path" work on visions for the future have identified many of the community values which we present here. We have organised the community values into the roles they play in the system.

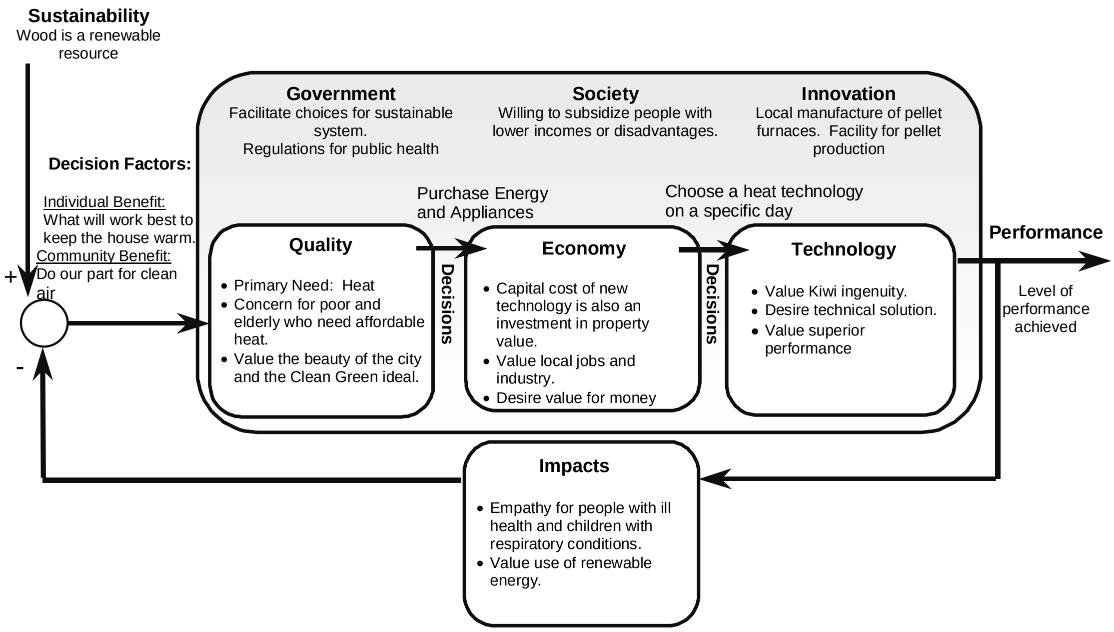

Figure 3 – Soft System Components and Linking Variables

Quality

New Zealanders, given the opportunity, will choose to be warm on frosty winter days. Our analysis has not discovered any cultural value for being cold. There is a shared concern for elderly and poor people being deprived of heating, and a strong sense of indignation at government regulations which might "take away my fire". The community also values the garden city ideal and clean, green image.

Economy

Christchurch people value locally-made products, and value local jobs and a strong local economy. The largest investment for most families is their home. People are willing to make capital investment that improves the value of their property. People here want good value for money. They like the chance to be in to win something in a draw.

Technology

Like people from many other cultures, New Zealanders expect a technical solution for most problems. People value Kiwi ingenuity, and desire net technology that provides improved performance. City residents, like people in other developed countries, desire "modern comfort and convenience" made possible through technology and an advanced energy supply and distribution system.

Impacts

People value a clean environment and good health. There is a sense of community responsibility to protect people who might be vulnerable. However, there is a tendency to suspect scientific data. There is a general lack of understanding of the health hazards posed by toxic by-products of combustion. The community values renewable energy on principle.

Primary Linking Variables – Perceptions and Decisions

The controlling parameter for the home heating and health system is the perception that open fires provide heat. This perception then leads to the decision to purchase a truck-load of firewood. Once the wood is purchased, it will result in air pollution. Thus, the whole problem of the winter air pollution over Christchurch results from the perception that a fire is a suitable way to heat the home.

Finding 4

> *The most critical change in the system to reduce air pollution is a change in the perception that an open fire is an effective source of heat.*

Sustainable Performance Goal for the Future

The SACEES methodology calls for definition of the sustainable performance goal as the first step in building the scenario. International standards for clean air provide the goal for emissions levels, and international health standards for indoor temperature provide the goal for heating energy consumption. Economics in a free, consumer-oriented society provides the format for the future goal of available and affordable a technology that performs according to the air and comfort goals. People can then choose the technology according to their quality-of-life preferences. The other goal in this project is a sustainable energy system.

Goal A – Community Quality of Life

- no violation of clean air health standards
- stable and sustainable energy resource and distribution system for home heating

Goal B – Individual Household Quality of Life

- heating technology available which is capable of attaining indoor comfort levels of 18°C on frosty nights
- extraction, processing and transport of energy for heating resulting in economic availability for all income levels
- heating technology not adding moisture to the house

First Iteration of the Five-Year Scenario

We will incorporate our best technological and regulatory ideas into the scenario and, basically, think through all of the possible problems, outcomes, follow on effects, and benefits. We will then either eliminate options as unacceptable (that is outside the possible decision matrix) or incorporate them into the scenario. The impacts on the rest of the system components and on the performance will be evaluated for those options which are incorporated into the scenario. Then, the procedure will continue for subsequent years.

The results of this initial analysis into the home heating and health problem have lead to a possible solution. The solution and the "story" of how the city reached a sustainable future are presented in a companion document. Here we present the solution parameters and the scenario for the development to the solution.

The solution starts in 2002 with the introduction of a "new" technology, and a new approach to the winter air pollution problem. The new technology is the pellet furnace, and it meets all of the criteria of the sustainable performance goals, as well as the criteria for acceptability by the community.

- uses a plentiful, renewable energy resource that is also currently a waste disposal problem
- delivers the heating value of the fuel to the home at high efficiency (85-90%)
- emission rates meet international standard for home heating appliances

- performance:
  - can deliver between 3 kW and 10 kW of heat depending on desired comfort level
  - high rate of radiant heat production and a visible flame
  - does not add moisture to the home
- both the appliance itself and the fuel are locally produced in factories providing good quality manufacturing jobs
- the distribution system for the fuel, and the utilisation of the appliance are convenient for people
- the cost of the appliance is comparable with other high-technology heating appliances, and the cost of the heat, per kW.h, is much lower than firewood or electricity
- the installation of the appliance improves the property value and helps to stop moisture damage

Sustainable Future

In the future, the most important change from today will be that when people think of heating the home, they do not think of a wood log or coal fire. They may think of a fire to set a mood for a romantic occasion, but not as a source of heat.

Well-insulated homes in the temperate Christchurch climate can effectively be heated with a highly-efficient heat pump, powered by renewable hydro-electric power. However, until the older, non-insulated homes are either remodelled or replaced, they will require a high rate of heat input and a radiant heat source. This heat source will be supplied by engineered bio-fuel burned in a highly-efficient furnace.

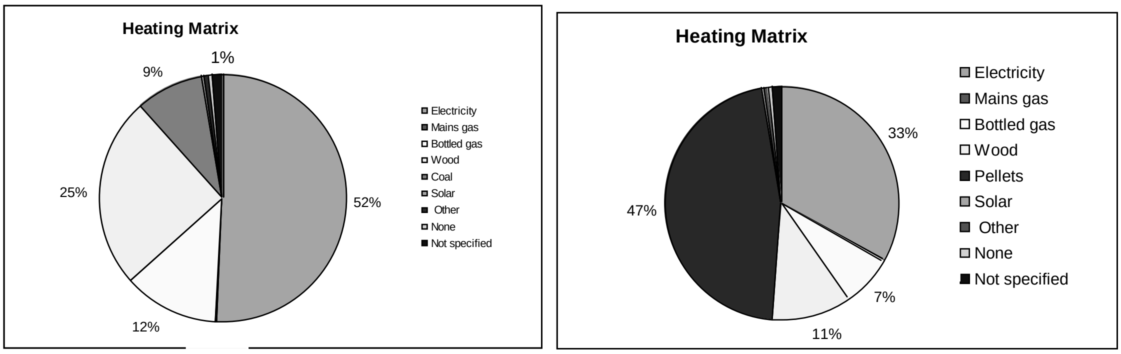

Figure 4. (a) Home Heating Survey Results 2002 (estimated 14,000 to 18,000 open fires among the coal and wood respondents) (b) Home Heating Survey Results 2009 (no people reporting using open fires for heat and 90,000 homes using pellet furnaces)

Scenario

Presently, there are approximately 1200 pellet furnaces installed in homes in Christchurch. Most citizens are not aware of the technology, thus it is “new” to people. The scenario calls for a rapid uptake of the technology.

The first principal factor in the uptake is the word-of-mouth and marketing whereby people become aware of the high level of performance.

> *“Have you seen those pellet fires? They crank out heat like crazy! My neighbour has one and their house is so warm.”*

The second factor is the ease of uptake thorough facilitating actions by the councils.

The third factor is through restrictions put on other combustion methods (no smoking allowed) during temperature inversion events through regulatory actions by the councils.

The scenario for the sustainable future calls for all old non-insulated homes to be heated with pellet fires, flue gas heaters, and the newest log burners. Insulated and newer homes will mainly rely on electricity, as their heating loads are likely not high enough to require the pellet furnace. Of course, the rate of 10,000 pellet furnace installations per year is a “maximum uptake rate” scenario. In practice, this final energy system state may take several more years, but it is entirely feasible that all households currently relying on open fires and coal for heat could be converted to pellet fires in the next five years.

References

1. Daly, Herman E., and Kenneth N. Townsend, Valuing the Earth – Economics, ecology, ethics, MIT Press, ISBN 0-262-54068-1, 1993.
2. Vitousek, Peter M., Paul R. Ehrlich, Anne H. Ehrlich, and Pamela A. Matson, Human Appropriation of the Products of Photosynthesis, BioScience 34, 6 May 1986.
3. Brundtland, G. H., et al.,Our Common Future – Report of the World Commission on Environment and Development, Oxford University Press, Oxford, UK, 1987.
4. Davies, G., Economia – New economic systems to empower people and support the living world, ABC Books, Sydney, New South Wales, Australia, 2004.
5. Capra, F., The Web of Life, Anchor Books, Doubleday, New York, USA, 1996.
6. OECD, Economic Outlook 69, Organisation for Economic Co-operation and Development, Paris, France, June 2001.
7. UK Government, A Better Quality of Life – A strategy for sustainable development for the United Kingdom, UK Government, May 1999. http://www.sustainable-development.gov.uk/uk_strategy/factsheets/summary.htm
8. Meadows, Donella H., Dennis L. Meadows, Jørgen Randers, Beyond the Limits – Confronting global collapse, envisioning a sustainable future, Chelsea Green Publishing Company, White River Junction, Vermont, USA, 1992.
9. Krumdieck, Susan, George Hooper, Strategic Analysis for Sustainable Christchurch City – Home Heating and Health Impacts, University of Canterbury, Christchurch, New Zealand, 2002.