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Tools for the Integrated Assessment of Sustainable Regional Energy Systems

Category: Tools for Managing Sustainability

Abstract

This project focuses on the development of a modelling framework for the integration of Life Cycle Analysis (LCA), externality costing and economic input – output analysis, with the aim of helping decision-makers assess the sustainability of regional development options. The framework is based on normalising, in monetary terms, economic, social and ecological costs and benefits, so that all impacts can be considered on the same basis, and trade - offs analysed. The New South Wales Hunter Valley, a centre for coal extraction, export and electricity generation is the study region for which the framework is being developed. The initial focus on energy - related costs and benefits is due to their global importance, and because it is highly likely that ongoing changes to the Hunter Valley's energy industry will have significant socio-economic effects as it moves, as all regions of the world must move, toward more sustainable energy systems.

There is a growing awareness that decision-making related to fuel and technology choice for power generation should take into account externalised costs and benefits. However, energy is only the starting point for the integrated assessment. The ExternE (Externalities of Energy) methodology developed by the European Commission has been modified for Australian conditions with, for example, water impacts receiving more attention than in European and North American applications. Model development is based at the University of Newcastle and will be ongoing. The model is accessed through a geographic information system (GIS), which is open to addition by other researchers who may focus on areas other than energy. The aim is to produce a transferable regional assessment model facilitating continual updating, trend analysis and knowledge expansion in regard to regionally specific impacts. This will provide a tool for the analysis of trade-offs inherent in decision making for the transition to regional sustainability.

In addition, it is acknowledged that assessment of regional sustainability requires more than the evaluation of developmental trade-offs described above. Sustainability is dependent upon maintaining or enhancing the resilience and adaptability of ecological, social and economic systems in response to short and long-term change. The project extends the trade-off analysis to incorporate these principles. A region may create a number of strategies that enhance this adaptability through experimentation and investment in technology and social systems that create a diversity of options capable of maintaining a desirable level of economic, social and ecological function in response to a wide range of possible changes. The modelling framework developed here provides a means of carrying out a cost - benefit analysis of any options identified, so that the

sustainability credentials of investments in technology, skills and social structures can be tracked and evaluated.

Finally, while it is widely recognised that all impacts on society, ecology and economy cannot be put into monetary terms without uncertainties involved. When applied consistently, externality valuation can provide a comparison of the sustainability of proposed development options expressed in terms relevant to most stakeholders i.e. economics. Consequently, the ExternE approach has been used as a basis for the analysis.

Introduction

Sustainability is a concept that stands quite apart from its environmental conservation precursors. While there are varying definitions of sustainability, in essence, the term attempts to encompass all the major elements that society broadly agrees are essential for a peaceful prosperous life for all. These elements are: (1) social sustainability, (2) ecological sustainability, and (3) economic sustainability. Achieving one without the others will not amount to a sustainable society. The goal of sustainability, and the transitional period required, creates a relatively new need for researchers, decision makers, and society as a whole to assess the appropriateness of the trade-offs that will have to be made between the social, ecological and economic implications of development options, during the transition to a sustainability society. Australia's Chief Scientist has illustrated these trade-offs graphically in Figure 1 (Batterham 2002). The term governance refers to the management of the transition.

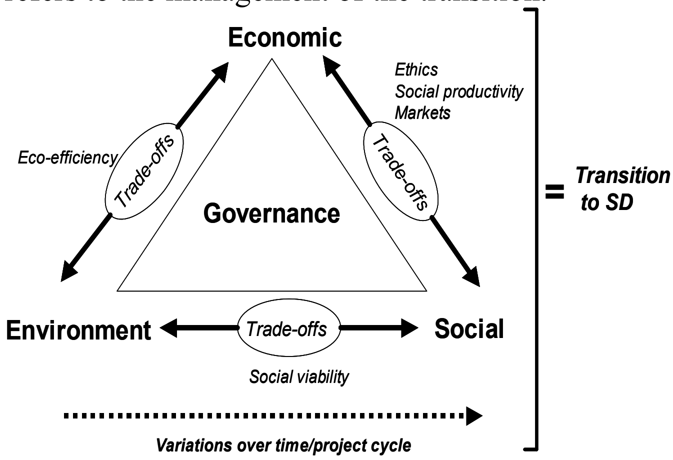

Figure 1 Trade-off Diagram (Batterham 2002)

Quantifying tradeoffs

The challenge in quantifying trade-offs lies in the choice of a common measure for economic, environment and social impacts. Perceived costs and benefits play a large role in decision making, and economists, in general, claim that getting the prices right is a prerequisite for market mechanisms to work effectively for the goals of sustainable development (NEA 2001). However, industrial systems, including energy production and use, create costs and benefits that are external to traditional price structures, these costs and benefits are known as externalities. An externality can be defined as any cost or benefit imposed upon third parties that were directly involved in a transaction (NEA 2001). Examples of externalised costs are damages to the environment such as climate change - caused by the emission of "greenhouse gases" and human health or ecosystem damages, resulting from the emission of localised pollutants such as SO_x, NO_x and particulate matter (PM). An example an externalised social benefit may relate to energy security. If costs and benefits are not internalised, consumers do not get price signals that lead them to make choices that are optimised from a sustainability (economic, ecological and social) perspective.

Economic theory and interdisciplinary research has developed approaches for assessing and internalising external costs and benefits of energy supply (NEA 2001). In principle, such methods provide a means to quantify and integrate externalised costs and benefits into the decision-making processes of corporations, governments and consumers. The tools developed for addressing externalities are generally aimed at monetary valuation of impacts and damages to produce an "externalised cost", which, once quantified, may be integrated into the total cost of the product, *eg* a unit of electricity. The World Energy Council, as part of its "Energy for Tomorrow's World" policy document states that, "Unless such prices reflect all costs (variable, maintenance and extension costs), including the cost of well-identified externalities related to energy security or environmental protection, they will distort individual behaviour to the point that the whole economy in which they occur may be unsustainable (World Energy Council 2002)." A price is a means of communicating information about the cost, scarcity and demand for a product or service; when externalities are not associated with the actual price that is paid, all the information that is required for a sustainable exchange to occur is not represented by that price.

Placing monetary values on objects or concepts which do not have a market, for example, natural ecosystems and the damages imposed upon others not directly involved in a transaction (i.e. externalities) is a difficult and often uncertain task. However, any development decision which trades off a proportion of ecological or social damage to receive an economic or social benefit, is in itsself a process of valuation. There is often minimal analytical justification for this trade-off; environmental impact assessments occur, however there is often no attempt to quantify what the externalised costs and benefits may be. The growing area of "externality valuation" provides a framework by which judgments of value can be shown in a relatively transparent manner, allowing the pathway to valuation to be seen by decision makers and the community.

Integrated Assessment

Quantifying the trade-offs required for a transition to sustainability needs a suitable assessment methodology. In doing this, the methodology needs to draw together a number of complementary tools to provide a transparent method of carrying out an Integrated Assessment which will determine the relative magnitudes of sustainability trade-offs that are occurring at present, and those which will result if a particular plan of action is carried out as part of a region's transition to sustainability. Integrated Assessments have been referred to as "A method of analysis that combines results and models from the physical, biological, economic and social sciences, and the interactions between these components, in a consistent framework, to evaluate the status and the consequences of environmental change and the policy responses to it " (Greenfacts nd).

Integrated Assessment can be applied locally, regionally, nationally or internationally, depending on the goal of the study. Brian Walker, Chair of the Beijer Institute for Ecological Economics, recently stated that there is a distinct need for a regional focus for sustainability research, "knowing only how Australia as a whole is faring (eg national sustainability indicators) tells us little about where, or how to fix sustainability problems. Some regions may be able to continue functioning in a productive way under present resource use patterns, while others may not. Sustainable planning needs to feed into decisions at all levels and the most sensible research unit is a regional or catchment basis" (Walker 2002 p9). In his (3 May, 2002) Australian Academy of Science Address, Graeme Pearman, Chair of the Joint Academies Committees on Sustainability, stated that, "decision-making concerning the development of specific regions of the Australian continent should no longer be based on single factor considerations such as employment, wealth generation, cultural protection or environmental protection. Rather all of these, and other factors need to be evaluated simultaneously based on complex whole of systems models" (Pearman 2002). The comments of both Walker and Pearman reflect the international concern for sustainable development, and the "think globally, act locally" mission statement of Agenda 21. A regional focus for sustainable decision-making makes sense because it is at the regional level where real world decisions have their effect on sustainability.

The aim of this study is to produce a transferable regional assessment framework based on normalising, in monetary terms, the economic, social and ecological costs and benefits of development scenarios, so that all impacts can be considered on the same basis, and trade-offs inherent in decision making for the transition to regional sustainability can be analysed.

Methodology

The overall strategy used in this study consists of five stages: Characterisation, Analysis, Normalisation, Assessment, and application of Regional Drivers. Each of the stages in the methodological framework are illustrated in Figure 1:

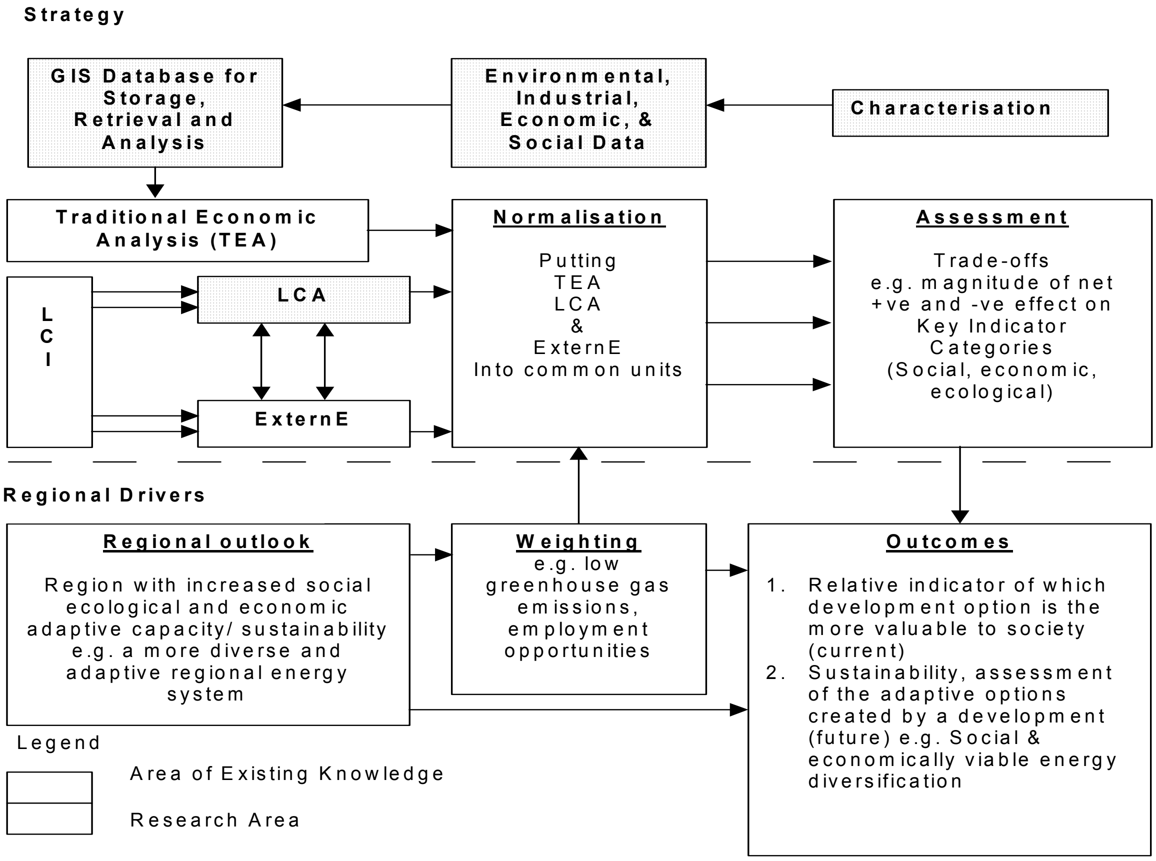

Figure 1 Methodological Framework

Characterisation: Sustainability analysis first and foremost requires the compilation of basic data on the ecological, economic, and social systems in the defined geographical area. Such a database needs to include;

Meteorology, environmental flows (rivers etc), land use (agriculture, nature reserves), land degradation (salinity, erosion) industrial activity, pollution inventories, Life Cycle Inventory Analysis of Industry, population data (health, demography, skills) economic flows (exports imports intra-regional flows) transport etc. It is fundamental that this data is continually updated, compiled and stored to allow an assessment of what is traded off if a certain development project or scenario is chosen. Because of the spatial dimension implied by regional assessment, the use of Geographic Information Systems (GIS) is the most sensible way to perform data storage, retrieval and analysis. An example of the kind of data and storage facility required is the Environmental Resources Information Network (ERIN) database developed by the Australian Department of Environment and Heritage (Department of Environment and Heritage 2004). ERIN provides environmental information for policy developers and decision makers on a national scale. Although ERIN is a valuable information source, higher resolution information is required for regional integrated assessments.

Analysis Models: A Traditional Economic Analysis (TEA) is required to quantify the direct, and flow-on costs and benefits of an industry to a region. This includes measuring how: (1) outputs from the sector of the economy which is under investigation are distributed to each of the other sectors; (2) inputs (per unit of output) from the sector are distributed; and (3) the effects of a change in the regional economy by change in: production of each sector, employment in each sector, income generated in each sector. A standard Life Cycle Inventory (LCI) and Analysis (LCA) is also required to quantify inputs, outputs and burdens[1] to the system under consideration. Life cycle inventories and analysis involve the quantification of burdens created by a product or process, from raw material extraction through to product delivery or use. The TEA, LCI and LCA methodologies are necessary inputs into the overall decision-making process. They are already well developed, and existing modelling approaches are utilised in this project.

Normalisation: The economic input - output modelling works in economic units. The analysis model used to normalise the social and ecological impacts created by the burdens identified in the LCA into monetary terms, is the ExternE (Externalities of Energy) approach (European Commission 1998). This is a major element of this research. ExternE was originally developed for the United States of America and European regions. As the name implies, the focus is on the energy streams, and a monetary value is placed on the impacts of a number of key factors in the process of supplying energy. In principle, the ExternE methodology can be applied in areas other than the energy sector. The information needed remains essentially the same, including:

Impact Data:	Effects of atmospheric pollution on human health. Accidents affecting workers and/or the public. Effects of atmospheric pollution on crops. Effects of atmospheric pollution on freshwater fisheries. Effects of atmospheric pollution on forests. Effects of atmospheric pollution on unmanaged ecosystems. Impacts of noise. Impacts of global warming. Impacts of mining on ground and surface waters. Impacts of coal mining on building and construction. Resettlement necessary though mineral extraction. Models for air pollution analysis.
Human Health Effects Valuation:	Exposure response functions to quantify the level of damage or benefit that a development is causing.

[1] A burden is any material or emission not directly part of the processing chain. Examples include: carbon dioxide from non-renewable sources, water usage, landfill volume.

Resource Depletion Valuation:	Specific to the Australian context, including water, land, etc.
Ecosystem Valuation	Contingent Valuation, Willingness to Pay etc

While LCI and LCA are used to quantify the inputs, outputs, and burdens of a particular activity, ExternE is applied to place a dollar cost or benefit on the social and ecology impacts of each aspect of the operation where data permits. Where an impact is known to occur, but a lack of data prevents detailed analysis, the impact is still identified to allow the assimilation of new information as it becomes available. The ExternE methodology is used to "quantify" social and ecological effects on the basis of a normalised monetary unit, with which traditional economic outcomes can be compared. See Appendix one for an explanation of the ExternE approach, and its use in the Australian context.

Assessment: Following the normalisation process, an assessment of the magnitude of positive and negative trade-offs is required for each of the Key Indicator categories (society, ecology and economy) so that the overall benefit of one option over another can be compared.

Regional Drivers: There is the need for the assessment process to interact with the regional drivers for development. For example, if the regional driver is for a more sustainable energy system, the regional planning focus might be aimed at a diversification of energy supply and utilisation technology to create a lower greenhouse gas emitting energy system. Due to the presence of uncertain chain in decision making for sustainability needs to also enhance social, economic and ecological adaptive capacity. It is extremely difficult to predict the medium to long-term future, for example most climate change policy is focused on a gradual change, however step changes in global climate are a possibility, for example alterations to the ocean conveyor (Gagosian R 2003). In regard to energy systems, we see a large amount of inertia and capital investment embodied in existing energy infrastructure. As a result, many believe a 30 – 50 year period is required to make a substantial transition to energy technologies that are capable of helping the world reach a sustainable equilibrium between resource extraction, and consumption, which is conducive to a satisfactory standard of living. These assumptions are primarily due to economic parameters that are relevant at present, and the assumption that the climate will change slowly. Such assumptions do not factor in the potential for large changes in needs, which may be brought about by step changes in the earth's climate and ecosystems.

The methodology of externality internalisation and economic analysis that the project is developing, can be effective in facilitating sustainable decision-making in a period of relatively stable socio-economic and ecological function, however resilience and adaptability are essential to avoid the negative consequences of rapid change. Resiliency and adaptability in this sense refer to a system having a wide enough range of possible evolutionary pathways to cope with a change in the external parameters that it operates within. An example of planning for adaptability is exhibited by the companies "BP and Shell, who are investing many millions of dollars in alternative energy technologies – to acquire technical expertise and organisational competence for their future deployment. They do this because they face future uncertainty about viable energy sources, technologies and uses, and this diversification provides them with requisite adaptability. They intend to be in a position to exercise, as real options, the profitable deployment of these technologies as the opportunity arises"(Brinsmead and Hooker 2003).

The regional drivers have a bearing on the weighting given to each issue, and therefore the outcomes when the assessment framework is applied. Resilience and Adaptability as regional drivers are seen as compatible areas of research that are being looked at by other researchers (Brinsmead and Hooker 2003) and will be considered as the project progresses.

The stages of the analysis, listed above, are steps in the overall determination of the sustainability of a region. There are many ways in which to apply the methodology and the following section illustrates an approach to assess the coal and electricity chain in the Hunter Valley region.

Hunter Valley Case Study

As stated by Walker (2002) there is a distinct need for a regional focus for sustainability research. The basis upon which a region can be defined can vary greatly (Walker 2002). Kemmis has written, "it is never possible to tell a place that is a region; either it is a region by its own internal logic or it is not a region at all (McMannus et al. 2000). For example, it is possible that the Hunter Valley may only be a region due to its current suite of industrial activities, for example coal mining in the Upper Hunter linking with the Newcastle export terminal. It is unclear what will define the Hunter region in 50 years or so. It has long been considered part of the greater metropolitan region of Sydney in NSW state planning documents. For the purposes of this study, the Hunter Region is defined by its catchment boundaries, as suggested by Walker (Walker 2002) and the physical environment within. However, measurable effects that occur outside the catchment boundary, as a direct result of activities within, are assessed.

The Hunter Valley is considered a good testing ground for Integrated Assessment methods, as it contains many competing land uses, such as agriculture, mining, industry, tourism and nature reserves which test the effectiveness of Integrated Assessments in regard to resource allocation issues, for example water allocation rights from the Hunter River systems. The project is being carried out the University of Newcastle and aims to provide a framework, and database allows other elements of the region to be added. The goal is to eventually bringing together all of the elements of the region which affect its sustainability, to allow a fully integrated assessment.

This study is concentrating on the externalities and regional economic effects of the energy generation system. The Hunter Valley catchment contains a large percentage of NSW electricity generation capacity (over 4000 MW), and a large amount coal extraction for local electricity generation and export. The Port of Newcastle handled 69.3 Mt of coal for export in 2001-2002 and approximately 13.5 Mt of domestically produced coal was used for power generation by the Bayswater and Liddell coal fired power stations in Upper Hunter Valley (NSW 2003).

The following describes how the Integrated Assessment steps have been applied to the Hunter Valley coal chain

Characterisation

A GIS database was used to store relevant data on coal-based activities in the Hunter Valley. The data compiled includes:

- Coal flows
- Coal transport routes
- Mine sites
- Electricity generators (Life Cycle Inventories, National Pollutant Inventory data & location data)
- Economic impact data for

- Electricity generators
- Coal mines
- Location and density of population
- Sensitive ecological areas and nature reserves
- Catchment boundaries, rivers

Figure 2 shows some of the data that has been compiled for the Hunter Valley.

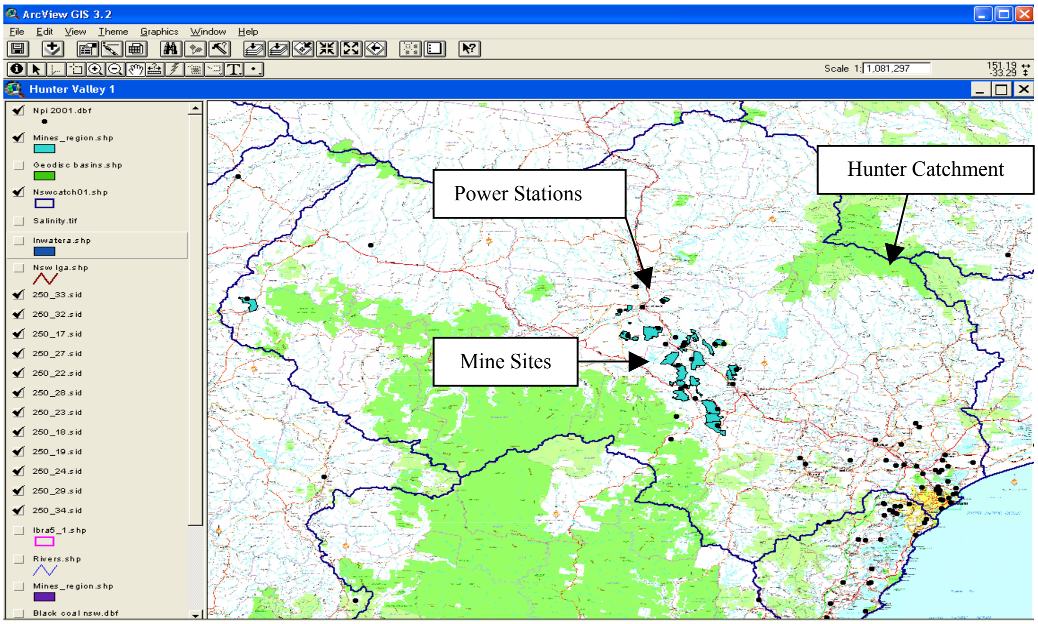

Figure 2 GIS Database of the Hunter Valley, including mine sites, national pollutant inventory power stations, land use, salinity affected areas.

The GIS database allows alternate scenarios such as the addition of a new power station to be assessed. For example, a new power station in a new location will affect the surrounding environment (e.g. population and ecosystems) in ways directly related to its spatial proximity to the certain environmental receptors. For example, pollution emitted from a power station will reach certain sections of the population based upon the location of its stack, the emission characteristics and meteorology. The data is stored in the GIS database and allows the impacts to be linked to their location, and impacts assessed.

For the Hunter Region there is no need to include in the GIS, the entire inventory needed to do a full LCI/LCA from the cradle to grave for the upper hunter power generators. This data is already available through collaboration with the LCA group at BHP Billiton Minerals Technology (Nunn et al 2001). If the study were to be carried out in a new region a full LCA would be required, and would have to be carried out either through the development of a module for the GIS or the use of an existing LCA software package. Most of the impacts related to a coal fired power station are a direct result of combustion, in regions where data availability does not permit a full LCA, National Pollutant Inventory data may be considered a satisfactory substitute. CO_2 emissions are not included in the National Pollutant Inventory[2], however locally relevant emissions such as NO_x and SO_x are.

Analysis

The economic analysis is being carried out in conjunction with the Hunter Valley Research Foundation, which has a well-established economic input-output model,

[2] http://www.npi.gov.au/

containing multiplier factors that model the interaction between industries within the Hunter Economy (HVRF nd). The use of this modelling capability allows the regional economic effects of alterations to the mix of enterprises to be assessed. A challenge in regard to carrying out a trade-off analysis when all factors are normalised to a monetary value, is deciding on the functional unit upon which the trade-off will be assessed. For example if a unit of electricity is chosen, the benefits and cost will differ from a functional unit based upon the export of a tonne of coal. Definition of the functional unit is an area of ongoing research and may change due to the specific purpose of an assessment.

Normalisation of Externality Results

Economic and Life Cycle Inventory data have been substantially compiled for the Hunter Valley. The next step is to normalise the social and ecological impacts of the burdens identified by the LCI into a monetised unit, allowing them to be compared with economic data. The air pollution modeling required for a full implementation of the ExternE methodology is currently underway. While this data is forthcoming, it has not been as extensive as is required for a full implementation of the ExternE methodology. Therefore to provide a benchmark for the full implementation of ExternE for the Hunter Valley, data from a number of European ExternE studies has been used to estimate the externalities for one coal fired electricity generator in NSW. An LCA of the Bayswater power station in the Upper Hunter Valley provided the basic inventory data for the following calculations (Nunn et al. 2001).

It is difficult to transfer externality results developed in Europe to other regions due do to the site-specific nature of damage functions. Australian based dose-response functions are being sourced wherever possible, and the model is built to allow the rapid assimilation of new information into the model. Therefore, it is important to note that the development of the ExternE methodology for Australian conditions is a continual process.

With the exception of greenhouse gases (which are a global issue), the level of airborne pollutant externalities can vary strongly from site to site; mainly due to differences in population density. The ExternE methodology has been applied to over fifty sites in the countries of the EU, and the results are sufficiently representative to permit general conclusions to be drawn for Europe. Table 1 shows results for central Europe, with an average (land and water) population density of 80 persons/km^2. Population densities were taken within a 1000km radius of the emission source. If these results are to be used for other regions, such as the Hunter Valley, the impacts of PM_{10}, SO_2 and NO_x need to be scaled in proportion to the population density within a radius of a thousand km around the pollution source. (Rabl & Spadaro 2001p 57 NEA2001).

CO_2 related costs are not dependent on population density, because it is a pollutant which acts globally. Rabl and Spadaro note that a large part of the damage cost of 0.029 Euro/kg of CO_2 reflects the loss of life due to tropical disease (Rabl & Spadaro 2001p 58 NEA2001).

Table 1 Typical damage costs per kg of pollutant emitted by European power plants

Pollutant	**Impact**	**Cost Euro/kg**
PM_{10} (Primary)	Mortality & Morbidity	15.4
SO_2 (Primary)	Crops, Materials	0.3
SO_2 (Primary)	Mortality & Morbidity	0.3
SO_2 (Via Sulphates)	Mortality & Morbidity	9.95
NO_2 (Via Nitrates)	Mortality & Morbidity	14.5

NO_2 (Via 0_3)	Crops	0.35
NO_2 (Via 0_3)	Mortality & Morbidity	1.15
CO_2	Global Warming	0.029

The values in Table 1 have been used for the purpose of providing an externality estimate for the Bayswater power station in the Upper Hunter Valley. Table 2 shows the values normalised for 1 person per km^2, and converted into Australian currency using an exchange rate of $ A 0.55 to 1 Euro, the approximate exchange rate at the time of the ExternE studies, there are arguments for using purchasing power parity to exchange externality values, however for this exercise exchange rate is suitable. The European figures have been developed for the population density within 1000 km of the pollutant source; the estimates for the Hunter Valley externalities have therefore been made on the same basis. The following exercise provides an estimation of the externality values that may be expected from a full implementation of the ExternE impact pathway approach in the Hunter Valley.

Table 2 Pollutant cost converted into Australian dollars and normalised for population density

Pollutant	**Impact**	**Cost $A/kg/person/km^2**
PM (Primary)	Mortality & Morbidity	0.350
SO_2 (Primary)	Crops, Materials	0.007
SO_2 (Primary)	Mortality & Morbidity	0.007
SO_2(Via Sulphates)	Mortality & Morbidity	0.226
NO_2 (Via Nitrates)	Mortality & Morbidity	0.330
NO_2 (Via 0_3)	Crops	0.008
NO_2 (Via 0_3)	Mortality & Morbidity	0.026

CO_2 Global warming is considered separately because it its damage function is not determined by population density. It has been adjusted into Australian dollars

CO_2	Global Warming	0.053

The average population density (land and Water) within a 1000 km radius of the Bayswater power station capacity, is approximately 2.6 persons/km^2 as determined from the 2001 census carried out by the Australian Bureau of Statistics.

Table 3 LCA results for the Bayswater Power Station per MWh (Nunn et al 2001)

Pollutant	Amount
PM10	0.081 kg
SOx	3.6 kg
NOx	2.23 kg
CO_2	932 kg

The population density and the externality cost of a pollutant per person per km^2 as shown in Table 2 were multiplied the LCA values shown in Table 3. The externalities for Bayswater power station would be approximately $54/ MWh using this basis.
Using a generation cost of AUD$40/MWh the total cost would be approximately $94 AUD/MWh.

The site-specific nature of externality analysis creates many issues in regard to transferability. If the average land population density for NSW of 7.9 Persons/km^2 is used the externality cost estimate using the above procedure is AUD$65 per MWh. While a full application of the methodology is required for specific situations, the two examples shown here illustrate that, in Australia, the externality costs of coal-fired electricity may be in the order of $50 - $65 per MWh. Global warming contributes over 75% of the overall externality costs in each of these examples. This reflects the fact that Australia's electricity generation capacity is generally situated away from population centres and the human health effects are reduced in comparison to the European implementation due to the lower population density surrounding the Hunter Valleys power stations. Other attempts at transferring ExternE results to Australia have reported externality figures ranging from AUD$110/MWh through to AUD$630/MWh (Diesendorf 2003). However the reliance of ExternE results on site specific population density and pollutant dispersion (with the exception of global warming) make all of estimates provided inadequate compared to a full implementation of the methodology which is underway in the research program.

The full application of ExternE for the Hunter Valley generation capacity is focusing on, pollutant dispersion modelling and detailed demographic analysis. Epidemiological and ecological studies, to determine the dose-response functions for exposure to pollutants are also required to refine the analysis, it is for this reason that a key feature of the modelling framework is the facilitation of the rapid updating of new regionally specific information that becomes available. The multidisciplinary nature of a university makes it one of the few organizations that can perform the long-term monitoring and development of regional information databases that are required to feed into such a regional Integrated Assessment framework.

Assessment

The assessment stage is where all the normalised impacts are brought together and the trade-off analysis carried out**.** Generally it could be considered that the benefits associated with electricity availability would be the same for any electricity production technology from fossil to solar. However, there are issues related to energy security and the economic impact of industries such as aluminium smelting which require high current baseload supplies. These are issues which require consideration if the Hunter were to alter the energy generation technology in use. Regionally specific research is underway in regard to these effects; however, at present, a comparison of generation costs with externalised costs is all that has been assessed (see the previous section). The system undergoing assessment in this project is the Hunter Valley Coal and Electricity Generation chain. Therefore the assessment is based on the externalised costs of these systems compared with the direct and indirect benefits or costs as reveal by economic input - output modeling.

Regional Drivers

Integrated assessment methods using externality valuations are under continual development. However, even though they are in a period of maturation they can, if used consistently across all options, elicit a better understanding of the costs and benefits of alternative development or policy scenarios, allowing trade-offs to be analysed and reported with objectivity. However, when planing for the uncertainty that the transition to long-term sustainability poses, a region will need more than the snapshot of trade-offs that the methodology described above provides. The framework under development provides information on the trade-offs which are occurring at present and will occur if the energy system of the Hunter Valley is altered within the current economic, social and ecological context, it does not assess the ability of the Hunter Valley region to adapt to uncertain change. Complementary methods for assessing a regions resilience and adaptability are required for this. Regional drivers will determine which alternative options will be assessed by the methodology under development. The enhancement of resilience and adaptability, along with impact reduction are among the regional drivers that are expected to form some of the alternative scenarios that will be assessed.

Conclusions

In summarising the work to date, the development of metrics which inform reasoned decision making as opposed to providing direct justification or rejection of a project are very useful, especially in regard to having matters considered in areas which decision makers find difficult to fit into decision frameworks which are essentially based on economics. The use of life cycle analysis, externality valuation and regional economic modelling, make it possible to assess the costs and benefits of our development choices, on the basis of the value which society puts on market and non-market resources. We already place values on the environment as soon as a development decision is made that degrades the environment in anyway. The clear advantage of externality valuation is that an externalised cost or benefit can be traced back to an actual environmental effect; for example, a pollution valuation can be traced back to pollutant concentration level. Of course, quantification of damage requires a sophisticated understanding of the damages that are occurring. In cases where no data is available, the potential impact is not be ignored it is left unquantified until the appropriate level of knowledge is obtained. In particular emphasis is placed on the proper consideration of trade-offs between social, economic and ecological factors, to ensure that the most sustainable regional development options are implemented.

There are a myriad of ways in which the revenue raised from including externalities in the cost of energy production could be used. It is important to keep in mind that sustainability is a long-term issue, and although supply and demand may set the right price for sustainable consumption if externalities are included in the costs of goods and services, it is extremely difficult for a market economy to predict environmental threshold changes which are perhaps the greatest worry in regard to the goal of a smooth transition to sustainability. Therefore, it is important that the revenue generated, if externality costs are to be added to the price of energy, be spent in such a way that it confers resilience and adaptability on regional economies. There may be many ways in which this could be achieved. For example, the money generated may be part of a joint fund managed by local government and the industry involved, conditions may be set that this revenue has to be spent in a way which diversifies the regional economy giving it more adaptive options. These concepts will be further explored as the modeling results are generated.

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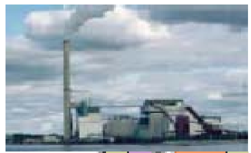
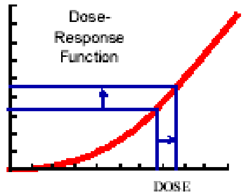
Appendix 1 Externality Valuation & ExternE

ExternE methodology developed buy the US DOE and the UN provides an externality valuation framework that is open to expansion and application in regions that have the ability to collect the data on the majority of parameters that are affected by a development pathway. Although there are a number of possible methods for estimating externalities, the Impact Pathway methodology used in the ExternE (European) and USA studies of the early 90s represents the most thorough approach used for energy systems to date. The ExternE methodology is consistent with Life Cycle Impact Assessment as it uses a bottom up approach to estimate the impacts of different emissions from different power generation and transportation fuel options from cradle to final impact (European Commission 1998). To evaluate the impact and damage cost of a pollutant, there is a need to carry out an impact pathway analysis, tracing the passage of the pollutant from the place where it is emitted to the affected population/receptor. The principal steps of this modelling analysis can be grouped as follows:



Emission - specification of the relevant technologies and a life Cycle Inventory of the environmental burdens they impose (*eg* kg of NO_x per kWh, emitted by power plant).

Dispersion - calculation of increased pollutant concentrations in all affected regions (*eg* incremental concentration of ozone, using models of atmospheric dispersion and chemistry for ozone formation due to NO_x).



Impact - calculation of the dose from the increased exposure and calculation of impacts (damage in physical units) from this dose, using a dose-response function (*eg* number of cases of asthma due to this increase in ozone).

Cost - the economic valuation of these impacts (*eg* multiplication of the cost of a case of asthma by the number of additional asthma cases in a population).

Modelling of the impact pathway for ExternE is done with the EcoSense Software developed by the Institute of Energy Economics and the Rational Use of Energy at the University of Stuttgart. (European Commission, 1998).The Eco Scene software has been developed for China as part of the Integrated Assessment of Sustainable Energy Systems in China (Eliasson B, Lee Y (2003) and in Brazil. However in this instance a separate modeling capability is being developed. The most notable departure from the EcoSence framework is the use of the CSIRO developed the Air Pollution Model (TAPM). TAPM is capable of modeling atmospheric chemistry and has been developed with extensive data for Australian Meteorology and topography.

There are many factors that need to be considered for the Australian context which were not covered in the other implementations of the ExternE methodology. The valuations have been carried out in European contexts and are not easily transferable to the Australian context. For example salinity and water consumption are major issues in

Australia and valuation studies in terms of returning environmental flows or salinity damage cost are on going. A range of studies will be drawn upon to provide values for salinity and water consumption; however, the main focus is the development of a framework that is conducive to assimilating the most recent values (Van Buren 2003).[i] Carrying out valuation studies for each of the parameters that are affected by power generation is a massive task in itself, and this is not a direct part of this study. Where possible Australian valuations and dose response functions are being used from sources such as the NSW EPA Envalue database (NSW EPA), however where appropriate information is not available factors from ExternE are being used.

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