Low Emission European Energy Scenarios

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EXTENDED ABSTRACT

Many countries face all of the three following environment and energy problems: reducing the impacts of air pollution on human health and ecosystems; controlling climate change and its impacts; and securing long term energy supplies adequate for providing services to people and the economy. This paper describes work that explores policy measures for addressing this trinity of problems in the European Union.

Fossil fuel combustion is the major source of anthropogenic carbon dioxide, and also one of the largest sources of air pollution. In richer countries, air pollution has been substantially reduced by a combination of fuel-switching and end-of-pipe emission reduction technologies such as catalysts on vehicles and flue gas treatment at power stations, but the limits to these technologies are now being approached and further reductions in air pollution will incur high marginal costs. Most countries are net importers of oil and gas, and as the reserves of these fuels decline, the problems of energy security and finding replacements will intensify.

One class of solutions that addresses all of these problems involves reducing energy demand through a mix of measures including behavioural change, demand management and efficiency, and switching to renewable energy sources. The author has developed six energy scenarios for each European Union (EU) country using mixes of these options for the period 2005-2050 using a socio-physical model of demand and supply technologies called SEEScen (Society Energy Environment Scenario). This model incorporates detailed technical modelling and can be used either in simulation or optimisation mode. It can rapidly generate scenarios for any country from International Energy Agency (IEA) statistics. One particular strength of this model is that it includes the effects of a range of behavioural changes such as reducing air travel demand, driving more slowly or selecting lower powered cars.

The energy flows, vehicle stocks and distances arising in these SEEScen scenarios were transferred into the Institute of Applied Systems Analysis (IIASA) GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) model for an accurate calculation of emissions and end-of-pipe emission control costs.

These scenarios: reduce EU25 CO_2 emissions by 30% and more over the period 1990-2020, substantially reduce SO_2 and NO_x emissions and the end-of-pipe emission control costs, and decrease energy import dependency.

Taken together the SEEScen and GAINS models provide an integrated assessment of energy strategy, fossil sourced CO_2 and the emissions of air pollutants. This assessment may be used to assess various policy options and strategies to meet multiple economic, environmental and energy objectives.

Because of its wide scope, it is not possible to describe many aspects of the study in this paper. A full report *Low Emission Energy Scenarios for the European Union* (Barrett, 2007) may be downloaded.

1. INTRODUCTION

The development of strategies in the European Union for the control of greenhouse gases, acidification, ozone and a range of air pollutants, use energy scenarios extensively. Energy consumption is a major cause of the emission of greenhouse gases (GHG), most notably carbon dioxide (CO_2), and of a range of atmospheric pollutants that damage human health and ecosystems. Therefore energy scenarios are key inputs to the projection of pollution emission and to the formulation of strategies to reduce pollution and achieve environmental objectives.

Energy scenarios largely determine the uncontrolled emissions of controlled primary air pollutants including sulphur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter (PM) and secondary pollutants including ozone and PM, prior to the application of 'End-Of-Pipe' (EOP) abatement technologies such as flue gas desulphurisation and catalytic converters.

2. SCENARIO CONSTRUCTION

The process of constructing the scenarios is described below under the headings: setting environmental targets, compiling exogenous assumptions, applying energy measures, and modelling the national energy systems.

2.1. Environmental targets

EU Member States have a range of environmental targets designed to reduce global warming and the impacts of air pollution on human health and ecosystems. The scenarios developed here aim specifically to address greenhouse gas targets, and National Emission Ceilings (NEC).

Greenhouse gas targets. Most of the individual countries of the European Union, and the EU25 as a whole, have committed to reductions in the emissions of a basket of greenhouse gases in the Kyoto protocol. The commitments are to changes in emission from a 1990 base to be achieved by 2008-2012. Only CO_2 from fossil fuel burning is included in the targets adopted for the energy scenarios, and it is assumed that this CO_2 emission has to meet the same percentage targets as the basket of GHGs. CO_2 arising from other combustion (e.g. forestry), or processes (e.g. cement manufacture), and other gases such as methane, are not included.

In this study, it is assumed that targets are met using emission control with measures within EU25 countries only; GHG control achieved by measures outside the EU25, through mechanisms such as the Clean Development Mechanism, is excluded. This study is investigating emission control for years later than 2010, with a particular focus on 2020. A question then is what the overall EU25 targets for GHG should be, and how these are allocated to individual countries through burden sharing as determined by factors such as energy use per capita, renewable resources and climate. It was beyond the scope of this work to assess burden sharing and so carbon reduction measures were applied according to the potential in each State such that the overall EU target was met.

National emissions ceilings. NECs are upper limits for each Member State for the total emissions in 2010 of the four pollutants responsible for acidification, eutrophication and ground-level ozone pollution (SO_2, NOx, VOCs and ammonia). Targets for these are not explicitly used in the energy scenarios, but are met by the later application of EOP measures in the GAINS model to SEEScen scenario data.

The energy scenarios are built by collating exogenous assumptions driving the scenarios, making assumptions about emission control measures, and then modelling them.

2.2. Exogenous assumptions

In all modelling exercises, there are data input to the model – exogenous data or assumptions – and data calculated endogenously through the relationships between variables in the model. The starting point for these energy scenarios is to compile assumptions about the basic drivers of energy consumption – population, households, GDP, and sectoral economic activity. Other exogenous assumptions include international energy prices and particular policies affecting sectors such as buildings, transport and electricity generation, but these are not explicitly modelled.

Most of the exogenous assumptions are taken from detailed scenarios developed using the PRIMES model by the National Technical University of Athens (NTUA, 2004).

2.3. Measures

In order to meet energy and environmental objectives, a mix of measures that physically change the energy system have to be implemented. These measures may be divided into five classes: behaviour, demand management, fuel mix, efficiency and End-of-Pipe (EOP) pollution control. Examples of the first four classes of 'energy and carbon' of NEOP (Non-End-of-Pipe) measures are shown in Table 1 in which the right-hand column 'Implementation yrs' gives typical time periods in years for full implementation. These periods depend on technology lifetimes, and social and economic factors and may be changed by policy.

The measure 'Effective comfort temperature' refers to the average temperature a building is maintained at. This temperature determines heating and cooling loads and may be altered by changing clothing levels and controlling the zoning and timing of heating/cooling systems so as to reduce energy demands.

A critical factor determining CO_2 emission is the future output from nuclear power stations which currently make EU CO_2 emission about 10% less than it would otherwise be. Future nuclear output is dependent on three factors: the lifetimes of existing plants; the building and commissioning of new plants; and the performance of the plants. Decisions about nuclear capacity are highly dependent on Government policies. In the scenarios with new nuclear stations, EU30pc20N and EU40pc20N, it is assumed that current nuclear generation declines by about 15%. In the no new nuclear scenarios, nuclear generation falls to zero by about 2030.

Table 1. Emission control measures

Class	**Examples**	**Implementation yrs**
Behaviour	Effective comfort temperature	10
	Transport demand management	20
	Aviation demand management	15
	Passenger from car to bus/rail	20
	Freight from truck to rail	25
	Downsizing cars	15
	Speed reductions on motorways	5
Demand manage-ment	Transport load factor	20
	Building insulation	40
	Demand management in services	30
Fuel mix	Shift to electric vehicles	35
	More renewable supply	40
Efficiency	Improved efficiency of energy converters	35

As shown in Table 2, six scenarios were modelled: a central scenario with a 30% reduction in EU25 CO_2 emission by 2030, called **EU30pc20N**, and five variant scenarios with various combinations of NEOP measures and different assumptions about nuclear power. The scenarios are generally labelled Region: Percentage reduction fossil CO_2 from 1990: reduction date: Nuclear (new nuclear as in PRIMES)/ No Nuclear (no new nuclear). The scenario of central focus is labelled **EU30pc20N**, meaning Europe Union: 30% reduction from 1990 by 2020; nuclear generation as assumed in PRIMES.

The second scenario (EU40pc20N) sets a 40% CO_2 reduction target with new nuclear stations, and the third (EU30pc20NN) a 30% CO_2 reduction target with no new nuclear stations The last three scenarios look at the effect of applying technological and behavioural options to the maximum separately and both together.

Table 2. Scenarios

Scenario Label	**Target: % CO_2 reduction from 1990**	**Nuclear energy**	**Measures**
EU30pc20N	30	New	Mix
EU40pc20N	40	New	Mix
EU30pc20NN	30	No new	Mix
TecNN		No new	Maximum technology
BehNN		No new	Maximum behavioural
TecBehNN		No new	Maximum technology and behaviour

2.4. SEEScen model

The energy scenario model is called SEEScen (Society Energy and Environment Scenario). Here it is used as a simulation model: assumptions about policy options are input to the model and it calculates the outcomes in terms of energy, costs and emissions. SEEScen does have a single year optimisation mode, but that is not used here; partly because of the conceptual problem of assigning costs to behavioural change, partly because optimising 25 countries over six scenarios and several time periods was not possible in the research schedule. A schema of SEEScen is shown in Figure 1 and its functioning is now briefly described.

- Delivered fuels by end use are multiplied by a set of efficiencies to produce useful energy consumed for the eleven end uses such that the delivered fuels calculated match historically recorded. This establishes useful energy consumption for the last year for which there are IEA data (2004).

- These useful energy data are then projected into the future using 'energy activity functions' based on exogenous, data. Every scenario for a particular country assumes the same demographic and economic changes - i.e. these are invariant across the six scenarios. In these scenarios, other exogenous data are used to describe transport demand and nuclear heating, electric heat pumps and cogeneration with district heating.
- Energy deliveries to the end user are calculated by dividing the useful energy by the appropriate projected efficiencies of end use converters.
- After adding on distribution losses, and allowing for imports and exports, the requirements for domestic inland energy supply may be found.
- Supply side efficiency improvements and fuel switching are then applied so that the fuel used in energy supply industries may

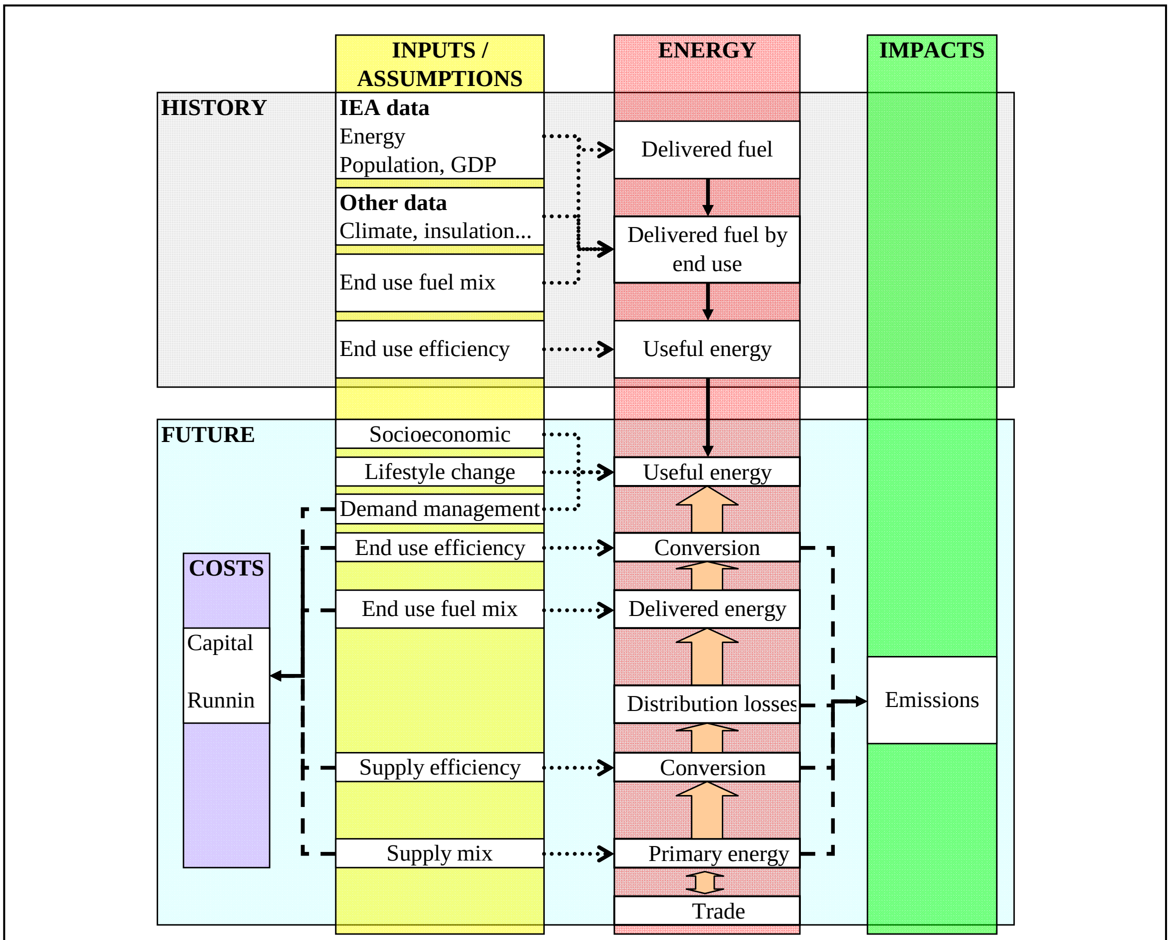

Figure 1. SEEScen Schema

generation.

- The basic projection of useful energy is then modified according to control measures, changes in behaviour such as car downsizing, and demand management such as insulation.
- Useful energy demands are allocated to an end use supply mix. For example, water heating might be allocated to a mix of energy converters including solar be calculated.
- If the potential electricity production from non-fossil sources is greater than domestic demand, the surplus is exported. This electricity could be used to replace carbon based generation in another country. SEEScen accounts for net trade for each country, but does not specify trade between countries.
- Emissions and economic costs are calculated for each component of the

energy system. Note that in the study only CO_2 emission calculations are used; other emissions are calculated with GAINS.

3. RESULTS

Six energy scenarios for each EU25 country were modelled with SEEScen, resulting in 150 sets of results. There is insufficient space here to report details of the scenarios; more may be found in Barrett (2007).

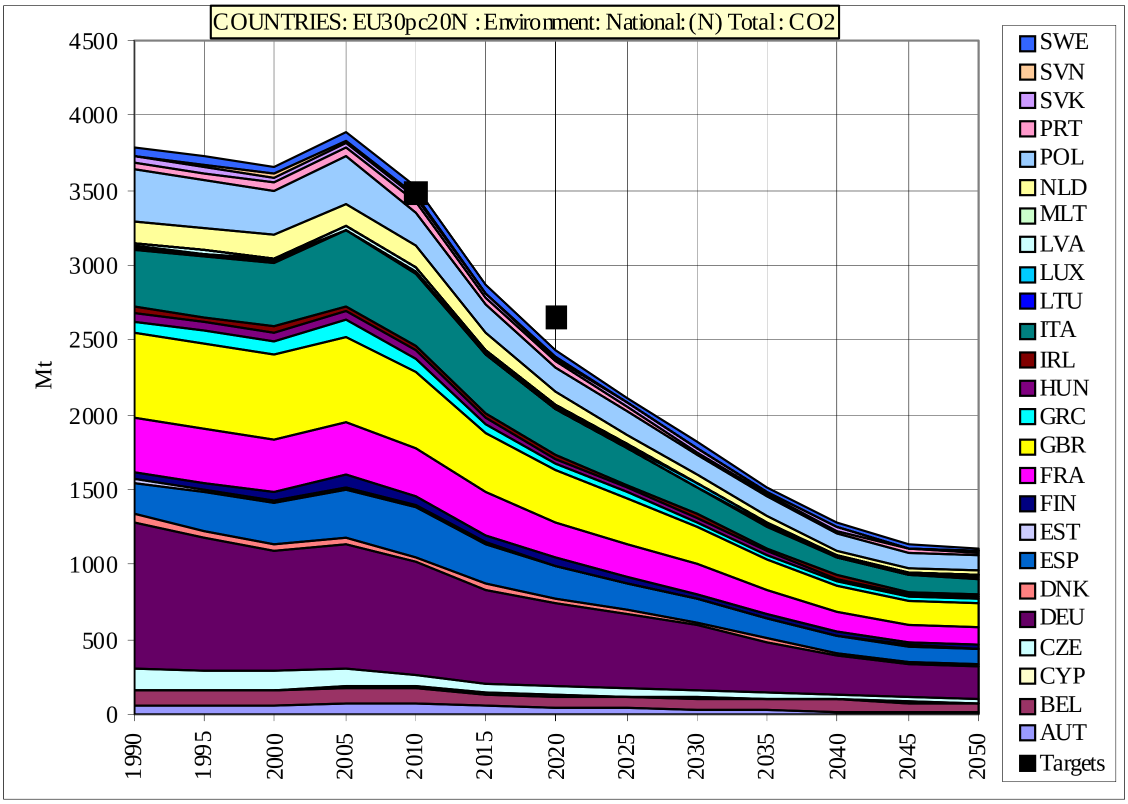

Figure 2. EU CO2 emission – EU30pc20N

3.1. Energy and CO_2

The CO_2 emissions of each country for the EU30pc20N scenario are shown in Figure 2. The Kyoto and 2020 30% targets are shown as black squares. The Figure shows how measures continue to reduce CO_2 emissions after the target year of 2020 because most of the technologies and measures require more than the 12 years between 2008 and 2020 to be fully implemented (see Table 1). This underlines the importance of the early introduction of measures to meet near term targets, and to reduce total CO_2 emission over the next 50 or more years.

3.2. Air pollution

SEEScen energy scenario data are input into IIASA’s GAINS model; see IIASA (2007) for more information about the GAINS model. GAINS is used here to calculate air pollution emission and emission control costs as determined by energy flows, vehicle stocks and traffic, and assumptions about control measures. SEEScen and GAINS are complex models and there are large amounts of data to transfer from SEEScen to GAINS. The categorisation and definitions of data are sometimes incompatible and so data have to be adjusted, aggregated and disaggregated, operations which inevitably required the exercise of judgement on the part of the author.

A major objective of the project was to compare the emissions from **EU30pc20N** SEEScen scenario (shortened label **EU30N**) with those from a composite of the national scenarios developed by each of the EU25 states; this composite scenario was modelled by IIASA and is referred to as **NAT_EUV_HDV,** (shortened label EUV - see Amann *et al* (2007) for a description). Both sets of energy scenarios were input into GAINS, and the resulting emissions compared. As can be seen in the following table, the **EU30N** energy scenario results in significantly lower emissions *and* control costs for all pollutants than the **EUV** composite scenario. This is most significant for SO_2, where there is a 16% reduction in emission and a 23% reduction in EOP costs.

The calculation procedure is likely to overestimate emissions from power stations. This is because in practice the plant with the highest emissions per energy produced would be displaced first: emissions per kWh of electricity and heat produced by power plant vary widely because of differences in fuels, efficiencies and existing emission controls, and it is likely that incremental reduction efforts would focus first on the plant with the highest emissions.

Table 3. GAINS: EU30N and EUV 2020 results

		EUV	EU30N	Reduction EUV-EU30N
Emission	**kt**			
NOx		6643	5321	20%
SO2		3831	3203	16%
VOC		5942	5725	4%
PM		3123	2917	7%
Control cost	**MEuro/a**			
NOx		43990	41345	6%
SO2		16298	12531	23%
VOC		3072	2954	4%
PM		9758	8135	17%
	Total	**73118**	**64965**	**11%**

Emissions from vehicles are estimated using vehicle travel distances and emission factors based on particular vehicles operating under certain driving cycles. The SEEScen **EU30N** scenario assumes some downsizing of cars, reduction in motorway speeds and modal shift. These measures will generally result in less air pollution per energy consumed and per vehicle distance, which, if not accounted for, will result in an overestimation of air pollution emissions and abatement costs arising from the **EU30N** scenario in GAINS.

For such reasons, it is probable that emissions and control costs incurred by the **EU30N** energy scenario would actually be lower than those estimated with the data inputs to GAINS.

4. DISCUSSION AND CONCLUSIONS

These six scenarios for 25 countries were developed over a relatively short period of time. Experts in each country will generally have better data for their countries, and a superior understanding of the best mix of CO_2 reduction measures to apply. However, these scenarios apply the same NEOP measures in a consistent manner across all countries using a single model. This approach is thought to lead to better comparability than using country scenarios generated with a range of models.

4.1. Main findings

The more important points concerning energy, CO_2 and air pollution are summarised here.

Energy and CO2

- For completeness international aviation and shipping should be included in the EU25 emissions inventory – these emissions are not generally reported in the study described here, but they were calculated. Plainly, international transport emissions are major contributors to global impacts.
- Large energy demand reductions are feasible in most sectors.
- Behavioural change is important, especially in car choice and use, and air travel demand.
- There is a general shift in most scenarios from fossil fuel heating, especially gas, to solar and electric heat pumps.
- Detailed modelling suggests that fossil electricity generation can be replaced by a mix of renewables to the extent that Europe might become a net exporter of renewable electricity.
- The most intractable problem is replacing fossil liquid transport fuels, especially for aircraft and ships.

Air pollution emission

- The low carbon measures allow for further reductions in air pollution, and a decrease in the EOP costs of achieving any given target.
- The emissions and costs calculated using SEEScen data in GAINS are probably overestimated because of detailed modelling issues.

4.2. Feasibility of scenarios

The feasibility of the scenarios may be assessed from a number of perspectives: technical, economic and behavioural.

Technical aspects. In most countries the measures are not implemented to the maximum and therefore, if the maxima are approximately correct, the scenarios are technically feasible from this perspective. The question of whether the EU will be able to import gas and oil as required in the scenarios is one whose answer requires analysis of global demand and supply; however, it is clear that the lower the demand for these fuels, the smaller will be the import problem.

Behavioural issues. Key to the EU30pc20N scenarios are assumed changes to t certain consumer behaviour in terms of technology and fuel choice.

Instruments. Instruments to implement measures have not be analysed in this study, but it is clear that the tailoring of instruments to effectively implement measures requires further thought as any low carbon scenario requires substantial and rapid changes both to the current policy stance and existing suites of instruments in most EU countries.

4.3. Data and modelling

There are many facets of data and modelling that could be improved. Some of the more significant items are listed below.

Data

General demand management and efficiency potential. There is no comprehensive source of data on demand management and efficiency in each EU country.

Renewable energy. Surveys of the technical and economic potential of the different renewable energies are required.

Energy modelling

Demand. The model changes the demand for useful energy according to functions based on per capita GDP and population. At present these functions do not account for factors such as:

- **Age structure and activity of population.** Apart from households becoming smaller, the average age of Europeans is increasing and patterns of economic activity will change because of this, and other economic trends.
- **Changes in expenditure pattern.** The carbon intensity (carbon per monetary value) of consumer expenditure may change as wealth increases:

These issues require further careful analysis. If simple growth functions without saturation are assumed in the modelling, long term energy demand increases inexorably after the potential technical savings are fully taken up.

Supply. More detailed modelling of energy supply would be helpful. This particularly relates to electricity systems with high fractions of renewable energy.

4.4. Conclusion

These scenarios help to identify where the largest problems arise concerning CO_2 reduction, and what the best solutions to these might be. The scenarios show how measures can simultaneously address the problems of air pollution, carbon dioxide emissions and energy security.

5. REFERENCES

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