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Modelling Socio-Economic Aspects of Bioenergy Systems: A survey prepared for IEA Bioenergy Task 29

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1 INTRODUCTION

The aim of IEA Bioenergy Task 29 "Socio-Economic Aspects of Bioenergy Systems"[2] is to identify and quantify the socio-economic and environmental impacts of bioenergy production systems. In particular, the Task is seeking to investigate the effects of bioenergy generation – both feedstock production and energy conversion – on the surrounding economic (financial, local industry creation, infrastructure development, regional value added, etc.), social (employment, education, health, etc.), and environmental climate. Thereafter, any identified and substantiated net regional gains and benefits can be used to promote the use of bioenergy to policy and decision makers in areas where the gains can be maximised and most widely felt.

To this end, the investigation necessitates an analysis of existing research models, which can capture, evaluate and numerate the social, economic and environmental impacts associated to bioenergy production. The most appropriate models can then be used to evaluate the impacts of bioenergy deployment. Thereafter, comparisons can be made between separate bioenergy systems and support mechanisms to identify the optimal bioenergy production structures which would accrue the greatest socio-economic gains.

After a brief overview of the breadth of factors under analysis, this paper will then seek to assess the ability of existing socio-economic models in deriving and enumerating a bioenergy project's impact upon key socio-economic variables. These factors are highlighted in Appendix 1 of this document. Research into these variables can either focus at a regional/local level or at the national level, and different research frameworks are therefore available for this task. Similarly, due to the wide range of criteria being studied, and the differing approaches to socio-economic research, it is unlikely that any one model will service the requirements of all socio-economic investigations. Therefore, it may be more appropriate to adopt a toolbox approach. This will allow the research to draw on appropriate methodologies given the circumstances and constraints of the particular area and/or system under investigation.

The models investigated in this paper are summarised in a non-technical manner[3] and detailed in terms of their background, underlying methodology, practical manipulation and their applicability to the aims of Task 29. For reasons of clarity and explanation, a glossary of terms and a summarising table can be found at the end of this paper. Similarly, contact points for acquiring each model can be found in the reference section.

2 ASPECTS OF SOCIO-ECONOMIC ANALYSIS

Socio-economic impact studies are commonly used to evaluate the local, regional and/or national implications of implementing particular development decisions. Typically, these implications are measured in terms of economic indices, such as employment and monetary gains, but in effect the analysis relates to a number of aspects which include social, cultural and environmental issues. The problem lies in the fact that these latter elements are not always tractable to quantitative analysis and, therefore, have been precluded from the majority of impact assessments in the past, even though at the local level they may be very significant.

In reality, local socio-economic impacts are diverse and will differ according to such factors as the nature of the technology, local economic structures, social profiles and production processes. A summary of some of the benefits associated with local bioenergy production is listed in Table 1.

The nature and extent of any particular plant's socio-economic impact will depend upon a number of factors. These factors include the level and nature of the capital investment, the availability of local goods and services, the degree of regional monetary leakages, the time scale of both the construction and

[2] See www.eihp.hr/task29.htm; Domac *et al.* 2000.
[3] In several cases bioenergy system analysis is not the only aim of the model.

operation of the plant, and various institutional and energy policy-related factors such as capital grants and subsidies.

Table 1. *Benefits associated with local bioenergy production*

Dimension	Benefit
Social Aspects	• Increased Standard of Living – Environment – Health – Education • Social Cohesion and Stability – Migration effects (mitigating rural depopulation) – Regional development – Rural diversification
Macro Level	• Security of Supply / Risk Diversification • Regional Growth • Reduced Regional Trade Balance • Export Potential
Supply Side	• Increased Productivity • Enhanced Competitiveness • Labour and Population Mobility (induced effects) • Improved Infrastructure
Demand Side	• Employment • Income and Wealth Creation • Induced Investment • Support of Related Industries

Accordingly, discussion of the identified impacts noted above will be discussed in the following sections.

2.1 The Social Dimension

In many ways the social implications arising from local bioenergy investment represents the '*woolly*' end of impact studies, nevertheless they can be broken down into two categories: those relating to an increased standard of living and those that contribute to increased social cohesion and stability.

In economic terms the 'standard of living' refers to a household's consumption level, or its level of monetary income. However, other factors contribute to a person's standard of living but which have no immediate economic value. These include such factors as education, the surrounding environment and healthcare, and, accordingly, they should be given equal consideration.

Moreover, the introduction of an employment and income-generating source, such as bioenergy production, could help to stem adverse social and cohesion trends (e.g., high levels of unemployment, rural depopulation, etc.). It is evident that rural areas in some countries are suffering from significant levels of outward migration, which mitigates against population stability. Consequently, given bioenergy's propensity for rural locations, the deployment of bioenergy plants may have positive effects upon rural labour markets by, firstly, introducing direct employment and, secondly, by supporting related industries and the employment therein (e.g., the farming community).

2.2 Macroeconomic Effects

The increased use of bioenergy, which exhibits both a broad geographical distribution, and diversity of feedstock, could secure long-run access to energy supplies at relatively constant costs for the foreseeable future. Moreover, the use of indigenous resources implies that much of the expenditure spent on energy provision is retained locally and is re-circulated within the local/regional economy.

Similarly, by securing a heat and power supply system based on indigenous resources, exposure to international fuel price fluctuations are minimised, thus reducing the risk of rising costs of production, transport, etc.

2.3 Supply Side Effects

Supply side effects are rather subjective in regional impact studies, as they are commonly deemed to be those impacts which are the result of improvements in the competitive position of the region, including its attractiveness to inward investment. These effects are likely to differ in kind and will depend upon the development, but generally such 'economies of speculation' relate to changes and improvements in regional productivity, enhanced competitiveness, as well as any investment in resources to accommodate any inward migration that may result from the development.

Taken together, these effects may result in the establishment of pockets of complementary economic activity, where related (and often local) industries mushroom in response to increases in local demand. Accordingly, supply side effects have a much broader scope, and as such quantitative assessments are much more speculative. Despite this caveat, some projects have been justified purely on the grounds that they may have significant long-term supply side effects, even if they are difficult to quantify with any confidence prior to the development.

2.4 Demand Side Effects

Demand side effects constitute the focal point of the majority of socio-economic impact studies, and are concentrated upon for several reasons. Most notably, they are relatively easy to define and the scale of the investment's impact can be quantified with reasonable accuracy. Moreover, it is the economic impact that is most important to regional developers and decision makers.

Demand side effects are primarily quoted in terms of employment and regional income. They can be categorised accordingly into:

- Direct Effects
- Indirect Effects
- Induced Effects
- Displacement Effects.

The derivation of the above should form the basis of socio-economic analysis. However, the extent to which these effects can be totally captured at a local level will depend crucially on the quality of the information available.

Considerable effort should be made to determine the extent and direction of capital flows both within the region under analysis and, more importantly, out of the specified region. If this 'leakage' element is ignored, then it gives rise to misleading spurious predictions about future employment and income gains. Furthermore, consideration should be given to the duration of the impacts, and only then can a tentative evaluation of the wider effects pertaining to some, or all, of the other factors be attempted.

3 MODEL SURVEY

3.1 ABM

3.1.1 Background

The Austrian Biomass Model (ABM) was developed for a bioenergy study in Austria, carried out by the Austrian Institute of Economic Research and partners. ABM is an economic model that compares the various options to increase biomass energy supply, focusing on the respective macroeconomic and environmental implications of such an increase. The study focuses on biomass as the quantitatively most important renewable resource in Austria, and considers three energy markets: electricity, heat and liquid fuels. By using *general equilibrium analysis* it is possible to quantify the impacts of deploying biomass energy on: the labour market; the foreign trade structure; the public budget; sectoral and overall gross production, and CO_2-emissions.

3.1.2 Underlying Model Theory

The Austrian Biomass Model uses a computable general equilibrium model (CGE), which is based on input-output (I/O) analysis (see Section 3.11 below), but also takes into account price-dependent flexible input coefficients. It is a model convenient for macro-economic analysis of impacts that affect not only parts of the economy but the economy in total.

The ABM model is a standard, static small open economy model, with specific features in the modelling of distinct technology choices within energy markets, and in its labour market modelling. A technology will only be used if it produces energy at lowest costs. Therefore whenever biomass technology is more costly, it is necessary to employ a public development programme that makes biomass technologies able to compete with the current fossil technologies. This can be done either by subsidies or by increasing the relative price of the fossil technologies. The model then distinguishes among the very many potential technologies and employs them according to their cost ranking until demand is met at production cost. For the labour market, *classical unemployment* is assumed. Public demand depends on public revenues, and for the household demand a linear expenditure system is assumed.

The idea is to show the complex and interdependent relationships of an economy by a general equilibrium framework so that the quantitative and price effects can be implicitly found if a policy strategy or a public development programme is introduced into the model. The net effect is quantifiable within the CGE model and it can differentiate between those technologies that cause an increase in both employment and Gross Domestic Product (GDP), those that cause an increase in employment but a decrease in GDP, and those that cause a reduction in both employment and GDP.

3.1.3 Practical Application

The study was realised in three steps. First, the primary biomass potential in Austria and the associated costs were evaluated. In a second step, 30 different bioenergy systems have been identified and compared to fossil fuel based technology. In a third step, a computable general equilibrium model of the Austrian economy was constructed to study the social, economic, and environmental impacts.

In each of the 34 sectors considered, the primary labour and capital inputs are combined with energy inputs via a nested *Constant Elasticity of Substitution* (CES) production function.[4] The intermediate inputs are modelled by a *Leontief* production function. To model foreign trade, it is common practice for small open economies to use the Armington assumption,[5] except for the energy sector, where a constant import-output coefficient is assumed to determine the import level.

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[4] In nested CES production functions, at each hierarchical level, separate factor substitution elasticities are calculated; within each level, these elasticities are assumed to be constant.

[5] Armington, P.S. (1969), "A Theory of Demand for Products Distinguished by Place of Production", International Monetary Fund Staff Papers 16, Wash. D.C., pp.159-178. Under the Armington assumption, domestic goods are treated as being different

Currently ABM is set in a General Algebraic Modelling System (GAMS) and its subsystem MPS/GE. PATH-Solver Version 3.0 is being used for the solution algorithms. ABM is a comprehensive modelling framework set at the national level, however, for use in countries other than Austria, it would require significant data and intellectual resources to configure the underlying data for use in other countries.

3.2 BEAM

3.2.1 Background

The International Energy Agency first initiated the BEAM (Bioenergy Assessment Model) project in 1992. The purpose of the project was to build a computer based model to compare various biomass production processes and conversion systems. With this said it concentrates more on the financial and technical feasibility of projects, rather than on the impact of any particular project on the surrounding environment and economy.

BEAM was developed in two phases:

Phase 1 (1992 – 1994): the first version of the Bioenergy Assessment Model (BEAM1) combined biomass production and conversion expertise.
Phase 2 (1994 – 1998): Phase II was aimed to extend the versatility of BEAM1 and resulted in a final product BEAM3 (Microsoft Excel-based).

There are several international participants in what is called the Integrated Biomass System (IBS) activity: they include Austria, Belgium, New Zealand, the European Union, the United Kingdom, and the United States. The development of the IBS thus extended the range of feedstocks and conversion products modelled in BEAM1 and increased the number of system variables, thereby increasing the flexibility of the final BEAM model.

3.2.2 Underlying Model Theory

Essentially BEAM3 is a collection of Excel modules, each of which models the costs and performance of a discrete part of an integrated bioenergy system. A range of bioenergy systems, in terms of different feedstocks, products, and conversion routes, can be modelled. Furthermore, an executive program is available for controlling the definition of the basic system to ensure that a feasible combination of feedstock, product, and conversion route is made.

Once a basic bioenergy system is defined, BEAM3 can be used to calculate technical and economic parameters for the system at a specific capacity based on the cost and performance characteristics of the chosen technology.

There are three modules in BEAM3 for modelling the entire bioenergy chain, from the production of a feedstock to the supply of an energy product. These three modules are:

1) A *Feed Production* module, which covers the cost and performance of feedstock production and transport to the fuel processing plant (before unloading);
2) A *Feed Pre-treatment* module, which covers the reception, storage, handling, and pre-treatment of the delivered feedstock to the point of conversion;
3) A *Feed Conversion* module, which covers the process that converts the prepared biomass feedstock into the selected energy product to the point of export.

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from imported goods, whereby relative demand is determined by price ratios (export levels of a particular goods category are determined in an analogous way).

The BEAM3 model enables the user to select a range of biomass production, conversion, and product systems. Thereafter, it compares the corresponding technical and economic outcomes, e.g., unit cost of production, technical performance, energy output, and profit, to identify the optimal system for development. These system options are shown in the following Table 2.

Table 2. *BEAM system options*

Feedstocks (each for one module)	**Products**	**Conversion routes** (each for one module)
• Short rotation forestry wood • Conventional forestry wood • Wood processing residues • Switchgrass • Miscanthus	Electricity	• Fast pyrolysis and diesel engine • Atmospheric gasification and diesel engine • Pressurised gasification and gas turbine combined cycle • Combustion with steam cycle
• Short rotation forestry wood • Conventional forestry wood • Wood processing residues • Switchgrass • Miscanthus	Electricity and heat	• Fast pyrolysis and diesel engine • Atmospheric gasification and diesel engine
• Short rotation forestry wood • Conventional forestry wood • Wood processing residues • Switchgrass • Miscanthus	Heat	• Combustion only
• Short rotation forestry wood • Conventional forestry wood • Wood processing residues	Ethanol	• Acid hydrolysis and fermentation
• Sweet sorghum	Ethanol	• Extraction and fermentation

3.2.3 Practical Application

BEAM3 can be used to quickly lead users through a process, whereby the consequences of changing individual components of an integrated bioenergy system can be clearly observed. Altogether, there are nine application examples given in the program. These are:

1) A comparison of financial viability of four power generation systems (5–100 MW_e) based on short rotation willow;
2) The examination of the conditions necessary to make fast pyrolysis-diesel engine systems competitive in the current (conventional) electricity generation market;
3) Identification of the cheapest options and sources of greatest cost in the generation of electricity (20 MW_e) from logging residues;
4) Investigation of the effects of limited feedstock availability (coppice willow) on the selection of conversion technology for maximising electricity output;
5) An assessment of the influence of three different feedstocks (forest residues, coppice, and miscanthus) on costs of electricity produced using combustion/steam cycle;
6) Estimation of electricity production costs for a 20 MW_e combustion facility based on conventional forestry using six different harvesting systems;
7) Investigation of possible regional differences in electricity costs in the USA using hybrid poplar and gasifier with combined cycle gas turbine (CCGT);

8) Generation of a predicted supply curve for ethanol produced in Minnesota/USA from hybrid poplar via hydrolysis/fermentation;
9) An assessment of the sensitivity of process and economic variables on the electricity product price for a 20 MW_e combustion plant using bark as a feedstock.

BEAM3 provides evaluative information for particular site, fuel, and conversion technology selection. In sum, BEAM3 is essentially a techno-economic model which can be used to assess the least cost option for a proposed bioenergy system. With respect to performance data, it is unable to denote its contribution to regional income or employment, as it does not identify the source of the factor inputs and the degree of capital leakages.

Table 3. *Summary of Strengths and Weaknesses of BEAM*

Strength	Weakness
• Can be used to compare a wide range of system options using common economic parameters.	• Can be cumbersome when used for certain tasks (e.g., supply curve generation).
• Enables system parameters to be defined by the user within sensible limits and impacts of such changes on product cost to be quickly determined.	• Information is not sufficient for site-specific detailed investigation.
• Has been constructed by experts in the biomass harvesting/conversion arena, therefore giving novices security in terms of the outcomes.	• Conservative in outcomes due to the use of established technology.
• Delivers a conservative and achievable outcome, rather than an optimistic outcome which might be based on novel or untried technology.	• Calculation is based on US$ and does not accommodate exchange rate fluctuations.
• BEAM3 leads users to question technical and economic outcomes, which in turn quickly raises the overall understanding of biomass energy systems.	• Biochemical conversion options are limited due to poor availability of data.

Practical application of the system is simple and is based on Excel spreadsheets. These lead the user through the parameters of the system and finally calculate the corresponding technical and economic outcomes, e.g., unit cost of production, technical performance, energy output, and profit. The model is particularly useful for developers designing bioenergy system and whilst it does indicate profit and expenditure, it does not specify a project's impact upon the local economy or environment.

3.3 BIOCOST

3.3.1 Background

BIOCOST can model the cultivation of dedicated energy crops and thus allows a cost comparison to be made with alternative crop production. It estimates bioenergy crop production costs for seven U.S. regions: the Lake States (MI, MN, WI); the Corn Belt (IA, IL, IN, MO, OH); Appalachia (KY, NC, TN, VA, WV); the Southeast (AL, GA, SC); the North Plains (KS, NE, ND, SD); the South Plains (OK, TX), and the Pacific Northwest (OR, WA – hybrid poplar only), where these regions correspond to major U.S. agricultural crop production areas.

BIOCOST is a user friendly version of the production cost models developed within the Biofuels Feedstock Development Program (BFDP) at Oak Ridge National Laboratory (ORNL) in Tennessee. This program was launched in 1978 by the U.S. Department of Energy.

3.3.2 Underlying Model Theory

BIOCOST estimates the full economic cost of producing bioenergy crops in 1995 U.S. dollars. Variable cash expenses (e.g., seeds, chemicals, fertiliser, fuel, repairs, and hired labour), fixed cash costs (e.g., overhead, taxes, interest payments), and the costs of owned resources (e.g., producer's own labour, equipment depreciation, land rents, opportunity cost of capital investments) are included in the estimated production costs. The approach is consistent with the methods used by the U.S. Department of Agriculture (USDA) to estimate the cost of producing field crops, and thus facilitates comparisons of bioenergy crop economics with those of conventional agricultural crops.

It is based on U.S. data, where the estimated default production costs for each region vary due to differences in assumed labour rates, fuel costs, machinery complement, variety planted, level of chemical and fertiliser inputs used, fixed costs, expected yields, and land rental rates.

BIOCOST models on-farm production costs only. Per ton transportation costs can be included in the cost estimates, but are not modelled as a function of distance, speed, or load size. Therefore, the assumption is made that typical transportation costs to the user facility are US$5–10 per dry ton (US$5.5–11 per dry Mg) for distances less than 75 miles (120 km).

Because bioenergy crops remain in production for several years, production costs are estimated for each year of rotation. The per acre cost of production over the lifetime of the rotation is estimated as a net present value using a 6.5% real discount rate. Estimated per ton costs are also net present values, and are based on the expected annual yields over the life of the rotation.

Given this type of economic analysis, the full economic costs can be used to inform policy analysis in such areas as national agricultural income, regional and international competitiveness, and agricultural productivity.

3.3.3 Practical Application

Essentially BIOCOST is a decision support tool to compare the profitability of differing agricultural crops. With respect to performance data, it is unable to denote its contribution to regional income as it does not identify the source of the factor inputs and the degree of capital leakages.

3.4 BIOSEM

3.4.1 Background

The BIOSEM (Biomass Socio-Economic Multiplier) project was a two-year project, which started in January 1997 under the FAIR Programme of DG IV under the European Commission's Fifth Framework Programme. The objective was to construct a quantitative economic model to capture the income and employment effects arising from the deployment of bioenergy plants in rural communities.

Nine countries were involved in the study, all of whom nominated a specific bioenergy plant and region within their own country. The bioenergy plants chosen varied in scale, technology and feedstock, and the impact of their installation upon the immediate economic locality was modelled by participating members. The project team involved academics, energy consultants and agriculturists from within the participating countries.

Using a traditional *Keynesian Income Multiplier* approach, the BIOSEM technique makes predictions about the income and employment effects arising from the installation of a bioenergy plant. It is intended for use in ex-ante impact assessments to provide forecasts of the associated costs and benefits of any proposed bioenergy scheme, with analysis divided between the feedstock and conversion systems.

3.4.2 Underlying Model Theory

BIOSEM is a quantitative model designed to capture the socio-economic effects of local bioenergy production. It can trace both the extent and distribution of income and employment gains, and can assess the merits of differing (energy and agricultural) policy packages, such as grants and subsidies on bioenergy production.

A range of biomass fuels and conversion processes can be modelled (e.g., from residues to dedicated energy crops), as can the recipient markets for heat and electricity. Modelling takes place in two phases: firstly, to identify the financial feasibility of the plant, and then, secondly, to determine the employment and income benefits from the complete bioenergy chain. It evaluates both the backward linkages (i.e., the impact of increased demand in the supply chain) and the forward linkages (i.e, the re-spending of additional regional income) before combining these figures to provide a complete analysis of the impact of bioenergy production on a local economy.

Phase 1 of the model, the financial assessment, is based on a cash-flow analysis of the plant over a twenty-year period. During this time, investment and profit margins can be traced to determine key financial indices for both feedstock production (gross margin) and for the conversion plant (such as the net present value, the internal rate of return, and the payback period). These can be used to assess the actual commercial feasibility of the plant. This is an important element, because unless the plant is economically viable, then no developer would undertake the investment. Consequently, all employment and income forecasts would be meaningless.

Phase 2, the socio-economic analysis, is based upon the Keynesian income multiplier technique. By this means, the model captures the following impacts:

- direct and indirect employment and income impacts for both agricultural and bioenergy plant activities;
- direct displacement impacts for any displaced agricultural activities;
- induced impacts caused by the spending of additional wages and profits for both agricultural and bioenergy plant activities.

To this end, the technique uses a spreadsheet structure to allow full transparency between all the calcula-tions. It is available in three versions allowing a variety of feedstock inputs to be used:

1) **BIOSEMv8** for crops having a three-year rotation cycle, such as Short Rotation Coppice (SRC);

2) **BIV8-ANN** for annual crops which undergo yearly planting and harvesting cycles;

3) **BIV8-PER** for perennial crops (and agricultural or forestry residues), where the establishment costs are borne only once (or not at all) throughout the life of the feedstock production process.

The model takes the form of five linked spreadsheets, which have the following format and structure:

- **Sheet A** is the "scene setter" and contains all the regional and plant input data upon which all the other sheets are based. This is the only interactive sheet within the model;
- **Sheet B** calculates the financial viability of crop production and the bioenergy plant over a 20-year period. It provides both annual and cumulative cash flows and investment indicators, i.e., net present values (NPVs) and internal rates of return (IRR), which can confirm the viability of the project, thus allowing subsequent employment and income analysis to take place;
- **Sheet C** calculates all the pecuniary leakages from the regional economy;
- **Sheet D** details the displacement effect of transferring one type of crop production to bioenergy production and the impact on the primary processing of the agricultural activity displaced. Sheet D reads data from sheet A and calculates the discounted net margin, the interest charge and the net

margin after interest for the displaced agricultural activity. In some instances the sheet may be redundant because the bioenergy feedstock is a by-product of another economic activity. For instance forest residues and straw are both by-products from other activities, therefore feedstock production does not displace any other productive economic activity;

- **Sheet E** calculates the final direct, indirect and induced multiplier along with the income and employment gains. The basic components of the gross effect are: the *direct effect*, the *direct displacement effect*, the *indirect effect*, the *indirect displacement effect*, the *induced effect* and the *total net impact*.

In summary, the BIOSEM technique will calculate the direct, indirect and induced employment and income effects arising from the increased demand for goods and services supplying the whole bioenergy chain. This means that the BIOSEM technique will be useful to project developers, regional economic development officers and agencies, and policy makers.

3.4.3 Practical Application

The model relies upon traditional Keynesian economic theory and although it is somewhat crude it provides sufficient detail to determine the potential impacts of a bioenergy installation. Moreover, it is particularly well suited to the assessment of individual plants in remote areas where acquiring detailed economic data on goods and service flows could be a problem.

The technique is relatively easy to use because of the transparency of the spreadsheet design. Data is only input in the first spreadsheet, therefore it is easy for the user to trace the implications of changes in key variables. Similarly, the output is easy to interpret and justify.

In the event that all the input information cannot be found, the model uses default data from the United Kingdom. This will compromise the validity of the outputs, and therefore every effort should be made to furnish the model with the correct information.

The spreadsheets are locked at present, but can be manipulated if the password is acquired. However, users must be aware of the implications of changing functions within the spreadsheets before they undertake such actions.

In respect of the model's ability to service the needs of Task 29, it is able to quantify the many of the demand side variables of socio-economic analysis and this can be complemented by qualitative analysis.

3.5 ELVIRE

3.5.1 Background

The ELVIRE (Evaluation of Local Value Impacts for Renewable Energy) model is an evaluation tool for development projects involving renewable energies. It has been developed by FEDARENE's working group on renewable energies and some of its member agencies, under the support from the ALTENER programme[6] of the European Commission's Directorate General for Energy.

The ELVIRE model evaluates the '*externalities*' associated with renewable energy projects, by weighing up the overall impacts of a project against its initial costs. It tries to provide answers to basic questions, like: What are the benefits of a local renewable energy project given that energy prices are low and that conventional energies are abundant? What is its contribution to sustainable development? What are the environmental benefits of such a project?

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[6] Since 1992, ALTENER has facilitated the creation of tools to assist decision-making and the promotion of renewable energies, as well as the implementation of information and know-how exchange networks throughout Europe.

ELVIRE is a true socio-economic model, in that it outlines a development's likely impact on 1) regional economic development; 2) employment; 3) the return on public finances; 4) sustainable development; and 5) the environment. ELVIRE permits the calculation of these listed externalities and hence provides public and private decision-makers with an evaluation tool for renewable energy projects.

3.5.2 Underlying Model Theory

The method used in ELVIRE relies upon both general accounting principles (e.g., return on investment) and multiplier analysis. With this combination, which is translated into a specific choice of evaluation methods and variables measured, ELVIRE seeks to provide a precise picture of the externalities created, while limiting the range of the investigation to be carried out. Consequently, it is well suited to areas where data availability is limited.

The ELVIRE model contains several stages in application, each of which can be represented by a separate table. In total there are five stages involved in a project evaluation process:

- **Stage 1** includes the initial values specific to the project to be evaluated. These values include financial data, microeconomic data concerning the energy balance and the operation phase of the project, as well as data allowing the investment to be broken down into its different components;
- **Stage 2** covers a range of social, environmental and industrial data, which characterise the project and can also be applied in a more general way to the economic activity in the region;
- **Stage 3** contains intermediate values, calculated on the basis of the previous information, and serves as a table for reference that the evaluators can use to check the validity of the results and certain model hypotheses;
- **Stage 4** incorporates the quantitative indicators of four types of criteria: 1) contribution to regional development; 2) contribution to job creation; 3) contribution to public finance; and 4) contribution to environmental protection;
- **Stage 5** describes the calculation results of the qualitative indicator in terms of the contribution of the project evaluated to the regional development, environmental protection, and sustainable development, as well as the project's replication potential.

The model can be easily constructed in any spreadsheet package and therefore allows considerable transparency within its methodology.

3.5.3 Practical Application

ELVIRE is designed to evaluate the social externalities associated with local renewable energy projects. The model can be applied to indicate the impact of government subsidies and grants on local employment, environmental protection and sustainable development, without neglecting an important component which is of great interest to policy makers: the public finance balance sheet. The model is particularly well suited to local and regional operators and decision-makers.

According to current information, the model has so far been applied to the following renewable energy projects:

- a PV plant at the photovoltaic park in Heraklion, Crete (GR);
- a photovoltaic electrification of isolated sites in the Les Ecrins National Reserve/Province-Alpes-Côte d'Azur (F);
- a solar hot water supply with guaranteed results ("SUNERGIE") in a hospital in Barcelona (E);
- a solar system for hot water supply in a hotel in Torremolinos/Andalusia (E);
- open air public swimming-pools solarisation in Poitou-Charentes (F);
- a solar drying of hay using air solar captors in the Province of Trento (I);
- a solar hay drying in the Roquefort area/Midi-Pyrénées (F);
- a bio-climatic architecture in social housing in Drôme/Rhône-Alpes (F);

- a windfarm at Canical/Madeira (P);
- an installation of two 500 kW aerogenerators at the Granadilla windfarm in Tenerife/Canary Islands (E);
- **a wood-energy district heating network in a rural township in the Nord-Pas de Calais (F);**
- a small scale hydropower plant in the Issaux Torrent in Aquitaine (F);
- a geothermal urban heating in St Ghislain/Wallonia (B).

ELVIRE is well suited to address the Task 29 research objectives, and will serve to familiarise agents with the inter-relationships which exist within regional economies.

3.6 EXTERNE

3.6.1 Background

The ExternE (Externalities of Energy) project was the first comprehensive attempt to use a consistent 'bottom-up' methodology to evaluate the external costs associated with a range of different fuel cycles. The European Commission launched the project in collaboration with the U.S. Department of Energy (DoE) in 1991. The EC and U.S. teams jointly developed the conceptual approach and methodology, and shared scientific information for its application to a range of fuel cycles. There have been four main stages to the programme's development, namely:

- the development of a methodology for the evaluation of externalities associated with fuel cycles;
- the application of the methodology to a range of fuel cycles with the development of an accounting framework for each fuel cycle;
- the application of the accounting framework to a different technologies and sites;
- the development of methods for the aggregation of the results such that they are of value to policy and decision makers.

To date, Stage 1 has been completed, Stage 2 and 3 are ongoing, and Stage 4 has just commenced.

The framework can be applied to a wide range of receptors, including human health, natural ecosystem, and the environment. In addition, the methodology is also being extended to address the evaluation of externalities associated with the transport and domestic sectors, and a number of non-environmental externalities such as those associated with the security of supply.

3.6.2 Underlying Model Theory

The methodology relies upon a whole fuel cycle approach to impact assessment. The term 'fuel cycle' refers to the chain of processes linked to the generation of energy from a given fuel. For example, the assessment of a bioenergy fuel cycle includes evaluation of the impacts associated with:

- Construction of new plant
- Harvesting
- Storage
- Transport of biomass
- Power generation
- Waste disposal
- Electricity transmission.

Analysis begins with the identification of the stages of the fuel cycle under assessment (see above). A comprehensive list of burdens and impacts is then described for each stage. Priority areas for assessment are identified, based partly on the results of earlier studies and partly on expert judgement. In practice the actual location and technologies are then selected as they determine the magnitude of many impacts.

Thereafter, the impact assessment and valuation are performed using the 'damage function' (or 'impact pathway') approach. This approach assesses impacts in a logical manner, using the most appropriate models and data available. Methods range from the use of simple statistical relationships, as in the case of occupational health effects, to the use of series of complex models and databases, as in the cases of acid rain and global warming. Accordingly, they include:

1) **Emissions.** Characterisation of the relevant technologies and the environmental burdens they impose;
2) **Dispersion.** Calculation of increased pollutant concentrations in all affected regions (air and water courses);
3) **Impact.** Characterisation of the population or receptor exposed to incremental pollution, identification of suitable exposure–response functions, and linkage of these to give estimated physical impacts;
4) **Cost.** Economic valuation of these impacts.

The final stage of the impact pathway analysis is a monetary evaluation. A welfare economics approach is adopted here. The techniques of monetary valuation fall into three different categories:

- direct valuation using market prices;
- indirect valuation via *hedonic* pricing or the travel cost method; and
- valuation using hypothetical markets by the contingency valuation method (CVM).

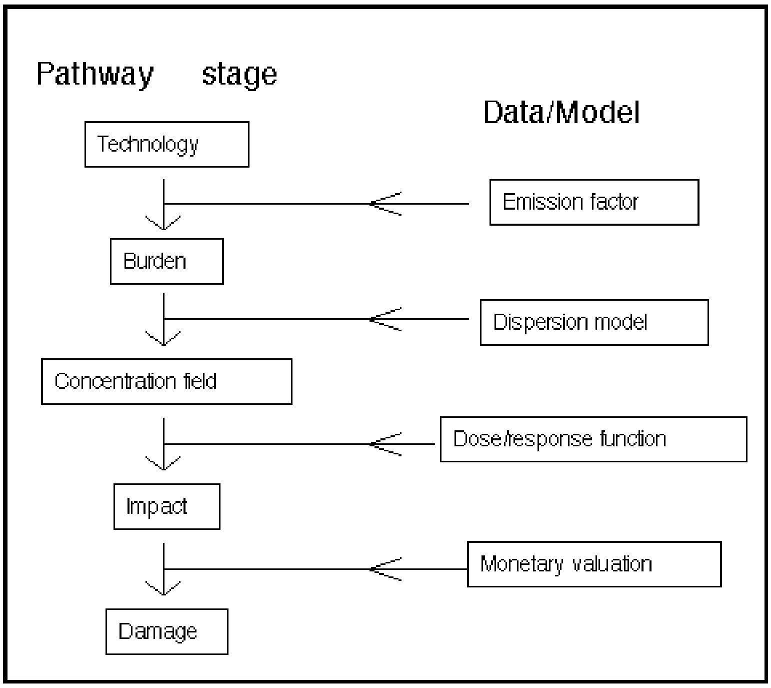
The value is measured by the willingness to pay (WTP) for improved environmental quality or willingness to accept (WTA) environmental damage. For all these techniques, the values obtained are specific to the time and place of the environmental impacts considered. In addition, most valuation is designed for considering large, rather than small, changes in environmental conditions.

The methodology relies upon a detailed definition of both the fuel cycle and the system within which the fuel cycle operates, with respect to both time and space. Accordingly, the data required for the analysis include:

- Technological and emissions data;
- Legal framework governing emissions, health and safety, etc.;
- Specifications of the fuel used;
- Meteorological conditions affecting dispersion of atmospheric pollutants;
- Demographic data;
- Condition of ecological resources;
- The value systems of individuals which determine the valuation of non-marketed goods.

All parts of the analysis are subject to uncertainty, which is characterised by a classification of high/medium/low levels by subject expert assessment of the quality of input data and models.

Figure 1. *Typical impact pathway approach*



3.6.3 Practical Application

The model is available for public and international use and has already determined the environmental and health impacts in both physical and monetary terms for a number of technologies and countries. The variables included are depicted in Table 4.

Table 4. *Variables included in ExternE*

• SO_2	• Public Health
• NO_x	• Materials
• Particulates (PM_{10})	• Crops and forests
• Aerosols	• Freshwater Fisheries
• Ozone	• Unmanaged ecosystems
• Radionuclides	• Occupational/Public accidents
• Methane	• Noise
• N_2O	• Land/Visual impacts
• CO_2	• Global Warming Potential

Results already exist at a national level for the U.S. and the EU and are given in both physical and monetary values for each kWh of energy generated from a number of technologies. Application of the model in countries that have not already been investigated may require external expertise from the core project team to undertake an ExternE analysis. Site specific analysis is possible but will require significant resources, both in terms of data and intellectual expertise, therefore it is more cost-effective to rely upon the published results if they are appropriate to the respective situation.

3.7 INSPIRE

3.7.1 Background

The INSPIRE (Integrated Spatial Potential Initiative for Renewables in Europe) project aimed to link renewable energy resource mapping with economic and life cycle analysis modelling (based on a Geographic Information System – GIS). Funded through the European Union Joule Programme, and drawing upon the expertise of several EU countries, the model has been developed into an integrated methodology for the assessment of resource availability, financial viability and environmental factors for biomass-to-energy options at both regional and national levels. Whilst this was initially conceived for biomass, it has been and can be applied to other renewable energy technologies as well.

3.7.2 Underlying Model Theory

INSPIRE is a framework for linking resource mapping with the economic assessment of biomass-to-energy projects. The model links different resource assessment models (developed using GIS) with various financial models, which include both project and market-driven scenarios.

The GIS models used to form the foundation data for the resource assessments are reliant upon local agricultural data. These then provide a window on the existing activities taking place and their associated gross margin. This data is derived from a number of sources and includes:

- Terrestrial surveys (e.g., Parish boundaries data-sets);
- Satellite remote sensing (RS Earth Observation, such as CORINE; e.g., for olive plantations);
- Agricultural statistics (e.g., Ministry of Agriculture, Farm Business Statistics; Farm Incomes Survey, Farm Management Pocket Book);
- The CORINE data-set produced by the European Commission has been particularly useful to this project, as it combines RS data such as land cover with more common features like roads and settlements.

Thereafter, the methodology is based on the concept of a 'trigger mechanism' that uses the base agricultural statistics (current land-use and farm income data) to determine existing incomes from agriculture. At the same time a set of potential incomes from biomass related activities are calculated using one of the inter-related financial models. These are:

- **RECAP.** As noted elsewhere in this paper, this is a project-driven computer model of biomass-to-energy systems. In one integrated model, all the costs from biomass production to final energy conversion can be studied. Within this framework RECAP can accommodate two scenarios, SRC is the primary feedstock with forest residues as the secondary support fuel, or the reverse where SRC is a minor component. Sensitivity analysis including Monte Carlo runs can identify key areas to concentrate future R&D efforts and quantify risks for the farmer and the conversion plant owner.

- **BIOSIM.** This is a market-driven model used for the Swedish test site to assess availability of forest/ wood fuels. The model converts wood availability to energy content, and uses this to generate the resource/cost map required for linking economics with resource analysis. The model then compares the resources and costs for possible markets to propose an efficient supply system. The model can be used locally, regionally, or at national level and can also accommodate ecological restrictions.

- **MODEST.** This model uses linear programming to minimise the capital and operational costs of energy supply and demand-side management over time. It has been applied to Swedish CHP systems, industrial systems, and national power systems. Similarly, it can also be applied to calculate the external costs of emissions, for example, CO_2. It is based on a number of complex energy, cost and mathematical interrelations.

By linking the existing resource data and the financial assessments of biomass production, the model is then able to operate a trigger mechanism. This trigger mechanism suggests that if the net profit margin for the biomass activity is greater than that of pre-existing farming activities, then the farmer may switch a proportion of that land to energy crop production. In cases where the resource already exists because it is a by-product (e.g., wood fuels and olive oil husks), the problem is simpler, as only resource–cost maps are needed. For example, the current value of existing forestry activities equates to the farm incomes maps described above.

This information is then linked to the markets for the bioenergy produced in terms of electricity, CHP and heat only. Areas that have an adequate resource are identified, and these are then constrained by the proximity of nearby demand (towns for heat and electricity sub-stations for power). The model assumes simply that a large scheme requires a larger town to use the heat than a small scheme. In general, proximity to the demand was the determining factor in the location of the most promising sites.

By using GIS data in conjunction with regional economic data, the model is able to locate existing and potential biomass sources, the location of potential sites, and the potential regional economic gains.

3.7.3 Practical Application

The model is able to predict the potential resource and the possible regional income derived from the production of biomass. It has already produced country specific data sets for several EU countries, but the framework can be applied to any country having sufficient and appropriate data sets.

3.8 RECAP

3.8.1 Background

RECAP (Renewable Energy Crop Analysis Programme) was developed by ETSU on behalf of the U.K. Department of Trade and Industry (DTI). It is designed to assess the financial feasibility of any biomass project using either dedicated energy crops or other biomass sources. RECAP is a versatile computer model of biomass-to-energy systems, which, in one integrated model, can study all the costs associated with bioenergy production. It models all the costs involved from production, harvesting, storage, and transport through to the conversion of energy crops to heat and power. Accordingly, it can make a financial assessment of both the feedstock chain and the conversion process. With this said, this model was a precursor to the financial analysis in BIOSEM.

3.8.2 Underlying Model Theory

RECAP is based on a cash flow analysis and allows the user to programme in various factors of production. It is programmed in Visual C++ and divided into six modules, namely:

- Key variables
- Machinery
- Labour
- Production
- Interface
- Conversion.

The key variables, machinery and labour modules provide data for the three process-related modules: production, interface and conversion.

The **key variables** module acts as an introduction and stores general variables, such as the area of crop grown and output figures.

The **machinery and labour** modules are the smallest modules, and act as the store for agricultural machinery and operating cost data as well as the associated wage rate .

All processes that occur until the fuel reaches the conversion plant are considered in the **production** module, including: establishment; management; harvesting; storage, transport to storage and grubbing-up.

The **interface** module calculates the quantity of primary fuel available for utilisation in each time period, taking into account: the fuel losses; the water content upper limit; the biomass water content in the various harvests; plant capacity; and the fuel supplied/stored.

Finally, the **conversion** module includes all data associated with the conversion plant, such as: capital costs; land costs; start-up costs; fuel costs; maintenance costs; operating costs; and decommissioning costs.

The model is built on a series of logical steps accounting for all the costs incurred throughout the energy crop's life. RECAP will calculate the timing of cash inflows and outflows for both the farmer and the conversion plant operator. This can be used to see when a project breaks even or when it starts to become profitable. RECAP also undertakes an investment appraisal by calculating the Net Present Value (NPV) and the Internal Rate of Return (IRR) for both the farmer and conversion plant operator. The model permits the user to change the costs at any stage of the bioenergy chain to see what impact this has on the farmer's net margin and the IRR and NPVs. A sensitivity analysis can be performed to investigate the effect of statistical variation of any number of inputs on the NPVs and IRRs. There is also a currency option that will convert all the figures into any currency chosen with a given exchange rate.

3.8.3 Practical Application

RECAP modelling provides results that are vital for steering the development of any particular energy crop system to ensure financial viability. Specifically, it provides:

- complete costs of model biomass-to-energy systems;
- net margins and internal rates of return for the farmer and the conversion plant owner;
- optimum system configurations under different scenarios at different scales of operation;
- viability of new conversion technologies;
- optimum harvesting, storage and drying strategies;
- risks to the farmer and the conversion plant owner;
- sensitivity analysis to identify the key system parameters;
- a guide for target areas for future R&D.

The model is available from the DTI electronically, but efforts to date to secure a copy have proved difficult. The model is financially comprehensive, although caution must be used when interpreting data. Experience and knowledge of the model's inherent inter-relations will facilitate its use and interpretations. It is available to the general public without the need for licensing.

3.9 RETSCREEN

3.9.1 Background

RETScreen is a renewable energy technologies (RETs) project assessment tool. It contains a pre-feasibility analysis tool, which is a computerised project assessment tool developed to help an energy project proponent prepare a preliminary evaluation of the energy performance, costs, and financial viability of potential RET projects.

The CANMET Energy Diversification Research Laboratory (CEDRL) originally developed the RETScreen tool in Canada, with the help of industry. Its aim was to assist and direct the implementation of Canada's Natural Resources Renewable Energy for Remote Communities (RERC) programme. However, the tool is applicable to other regions of the world, too.

The principle objective of the RETScreen tool is to help project developers to reduce the costs, time, risks and errors associated with preparing feasibility studies for RET projects. The framework includes separate Excel spreadsheets for RET project evaluation, a detailed user manual, and a database. The framework allows the user to become more efficient in preparing pre-feasibility analysis and leads to more accurate evaluations.

This software tool is intended to be used by technical and financial personnel from electric utilities, and by community planners, consulting engineering firms, government and development agencies, financial institutions, R&D groups, universities, private power developers, and product suppliers.

3.9.2 Underlying Model Theory

RETScreen is based on Excel workbooks. There is one Excel workbook for each RET. Each technology workbook file contains three linked worksheets. These are 1) The Energy Model worksheet; 2) A Cost Analysis worksheet; and 3) The Financial Summary worksheet.

The framework is user friendly and leads the analysis through a four step procedure:

- **Step 1.** Choose the appropriate RET to service the needs of the community. The choice will be dependent upon a number of factors, such as: current and future energy/power demand; current and future conventional energy project costs; renewable energy resource availability; current and future RET project cost; market and/or financial conditions; project proponent experience; and other non-financial factors related to the deployment of RETs.
- **Step 2.** Complete computer worksheets. The user will be required to input baseline cost data for the project into the appropriate workbook. At the end of the data input, the Financial Summary worksheet will summarise the results of the previous two worksheets and compare them with the costs from conventional energy projects. A number of different financial feasibility indicators will then be calculated for the decision-maker's consideration. This step will be repeated several times in order to optimise the design of the renewable energy project from an energy production and cost standpoint.
- **Step 3.** Perform a sensitivity analysis. This helps to determine the parameters that are crucial to the financial viability of a project. It can also indicate the minimum parameter values for the system to be viable. With this step completed, the results from the RETScreen process should provide the project proponent with enough technical and financial information to determine which technology or technologies do or do not warrant further investment.
- **Step 4.** Consider other attributes of RETs projects. This step aims to assess the non-financial attributes typically associated with the implementation of RETs projects. These relate to the environment, risk management, socio-economic impacts, and project or technology-related considerations. Most of these attributes are also project specific, and can be significant in terms of project stakeholder values, needs and planning objectives. The information provided in this step is mostly qualitative but nonetheless valuable.

RETs projects can be well suited for remote areas due to the higher cost of providing conventional energy in those regions. To facilitate RET project proponents assess some of these high value opportunities. Version 98 of RETScreen also includes a database of 300 Canadian remote communities, which contains two categories of information: 1) community level data; and 2) renewable energy resource data. It should be noted, however, that although these estimated data could be applied to the RETScreen Workbook files, some local data gathering would still be required for the preliminary evaluation.

3.9.3 Practical Application

At present, the 98 version of the RETScreen tool can be applied to examine the following RETs:

- **Wind energy projects** from larger scale wind farms to smaller scale wind-diesel hybrid system application;
- **Small hydro projects** from larger scale small hydro developments to smaller scale mini and micro generation applications;
- **Photovoltaic projects** from larger scale central generation plants to smaller scale distributed generation applications;
- **Solar ventilation air heating (VAH) projects** from larger scale industrial building developments to smaller scale residential applications;
- **Biomass heating projects** from larger scale developments for clusters of building to individual building applications.

RETScreen provides a tool to minimise the information required to quick-screen potential RET projects. In this sense, the use of this tool should be limited to analysis at the pre-feasibility level. Results are computed in common Megawatt-hour (MWh) units for each comparison of different technologies, and a number of financial analysis indicators are also provided for decision-makers.

A primary value of this tool comes from the fact that the RETScreen tool combines the energy production costs and financial analysis for the various RETs in one standard format and computer package. Some of the main benefits from using the tool are stated below:

- reduces the costs, time, risks and errors associated with preparing pre-feasibility project studies;
- facilitates decision-makers' consideration of RET projects;
- provides a low-cost preliminary design method for project developers and industry;
- facilitates training and information transfer for RET projects;
- increases the initiation of project studies which help identify the best opportunities for successful implementation of RET projects.

It is important to keep in mind that the RETScreen tool is a pre-feasibility analysis model for performing preliminary evaluations for possible RET projects. Thus there are *limitations* that the current tool cannot overcome, some of which are listed next:

- The model is 'static', rather than 'dynamic', in that the user evaluates each of the technologies independently of one another, rather than in an integrated fashion;
- Only annual energy production is considered, rather than a more detailed time series which would consider energy production and load variation on a much shorter time scale;
- Genetic load duration curves are used for isolated diesel-grid electrical generation applications;
- The tool cannot evaluate smaller scale projects where energy storage is required;
- The user will have to obtain additional data for regions not provided in the current database;
- The range of cost data provided is primarily based upon Canadian and U.S. projects (costs will likely vary in other regions);
- Only pre-tax calculations are performed as part of the RETScreen pre-feasibility analysis model. The tax status of the project proponent could impact the financial outlook of the project and therefore should be considered in a more detailed feasibility study;

- It is assumed that the user will have access to information regarding the avoided costs of energy and/ or capacity, for the conventional energy systems that the potential RETs projects are being compared with. Information in the manual only helps to provide a 'ball-park' estimate of these avoided costs;
- Project cost information is provided in Canadian dollars with 1997 as the base year. The user will have to apply a currency exchange rate for projects outside of Canada and verify the current values of the cost data;
- Much of the data in the Canadian Remote Communities Database consists of 'rough' approximations and should be verified with local data, if available. In each case, the database provides a starting point for preparing a sensitivity analysis.

Moreover, there are some *specific limitations* associated with the RETScreen Biomass Heating Project model:

- The use of large scale district energy systems has not been validated for the current version of the model;
- The model does not calculate the cost of biomass fuel, rather it requires the user to input in the phase of sensitivity analysis;
- The cost model focuses on the biomass heating system components and assumes that the user will have detailed information for local building costs for the combustion plant, which can represent a significant portion of the overall system cost.

RETScreen is essentially designed for assessing the commercial viability of projects during the pre-feasibility stage. Consequently its output concentrates on performance and financial data, whilst further socio-economic considerations are investigated qualitatively.

3.10 SAFIRE

3.10.1 Background

The SAFIRE project, supported by the Commission of the European Communities' Directorate-General for Research and Development (DG XII) under the Joule II programme, was developed by several participants, including:

- Energy for Sustainable Development Ltd (ESD, UK)
- Institut für Energiewirtschaft und Rationelle Energieanwendung (IER, Germany)
- Institute des Aménagements Régionaux et de l'Environnement (IARE, France)
- Zentrum für Europäische Wirtschaftsforschung GmbH (ZEW, Germany)
- Fraunhofer Institut für Systemtechnik und Innovationsforschung (FISI, Germany)
- Coherence (Belgium)

SAFIRE is an engineering-economic bottom-up model for the assessment of first-order impacts of 'rational' (i.e., renewable and new non-renewable) energy technologies on a national, regional or local level against a background of different policy instruments and scenario assumptions. SAFIRE is a framework that consists of a database and a computer model that provides decision-makers with a tool to evaluate the market and impact of new energy technologies and policies. Currently, SAFIRE is being updated to take into account the calculation of baselines within the Kyoto framework.

3.10.2 Underlying Model Theory

SAFIRE can be applied to assess the impact of energy technology and associated policies on a number of economic indicators:

- Market penetration
- Net employment creation
- Pollutant emissions (6 types)
- Value added
- Import dependency
- Capital expenditure
- External costs
- Government expenditure

The time horizon of the model version is over a 36 - 40 year time period, depending upon the base (starting) year specified by the user. The base year is totally flexible, with calculations made for every year within the time period. Outputs are available for a number of marker years.

SAFIRE is data-driven. The software includes an extensive database for 22 renewable energy technologies (RETs), eight new non-RETs and seven fuelling options for co-generation plants including fuel cells, similarly it has a domestic sector demand side management option. Table 5 provides an overview of these options and the sectors in which they can penetrate.

The range of countries within SAFIRE include the EU-15, four other Western European countries (Cyprus, Iceland, Norway, Switzerland), 12 Central and Eastern European countries, and eight other countries worldwide (Brazil, Canada, China, India, Indonesia, Japan, Mexico, USA).

The SAFIRE database is divided into two areas; these are firstly the base year (based upon actual statistics) and secondly the future scenario (based on future data assumptions). For a given location and scenario, the primary SAFIRE calculation uses a substitution methodology to assess the potential future supply of rational energy, whilst matching a demand matrix defined by the user. If the demand side management module is activated, this is calculated first, as it directly affects domestic sector demand. In the main SAFIRE calculation, priority is given to *decentralised* heat and electricity generation and, in a second stage, to *centralised* heat and electricity generation (district heating & electricity). Decentralised is defined as the primary output being generated for on-site consumption.

The SAFIRE calculation is divided into eight stages:

1) Energy demands
2) Demand side management calculation (if activated)
3) Renewable energy technical potential
4) Renewable and non-renewable energy market potential (decentralised only)
5) District heating market potential and penetrations
6) Renewable and non-centralised non-renewable market penetration
7) Centralised electricity market penetration
8) Cost benefit analysis.

The fuelling options open to co-generation, which is assumed to be all decentralised (district heating co-generation is treated separately), are listed in Table 5. The most important feature of the co-generation methodology is the calculation status of liberalisation on the electricity market. This directly affects the revenues received for co-generation output and hence the size of plant constructed.

Table 5. *SAFIRE technology / sector matches*

technology / sector	dom.	comm./inst.	industry	agric.	transp.	centr. el.
(a) renewable energy technologies						
onshore wind	●	●	●	●		●
offshore wind						●
large-scale hydro (≥ 10 MW)						●
small-scale hydro (< 10 MW)	●	●	●	●		●
PV†	●	●	●	●		●
active solar thermal	●	●	●			●
passive solar design‡	●	●	●			
forest residues**	●	●	●	●		●
energy crops*	●	●	●	●	●	●
solid agricultural wastes	●	●	●	●		
liquid agricultural wastes	●	●	●	●		
solid industrial wastes	●	●	●	●		
liquid industrial wastes	●	●	●	●		
municipal solid wastes	●	●	●	●		●
municipal digestible wastes	●	●	●	●		
landfill gas	●	●	●	●		●
wave power						●
tidal power						●
geothermal	●	●	●	●		●
(b) new non renewable energy technologies						
fuel cells		●				
heat pumps		●				
IGCC, PFBC, HOCC, OCGT,						●
CCGT, PWR						●
(c) co-generation fuelling options						
solid biomass	●	●	●	●		
solid wastes		●	●	●		
biogas		●	●	●		
natural gas	●	●	●	●		
coal (+ products)		●	●	●		
heavy fuel oil		●	●	●		
light fuel oil (incl. diesel)	●	●	●	●		
(d) demand side management technologies						
refrigeration & freezing	●					
lighting	●					
insulation	●					
other appliances	●					

Notes: ● refers to a possible technology-sector combination within SAFIRE. The user can specify which combinations are relevant to the area being studied. † For decentralised use assumed to be building-integrated systems. ‡ Passive solar design comprises passive heating for the domestic and the commercial/institutional sector and day-lighting and cooling for the commercial/institutional sector only. * Wood crops, ethanol and biodiesel.

For *centralised* electricity generation and analyses at a national level, the mix of plants is computed on a least-cost dispatching basis. The calculation of the demand for centrally generated electricity is based on the generation level in the base year (calculated from historical data), the electricity demand growth over the model horizon (user-entered for each sector), the retirement of old plant stock, and the contribution made by RETs and new non-RETs for decentralised use.

Eight different cost-benefit indicators are calculated by SAFIRE: pollutant emissions, employment, government revenues, energy and cost import dependency, value added, total and local capital expenditures, and external costs. These indicators are calculated as *net* effects, taking into account the impact of the new technology on the one hand and the impact caused by the displaced conventional technology on the other hand.

Two further features of SAFIRE are also worth mentioning. Firstly, the user determines all of the parameters within SAFIRE. Consequently, the user has to decide upon the exogenous factors that make up each scenario (e.g. sectoral demand fuel shares, energy demand growth, consumer attitudes, energy prices, etc). Secondly, SAFIRE allows for the modelling of district electricity schemes in small scale regional analyses[7], wherein, any surplus electricity is sold to the grid and hence reduces the demand for centrally generated electricity.

3.10.3 Practical Applications

SAFIRE has been used for a number of applications. Since the completion of the original project, it has undergone numerous developments. These include: an extension of the methodology to reflect the whole European energy sector, to improve user friendliness, to modernise the methodology to a more recent time-scale, and is now being expanded to include energy efficient technologies and to cover a global scale.

The model has been used for a variety of applications, ranging from micro-level local planning to market assessment for companies and international agencies, from cost benefit analyses for public institutions to local, regional, national and EU policy and planning. Some key projects for which SAFIRE has been used (since 1994) are listed below:

- Development of the Indicative Member State renewable electricity targets for the proposed Directive on the promotion of electricity from renewable energy sources in the internal electricity market (DG TREN, 2000);
- Future Cogen: The European Cogeneration Study (DG TREN, 1999 – 2001);
- The impact of renewable energy on employment and economic growth (DGXVII, 1997 – 2000);
- Energy technology dynamics and advanced energy system modelling (DGXII, 1998 – 1999);
- Demand side management under liberalising electricity markets (DGXII, 1997 – 1999);
- Technical and economic assessment of renewable energy resources in Bulgaria (DG1a, PHARE, 1995 - 1997);
- Renewable energy assessment of Carinthia (DGXVII, 1995 – 1997);
- Renewable energy and employment generation (Ministry of Energy, France, 1996);
- Assessment of renewable energy employment potential in the Netherlands (Coopers & Lybrand, 1996);
- Determining the effects of carbon dioxide (Friends of the Earth, UK, 1998);
- Strategic penetration & adoption of renewables (DGXII, 1995 – 1997);
- Rural diversification and local energy planning (Dept. of Trade and Industry, UK, 1994).

The model is in the public domain, but may require back up support from the core team to help use the software for research analyses. The framework is quite user friendly and leads the user through the analysis to derive appropriate output. The model is well suited to deliver employment, wealth generation, and environmental output.

3.11 I/O MODELS

3.11.1 Background

Input-Output (I/O) models have a strong theoretic economic history. They are generic in format and can be used as either 'stand-alone' evaluation tools, or they can provide inputs to more comprehensive evaluation models, e.g., ABM or SAFIRE. To date I/O models have been the most favoured form of research pertaining to the impacts of renewable energy technologies at a national level. This is because they are able to provide estimates of jobs generated with respect to either monetary or energy units. One

[7] In this context these are schemes where electricity is generated by local renewable energy plants not sited at the point of immediate use, designed to meet the electricity demand of a local community.

of the most attractive features of I/O analysis is that it is able to take account of jobs displaced as well as those generated by direct and indirect employment. Similarly, it is able to determine the income multiplier to derive the overall increase in regional income given any given investment.

3.11.2 Underlying Model Theory

I/O models rely upon a table called the 'Social Accounting Matrix', of which the I/O table is a subset detailing all the relevant inter-industry flows. These present all the different industry inputs required to provide a given quantity of output. They are based on the assumption that the amount of i's output required for the production of j's output, (X_{ij}), is proportional to sector j's output (X_j). Thus in order to develop a framework for modelling changes in product demand or supply, tables of coefficients are prepared, defining the inputs required for every end product within the economy, e.g., $X_{ij} = a_{ij} X_j$.

Thereafter, if the coefficients, (a_{ij}), are represented in a matrix format (A), the multiplier can be derived by inverting the matrix and then this may be used to establish the overall changes in sectoral outputs resulting from changes in final demand.

I/O tables are a standard output from National Statistic offices, however, they tend not to be compiled annually but rather in two or five year intervals or even less frequently.

The analysis of employment and income effects using I/O tables is more robust and authoritative than other modes of investigation. They are usually compiled at the national level, although regional models have been compiled for specific areas.

I/O accounting structures are a 'snapshot' model, in that the I/O is obtained at a specific point in time. This means that the model will only reflect a specific stage of technological development and will not be able to accommodate any technical changes or increases in efficiencies or reductions in factor inputs thereafter. Similarly, it is worth noting that I/O models tend to be demand deterministic, since they assume that supply is infinitely elastic at the cost price and that excess production always exists. This is quite unlikely to be the case for the majority of renewable energies because of the variability of some RE's and the rotational nature of others (e.g., coppice).

Finally, the fact that the introduction of electricity, or heat, as a factor output, is a new activity into an area, this tends to complicate I/O modelling further. The growth of a new industry producing import substitutes necessitates, firstly a change in the existing coefficients in the A-matrix, and secondly, the inclusion of a further row or column. Together, these manipulations require significant intellectual resources and data inputs.

3.11.3 Practical Application

To date, there have been several investigations into the employment and economic growth impacts of renewable energies using I/O models. However, they have largely been compiled at the national level. It would be possible to derive regional I/O models for application to bioenergy projects, however, the data required for this task is significant. This is partly because the model specification must be adjusted to compensate for the imbalance which exists between regional and national coefficients, with the result that the A-matrix would have to be modified to mirror the use of regionally imported goods as well as those produced locally. The difficulty of this task would be further compounded by a possible shortfall of data at the regional level, as it is unlikely that the depth of information required would be available.

In conclusion, whilst they deliver robust estimates about employment and income impacts, as well as the direction of any gains or losses, I/O models require significant data and intellectual resources. With this said they are probably more useful at the national level rather than the local or regional level.

4 SUMMARY AND CONCLUSIONS

The purpose of this survey article is to provide a basis for work undertaken within IEA Bioenergy Task 29 "Socio-Economic Aspects of Bioenergy Systems". Particularly, the investigation aimed to discover the type, format and availability of existing research models and frameworks which would best serve the needs of further socio-economic research into the deployment of bioenergy. To this end the Task is focusing on key socio-economic variables which are detailed in Appendix 1 of this document. You will note from this table that the areas of greatest interest are those of employment, regional economic development, and finally the environment in terms of CO_2 saved.

However, with this said a number of the proposed models examined do not produce output variables of this kind. They are essentially techno-economic models, which deliver performance and cost data to help developers decide upon the structure and technology of specific project developments. And whilst they do provide details of expenditure and profit, they do not specify the direction and source of those capital flows and neither the source of the employment generated. Therefore, they are not wholly suited to the requirements of Task 29.

Nevertheless, there are a number of models which do meet the requirements of the proposed Task 29 research, not only in delivering information on the amount of employment or income generated, but also about environmental factors as well.

Many of the specific socio-economic models are project lead. This is because very often, the exact impact of any bioenergy development is directly dependent upon the specific location, technology, the feedstock and the availability of good and services in the area. Because of this, it is important to note the type and depth of data required for input into the model in order to build up a regional picture of the local economy. Very often the formulation of socio-economic impact studies are hindered by the absence of regional data and this should be borne in mind from the outset of model selection.

In contrast, others are based at a national level and whilst they are beneficial for policy analysis, it may be difficult to extract sufficient detail from them if looking at projects in isolation.

With this said, the investigation promotes a toolbox approach to model selection, whereby a range of appropriate models are identified and then they can be used in accordance with the aims of the users. To this end, the tables detailed in Appendix 2 and 3 offer some guidance on model selection. The first summarises the key elements of each model, whilst the latter denotes the expected output and to what extent it accords with the specified research objectives of the task. These two tables suggest that the optimum models for use by Task 29 members are:

- BIOSEM
- ELVIRE
- SAFIRE
- EXTERNE
- INSPIRE.

Accordingly, the most appropriate models may thereafter be used to provide research tools to identify the benefits and drawbacks of further bioenergy deployment.

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GLOSSARY OF TERMS

Classical Unemployment – Classical unemployment describes the unemployment created when the wage rate is deliberately maintained above the level at which labour demand and supply equilibrate (equal or clear). It can be caused either by trade union intervention, or enforcement of the minimum wage rate, both of which impose a wage above the equilibrating wage rate.

Constant Elasticity of Substitution – The constant rate at which one factor input is substituted for another with overall output remaining constant.

Direct Impact – Net direct effects accounting for the primary economic impact. They result from the direct expenditure on goods, services and labour in both the feedstock and conversion phase, net of any displacement activity. In terms of bioenergy production, the net direct effects consider the following:

- Net effects on incomes and employment; these may arise from:
    1. Bringing into productive use land which would otherwise be unused, such as set aside;
    2. The transfer of land from alternative agricultural uses, such as arable cropping or livestock grazing.
- Net effects on incomes and employment for those directly employed by the feedstock process and the conversion plant investment.

Displaced Impact – There are two elements to the displacement impacts:

1. Market displacement - In the context of bio-energy production, market displacement refers to the quantity of electricity and/or heat that is displaced by a new supply of energy;
2. Factor displacement - Factor displacement relates to the repercussions in the supply chain from an increased or reduced demand for input goods and services. For example the production of energy crops may displace other farming activities or land use. Similarly additional employment opportunities resulting from the construction of the plant may displace skilled labour elsewhere.

Econometric – The discipline within economics that attempts to measure and estimate statistically the relationship between two or more economic variables.

General Equilibrium Analysis (GEA) – The analysis of the inter-relationships that exist between sub-sectors of the economy. It assumes that events in one sector can have such a significant impact on other sectors that feed back effects in turn, are likely to affect the functioning of the first. Thus in GEA, an attempt is made to determine the nature and strength of inter-sectoral linkages using such tools as Input-Output analysis.

Hedonic Pricing – Hedonic pricing is typically used to value impacts to amenity, recreational sites, or aesthetics. Where a public good is effected and behaviour in a related market is observed, the change in value in the associated market is captured by hedonic pricing. The best example of this is if an increase in noise or visual intrusion affects property. Accordingly the intrusion will affect the value of the property and capturing this effect is called the hedonic pricing method.

Indirect Impact - Net indirect effects arise from the increased demand for goods and services which directly supply the bioenergy project, net of any displaced activity resulting from the reduced demand for other goods and services supplying the displaced activity.

The simple assumption is that any additional demand will create further activity in the supply chain of indirect goods and services. This re-iterative process is captured by the indirect multiplier. This is calculated accordingly:

Indirect multiplier $= 1/(1-x)$,

where x is the ratio of the amount of direct expenditure from the project within the region to the direct expenditure from the project.

Induced Effect – The induced impact results from the re-spending of money income and profits within the region. This effect is calculated via the a multiplier (commonly known as the consumption multiplier) which can be expressed as follows:

Induced multiplier = 1/(1-y)

where y is the proportion of additional incomes which are spent on goods and services produced within the region (after allowing for tax payments, savings and expenditure on goods produced elsewhere, rent payments etc.).

Leontief Production Function – The inversion of the factor co-efficients, which are derived from the construction of an economies' Input-Output table.

Macroeconomics – The branch of economics concerned with the study of aggregate economic behaviour. It investigates the economy as a whole and seeks to identify the determinants of national income, employment, output and prices.

Microeconomics – The branch of economics concerned with the study of consumers, individual firms and the determination of market prices and quantities transacted in terms of factor inputs and goods and services.

Monte Carlo Simulation – A technique for dealing with complex resource allocation problems which cannot be solved by mathematical analysis. The technique relies upon defining a typical life history of a system, the current problem and rules of operation. Repeated runs of the simulation are then carried out, but slightly altering the rules of operation each time. It enables experimentation within a system with the overall aim of improving performance and optimisation.

Multiplier – The multiplier denotes the situation whereby an initial increase, or decrease, in the rate of spending will bring about a more than proportionate increase or decrease in national income. It is a cumulative impact and best viewed in a series of successive rounds.

Welfare Economics – This branch of economics is concerned with the way economic activity ought to be arranged so as to maximise economic welfare. It employs value judgements about what ought to be produced, how production should be organised, the way income and wealth should be distributed, both now and in the future.

APPENDIX 1

The following table A.1 denotes those factors in which Task 29 Member countries have greatest interest. Their scoring is purely subjective, based on the comments from each of the experts within the respective countries participating in Task 29. They are ranked on a scale according to: 1 – high; 10 – low.

Table A.1. *Importance of key socio-economic variables in Task 29 research*

Socio-Economic Variables	Importance Factor
• Regional Employment Created	1.6
• Regional Activity Created	2.3
• Regional Economic Gain	2.6
• Increased Regional Incomes	3.1
• Regional Return on Investment	3.1
• Replication Potential	3.9
• Avoided Unemployment	2.0
• Support of Related Industries	4.3
• Education	4.6
• Health	5.9
• Poverty Alleviation	5.0
• Conventional Energy Displaced	3.3
• Stimulation of LFA	2.9
• Rural Diversification	4.4
• Rural Depopulation	3.9
• Land Management	4.9
• Quality of Life	0.0
• CO_2 Saved	3.0
• SO_2 Saved	5.4
• NO_x Saved	5.4
• Noise / Visual Impact	6.1
• Biodiversity	6.3
• Land Management	6.0

APPENDIX 2

Table A.2. *Model survey summary*

Model	Classification	Short Description	Input Parameters	Output	Application to Bioenergy (so far)	Application Level
1. ABM	• Computable general equilibrium model.	• Model to quantify the impacts of fostering bioenergy use on the labour market, balance of trade, public budget, sectoral/overall gross production, and CO_2 emissions.	• Labour, capital and energy.	• Change in employment, balance of trade, public budget, production levels, and CO_2 emissions.	• Electricity, heat and liquid fuels (30 different bio-mass systems).	• National level (34 sectors of the economy).
2. BEAM	• Cost and technical performance analysis of integrated bioenergy systems in Excel modules	• Can be used to model different bioenergy systems and calculate the technical and economic parameters for the system at a specific capacity based on cost performance characteristics associated with the system chosen.	• Choices of different bioenergy systems in terms of feedstock, products, and conversion routes. Users can input/change the default values of some parameters, like, exchange rate, project life, annual interest rate, inflation rate, maintenance cost, overhead cost, labour cost, etc.	• Technical and economic indices of different bioenergy systems. These include unit production cost and technical performance, NPV, Payback and other financial parameters	• Electricity generation, heat and liquid fuels.	• Provides a financial assess-ment of local bioenergy production projects.
3. BIOCOST	• Cost calculation model.	• Model to estimate bioenergy crop production costs (default values for the U.S.).	• Labour rates, fuel costs, machinery data, chemical and fertiliser inputs, fixed costs, expected yields, land rental rates, and the discount rate.	• Full economic costs of producing bioenergy crops.	• Crop production (mainly U.S. regions).	• Local, regional, or national level.
4. BIOSEM	• Combination of cash-flow analysis and Keynesian economic model in spreadsheet format.	• Quantitative model designed to capture the socio-economic effects of local bioenergy production; can be used to assess the merits of different policy packages on bioenergy production.	• Regional and bioenergy plant input data.	• Financial viability of crop production and bioenergy plants; final direct and indirect induced multipliers along with the income and employment gains, etc.	• Electricity and/or heat production.	• Regional and local bioenergy project evalua-tion.
5. ELVIRE	• Combination of traditional 'ex ante' project evaluation and regional externality analysis.	• Aims at evaluating the 'externalities' associated with renewable energy projects by weighing up the overall impacts of a project against its initial costs.	• Relevant financial data and microeconomic data concerning the energy balance and the project operation phase, and a range of social, environmental and industrial data that characterise the project and the area.	• Externality indices in terms of the contributions of the project to the regional development, environmental protection, and sustainable development etc.	• Electricity and / or heat production.	• Regional bioenergy model.

Models	Classification	Short Description	Input Parameters	Output	Application to Bioenergy (so far)	Locality
6. EXTERNE	• Externality evaluation approach – "Impact Pathway".	• Aims at evaluating the external costs of a wide range of different fuel cycles and providing policy makers with a synthesis of information on a broad variety of effects, to allow for better decision making.	• Model is very data intensive requiring information about the whole life cycle. This includes emission data, environmental data, ecological data, demographic data, and economic valuations.	• Environmental, economic and sustainability indices.	• Heat and electricity production.	• Used for national or project lead scenarios
7. INSPIRE	• Renewable energy resource mapping by GIS and economic analysis.	• Integrated methodology for the assessment of resource availability, financial viability and environmental factors for biomass-to-energy options at both regional and national levels	• Regional/local GIS data on available resource and economic profile coupled with project costings..	• Spatial mapping of the resource flows and the associated economic gains to the region. Determines the economic viability of the bioenergy project	• Heat and/or electricity production.	• Regional or national
8. RECAP	• Project based model to assess economic viability of biomass to energy projects.	• Aims to assess the commercial viability of biomass projects throughout the supply chain, differentiates between the supply and conversion processes.	• Project costings for biomass production and supply as well as the costings and revenue from the conversion plant.	• Standard financial indices such as NPV, the Internal Rate of Return (IRR) and the Payback period of the project.	• Electricity and/or heat production	• Regional, project lead
9. RETScreen	• Pre-feasibility analysis.	• The objective is to help renewable energy project proponent to reduce the cost, time, risks, and errors associated with preparing feasibility studies for the project.	• Users need to input / adjust parameters on the site conditions, biomass heating system, peak load heating system, and back-up heating system. Examples are: various capital and installation costs, operating costs, energy cost escalation rate, discount rate etc.	• Evaluation results of a potential biomass heating project, in terms of energy performance, cost, financial viability etc.	• Biomass heating.	• Local biomass heating project.
10. SAFIRE	• Engineering-economic bottom-up model.	• Database and computer model that provides decision makers with a tool to assess the market and impact of new energy technologies against a background of different economic instruments and policies.	• Data on resources available, installed capacity, non-renewable energy, plant, load duration curve, cost of RETs, demand activity, specific energy consumption, industrial sector use matrix, cost benefit analysis coefficients, etc. Besides, users are allowed to select or even change various scenario assumptions.	• Results on energy demands, technical potentials and market potentials for renewables, market penetration, cost benefit indicator, pollutant emission, and other externalities.	• Various types of analysis on renewable energy potentials and impacts, including co-generation.	• Choice between local, regional, and national level.

Models	Classification	Short Description	Input Parameters	Output	Application to Bioenergy (so far)	Locality
11. I/O MODELS	• General Equilibrium model.	• Standard accounting method to determine the economic impact arising from an increase/decrease of demand for goods and services	• Very data intensive and will require the manipulation of national I/O tables.	• Results identified in terms of the increase in output and employment. Also delivers standard multipliers and considers the displacement effects of the new activity	• Electricity and / or Heat production.	• I/O modelling is best suited to national analysis as they are difficult to construct at a local level.

APPENDIX 3

Table A.3. *Suitability of Models for Task 29*

Socio-Economic Variables	Importance Factor	ABM	BEAM	BIOCOST	BIOSEM	ELVIRE	EXTERNE	INSPIRE	RECAP	RETSCREEN	SAFIRE	I/O
Regional Employment created	1.6											
Regional Activity Created	2.3											
Regional Economic Gain	2.6											
Increased Regional Incomes	3.1											
Regional Return on Investment	3.1											
Replication potential	3.9											
Avoided Unemployment	2.0											
Support of Related Industries	4.3											
Education	4.6											
Health	5.9											
Poverty Alleviation	5.0											
Conventional Energy Displaced	3.3											
Stimulation of LFA	2.9											
Rural Diversification	4.4											
Rural Depopualtion	3.9											
Land Management	4.9											
Quality of Life	0.0											
CO_2 Saved	3.0											
SO_2 Saved	5.4											
NO_x Saved	5.4											
Noise / Visual Impact	6.1											
Biodiversity	6.3											
Land Management	6.0											