METHODOLOGIES FOR ENVIRONMENTAL, MICRO- AND MACRO-ECONOMIC EVALUATION OF BIOENERGY SYSTEMS[1]

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Paper presented at the European Conference on Biomass for Energy, Environment, Agriculture and Industry, 1996, Copenhagen.

ABSTRACT

An overview is given of methodologies used for evaluation of bioenergy systems on environmental, micro- and macro-economic aspects. To evaluate micro-economic impacts net present value and annualised cost calculation are used. For environmental impacts, methods used are: qualitative studies, energy analyses, life cycle assessments, LCA-related methods specially developed for bioenergy systems, and externality studies. Macro-economic impacts can be assessed by single direct indicators, efficiency prices, input-output analyses, social accounting matrices and general equilibrium models. Problems in the various methodologies are: assessment of costs for farm labour and land prices, environmental aspects on land-use, and weighing of different environmental impacts. Input-output analysis is a helpful tool, but also has several limitations. An important input parameter in all assessments is the energy crop yield. It can be based on testplots, crop production models and comparable crops in practice. Because statistical data lack, extrapolation to commercial farm practice remains a problem in all approaches.

INTRODUCTION

Biomass energy systems are different from conventional fossil fuel energy systems in many aspects. The main differences can be found with the production of energy crops and subsequent logistics. There are other kind of actors involved and one has to deal with environmental impacts that do not occur in fossil fuel systems, but that are closely related to common agriculture. This poses additional demands on the methodologies used to evaluate these systems. Different approaches have led to different results of evaluations of comparable systems.

The main objective of this paper is to evaluate methodologies that have been used to assess environmental, micro- and macro-economic impacts of bioenergy systems. The focus is on evaluation of the whole integrated chain of bioenergy systems with energy crops as a resource.

On the basis of this assessment, a general framework will be developed to assess bioenergy systems on their main impacts, potentials and bottlenecks. The methodologies are categorised on the basis of the type of impacts studied, being micro-economic, environmental and macro-

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[1]This study is part of the 4 year research *Assessment of biomass energy systems* within the framework of the Dutch National Research Programme on Climate Change. Topics studied in this project are: (i) the relationship between energy farming and biodiversity; (ii) yield potentials under various land-use options and (iii) biomass conversion to methanol and hydrogen; (iv) methodological framework to assess biomass energy systems.

economic. Different methodologies that have been used will be highlighted followed by short discussions of the main methodological problems that are left. The paper finalises with a separate discussion on one of the main input parameters, the yield of energy crops. More details can be found in the article on which this paper is based (Broek *et al.*, 1996b).

MICRO-ECONOMIC IMPACT EVALUATION

The main aim of a micro-economic impact evaluation is to calculate costs and benefits against normal market prices. This can be done on the basis of net present value calculations or on a annualised costs basis. To compare bioenergy systems with fossil fuel systems it is useful to present costs in comparable units (e.g. per kWh or GJ).
Some problems can arise in calculating costs for farmers. Generally, it is not exactly known what farmers see as the exact monetary value of their means of production. They appear to attach a higher value to the use of the production factors inside the farm instead of outside (Lysen *et al.*, 1992). One can differentiate between own-labour and external-labour. External labour can be treated as a straightforward cost item. For own-labour the marginal product of family labour may be included (Elhorst, 1990).
Land cost is sometimes assumed to be equal to land rent (Lysen *et al.*, 1992). Another (more representative) approach is to use the opportunity costs of the soil, reflected by forgone income of the replaced crop (Broek *et al.*, 1996a). This income should be based on the same costs items as used in the production costs of the energy crop[2]. In the case that a utility or any other investor decides to buy land for the purpose of energy crop growing, one could simply calculate annualised costs, based on the assumption that soil does not depreciate.
The correct value of the discount rate to be used depends on the alternative ways in which the money could be spend. In the case that investors have limited aims for their money (as could be the case with farmers and public utilities) the discount rate could be lower than market-opportunity costs of money. Rijk (1994) suggests that it may be suitable to use a lower discount rate for farmer investments in the Netherlands, because most farmers invest from their own savings. However, the minimum opportunity cost is the bank interest rate.

ENVIRONMENTAL IMPACT EVALUATION

Impacts to the environment include emissions to air, water and soil, but also impacts on biodiversity and landscape, physical impacts on the soil and use of resources.
Different types of methods
Many qualitative studies can be found on environmental aspects biomass energy systems (e.g. (Ravindranath *et al.*, 1995)). Bioenergy systems are often analysed here on potential effects. Qualitative (or indirect quantitative) comparisons are made with emissions of fossil fuel systems and emissions of agricultural systems.

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[2] An approach like this is followed by Biewinga (1996). Here labour is treated as external labour and land-cost as land rent. The total equation then becomes: $TC_b = BC_b + LC_b + OPC_b + (R_r - (BC_r + LC_r + OPC_r))$. With subscript “b” referring to biomass crop and ”r” to the replaced crop, TC: total costs for biomass crop off-field, BC: cost for building and land, LC: labour cost and OPC: production cost other than buildings, land and labour, R_r: revenue of the replaced crop. Cost for land and buildings are the same for both crops, thus: $TC_b = (OPC_b - OPC_r) + (LC_b - LC_r) + R_r$. Biewinga also includes an area grant for the energy crop in the cost price.

The most basic approach for a quantitative environmental impact analysis is a comparison between the energy input and output of the system (e.g. (Börjesson, 1996; Lysen *et al.*, 1992)). The evaluation criterion that is most often used is the net energy output per hectare. Energy output/input ratio's are also used. This, however, seems to be a less useful criterion, which is also very sensitive for manipulation[3].
The general methodology for life cycle assessment (LCA) has been described by Heijungs (Heijungs *et al.*, 1992). In LCA, potential environmental impacts are assessed of a complete life cycle of a product or service; a "cradle to grave" approach. The LCA methodology has been tested for energy technologies, which has led to specific methodological recommendations (Brummelen *et al.*, 1994). Methodological adaptations for agricultural products have also been made (Wegener Sleeswijk *et al.*, 1996). One case study concerned biomass energy (Sengers *et al.*, 1996). Some of the methodological additions are: (1) the soil should be considered as part of the environmental system and the harvestable product as part of the economic system; (2) nutrient balances are a suitable way to assess their soil emissions; (3) desiccation should be added as criterion; (4) for some emissions one should distinguish between problem and non-problem areas; (5) allocation has been elaborated for of crop rotation, co-production and recycling.
Methodologies have been developed in ongoing projects to evaluate environmental impacts specifically for biomass energy systems (Biewinga *et al.*, 1996; Projektgemeinschaft Bioenergietrager, 1994). These methods have a regional approach and are to some respect in between LCA which deals with potential effects and Environmental Impact Analysis, which deals with impact of a specific project on a specific location. The methodology for assessment of environmental impact of bioenergy crops by Biewinga has been applied to various potential energy crops in four different regions in Europe. Beside some other criteria, the effects of cultivation of energy crops has been assessed on the basis of the main emissions to air, soil and water. As functional unit both 1 GJ and 1 hectare has been used. The most suitable functional unit has been chosen per criterion. Indirect effects (being consequences for other crops in the rotation or consequences outside the farm) have been included. The *Projekt-gemeinschaft Bioenergietrager* used a comparable approach. The method is applied to different regions in Germany, which are categorised by soil types and annual rainfall. Beside this, the research is also directed to assess energy crops under different levels of intensity. For the biomass energy chain the production of fertilisers, seeds, cuttings, pesticides and herbicides are included. A set of emissions to air are compared over the whole life-cycle of biomass energy and fossil energy. For the cultivation of energy crops additional criteria are included.
A last type of studies that deal with environmental impacts are studies on external effects on energy systems, or biomass energy systems in particular. These studies try to monetarise environmental impacts of (bio-)energy production. Examples of these kind of studies are (Hohmeyer, 1988; ORNL *et al.*, 1992). Much work on methodology development is going on at the moment.

Two main problem areas are the aspect of land-use and the weighing of the resulting criteria.
<u>Land-use / reference system</u>. Generally, when studying the environmental impacts of bioenergy systems, one is not only interested in the absolute emissions that are caused by this system, but also by the comparison of these impacts with systems that fulfill the same functions. Therefore, bioenergy can be compared with conventional energy. Because land in

[3] Example: when one assumes that, in the production system of biodiesel, the transport media use biodiesel instead of normal diesel, this has no overall effect on the environment, because each litre of biodiesel that is used in the system can not be used elsewhere. However, it does influence the output/input energy ratio positively.

general is a scarce resource, bioenergy will generally replace another functional type of land-use and is therefore not just an additive effect. Different approaches are: (1A) no reference system for land-use is included (Sengers *et al.*, 1996); (1B) idem, but land-use is inc luded as an environmental impact (Wegener Sleeswijk *et al.*, 1996); (2A) because biomass energy replaces another type of land use, the difference is considered between the environmental aspects and thus include the replaced function as a reference system (Biewinga *et al.*, 1996); (2B) the replacement of a land-use option by bioenergy systems may cause an indirect effect elsewhere, which could also be included in the analysis. According to 2A, the *Projektgemeinschaft Bioenergietrager* (1994) used permanent set-aside as reference system for both annual and perennial energy crop and rotating set-aside for annual energy crops only. Approach 2B is discussed by them but not implemented. In option 1A and 1B one compares systems with different land-use and in options 2A systems with different output products. In approach 2B land-use and output products are also not necessarily the same.
Weighing of final scores. An important item is the way in which one (e)valuates the resulting outcomes on different environmental criteria. There is no objective way of dealing with it. One point of view could be that an evaluation of environmental aspects should only give qualitative statements on its various outcomes and pinpoint specific problems and possible solutions. The final judgement is left to the reader or the user of the report (e.g. policy makers). Some quantitative approaches are: (1) societal monetary valuation of environmental damage; (2) evaluation on the basis of prevention costs; (3) judgement of experts; (4) distance-to-target principle. In the last approach the seriousness of the effect is assessed on the basis of the present magnitude of the effect and the target level. Normalisation could take place by dividing each impact by the total impact that takes place in a certain region (Goedkoop, 1995). After a simple normalisation step, Biewinga (1996) weighed the normalised scores on the basis of three factors: the general relevance of the criterion, the contributions of energy crops to it and the reliability of the assessment. Weighing factors were determined by expert judgement.

MACRO-ECONOMIC IMPACT EVALUATION

Main indicators for macro-economic impacts of bioenergy systems are impacts on: (a) gross domestic product (GDP); (b) balance of payment; (c) government budget deficit; (d) employment. Other impacts that could be included are opportunities for the national industry to develop and sell hardware and knowledge in the future. We now discuss some different approaches to assess first four impacts: (1) Quantification of (direct) employment needed in the biomass energy supply chain. This can be compared by direct employment of the systems which it replaces (Biewinga *et al.*, 1996). Other basic indicators could be the direct effect on imports and exports. (2) Assessing direct macro-economic effects by using efficiency prices, which reflect the true scarcity of commodities and factors of production (Kuyvenhoven *et al.*, 1989). A weakness of this method is that generally financial assets in the hands of the government have a higher value than financial assets in the hand of private consumers, which is not reflected in this method (Burg, 1991). (3) Estimation of indirect effects by means of input-output (I/O) tables (e.g. (High, 1995)). These studies can basically also be undertaken on regional or local scale. Limitations are: (i) It is a static analysis of the past situation of the economy; (ii) I/O analysis is demand driven and assumes under-utilisation of the production sector capacities; (iii) prices are fixed; (iv) I/O analysis almost without exception leads to positive effects of the expenditure; it (often wrongly) presuppose a Keynesian investment policy (Burg, 1991); (v) no income distribution effects can be assessed. (4) Extended input-output analysis by using social accounting matrices (SAM's). SAM's can be considered as a complete representation of a closed economic cycle: all incomes can be found back as expenditures in the model. They do not have the last disadvantage of I/O models (Keuning *et al.,* 1985). (5) Calculating macro-economic effects by general equilibrium models. These more sophisticated macro-economic models, referred to as general equilibrium models, solve some of the limitations that have been mentioned above. To be consistent with the macro-economic policy of the government van den Burg (1991) states that macro-economic appraisal should be based econometric models that are also used for macroeconomic policy.

ASSESSMENT OF YIELDS OF ENERGY CROPS

Projections of commercial energy crop yields are surrounded with many uncertainties, mainly caused by the fact that at present there are only a few energy crop plantations in the world. Statistical databases on yields, which do exist for food crops, lack for energy crop yields. Three methods to assess yields are discussed.

Yields based on Field Experiments. Test plot yields have often been used in evaluation studies (Bulfin *et al.*, 1995; ESBC, 1995). Problems that occur with test plot yields are: (1) testplots may be designed for more purposes than yield levels; (2) management at field experiments is more intensive than in actual practice and knowledge is higher; (3) plots can be too small; (4) there can be indistinctness about the definition of “yield”; (5) soil quality is often relatively high (Biewinga *et al.,* 1996; Nonhebel, 1995). No attempts have been found in literature in which test plot yields are consistently corrected to assess commercial yields.

Yields based on Crop Productivity Model calculations. The big advantage of crop productivity models is that a more consistent base can be created for assessment of yields of different energy crops in different regions, even if there is no practical experience with certain crops in some regions. Two approaches are discussed. In the first approach the crop growing model concentrates on potential and water-limited production on the basis of solar radiation, temperature, the main crop parameters (light use efficiency, harvest index and growing season) and regional precipitation data (Nonhebel, 1995). The model has a daily time step. Resulting regional water limited yields are corrected by means of a regional yield factor (RYF). This factor is the ratio between model-calculated water-limited yield and (statistically determined) actual yields of well known food crops in the considered region. The RYF is thus determined by geographical parameters (e.g. soil type), the development of agriculture in a region and the crop on which the RYF is based. It is questionable whether the crop that is used to calculate the regional yield factor is representative for biomass energy crops, which are often perennial crops. In the second approach more detailed crop models are used, which include soil characteristics and management practices. In a study by Graham (1995) for switchgrass yields a model (EPIC) is used which can accept various soil horizons and includes management input data. Yields of switchgrass were corrected by comparing switchgrass testplot yields with commercial hay yields in the various regions.

Yields based on comparable commercial crops. Rijk (1994) estimated future willow yields on the basis of yields of commercial wicker plantations. A weak point is that the accuracy of the measurement is uncertain. To project eucalyptus yields in Africa, Marisson (1995) used a linear regression of the relationship between yields and local average annual precipitation, based on commercial eucalyptus plantations in Brazil. Weak spots of the method are: (1) there is quite some difference in solar radiation and growing seasons between different regions of Africa and Brazil; (2) no account is taken for the timing of the precipitation; (3) plantations in Africa are assumed to have the same level of management intensity as the Brazilian ones (no nutrient limitations). Ravindranath (1995) uses estimates of productivities in various farm forestry projects in India.

CONCLUSIONS

Many studies have been undertaken on various impacts of bioenergy. Micro-economic impacts are evaluated by means of net present value and annualised cost calculations. Assessment of costs for farm labour and land prices remain points of attention. To evaluated environmental impacts, methods used are qualitative studies, energy analyses, life cycle assessments, LCA-related methods specially developed for bioenergy systems, and externality studies. How to include land-use in relation to the reference systems and the weighing of different environmental impacts remain problem areas. Different methods used to assess macro-economic impacts are: single direct indicators, efficiency prices, input-output analyses, social accounting matrices and general equilibrium models. Data availability and suitable models are constraints to overcome to limitations of the simpler approaches. Energy crop yields can be based on testplots, crop production models and comparable crops in practice. The main problem with approaches which are based on test plots and comparable commercial crops is the representativeness of their yields for other management practices and other regions. Extrapolation from crop production models to actual practice is also still uncertain.

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