OPTIMIZING THE GREENHOUSE GAS BENEFITS OF BIOENERGY SYSTEMS

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The Authors of this paper are the Task Leader and the National Team Leaders (or associates) of IEA Bioenergy Task 38. IEA Bioenergy is a collaborative network under the auspices of the International Energy Agency (IEA) to improve international co-operation and information exchange between national bioenergy RD&D programmes. IEA Bioenergy Task 38 integrates and analyses information on GreenHouse Gases (GHG), bioenergy, and land use; thereby covering all components that constitute a biomass or bioenergy system [1].

ABSTRACT: Energy decisions consider multiple objectives such as job creation, energy security, environmental benefits, enhancing energy efficiency and reducing GHG emissions. When assessing the efficiency of energy systems or their GHG balance the approach often practiced is to use measures such as input-output ratios or emissions per unit of output. In case of bioenergy systems this can be misleading. The system boundary needs to be set wide enough to include emission reductions achieved by the energy and non-energy products of the bioenergy system. Several different situations are conceivable in terms of the factors that limit the amount of GHG mitigation that can be achieved, each requiring a different arithmetic for evaluating GHG efficiency. Four different cases of limiting factors are presented: 1. available biomass, 2. attainable bioenergy market share, 3. available land for biomass production, and 4. available funds for GHG mitigation. In all of these cases the GHG emission savings should be calculated by comparing to a reference energy system, which will in most cases be based on fossil fuels.

Keywords: bioenergy systems, greenhouse gas emissions, GHG mitigation, optimization

1 INTRODUCTION

This paper discusses ways of optimizing GHG benefits when energy strategies based on biomass are considered by policymakers at the macro-level. One important driver in energy choices by companies is usually the economics, which may or may not reflect GHG implications. Carbon taxes and cap-and-trade restrictions are examples of instruments that could reflect GHG implications. Microeconomic considerations are not considered in this paper.

Policy decisions on energy, whether at national, regional, municipal or other levels, will usually take into account a portfolio of issues, such as job creation, environmental benefits like biodiversity, GHG mitigation, soil erosion, local air pollution, dependence on imported energy sources, energy security, etc. In other words, energy decisions consider multiple objectives.

Policy decisions aimed at GHG mitigation will usually focus on emissions that occur within a certain jurisdiction, e.g., a country, as this is what will impact on a national GHG inventory and will be relevant for GHG emission limits such as in the Kyoto Protocol. If the full life-cycle impacts of energy choices are considered, some share of the life cycle emissions may occur in other countries. Further, emission *reductions* (compared to a business as usual baseline scenario) in other countries may be of relevance. For example, the project mechanisms of the Kyoto Protocol (Joint Implementation and Clean Development Mechanism) require consideration of the full fuel cycle emissions, as well as emission reductions.

The system boundary will not always include all relevant effects on the GHG balance even within the country where the biomass use occurs. Some impacts on the GHG balance that arise within the country where biomass use occurs may even be overlooked or impossible to consider in setting the system boundary. For example, bioenergy strategies may have impacts on carbon sequestration in forests or agricultural lands. However, if such sequestration effects are not required to document nor is there an incentive to enhance them (e.g. because they are not accounted for under the Kyoto Protocol or other policy framework in the country of interest), then they may not be taken into account.

This paper is intended to provide guidance on optimizing of the GHG benefits of bioenergy systems and to inform decisions by policymakers on R&D funding, subsidies or tax breaks, environmental regulations, investment decisions at government levels, and similar issues.

2 METHODS: GHG OPTIMIZATION WITHIN A DEFINED SYSTEM

When assessing the efficiency of energy systems in terms of GHG mitigation, many analysts to date have used measures such as

• input-output ratios or cumulative energy invested per energy delivered (Figure 1) (Note: Energy inputs only include the auxiliary energy from fossil fuels; energy outputs are used to replace fossil fuels. Thus, the input-output ratio is a measure of the *fossil fuel replacement efficiency*.)

• emissions per unit output – output being one kWh of electricity, heat, a combination thereof, or liquid fuel (Figure 2). While energy input-output ratios can be very useful for evaluating the efficiency of individual processes, this type of measure can be misleading in a broader energy systems context. For example, optimizing a bioenergy system for these measures may lead to an essentially zero-energy input or zero-emissions energy system by using its own product (useful energy) as an input, but then a lower amount of energy will be available to outside markets. This may lead to a smaller overall GHG benefit to the atmosphere (Figure 3) [1].

Figure 1: A biomass energy system with its energy inputs and outputs, GHG emissions, and a service unit (one kWh of power and/or heat, or fuel). The bold arrows show the energy flows that are used for calculating the input-output ratio of energy.

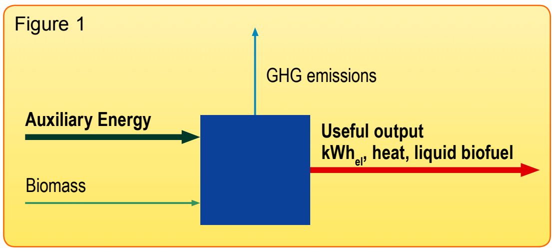


Figure 2: As Figure 1, but here the GHG emissions are calculated per unit of output.

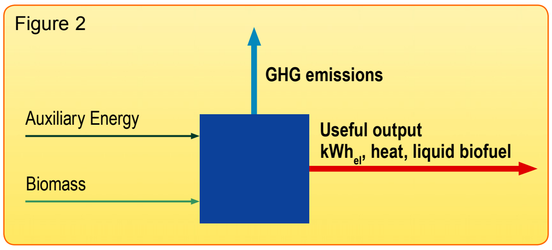
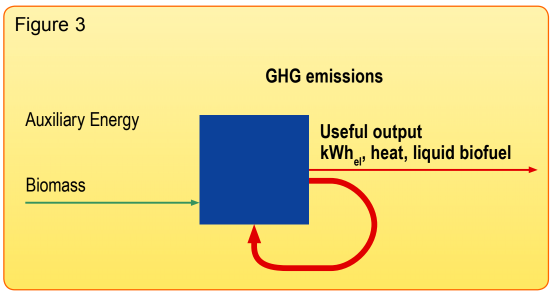
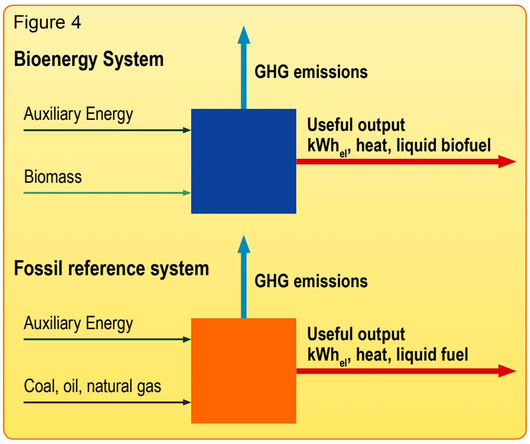


Figure 3: As Figure 2, but energy inputs and/or GHG emissions are minimized by using some of the energy output to operate the system.



Thus, the system boundary needs to be set wide enough to include emission reductions from using the products of the bioenergy system, including its non-energy by-products (Figure 4) [2]. A reference energy system can be defined specifically for a country or region. It could be based on coal, oil, natural gas, or other energy carriers. As each fuel differs significantly in GHG intensity, and also the conversion efficiency can vary, the reference energy system must be chosen carefully. And finally, there are different methodologies available to calculate the GHG intensity of a reference system. For example, in the case of electricity grids, one could use the average GHG intensity of the entire system, the GHG intensity of the *build margin* or of the *operating margin*.[1] For details of different possible "baseline methodologies" see the website of the Clean Development Mechanism [4].

Figure 4: As previous figures, but the GHG balance includes a comparison with a reference energy system.



The analysis also needs to consider the limiting resource that will define the extent to which land management and biomass fuels can mitigate net C emissions: Several different limitations are conceivable, each requiring a different measure of GHG efficiency (details are discussed in Table 1):

1. **Available biomass:** Considering use of a finite biomass resource, the GHG emission reduction per unit of biomass should be maximized. This is the case for forestry or agricultural residues, wood processing waste, etc.
2. **Market-share targets:** For reaching policy targets for bioenergy or biofuels in terms of market share, GHG savings per unit of output (electricity, heat, liquid fuel) should be used.

[1] The build margin represents the effect of a new plant on offsetting the need for other plants that would have been built. The build margin emissions rate is likely to differ from the average rate for two reasons. 1) Conversion technologies are improving, generating more electricity from less fuel, and 2) the average fuel mix may change, e.g. combined cycle natural gas plants may begin to replace coal plants. The operating margin represents the effect of a new plant on the operations of existing power plants. Operating marginal emissions rates are likely to differ from the average because baseload plants are designed to operate at high capacity factors and provide power day and night, whereas load following plants provide additional power as needed throughout the day. Emissions rates of the generators serving the two load types may differ substantially [3].

Table 1: Maximizing GHG emission reductions when biomass, demand for bioenergy, available land, or available funds for GHG mitigation are the limiting factor.

Case	Limitation	Relevant measure	Consequence
1	Available biomass (e.g. wastes)	GHG savings per tonne feedstock	▪ Favours most efficient use of biomass, even if at greater cost ▪ Allows external fossil inputs if they enhance biomass use efficiency ▪ Can compare between different outputs (electricity, heat, fuel) ▪ Ignores the variations in amount of biomass recovered when using different recovering systems (e.g., recovery of logging residues)
2	Demand for bio-energy (e.g. from policy targets for bio-energy or biofuels in terms of market share	GHG savings per unit output (electricity, heat, road-fuel)	▪ Favours biomass conversion processes with low GHG emissions, even if inefficient or costly ▪ Ignores the amount of biomass, land or money required ▪ Easy to distort ▪ Cannot compare between different outputs
3	Available land for biomass production	GHG savings by biomass production per ha of available land	▪ Biomass yield and conversion efficiency are paramount ▪ Greater GHG emissions from production (e.g., fertilizers) may be acceptable if that increases the biomass yield ▪ Costs not considered ▪ Can compare between different outputs (electricity, heat, fuel)
4	Available funds for GHG mitigation	GHG savings per €	▪ Will favour “close to economic” biomass options over more efficient but more expensive ones ▪ Can compare between different outputs (electricity, heat, fuel)

3. **Available land for biomass production:** This measure should be used where agricultural or forestry energy crops are used, but land is limited. In this case the GHG emission reduction per ton of biomass (as recommended in (1) above) may be misleading. For example, a system with low yields, yet zero energy inputs, may look very attractive in terms of GHG emission reductions per unit of biomass or contained energy, but overall, per ha of land, the benefits may be limited. Thus the GHG benefits per unit of land will be a superior indicator from a land-use efficiency perspective. An example is that biodiesel from rapeseed may yield less GHG mitigation per ha of land than liquid biofuels produced from lignocellulosic materials with higher per-ha yields, despite the possibly greater emission reduction per unit of biomass for biodiesel than for lignocellulosics.

4. **Available monetary resources for GHG mitigation:** The GHG savings per € invested in GHG mitigation may be the measure of choice, as funding is always limited. In assessing this measure, external costs and benefits should be taken into account. This measure is relevant for assessment of programs for emission reductions that use tax breaks or subsidies; national emission-credit purchase programs; Joint Implementation / Clean Development Projects; and emissions trading in general. In other words, it can be used by project developers as well as by policymakers.

In all these cases the *GHG savings* per unit of the *relevant measure* should be calculated by comparing with the emissions of a reference energy system. The choice of the *relevant measure* will not always be clear-cut, and more than one of the four listed optimization objectives may apply.

Other issues that will influence the outcome of the analysis, but are not discussed here in detail:

- Alternative uses for the biomass: does one save more GHG (according to one or more of the relevant measures listed) using the biomass for heat, electricity, biofuel, or as a raw material for products? For example, the introduction of subsidies for the energy use of wood chips can remove supplies from board manufacture, which may save more GHG gas, and may provide more local employment.
- The speed of the change: it may be counter-productive to introduce fiscal or other measures which result in sudden changes, affecting biomass demand before producers have time to react. In the previous example the negative effects may be avoidable by *gradually* introducing the incentives for using wood-chips, so that the supply can expand fast enough to keep up with the increasing demand.
- The relevant measure can change with time, complicating the task of optimizing GHG benefits. For example, GHG savings in the early stages of a bioenergy programme are likely to be limited by the funds available, but later the amount of land may become limiting.
- “Leakage” effects: using more biomass in one place may have effects on biomass use in other places due to market price effects. For example, even if only domestically-grown oilseeds are used to make biodiesel, the tighter domestic market for vegetable

oils then pulls in imports. Even if there is a sustainability-certification-scheme for all imported oilseeds, the effect on the world market may be to encourage production also by non-sustainable producers.

3 CONCLUSIONS

When assessing the effectiveness of policy decisions on biomass energy in terms of their energy and GHG balance, it is important to carefully set the system boundary so that all GHG consequences of such decisions are included. Enhancing benefits in one part of the system can reduce benefits in another, and such trade-offs can only be adequately included if the system boundary is set wide enough.

The appropriate choice of the *relevant measure* in the optimization and comparison is critical. GHG benefits can be optimized with respect to (at least) the following limiting factors:

- per ton of biomass feedstock,
- per unit of bioenergy output that can be absorbed by a specific market / sector,
- per hectare of land, or
- per unit of monetary resources spent for GHG emission reduction.

The appropriate choice is highly dependent on the specific situation. And whatever the relevant measure, GHG objectives are only one aspect that policymakers must consider when comparing energy choices or selecting among them.

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