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# Assessing the welfare effects of promoting biomass growth and the use of bioenergy - a simple back-of-an-envelope calculation[1]

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**Abstract**

Using a growth model that accounts for environmental and climate externalities, we take a closer look at the welfare effects of promoting biomass growth and the use of bioenergy. As an illustration, a forest hypothetical intensive forest cultivation project is simulated. Costs and benefits of the project show that we need not only determine the postive effects of promoting biomass growth and the use of bioenergy, such as substitution away from fossil fuels and carbon sequestration. But more importantly, to achieve a balanced measure of the effects on the climate, we must also incorporate all carbon emissions that is associated with bioenergy. Not doing so will over-estimate the positive climate effects of increasing the use of bioenergy.

# 1 Introduction

The Europe 2020 strategy is a strategy for a sustainable future in Europe. It puts forward a vision for the 21st century regarding the social market economy. Three priorities are made: smart growth, sustainable growth, and inclusive growth. In particular addressing sustainable growth a central target is the "Triple 20 by 2020" target, i.e., the reduction of greenhouse gas emissions by at least 20 percent compared to levels in 1990, a share of renewable energy consumption amounting to at least 20 percent of total energy consumption, and making the energy consumption 20 percent more efficient (European Commission, 2010).

To successfully meet the targets set for 2020 it is important to carefully consider various policy measures. One type of relevant measures to analyze in this context relates to forestry. Focusing on the forest sector as a supply of raw materials, bioenergy, carbon sequestration, and other environmental attributes the overall aim of this paper is to present policy guidance on a general level.

The purpose of the paper is more specifically twofold. First, based on the model framework in Lundgren et al. (2008), we derive a cost-benefit rule that properly accounts for relevant impacts from forest policy, including both carbon emissions and other environmental impacts. Second, in perspective of the relatively short term targets of the European 2020 strategy, we treat bioenergy as not being carbon neutral. Not being immediately captured by regrowth, carbon emissions from, e.g., combustion of biomass, has impact on the climate.

Indeed, recent studies have claimed that there are inadequacies when it comes to appropriately accounting for carbon emissions and other environmental consequences that stem from increasing the use of bioenergy. For instance, Searchinger et al. (2009) points at a "climate accounting error" that originates from treating bioenergy as being carbon neutral. Cherubini et al. (2011) assert that assuming biomass combustion as climate neutral underestimates the climate impact of bioenergy. Here we contribute to the literature by addressing this issue within the framework of welfare economics.

To fulfill our purpose we illustrate the links between the use of bioenergy, the environment, and the climate by performing a back-of-an-envelope cost-benefit analysis of a hypothetical forest intensive cultivation project.[1] The project's objectives are: 1) to increase overall growth and carbon sequestration in the forest, 2) to increase bioenergy use, and 3) to substitute fossil

[1] The design of this hypothetical project is based on a governmental proposition provided in the Swedish Government Bill 2007/08:108. Larsson et al. (2009) is an attempt to assess the effects of such a project.

energy with bioenergy. We assess the societal costs and benefits of the project and especially take a closer look at the climate effects and its dependency on assumptions about emissions from bioenergy. Not the least the assumption of carbon neutrality is interesting to scrutinize. For instance, in Sweden, a country with the political ambition to set a good environmental example for other countries to follow, renewable resources as, e.g., different types of biomass for heating, are in practice often tax-exempted both concerning carbon and energy contents.

Results show that we need to assess the positive outcomes of promoting biomass growth and the use of bioenergy, such as substitution away from fossil fuels and carbon sequestration. But more importantly, to achieve a balanced measure of the effects on the climate, we must also incorporate all carbon emissions that are associated with bioenergy (incineration and combustion). Not doing so will over-estimate the positive welfare effects of increasing carbon sequestration and the use of bioenergy. Referring to the 2020 policy ambitions in EU, and the targets to achieve, this is most crucial. Only accounting the benefits from bioenergy use, and omitting the costs by assuming carbon neutrality, as often is made in, e.g., Sweden, may lead to unfortunate policy measures being taken.

The paper is outlined as follows. Next, drawing mainly from Lundgren et al. (2008), we describe the model and its assumptions. Then we present the hypothetical forest intensive cultivation project and perform a back-of-an-envelope cost-benefit analysis to assess the welfare effects of the project. We end with a concluding comment.

# 2 The model

From a (selected) review in Lundgren et al. (2008) it is concluded that most analyses of promoting bioenergy rely on models that do not consider all relevant aspects. Thus, these models can be viewed as "partial models" since they do not account for the complete economic and ecological system, which may lead to faulty conclusions concerning policy issues. Most of them do not explicitly consider environmental or/and climate externalities, so they may not be suitable for welfare analysis. These effects are certainly relevant when, e.g., considering the costs and benefits of bioenergy as an alternative to fossil fuels. If we want to take such an externality into account an approach that includes valid descriptions not only of the economy, but also of the underlying environment and climate, is required. Here we propose such a model.

First, some fundamental assumptions and simplifications of the model.

The model can be considered "closed", i.e., there is no trade. Further, no technological progress is explicitly modeled, and there is no accumulation of knowledge. These assumptions may be restrictive, but we believe that the gain in simplification and transparency of the model outweighs the cost of introducing the complexities associated with including these features at this point. Admittedly, economic production of bioenergy, and the phasing out of fossil fuels, very likely rely on both technical progress and accumulation of knowledge (e.g., from R&D), and future extensions could include these features. The present model focuses on including the relevant components in terms of sectors affected by biomass growth, bioenergy production, and the related economic and ecological interactions.

We start by outlining the basic building blocks of the model; the utility function, production functions, and man-made capital and natural stocks, including the environment. We assume that a social planner will maximize the current and future discounted utility of the economy.

The representative consumer in the economy receives utility from consumption and environmental factors. How the consumers value these utility inputs depends ultimately on their preferences as represented by a utility function. Specifically, it is assumed that preferences and the utility function can be expressed as

$$U(C, E, G), \tag{1}$$

where $C$ is consumption of goods and services, $E$ is an environmental stock that are not directly related to carbon emissions, and $G$ is concentration of carbon in the atmosphere.[2] $U$ is increasing and concave in $C$, and decreasing and concave in $E$ and $G$; meaning that increases in $C$ imply higher wellbeing at a decreasing rate, and increases in $E$ and $G$ signify disutility at an increasing rate. The environmental factors affecting utility can be summarized in the two stocks $E$ and $G$, defined as environmental status (not carbon related), and the concentration of carbon in the atmosphere, respectively. $E$ is a composite of all environmental changes that is not related to carbon, e.g., loss of biodiversity and recreational values due to increased use of fast growing tree species for bioenergy.

The economy is divided into two sub-sectors and one main "aggregate" sector. The sub-sectors are defined as two extractive sectors, and the "aggregate" sector is defined as the rest (consumption and investment goods). Specifically, these sectors and the associated stocks are defined as, 1) fossil fuels, $F$ - stock of fossil resources; 2) forest products, $R$ - stock of forest

[2] It may seem more natural to have temperature as argument, but here we assume that there is a direct monotonic realtionship between temperature and concentration.

biomass; and 3) consumption and investment, $K$ - man-made capital. The stocks $F$ and $R$ are both measured in carbon units.

The total biomass stock depend on both the growth and harvest of the forest. Hence, changes in the total stock of biomass, either positive or negative, also affect the carbon storage ability and, consequently, the carbon concentration in the atmosphere. The fossil resource is non-renewable and will be steadily depleted over time if consumed. The fossil and forest resource extraction technologies are written

$$g^F(L^F), \text{ and } g^R(L^R),$$

where $L^F$ and $L^R$ are labor used in forestry and fossil fuel extraction, respectively.[3] We assume that the extractive production functions are increasing and concave in labor. The dynamics of the fossil and biomass resources are then given by

$$\dot{F} = -g^F(L^F), \tag{2}$$

and

$$\dot{R} = Z(R) - g^R(L^R), \tag{3}$$

where $Z(R)$ is a standard inverted $U$-shaped biomass growth function with $Z_R > 0$ and $Z_{RR} < 0$.

The environmental state or condition that is not carbon related is simply assumed to be governed by the activities in the extractive sectors of the economy,[4]

$$\dot{E} = h\left[g^F(L^F), g^R(L^R)\right] = a\left[g^F(L^F) + g^R(L^R)\right] - b\ln E, \tag{4}$$

where $a$ is a common impact parameter for the two types of resource extraction, and $b\ln E$ is the rate at which the environment recovers (with diminishing returns). This relation summarizes all environmental effects that are not connected to changes in carbon concentrations in the atmosphere.

The change in the concentration of carbon in the atmosphere is described by the dynamics of the fossil resource, the biomass growth, the bioenergy use rate, and how much carbon is emitted from the change in stock of refined solid wood products,

$$\dot{G} = -\left[\dot{F} + Z(R) - \alpha g^R(L^R) - \gamma\dot{S} + \theta\ln G\right], \tag{5}$$

[3] For simplicity, we ignore capital and the level of the resource stocks as arguments in these technology specifications.

[4] Of course, we could include final consumption $C$ here also, but leave it out to focus on natural resource use.

where

$$\dot{S} = (1-\alpha)\, g^R(L^R) - \delta S,$$

so that,

$$\dot{G} = -\left\{ \dot{F} + Z(R) - \alpha g^R(L^R) - \gamma \left[ (1-\alpha)\, g^R(L^R) - \delta S \right] + \beta \ln G \right\}.$$

The parameter $(1-\alpha)$ is the proportion of the harvested biomass that still binds carbon to some extent (houses, boats, sun-decks, etc.), and $\alpha$ is the proportion of the harvest devoted directly to bioenergy, i.e., carbon immideately released into the atmosphere. $S$ is the stock of refined solid wood products (some sort of solid state product from harvested biomass) that emit carbon at some rate, $\gamma$, and $\delta$ is the decay rate of this stock.[5] The last term, $\beta \ln G$, represents the ability of the atmosphere to recover back to a "normal" level of carbon over time. This recovery rate is diminishing in the level of carbon in the atmosphere. That is, the ability to recover decrease with higher levels of carbon concentration.

Finally, consumption and investment goods are produced according to

$$C + \dot{K} = f\left[K, L - L^F - L^R, g^F(L^F), g^R(L^R)\right] \tag{6}$$

where $\dot{K}$ is net investment in man-made capital and $L$ is the fixed total amount of labor (population). This is a constant returns to scale aggregate production function of the economy, which also gives the $K$-capital dynamics.

The total change in the concentration of carbon in the atmosphere is summarized in (5). If all stocks are are in steady state, $\dot{F} = \dot{R} = \dot{E} = \dot{G} = \dot{S} = \dot{K} = 0$, then we can write the long run level of carbon concentration in the atmosphere as (recognizing that $g^R = Z$ in steady state),

$$G^{ss} = \exp\left[ -Z^{ss}(R) \left( \frac{1-\alpha}{\beta} \right) \right]. \tag{7}$$

It is easy to see that in steady state the stock of carbon, $G^{ss}$, is decreasing with the steady state growth of biomass, $Z^{ss}(R)$, and increasing with bioenergy use, $\alpha$.[6] That is, if we increase the use of bioenergy, then the long run level of carbon in the atmosphere will increase. This means that if we want

[5] Both $\gamma$ and $\delta$ can be viewed as vectors of many different dissipation and depreciation rates, depending on what specific solid product is considered. For example, toilet paper has a much higher dissipation and depreciation rate than lumber for construction.

[6] If we permit the non-renewable resource to be out of steady state (i.e. harvested), then $G^{ss}$ would be, not surprisingly, increasing in $g^F$, the harvest rate.

to decrease the level of carbon in the atmosphere, then we should promote growth and be careful in using too much bioenergy, since that will counteract the positive growth effect. In next section we take a closer look at this issue.

A social planner sets out to maximize the infinite stream of discounted utility given by (1) subject to (6), (2), (3), (4), and (5) given initial values for all stocks. The social discount rate that is used to discount future values into current value is denoted $r$. The formal problem is written

$$\begin{aligned}
V &= \max_{\{C,L^F,L^R\}} \int_0^\infty e^{-rt}U(C,E,G)dt, \\
& \quad s.t. \\
\dot{K} &= f\left[K,\left(L-L^F-L^R\right),g^F(L^F),g^R(L^R)\right]-C,\ K(0)=K_0, \\
\dot{F} &= -g^F(L^F),\ F(0)=F_0, \\
\dot{R} &= Z(R)-g^R(L^R),\ R(0)=R_0, \\
\dot{E} &= h\left[g^F(L^F),g^R(L^R)\right]=a\left[g^F(L^F)+g^R(L^R)\right]-b\ln E,\ E(0)=E_0, \\
\dot{G} &= -\left[\dot{F}+Z(R)-\alpha g^R(L^R)-\gamma\dot{S}+\beta\ln G\right],\ G(0)=G_0, \qquad (8) \\
\dot{S} &= (1-\alpha)\,g^R(L^R)-\delta S,\ S(0)=S_0,
\end{aligned}$$

where the optimal social value function is given by $V$. The present value Hamiltonian is then

$$\begin{aligned}
H &= e^{-rt}U(C,E,G) \\
&\quad +e^{-rt}\lambda\left\{f\left[K,\left(L-L^F-L^R\right),g^F(L^F),g^R(L^R)\right]-C\right\} \\
&\quad +e^{-rt}\lambda^F\left[-g^F(L^F)\right]e^{-rt} \\
&\quad +e^{-rt}\lambda^R\left[Z(R)-g^R(L^R)\right] \\
&\quad +e^{-rt}\lambda^E\left\{a\left[g^F(L^F)+g^R(L^R)\right]-b\ln E\right\} \qquad (9) \\
&\quad +e^{-rt}\lambda^G\left\{g^F(L^F)-Z(R)+\alpha g^R(L^R)+\gamma\left[(1-\alpha)\,g^R(L^R)-\delta S\right]-\beta\ln G\right\}
\end{aligned}$$

where $\lambda$, $\lambda^F$, $\lambda^R$, $\lambda^E$, $\lambda^G$, and $\lambda^S$ are the current value shadow prices associated with the different stocks. First order conditions for an optimal solution are

$$
\begin{aligned}
H_C &= H_{L^F} = H_{L^R} = 0, \\
\dot{\lambda} - r\lambda &= -H_K, \\
\dot{\lambda}^F - r\lambda^F &= -H_F, \\
\dot{\lambda}^R - r\lambda^R &= -H_R, \\
\dot{\lambda}^E - r\lambda^E &= -H_E, \\
\dot{\lambda}^G - r\lambda^G &= -H_G, \\
\dot{\lambda}^S - r\lambda^S &= -H_S,
\end{aligned} \tag{10}
$$

together with the usual transversality conditions associated with infinite horizon problems. It is assumed that this is a well-behaved optimization problem which generates value maximizing solutions for the time paths of all stocks and and controls in (8); $K^*$, $F^*$, $R^*$, $E^*$, $G^*$, $S^*$, and $C^*$, $L^{*R}$, $L^{*F}$ (asterix indicating optimal path).

# 3 The project and cost-benefit analysis

This section aims to investigate the effects on $V(\theta)$, the optimal social value function, of a project $\theta$ that increases biomass growth and harvest, promote the use of bioenergy, and also induce substitution away from fossil fuels. The main purpose of the project is to increase the growth of the forest by intensive cultivation practices, such as fertilizing, or/and expanding the legal defininition for forest land and potential forestry operations. We do not specify here exactly how the outcome of the project is achieved (exactly what policies are used etc), but merely introduce it into the model as a policy parameter, thereby implicitly assuming that the social planner designs the appropriate policy needed.

How the project enters the functions and parameters of the model can be summarized as follows (subscript denote derivative),

$$
\begin{aligned}
Z(R;\theta),\ Z_\theta &> 0,\ \text{(biomass growth effect)} \\
g^R(L^R;\theta),\ g^R_\theta &> 0,\ \text{(biomass harvest effect)} \\
\alpha(\theta),\ \alpha_\theta &> 0,\ \text{and if } \alpha = 0 \text{ then } \alpha_\theta = 0,\ \text{(bioenergy use effect)} \\
g^F(L^F;\theta),\ g^F_\theta &< 0,\ \text{(fossil substitution effect).}
\end{aligned}
$$

This simply means that the project $\theta$ will increase or promote biomass growth and harvest, while at the same time also promote bioenergy use and induce substitution away from fossil fuels. In addition, there is a policy cost to the project represented by $I(\theta)$, with $I(0) = 0$, $I_\theta > 0$, and $I_{\theta\theta} > 0$. The project cost enters the optimization problem in the consumption and capital accumulation equation so that

$$C + \dot{K} = f\left[K, L - L^F - L^R, g^F(L^F), g^R(L^R)\right] - I(\theta). \tag{11}$$

That is, consumption and net investments are decreasing with the size of the project.

Consider the envelope properties of optimal social value function, $V(\theta)$. The dynamic envelope theorem postulates that the first partials of $V(\theta)$ are found by $(i)$ differentiating the Hamiltonian for the optimal control problem directly with respect to the parameter/project of interest, $(ii)$ holding the state, costate, and control fixed, then $(iii)$ evaluate the partials along the optimal paths for these variables, and $(iv)$ finally integrate the result over the planning horizon. This implies we can differentiate the Hamiltonian directly with respect to the project prior to substituting in the optimal trajectories. The derivation of this convenient result in Caputo (1990) is rather lengthly and involved (however, a simple example at the end of the article makes it highly operational). An alternative and neater derivation of the same result can be found in e.g. Aronsson et al. (2004) (see also references therein). Their trick is to introduce an artificial state variable in terms of the parameter of interest (in their case it represents a policy project). Assume we want to examine the project $\theta$. Then the co-state dynamics is represented by $\dot{\theta} = 0$, $\theta(0) = \theta$. The co-state variable or shadow price of $\theta$ is $\lambda^\theta = V_\theta$. It is now easy to show from the co-state optimal condition that $\lambda^\theta = V_\theta = \int_0^\infty H_\theta dt$. The result is derived by integrating the dynamic first-order condition, $\dot{\lambda}^\theta = -H_\theta$, for the "petrified" state variable, $\theta$, over $(0, \infty)$, and then setting $\lambda^\theta(\infty) = 0$ (the transversality condition).

Using the results derived in Caputo (1990) and Aronsson et al. (2004) and differentiating the Hamiltonian along the optimal path with respect to the project $\theta$ gives,

$$H_\theta \mid_{optimal\ path} = e^{-rt} H_\theta^* \left(t; \theta\right),$$

so that the dynamic envelope theorem yields,

$$V_\theta(\theta) = \int_0^\infty e^{-rt} H_\theta^* \left(t; \theta\right) dt. \tag{12}$$

This summarizes the welfare impact of the project $\theta$ and gives us the cost-benefit rule (optimal path arguments $(t; \theta)$ are supressed from hereon).

Differentiating the Hamiltonian (or optimized value function) specified in our model generates a number of welfare effects and we now turn to examining them in more detail. The effects are divided into several sub-effects and below we go through them separately, focusing on the climate effects or carbon balance.

First of all, there is a cost to venture into the project $\theta$ as described in (11). This cost $(PC)$ is represented by

$$PC = -\int_0^\infty e^{-rt}\lambda^* I_\theta dt,$$

which is simply the present value of all marginal costs induced by the policy valued at the price of consumption and capital goods along the optimal path.

The market effects $(ME)$ are defined as the part of the derivative of the optimized Hamiltonian that is associated with the production of consumption and investment goods,

$$ME = \int_0^\infty e^{-rt}\lambda^* \left(f_{g^F} g_\theta^{*F} + f_{g^R} g_\theta^{*R}\right) dt. \tag{13}$$

Assuming marginal product pricing and that by assumption $\int f_{g^F} g_\theta^{*F} < 0$, this implies that the net effect is positive, $ME > 0$, if $\int_0^\infty f_{g^R} g_\theta^{*R} > -\int_0^\infty f_{g^F} g_\theta^{*F}$. That is, the value of increased production of forest products - bioenergy and different types of wood products - exceeds the value of decreased fossil fuel production due to substitution.

The value of the natural resource stocks $(SE)$ in the economy are affected in the following manner by the project;

$$SE = \int_0^\infty e^{-rt}\left[-\lambda^{*F} g_\theta^{*F} + \lambda^{*R}(Z_\theta^* - g_\theta^{*R})\right] dt. \tag{14}$$

This is the change in the *in situ* value of the two resources fossil fuels and wood biomass as a result of the project $\theta$. Since the *in situ* prices of the fossil and biomass resource, $\lambda^{*F}$ and $\lambda^{*R}$, are both positive, $SE$ is positive only if $\int_0^\infty \left(\lambda^{*R} Z_\theta^* - \lambda^{*F} g_\theta^{*F}\right) > \int_0^\infty \lambda^{*R} g_\theta^{*R}$; i.e., the value of increased growth less the decrease in extraction of the fossil resource has to outweigh the value of increased extraction of biomass.

Environmental effects $(EE)$ are impacts on air, ground, and water quality of the proposed project. Biodiversity changes are another possible environmental effect. These effects are summarized by the stock of environmental degradation;

$$EE = \int_0^\infty e^{-rt}\lambda^{*E}\left(h_{g^F} g_\theta^{*F} + h_{g^R} g_\theta^{*R}\right) dt = \int_0^\infty e^{-rt}\lambda^{*E} a\left(g_\theta^{*F} + g_\theta^{*R}\right) dt. \tag{15}$$

The environmental effects (not associated with carbon) of the project $\theta$ are favorable if $-\int_0^\infty g_\theta^{*F} > \int_0^\infty g_\theta^{*R}$.

Climate effects ($CE$) are summarized by the impact the project has on changes in the amount of carbon in the atmosphere. That means we are interested in looking closer at the partial derivatives of the Hamiltonian represented by $\lambda^{*G}\dot{G}_\theta$, in particular (after some rearranging),

$$CE = \int_0^\infty e^{-rt}\lambda^{*G}\left[g_\theta^{*F} - Z_\theta^* + (1-\gamma)\left(\alpha_\theta g^{*R} + \alpha g_\theta^{*R}\right) + \gamma g_\theta^{*R}\right] dt. \quad (16)$$

Climate effects depend on the change in resource dynamics, $\dot{F}$ and $\dot{R}$, the level and increase in harvest, $g^{*R}$ and $g_\theta^{*R}$, the level and increase in bioenergy use, $\alpha$ and $\alpha_\theta$,[7] and the amount of carbon dissipation from solid wood products, $\gamma$. $CE$ are increasing (carbon concentration goes down) if the integral defined in (16) is positive. That means the substitution and growth effect (the climate benefits),

$$\int_0^\infty \left(g_\theta^{*F} - Z_\theta^*\right) dt,$$

have to outweigh the effects of increased harvest of biomass and use of bioenergy (the climate costs),

$$\int_0^\infty \left[(1-\gamma)\left(\alpha_\theta g^{*R} + \alpha g_\theta^{*R}\right) + \gamma g_\theta^{*R}\right] dt.$$

Now let us take a closer look at what carbon neutrality implies. If we only consider the climate benefit side of the project, the positive effects are over-estimated. For example, in a model (mind) setting where bioenergy is carbon neutral, the growth effect would always neutralize the bad climate effects through emissions from increased bioenergy use. That is, setting

$$\int_0^\infty \left(-Z_\theta^*\right) dt + \int_0^\infty \left(\alpha_\theta g^{*R} + \alpha g_\theta^{*R}\right) dt = 0,$$

then the climate benefits and costs of the project reduces to the substitution effect and increased/decreased dissipation from solid wood products only,

$$\int_0^\infty g_\theta^{*F} dt + \int_0^\infty \gamma\left[g_\theta^{*R}(1-\alpha) - \alpha_\theta g^R\right] dt.$$

[7] To account for increased emissions from land conversions as a result of increasing bioenergy use, we could introduce "land conversion" emissions modeleled as increasing with the parameter $\alpha$.

If carbon emissions from the increased use of bioenergy surpass the increase in carbon sequestration in growing biomass, then we will overestimate the positive effects, and vice versa. However, if we correctly take the bad climate effects into account, as in (16), then for slow growing biomass, e.g. Swedish forests (50-100 years rotation), the short run "excess" carbon emissions from increasing the use of bioenergy are likely to be significant.

In general, for the project $\theta$ to be welfare increasing, the sum of the above described effects have to be positive. This implies that if the costs and benefits associated with $\theta$ are such that,

$$V_\theta = PC + ME + SE + EE + CE > 0,$$

then the project is socially desirable. This is the first-best, central planner cost-benefit rule. In a second-best, decentralized economy with externalities and imperfections, the cost-benefit rule would be essentially the same but more complex. The basic point conveyed in this paper would, however, maintain in a second-best setting. See e.g. Aronsson et al. (2004) ch 2, 5 and 6 for examples where a central planner's cost-benefit rules are compared to the decentralized case when externalities are present.

# 4 Conclusion

Addressing the Europe 2020 strategy (European Commission, 2010), in particular the "Triple 20 by 2020" target, the overall purpose of this paper has been to provide some general policy guidance concerning forestry related energy and climate policy. From a welfare and sustainability perspective it is in this context important to regard the forest not only as a supply of raw materials, but also as a supply of bioenergy, carbon sequestration, and other environmental and ecological attributes. When evaluating forest policy, which has positive as well as negative effects on these societal interests, it is crucial to consider both benefits and costs.

The purpose of this paper has specifically been twofold. First, by simple back-of-an-envelope calculation, a cost-benefit rule that properly accounts for relevant impacts from forest policy was derived. Second, in perspective of the relatively short term targets of the European 2020 strategy, we treated bioenergy as not being carbon neutral (positive carbon release). The contribution to the literature on forest economics and policy is that we model effects of forest policy on both the economic and ecological system, including the consideration of, e.g., carbon emissions from bioenergy use.

Based on our theoretical modeling we suggest a cost-benefit rule where the net welfare effect is $PC+ME+SE+EE+CE$, which is the sum of the project's costs, the value of its net market effects, net effects on natural resources, net environmental effects, and of its net climate effects, respectively. Only when the total net welfare effect is positive the project is socially desirable.

Focusing particularly on the climate effect, our results show that it is crucial to account for bioenergy emissions when assessing the welfare effects of forest projects aimed at increasing carbon sequestration and promoting the use of bioenergy. Not doing so will over-estimate the projects' positive effects on the climate, and therefore also on the welfare and its role for sustainable development. This analytical result is in line with recent comments on erroneous carbon accounting for bioenergy (e.g., Lundgren et al., 2008; Searchinger et a., 2009; Cherubini et al., 2011). However, note that this is contrary to policy sometimes pursued in practice. For instance, in Sweden renewable resources such as, e.g., bioenergy, are generally regarded as climate neutral and is often tax-exempted both regarding energy content and carbon release.

The conclusion made is based on a theoretical model characterized by some restrictive assumptions and simplifications. However, relaxing assumptions and complicating the model further would not alter the general conclusion made.

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