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Greenhouse gas taxes on animal food products: rationale, tax scheme and climate mitigation effects

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Abstract Agriculture is responsible for 25–30% of global anthropogenic greenhouse gas (GHG) emissions but has thus far been largely exempted from climate policies. Because of high monitoring costs and comparatively low technical potential for emission reductions in the agricultural sector, output taxes on emission-intensive agricultural goods may be an efficient policy instrument to deal with agricultural GHG emissions. In this study we assess the emission mitigation potential of GHG weighted consumption taxes on animal food products in the EU. We also estimate the decrease in agricultural land area through the related changes in food production and the additional mitigation potential in devoting this land to bioenergy production. Estimates are based on a model of food consumption and the related land use and GHG emissions in the EU. Results indicate that agricultural emissions in the EU27 can be reduced by approximately 32 million tons of CO_2-eq with a GHG weighted tax on animal food products corresponding to €60 per ton CO_2-eq. The effect of the tax is estimated to be six times higher if lignocellulosic crops are grown on the land made available and used to substitute for coal in power generation. Most of the effect of a GHG weighted tax on animal food can be captured by taxing the consumption of ruminant meat alone.

1 Introduction

Greenhouse gas (GHG) mitigation has increasingly been put on the political and scientific agenda. Most interest has been directed toward reducing emissions of

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carbon dioxide (CO_2) from the energy and transport systems. Various policies have been put in place such as subsidies for renewable energy, energy efficiency policies, and CO_2 emission trading schemes. Even though CO_2 from the energy and transport systems is the largest contributor to climate change, CO_2 from agricultural land-use changes, energy use at farms and fertilizer production and methane and nitrous oxide from agriculture represent roughly 25–30% of global GHG emissions (IPCC 2007; Houghton 1999; Steinfeld et al. 2006).

A number of studies have pointed to the potential for increasing the cost-effectiveness of price-based climate policy instruments (e.g. emission taxes or trading schemes) by also including the non-CO_2 greenhouse gases recognized in the Kyoto Protocol (Reilly et al. 1999; Manne and Richels 2001; Weyant et al. 2006). A wider inclusion of non-CO_2 gases in climate policies would have implications particularly for agriculture, since that sector is responsible for about 60% of global non-CO_2 emissions (IPCC 2007). In their review of policies to reduce agricultural GHG emissions, Povellato et al. (2007) concluded that the agricultural sector potentially offers GHG abatement at relatively low costs. But they also noted that in reality the potential efficiency gains from introducing price-based instruments in agricultural production may be offset by high transaction and monitoring costs.

In the EU, high monitoring costs are also paired with comparatively low potentials for reducing GHG emissions in agriculture via technology. As will be argued in the next section, these and other circumstances speak in favour of the use of output taxes (e.g. consumption taxes) on agricultural goods instead of emission taxes (e.g. taxes on methane and nitrous oxide), or equivalent policies, on agricultural production. Animal food products, such as meat, are agricultural goods characterized by high emission intensities, with large divergences in emissions per food unit between different types of food product, and significant substitutability in consumption. Stehfest et al. (2009) showed that dietary changes on the global level have a rather large impact on the carbon abatement cost. However, they did not examine how dietary changes might occur. In this paper we argue that consumption taxes on animal food differentiated by GHG emissions per food unit would change the average diet and could be a cost-effective policy for mitigating agricultural GHG emissions in the EU.

In addition to the associated GHG emissions, livestock production requires large areas of land for feed and pasture production. A tax-induced decrease in the consumption of animal food would therefore also decrease the area of land used. This could facilitate an increase in bioenergy production and thus contribute to additional reductions in GHG emissions.

The purpose of this paper is to estimate the magnitude of the GHG mitigation from imposing consumption taxes, differentiated with respect to average GHG emissions per food unit, on animal food products in the EU. Two types of mitigation effects are assessed. First, we estimate the effect on the emissions from food production that follows from the tax-induced changes in food consumption. Second, we estimate the decrease in agricultural area related to the changes in food production, and the mitigation effect in devoting this land for production of bioenergy which is assumed to replace fossil fuels.

The next section discusses why GHG weighted consumption taxes on food may be an effective climate policy instrument. Section 3 describes the method and data used in the analysis. In Section 4 the results are presented, while Section 5 tests the sensitivity of the results to changes in main parameters. In Section 6, we discuss some implications of the results and limitations to the analysis. Finally, conclusions are presented in Section 7.

2 Differentiated consumption taxes on food as a climate policy instrument

Overall, a policy maker has the choice between command-and-control instruments (e.g. performance standards, stipulated technology), information provision (e.g. public information campaigns) and price-based approaches (e.g. taxes, subsidies). Within the domain of price-based instruments, there is also the choice between taxes on the emissions as such and taxes on the outputs (or inputs) that are related to, but normally not perfectly correlated with, the emissions. Although taxes on emissions are generally preferable because they directly address the discrepancy between private and social cost, in some cases they may be less cost-effective than taxes on outputs or inputs. Schmutzler and Goulder (1997) examined under which circumstances it is optimal for society to impose output taxes to deal with environmental externalities rather than emission taxes. They found that output taxes are optimal if (1) costs of monitoring emissions are high, (2) there are limited options for reducing emissions apart from output reduction, and (3) the possibilities for output substitution are great. In this section we will argue that these conditions are fulfilled for GHG emissions from food production.

At the global level, GHG emissions from food and agriculture are dominated by soil/vegetation carbon losses from conversion of forests and other land to agricultural

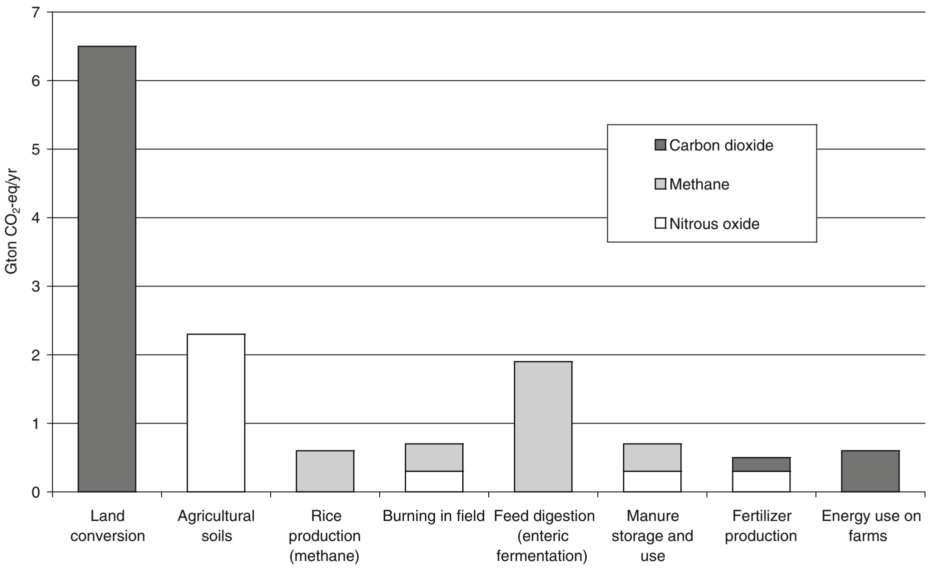


Fig. 1 Order of magnitudes for current GHG emission sources in global food and agriculture. All numbers in billion metric tons CO_2 equivalents per year. Sources: Compiled from IPCC (2007), Houghton (1999), Steinfeld et al. (2006), Lal (2004), Koungshaug (1998). All numbers are subject to considerable uncertainty, especially the CO_2 emissions from land conversion to agriculture

land, nitrous oxide from nitrogen-fertilized agricultural soils, and methane from enteric fermentation in ruminants (Fig. 1). Emissions from energy use (on farms) and fertilizer production make up roughly 8% of global agricultural emissions, and are small compared to those of methane and nitrous oxide. In the EU, soil and vegetation carbon losses from agricultural land are negligible (or possibly even negative), and methane and nitrous oxide by far make up the great majority of agricultural GHG emissions. In this paper, we therefore mainly address mitigation and policy options for these gases.

To enable levying of taxes on the actual emissions of methane and nitrous oxide in agriculture, emissions would have to be monitored at the farm level. Emissions of methane from enteric fermentation in the digestive tract of ruminants are correlated with feed intake, but can differ considerably between individual animals, even when feed composition and other factors are similar. For instance, for cattle consuming the same feed, emissions can vary by up to a factor of two (Lassey 2007). Therefore, to accurately monitor methane from enteric fermentation, emissions from a significant sample of animals at the farm would have to be measured regularly. Nitrous oxide emissions from agricultural soils are correlated with nitrogen fertilizer input, but variation is much larger than in the case of enteric methane, with fluctuations of several orders of magnitudes over short time scales (Bouwman and Boumans 2002; Snyder et al. 2009). Consequently, uncertainty ranges for factors relating emission levels to nitrogen input spans more than one order of magnitude (IPCC 2006). An accurate monitoring of nitrous oxide emissions would require virtually continuous measurement for a great fraction of the fields at a farm. Obviously, for both methane and nitrous oxide the costs of such extensive emission monitoring schemes would be extremely high.

Agricultural GHG emissions per unit of food produced can be reduced by improvements in agricultural productivity and/or by dedicated technological or agronomic mitigation measures. Overall, GHG emissions per unit of food have decreased over time and are likely to continue to do so (Cederberg et al. 2009a; Capper et al. 2009; Vergé et al. 2009). These reductions have largely been due to increased agricultural productivity as a result of changed practices and technologies that have been economically viable, such as higher-yielding crop varieties and improved livestock management.

In many regions, especially in developing countries, there is still substantial scope for cost-effective improvements in agricultural productivity, which—if exploited—will contribute to GHG mitigation. In contrast, the GHG mitigation potential and cost-effectiveness of dedicated mitigation measures are in most cases relatively low, even in the case where farmers would have to pay a substantial price for their GHG emissions. Beach et al. (2008) estimated that the global emissions of methane and nitrous oxide from livestock could be reduced by 10–15% for a carbon price of €100 per ton CO_2-equivalents. Smith et al. (2008) estimated that the technical potential to reduce methane from livestock corresponds to 12% of present emissions. For nitrous oxide the technical reduction potential was estimated at 5% of current emissions. Wirsenius and Hedenus (2010) estimated that the technical potential by 2020 for reducing GHG emissions in EU agriculture is of the order of 20–10% per unit of food for all major meat categories and milk. Their study took into account several technological and agronomic mitigation measures, including altered feed rations to reduce emissions from feed digestion, improved manure management, increased nitrogen fertilizer efficiency, nitrification inhibitors, pH reduction in manure (for reducing ammonia emissions) and use of biofuels for transportation, machinery and energy use. However, it did not include estimates of reductions from productivity improvements.

The limited potentials in agriculture of dedicated mitigation measures are due to mainly two reasons. First, most of the GHG emissions are related to intrinsic characteristics of the agricultural system. The digestive system of ruminants inevitably involves production of methane at significant levels that cannot be drastically reduced without fundamentally manipulating the digestive process. Similarly, nitrous oxide production is an inherent part of the nitrogen cycle, and a high nitrogen turnover per unit area—which is required for high crop yields—inevitably entails production of significant amounts of nitrous oxide. Second, the majority of the GHG emissions have a non-point source character, which means that the prospects for substantial emission cuts by end-of-pipe technology or similar are poor. As illustrated in Fig. 2, in European milk and beef systems—which are the animal food systems that dominate total GHG emissions from livestock in the EU—around 70% of the emissions are of non-point source character.

Using a nutritious and healthy diet as the norm, it is obvious that there is a considerable substitutability between different sorts of food, since nutritional requirements can be met by a vast number of combinations of different food types. Substitutability is still substantial when using more restricted criteria, such as preferences for meaty texture, since several different meat types are available on the market, as well as vegetable-based meat substitutes. Substitution between equivalent food types offer substantial GHG reduction prospects, due to very large, and inherent, differences in GHG emissions per food unit (Table 1). For instance, if pork or chicken are substituted for cattle meat (beef), total GHG emissions are reduced by about 80%. If beans containing an equal amount of protein are substituted for cattle meat, emissions are cut by more than 99%.

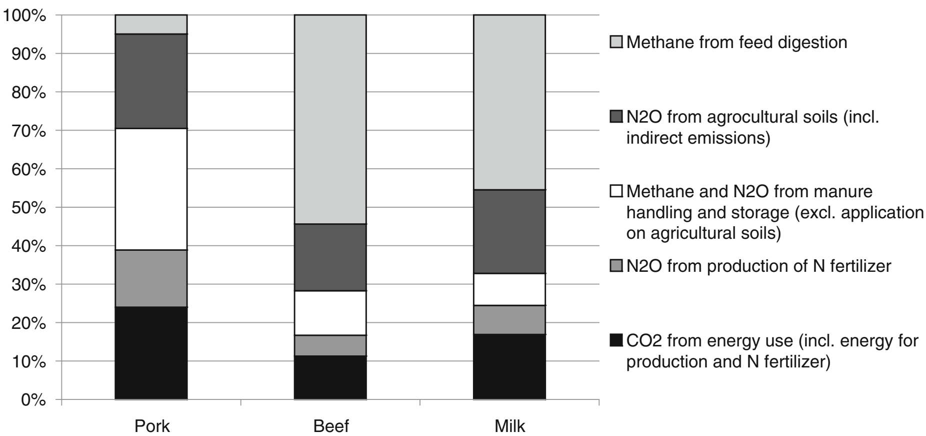


Fig. 2 GHG emissions by source for major animal food systems, expressed as a fraction of total GHG emissions in each system. Source: Compiled from Cederberg et al. (2009a)

Table 1 Assumed GHG emissions per unit produced for food systems in the EU27

	Ruminant meat		Pork	Poultry	Dairy products	Eggs	Cereals	Other vegetable products
	Dairy bulls and heifers	Beef cattle						
GHG emissions (kg CO_2-eq/MJ Metabolizable Energy (ME))	2.2	3.5	0.51	0.37	0.44	0.36	0.05	0.02

Sources: Estimates based on Aiking et al. (2006), Basset-Mens and van der Werf (2005), Casey and Holden (2005a, b), Cederberg and Darelius (2000, 2001), Cederberg and Mattsson (2000), Cederberg and Nilsson (2004), Cederberg and Stadig (2003), Cederberg et al. (2009a), Garnett (2007), Angervall et al. (2008), Lovett et al. (2006), Nemry et al. (2001), Thomassen et al. (2008) and Williams et al. (2006)

Hence, it can be concluded that output taxes on food are likely to fulfil the optimality conditions formulated by Schmutzler and Goulder (1997). In order to obtain a more cost-effective reduction of GHG emissions, the output taxes should be differentiated to the GHG emission levels per unit of food for a category of food. To minimize information and administrative costs, such differentiation could be based on average emission levels for all food producers on entire markets (e.g. EU), rather than emission levels specific for individual producers. Although the variations in emission levels between individual producers within a food category are significant, they are in general much smaller than the differences between food categories. Using average instead of producer-specific numbers decreases the tax's cost-effectiveness in reducing emissions, but must be weighed against the high information and administrative costs for a scheme based on producer-specific data.

Further, to avoid emission leakage, the output tax should be levied at the consumption level rather than at the production level. Levying the tax on production in the EU would create a cost disadvantage for EU producers in relation to producers outside the EU, which would lead to a higher import ratio in EU food supply. Although the GHG emission from EU food production would decrease due to lower production in the EU, global emissions would not decrease to the same extent since non-EU production would tend to increase due to larger exports to the EU. Global emissions might even increase since non-EU food production in many cases has higher GHG intensity than in the EU—this applies in particular to cattle meat production in the tropics (Cederberg et al. 2009b). Yet, even in the case with a tax levied at the consumption level, emission leakage would not be entirely avoided since decreased demand for meat from the EU would depress world meat prices and result in increased meat consumption in non-EU countries. However, the emission leakage in this case would almost certainly be considerably lower than in the case with a tax levied at the production level.

3 Methods and data

This section first describes some general features of the methodological approach used in this study. The two following subsections describe the data and methodology used for calculating GHG emissions and land requirements in food production. Next, we present data on land requirements and GHG balances for six different biomass-based energy options considered as alternative uses of the agricultural land released from use in food production. In the two last subsections, we describe details of the tax scheme considered in this study, and the data and methodology for estimating the impact of the tax scheme on food production levels.

3.1 System boundaries and calculation design

The principal calculation issue of this study was to assess the impact on GHG emission levels from (tax-induced) higher consumer prices on food in the EU27. For simplicity, the food and agricultural system of the EU27 was used as a proxy for the tax-induced system changes. In a pure computational sense, this means that the tax-induced changes of food consumption in the EU were assumed to fully translate into corresponding changes only on agricultural production within the EU, and not outside the EU. This is a reasonable approximation as the import corresponds to less than 10% of the domestic production for all our animal food categories. Still, as discussed in Section 6, this approximation is likely to contribute to an underestimation of the GHG mitigation potential.

Land use and GHG emissions related to food consumption were calculated using a model of the EU27 food and agriculture system in which food products were categorized into the sub-systems, ruminant meat (cattle meat, i.e. beef, and sheep meat, i.e. lamb and mutton), pork, poultry, eggs, milk, cereals, and an aggregated group for all other vegetable products. Data for beef production was used as a proxy for all ruminant meat and milk production. This is a reasonable approximation as beef dominates the EU consumption of ruminant. Further, ruminant meat was represented by two sub-systems, dairy cattle bulls and heifers and beef cattle. Dairy bulls and heifers are surplus calves from dairy farms that are reared for slaughter; this meat can be considered as a by-product of milk production whose supply level is determined by the milk production level. When dairy cows are culled, this meat is supplied to the market and can hence also be considered as a by-product from milk. Beef cattle meat systems consists of beef suckler cows that produce calves that are reared for meat production. When the required production level of beef cattle meat was calculated in the model, the dairy cattle meat supplied as by-product from milk production was fully accounted for, i.e. beef cattle meat supply was assumed to fill the gap between total cattle meat consumption and dairy cattle meat supply.

The study also distinguishes between the *average* characteristics of EU food production systems, and the characteristics of the *marginal* changes of food production that occur as a result from the tax-induced changes of food consumption. This distinction is crucial due to the significant physical (and economic) linkages that exist between different food systems, mainly in terms of use of by-products from the food industry (bran, oil cakes etc) as feed in animal food systems. For the EU, the use of such residues on average may amount to about 5–25% of total feed use depending on the type of animal food system (Wirsenius 2000). Since the produced amount of these residues is fixed—given unchanged production of the main products (flour, vegetable oil etc)—a marginal increase in animal food production was assumed to be based on a feed ration *without* residues, and hence lead to an increase in land use corresponding to a feed ration consisting only of cropland-produced feedstuffs and/or permanent pasture. Analogously, a marginal *decrease* of animal food production was assumed to lead to a decrease in land use corresponding to a feed ration consisting only of land-produced feedstuffs.

Since food industry residues account for a major part of the protein in feed rations for milk cows, pigs and poultry, the marginal production systems for those animals included a protein-rich crop to compensate for the exclusion of the residues, and thereby yet obtaining feed rations of adequate protein content. The protein-rich crop in the model systems of this study was assumed to have the characteristics of soybean (whole bean).

Using the same logic for the by-product dairy cattle meat as above for food industry residues, a change of ruminant meat consumption was assumed to lead to a corresponding change of only beef cattle meat production.

3.2 Greenhouse gas emissions from food production

There is poor agreement among available estimates of GHG emissions in EU food production. Studies generally refer to individual farms, which makes results dependent on site-specific practices and agricultural conditions. In addition, for the cattle sector results depend on the methodology used when allocating emission burdens between milk and meat. However, using a large collection of studies as basis, reasonable averages of current GHG emissions from food systems in the EU were estimated, see Table 1. These emission data were used in the model developed in this study to calculate the total food-related GHG emissions in the EU27 as a function of tax-induced changes in food production. All studies referred to here are based on estimates from EU15 countries rather than on estimates for EU27. However, the majority of the EU27 food production is located in the EU15 countries. Still, these estimates may slightly underestimate the real average emission levels since emissions per unit of food are likely to be higher in the newer member states.

3.3 Land requirements of food production

Food consumption and its related land use were parameterized in a simple model using an approach similar to the one in Wirsenius (2000, 2003) and Wirsenius et al. (2010). Data on food consumption per capita in the EU27 were compiled from the FAO statistical data base (FAOSTAT), see Table 2. Additional model parameter values that were directly based on FAOSTAT data included trade, non-food uses of agricultural commodities and storage and distribution losses.

Data in Wirsenius (2000, 2003) and Wirsenius et al. (2010) on feed/feedstock-to-food conversion efficiencies, feed rations and crop and pasture yields were used to assume a priori values on these parameters in the model. These parameter values were thereafter fine-tuned to make the model values on crop production, feed use, cropland and permanent pasture area match the corresponding data for EU27 in FAOSTAT. The obtained estimates on conversion efficiencies are presented in Table 2. Details on obtained estimates on feed rations and crop and pasture yields are given in the Appendix. The resulting estimates of land requirements per unit of food produced are given in Table 3. The calibrated model was then used to calculate food-related land use in the EU27 as a function of the tax-induced changes in food production.

Table 2 Assumed pre-tax food consumption per capita and feed/feedstock efficiencies in production of animal and vegetable food in the EU27

	Ruminant meat		Pork	Poultry	Dairy products	Eggs	Cereals	Other veg. products
	Dairy bulls and heifers	Beef cattle						
Consumption (MJ ME/cap/day)	0.41		0.81	0.42	1.8	0.19	5.1	5.2
Conversion efficiency[a]	4.0%	2.0%	18%	20%	15%	13%	78%	60%

Sources: Consumption numbers were compiled from FAOSTAT data. Feed and feedstock conversion efficiencies were estimated from data in Wirsenius (2000, 2003) and Wirsenius et al. (2010)
[a]Conversion efficiency here refers to gross energy content of product divided by gross energy content of either feed (animal food) or feedstock (vegetable food)

3.4 Land requirements and greenhouse gas balances of bioenergy

In this study, we analyzed alternative uses for bioenergy purposes of the land no longer used for feed and pasture production as a result of the considered GHG tax. A GHG weighted consumption tax of food would only be conceivable as part of an overall stringent long-term climate policy in the EU. Within a stringent climate policy context, it is reasonable to assume that higher carbon emission costs would further stimulate bioenergy production. We therefore defined six different scenarios in which the land made available is used for bioenergy, and additional GHG mitigation is achieved through the substitution of this biomass for fossil fuels. The scenarios are not intended to predict any expected outcomes but to illustrate the potential to use land currently dedicated to livestock production for other productive uses. We therefore chose simple categorical cases and did not take into account the economic conditions which determine actual land use decisions.

In two of the four Biofuels for Transport (BfT) scenarios, GHG mitigation is assumed to be obtained by growing either wheat for bioethanol or rapeseed for biodiesel (RME), which replace petrol and diesel, respectively. In the other two BfT scenarios, lignocellulosic (LC) crops instead of food crops are grown as feedstock for production of transportation fuels—bioethanol or synthetic diesel—which are assumed to replace petrol and diesel. In the Biomass for Power (BfP) and Biomass for Heat (BfH) scenarios, lignocellulosic crops are grown and used for power and heat generation, assumed to replace coal-based power and oil-based heat, respectively.

Table 4 presents the data used on land requirements and GHG emissions of the considered bioenergy options as well as GHG emission data of the assumed fossil fuel-based alternatives. Emission data for transportation fuels were estimated from the Well-to-Tank (WTT) report (Edwards and Larivé 2007). For ethanol from wheat, data refer to emissions in production with current conventional production technology and with the by-product DDGS (distiller's dried grains with solubles) used as fuel.

Soil carbon losses from land use change were calculated according to Tier 1 guidelines in IPCC (2006). Carbon losses from the conversion of permanent pasture to cropland were estimated at 62 ton CO_2 per hectare. Soil carbon stocks in land used for the cultivation of lignocellulosic crops were assumed to be comparable to

Table 3 Assumed land use per unit produced for food systems in the EU27

	Ruminant meat				Pork		Poultry		Dairy products		Eggs		Cereals	Other veg. prodb
	Dairy bulls and heifers		Beef cattle											
Land (m^2/MJ ME)														
Cropland	2.4	2.7	2.9	3.5	0.71	1.0	0.81	1.1	0.52	0.71	0.5	1.2	0.18	0.36
Permanent pasture	3.1	3.1	11.3	11.3					0.47	0.47				

For animal food systems, data are given for land use on average (numbers on left-hand side) and land use for marginal changes in production (numbers on right-hand side; see Section 3.1 for explanation of "average" and "marginal" production systems)
Sources: Calculated from conversion efficiencies in Table 2 and data in Tables 7 and 8 in the Appendix

Table 4 Assumed land requirements and GHG emissions per unit of final energy use for different energy forms in the EU27

	Ethanol from wheat	Ethanol from LC crops	Petrol	RME	Syn-diesel from LC crops	Diesel	Power from LC crops	Coal based power	Heat from LC crops	Oil based heat
Yield per land area (GJ LHV/ha/year)										
Cropland	46	45	Not applicable	42	72	Not applicable	72	Not applicable	160	Not applicable
Former permanent pasture	23	23	Not applicable	21	36	Not applicable	36	Not applicable	81	Not applicable
GHG emissions (kg CO_2-eq/GJ LHV)										
Excluding soil carbon losses	51	27	86	47	11	88	19	270	7	93
Including soil carbon losses	78	38	86	77	18	88	27	270	10	93

Land requirements are expressed as energy yield per area unit, with separate numbers for yields on cropland and land previously used as permanent pasture
Sources: Yield numbers for wheat ethanol and RME were based on Edwards and Larivé (2007). Emission numbers for ethanol and synthetic diesel from lignocellulosic crops were estimated from Londo et al. (2008) and emissions for all other energy forms from Edwards and Larivé (2007)
RME rapeseed methyl ester ("biodiesel"); *LHV* lower heating value; *LC* lignocellulosic

stocks in managed forest land, and losses from the conversion of permanent pastures for this purpose were assumed to be 26 ton CO_2 per hectare. Carbon losses were allocated over time using a time horizon of 100 years.

3.5 Greenhouse gas differentiated consumption tax schemes

As already discussed in Section 2, cost and emission leakage arguments speak in favour of imposing an output tax on food at the consumption rather than the production level, with the tax differentiated by the GHG emission levels per unit of food. Therefore, the tax scheme considered in this study has these characteristics. The differentiation by GHG emissions means that taxes are assumed to be weighted according to the average production emission intensities for the food categories. Thus, for each category the tax per ton CO_2-eq was multiplied by the number of tons of CO_2-eq emitted in the production of a ton of product (Table 1). Ruminant meat was taxed according to the emission intensity in marginal cattle meat production, i.e. beef cattle meat. Ideally, imported food should be taxed based on the actual emission level in the region of origin. This would, however, be very difficult due to limited data availability, and for that reason we did not consider that option. This option would also be problematic to impose due to trade regulations in the WTO.

We included all greenhouse gases originating from food production in our tax scheme even though CO_2 from energy is more efficiently taxed directly, i.e. at fuel consumption level. In a real world tax scheme this must of course be considered. However, for two reasons we did include all gases in the tax scheme in this study. First, there is a lack of data on emissions levels from food where CO_2 is presented separately. Second, we aimed at estimating the effect on food consumption of a stringent climate policy. If a GHG weighted consumption tax on animal food products were imposed it is likely that CO_2 from energy would be taxed at similar rate. Thus, by including CO_2-emissions in our tax scheme we in effect assess the impact of a tax regime similar to a food consumption tax based on only nitrous oxide and methane combined with a CO_2 tax at an equivalent level on fossil fuels.

In principle, all categories of food should be subject to a GHG weighted consumption tax. However, in the tax scheme in this study, vegetable food was exempted due to their generally much lower GHG emissions per food unit, and their lower elasticities, compared to animal food. The low GHG emissions and elasticities mean that the administrative costs of vegetable food taxation relative to the achieved emission reduction would probably be much higher than for animal food. We also exempt fish and seafood from taxation, mainly due to lack of elasticity data. Still, fish and seafood do cause large GHG emissions, primarily CO_2 from fossil fuels, and these emissions should also be taxed in the long run. In summary, these exemptions mean that the food categories included in the tax scheme of this study are ruminant meat, pork, and poultry, and eggs and dairy products. It may be that separate categories also could be defined for labelled types of production, for instance organic farming, but we will not study that here.

3.6 Tax-induced changes in food consumption and production

When estimating the effect on food consumption of the tax scheme described in the previous section, we considered the effect in the long run when consumers have had time to realize the utility gains to be made by adapting their eating habits to the imposed changes in relative food prices. For the long term, we may also assume a perfectly elastic supply and that the burden of taxation in long-run equilibrium falls entirely on consumers. Thus, the changes in produced quantities of different food products were assumed to equal the taxation-induced changes in consumed quantities.

Substitution between all previously defined food categories except fish and seafood was assumed to result from the tax scheme. On the basis of available elasticity data (see below), the change in demand for fish and seafood resulting from taxation of other animal food was assumed to be negligible. For simplicity, therefore, cross-price elasticities between fish and other animal food were assumed to be zero.

Hence, the demand functions take the form:

$$D_i^{\mathrm{Tax}} = D_i^{\mathrm{Ref}} \cdot \prod_j \left[\frac{P_j^{\mathrm{Tax}}}{P_j^{\mathrm{Ref}}} \right]^{\varepsilon_{ij}} \quad \text{where} \quad P_j^{\mathrm{Tax}} = P_j^{\mathrm{Ref}} + c_j \cdot t \quad \text{and} \quad i \in I,\, j \in J \subset I$$

J ruminant meat, pork, poultry, dairy products, eggs
$I \backslash J$ cereals, other vegetable products

The reference, i.e. pre-tax, demand, D_i^{Ref}, represents the average pre-tax per-capita consumption of food category i in EU27 (numbers shown in Table 2). The subsequent terms on the right-hand side give the relative change in demand as a function of the relative changes in the prices of the animal food categories and their respective own- and cross-price elasticities of demand, ε_{ij}. Reference, i.e. pre-tax, prices, P_j^{Ref}, used for the calculations are presented in Table 5. Prices were estimated from EUROSTAT (2008) data on per capita household expenditure by consumption purpose. In order to approximate the average price paid by consumers the expenditure on each food category was divided by FAOSTAT figures on per capita consumption of the respective category in the EU.

Available data on demand elasticities for the aggregate EU region are limited, in particular estimates for the long run. Instead, average short-run price elasticities for the EU were estimated from data for France (Allais and Nichèle 2007) and for the UK (Fousekis and Revell 2000; Fraser and Moosa 2002) and for Greece (Karagiannis et al. 2000). These averages were then adjusted with a long-run adjustment factor estimated from the dynamic Almost Ideal Demand System (AIDS) models in Burton and Young (1992), Karagiannis et al. (2000) and Allais and Nichèle (2007). Unconditional elasticities were derived following Carpentier and Guyomard (2001) and missing cross-price elasticities estimated by imposing symmetry conditions on the elasticity matrix. The resulting elasticity values are shown in Table 6.

Table 5 Assumed pre-tax consumer prices on animal food products in the EU27

	Ruminant meat	Pork	Poultry	Dairy products	Eggs
Price (€/kg)	8.8	5.2	3.7	0.8	2.6

Sources: Estimates based on EUROSTAT (2008) data on per capita household expenditures and FAOSTAT (2008) data on per capita food consumption. For meat products, prices are per carcass weight; for dairy products, per whole-milk weight

Table 6 Assumed own and cross price elasticities of food demand in the EU27

Demand	Price				
	Ruminant meat	Pork	Poultry	Dairy products	Eggs
Ruminant meat	−1.30	0.30	0.30	−0.05	0.00
Pork	0.30	−0.80	0.30	−0.04	0.00
Poultry	0.60	0.50	−1.00	−0.04	0.00
Dairy products	−0.03	−0.03	−0.02	−0.50	0.00
Eggs	0.01	0.01	0.00	0.01	−0.50
Cereals	−0.01	−0.01	−0.01	0.01	0.00
Other veg products	0.00	−0.01	0.00	0.00	0.00

In the sensitivity analysis (Section 7), additional calculations were made using different elasticities
Sources: Estimates based on several sources, including Allais and Nichèle (2007), Fousekis and Revell (2000), Fraser and Moosa (2002), Karagiannis et al. (2000). For details, see text
Each column shows how demand changes for a change in price of the commodity, e.g., for a 1% increase in the relative price of poultry, demand for ruminant meat increases by 0.3%

4 Results

This section first presents the estimates on reduced GHG emissions in food production. Thereafter, results are presented on how much land becomes available as a result of tax-induced changes in consumption and the GHG mitigation of using this land for bioenergy purposes. Finally, the changes in the average food consumption per capita are presented. Results for GHG weighted consumption taxes equivalent to €60 per ton CO_2-eq are presented in more detail. This can be considered as a not unlikely order of magnitude of future carbon emission costs, assuming a stringent long-term climate policy in the EU.

4.1 Reductions in greenhouse gas emissions from food production

Figure 3 shows the reductions in emissions estimated to occur from tax-induced changes in food consumption. For comparison, GHG emissions from the EU27

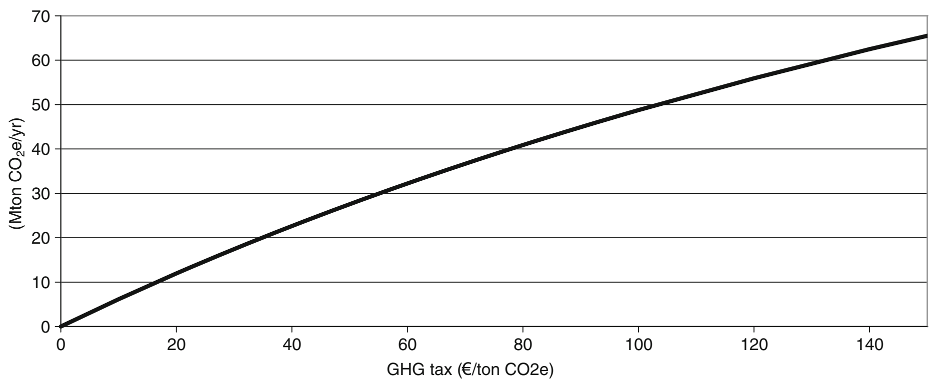
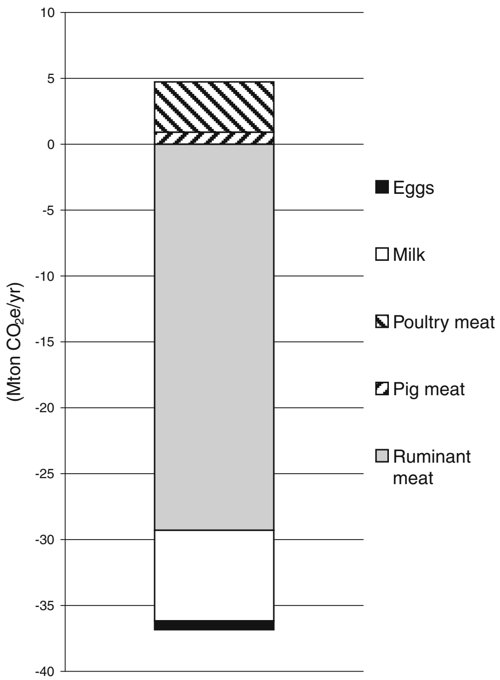


Fig. 3 Reductions in GHG emissions from food production, with consumption taxes on animal foods differentiated by their GHG emission intensity in production

agricultural sector were estimated at 480 million ton CO_2-eq per year in 2005 (EC 2006). Based on the life cycle GHG emission data used in this study (Table 1), total GHG emissions attributable to EU food consumption can be estimated at 510 million tons per year. Since the latter number refers to life cycle emissions, it includes emission sources not covered in emissions statistics for EU agriculture, such as CO_2 from fossil fuel use on farms and GHG emissions from fertilizer production, as well as emissions related to net-imports of feed and food. Assuming GHG weighted consumption taxes corresponding to €60 per ton CO_2-eq, the estimated net reduction is 32 million ton CO_2-eq, which corresponds to a 7% reduction of current GHG emissions in EU agriculture. It should be noted that CO_2 from land-use change is not included here. A less land demanding diet in Europe is also likely to affect the global scarcity of land and thus tropical deforestation. Similar connections have been studied for corn-ethanol expansion in the US (Searchinger et al. 2008) and are likely to apply also for decreased meat and milk consumption in the EU.

Figure 4 shows how the net change in GHG emissions is related to changes in quantities produced of different food categories. The predominant share of the total reduction in emissions is due to a reduction in ruminant meat production. Consumption of pig and poultry meat increases due to substitution of ruminant meat, which gives an increase in emissions from pig and poultry meat production and a net reduction which is around 10% smaller than the gross GHG reduction related to decreased egg, milk and ruminant meat production.

Fig. 4 Reductions in GHG emissions from animal food production for GHG weighted consumption taxes on animal food equivalent to €60 per ton CO_2-eq



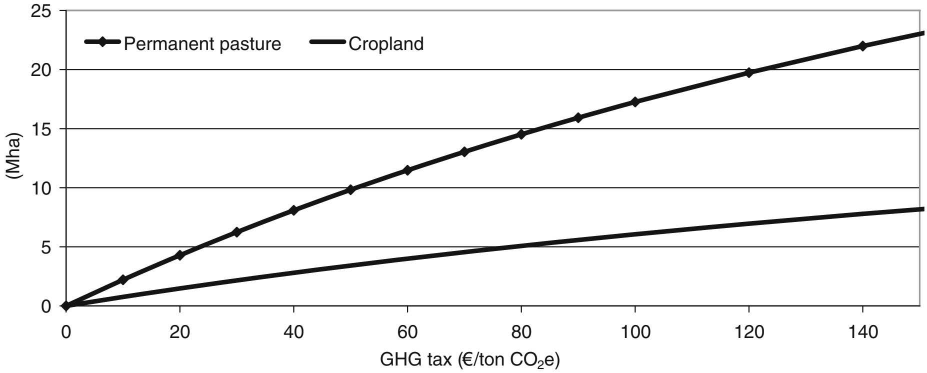


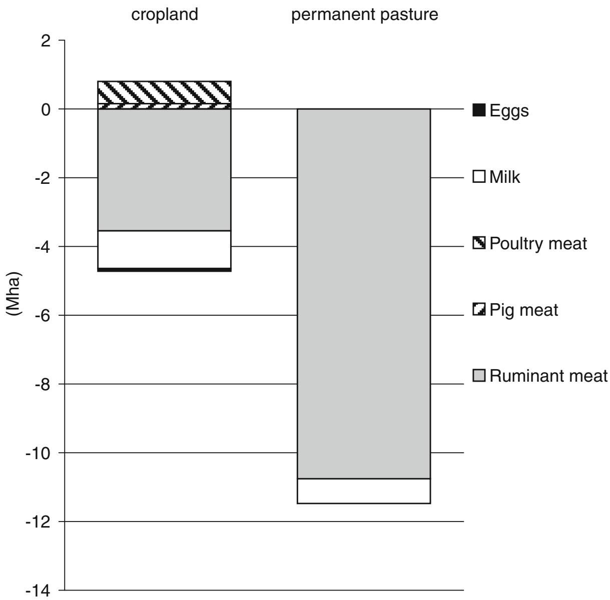
Fig. 5 Reductions in land use for food production for consumption taxes on animal food differentiated to their GHG emission intensity in production

4.2 Reductions in land used for food production

The reductions in land area dedicated to food production resulting from GHG taxation are presented in Fig. 5. For GHG weighted consumption taxes corresponding to €60 per ton CO_2-eq, an estimated 11 million hectares of permanent pasture and 4 million hectares of cropland are made available for alternative uses. This can be compared to the total areas of approximately 70 million hectares of permanent pasture and 120 million hectares of cropland in the EU27 (FAOSTAT 2008).

Figure 6 shows, for taxes corresponding to €60 per ton CO_2-eq, how the net reductions in land use are related to changes in production quantities for different

Fig. 6 Changes in land use for food production for GHG weighted consumption taxes on animal food equivalent to €60 per ton CO_2-eq



food categories. Of the total for both permanent pasture and cropland, the major share is made available through a reduction in ruminant meat production. This is because the tax scheme is estimated to reduce ruminant meat consumption the most but also because ruminant meat production is by far the most land demanding type of animal food production. The production of one ton of beef cattle meat requires about 3 ha of cropland and 9 ha of permanent pasture, whereas pork and poultry production requires less than 1 ha of cropland per ton (Table 3). Therefore the increases in consumption and subsequently in production of pork and poultry only slightly reduce the total area of cropland made available.

4.3 Greenhouse gas mitigation from bioenergy on land made available

The land no longer required for food production can be put to alternative use. If the land is used for bioenergy in order to replace fossil fuels, additional reductions in GHG emissions can be achieved. As described in Section 3.4, six different bioenergy scenarios were considered. Figure 7 shows the combined, net GHG reductions which would be achieved in these scenarios for GHG weighted consumption taxes corresponding to €60 per ton CO_2-eq.

In the first set of Biofuel for Transport (BfT1) scenarios, wheat-bioethanol and rapeseed-biodiesel, the net GHG reductions from bioenergy are much smaller than those in food production; this is due to the relatively high GHG emissions in the production of these biofuels. Despite its large area, the use of former permanent pasture for wheat-ethanol and rapeseed-diesel results in almost negligible GHG

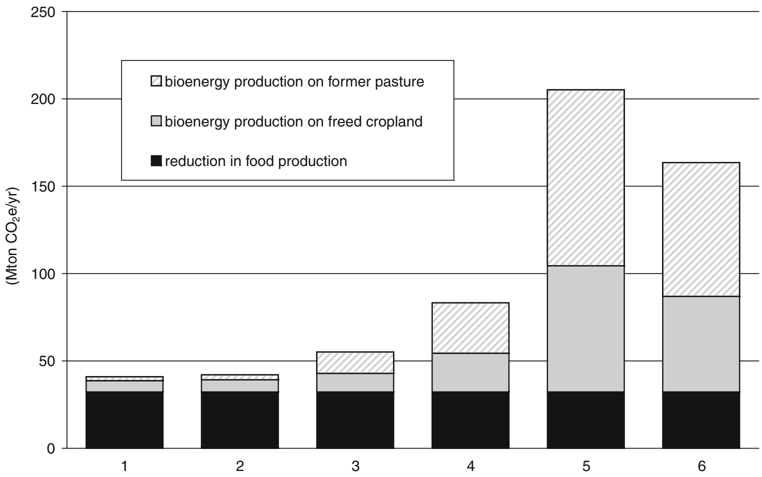


Fig. 7 Scenarios of reductions in GHG emissions from tax-induced changes in food production and bioenergy production on land made available from reductions in land-intensive food production. Results are shown for GHG weighted consumption taxes corresponding to €60 per ton CO_2-eq. The first *two bars* on the left show emission reductions for conventional biofuels for transport (BfT), wheat-ethanol and rapeseed-biodiesel, while the *next two bars* show reductions for transportation fuels produced from lignocellulosic crops. The *Biofuel for Power (BfP) bar* shows the reductions obtained by using lignocellulosic crops for power generation replacing coal-based power. The *Biofuel for Heat (BfH) bar* shows reductions when using lignocellulosic crops for heat generation replacing oil-based heat

reductions. This is because of the lower productivity on permanent pasture land but also the high soil carbon losses when ploughing up and converting permanent pastures to cropland, which the relatively low gains from substituting petrol and diesel with wheat-ethanol and rapeseed-diesel can just barely compensate for.

Soil carbon losses are smaller if lignocellulosic crops instead of food crops are planted on former pasture. The climate benefit from using former pasture for bioenergy is therefore greater in the scenarios in which lignocellulosic crops are used as energy feedstock. In the synthetic diesel case, high process conversion efficiency and low life cycle GHG emissions contribute to GHG reductions far greater than in the other transportation fuel scenarios. The GHG reductions in this scenario exceed the reductions obtained through tax-induced changes in food consumption alone.

In the Biomass for Power and Biomass for Heat scenarios, GHG reductions are much greater than in all other scenarios, and they greatly exceed the direct reductions achieved through tax-induced structural changes in EU agriculture towards less GHG intensive food. The bioenergy reductions are six times higher than the food-related reductions, if biomass is assumed to replace coal as fuel in electricity production. Assuming instead that biomass substitutes oil in heat generation reductions are approximately four times higher.

4.4 Changes in food consumption

Figure 8 shows how per capita consumption of food is estimated to change with GHG weighted consumption taxes corresponding to €60 per ton CO_2-eq. On average, consumption of ruminant meat goes down by 15% compared to the current level. The consumption of pork and poultry instead increases by 1% and 7% respectively due to substitution between the meat categories. In total, food consumption is reduced by 1% in energy terms.

Figure 9 shows the consumption taxes per kilo food product for GHG weighted taxes corresponding to €60 per ton CO_2-eq. The percentage figures above the

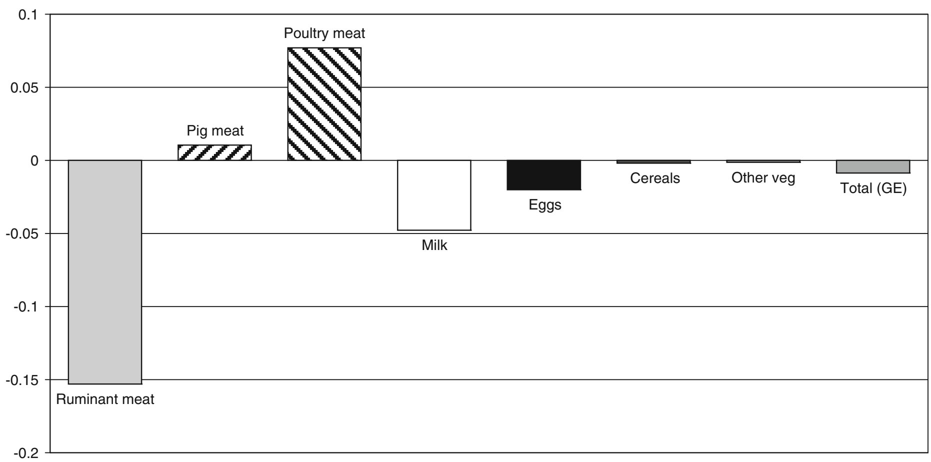


Fig. 8 Changes in food consumption for GHG weighted consumption taxes on animal food equivalent to €60 per ton CO_2-eq. GE: gross energy

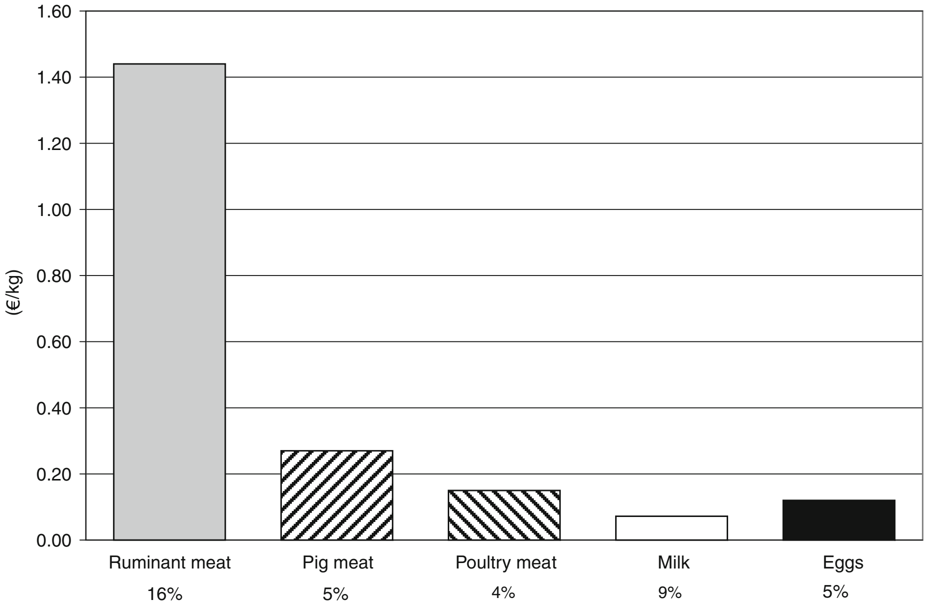


Fig. 9 Taxes per kg (fresh weight) food product for GHG weighted consumption taxes on animal food equivalent to €60 per ton CO_2-eq. *Percentages on top of bars* show the corresponding relative increase in consumer price

bars give the relative price increase per kg food. For ruminant meat, a GHG tax corresponding to €60 per ton CO_2-eq would thus mean a tax of €1.4 per kilo, which on average would represent a price increase of 16%.

5 Sensitivity analysis

The most significant sources of uncertainty in this study are the price elasticities of demand and the average consumer prices of food commodities in the EU. These parameter values have been calculated specifically for this study and there are few comparable data available to substantiate their magnitude. We therefore performed a basic sensitivity analysis in which we decreased the own-price elasticities from the base-calculation values (Table 6) by 50%. This corresponds approximately to the smallest values found in surveyed references. Cross-price elasticities were left unchanged to maintain reasonable values for the other elasticities within the demand system. An upper limit was assumed by increasing both own and cross-price elasticities by 50%, which corresponds to the highest values found. These changes were also checked for consistency with reasonable values for the other elasticities within the demand system.

Figure 10 shows the obtained ranges of total GHG reductions for the above mentioned changes to the demand system. The total emissions reductions include both the reductions from changes in food production and the reductions from bioenergy production on the agricultural land made available. The figure clearly

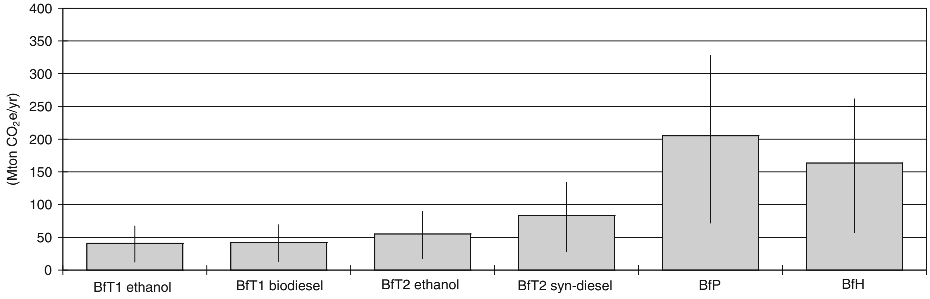


Fig. 10 Sensitivity analysis ranges of GHG emission reductions for GHG weighted consumption taxes on animal food in combination with bioenergy production on land freed from use in food production. Ranges are shown for the six different bioenergy scenarios (see Section 4.3) for consumption taxes corresponding to €60 per ton CO_2-eq

demonstrates that results vary considerably for the demand elasticity spans found in the surveyed references.

6 Discussion

This study of the climate mitigation effects of GHG weighted consumption taxes on food is based on a basic consumer theory, which uses demand elasticities for predicting price-induced changes in consumer demand. Due to the substantial uncertainties in the elasticity estimates, the quantitative results in this paper should be interpreted with care.

In addition, this methodological approach does not allow for any consideration of the potential dynamic effects of taxation, such as providing consumers with information and influencing social trends and individual preferences. Demand elasticities may be increased by public information about the climate impact of different kinds of food and the possibility of changing food habits. The effectiveness of GHG weighted taxation on food could therefore be enhanced if it were complemented by information efforts.

Another important complement to GHG weighted consumption taxes are policy measures that stimulate the exploitation of the technical reduction potentials that, although limited, do exist. Output taxes, in contrast to emission taxes, do not provide continuing incentives for implementing technical measures that reduce emissions at production level. Therefore, the GHG weighted consumption taxes should probably be complemented with performance standards and technology stipulations, in particular in those areas where substantial technical potential exists, such as manure storage and handling.

The results of this study indicate that reduced ruminant (cattle and sheep) meat consumption accounts for the greater part of the climate mitigation effects. Even though the effectiveness of the tax scheme would be slightly reduced, a GHG tax on ruminant meat alone would have significantly lower administrative costs, and would still lead to a GHG mitigation corresponding to about 80% of that for the tax scheme considered in this study.

Although ruminant meat production involves substantial environmental costs, it also generates benefits which deserve attention. In many parts of Europe, grazing cattle and sheep are important for biodiversity and landscape conservation. Reduced consumption and production of ruminant meat can therefore cause concerns regarding potential losses of biodiversity and aesthetic values. However, cattle and sheep farming in pastoral areas of high non-market value are probably best preserved through direct subsidies or comparable policies. Protecting all cattle and sheep farmers from reductions in demand has the socially undesirable effect of retaining as permanent pastures those areas which, from a stringent climate policy perspective, are better suited for bioenergy purposes.

Losses of soil carbon present an additional concern regarding conversion of permanent pasture to other uses. However, the results of this study suggest (see Fig. 7) that there are biomass energy pathways which imply considerable net reductions in GHG emissions, also when taking into account the soil carbon losses from putting pastures into bioenergy crops production and the generally lower biomass productivity of permanent pasture land.

These estimates of GHG mitigation potential from bioenergy did not include the potential loss of the carbon sink that may exist in permanent pastures. Measurements on temperate grassland ecosystems in Europe and North America have shown a carbon sequestration of 200–600 kg carbon per ha per year (Jones and Donnelly 2004). Recent measurements on European grasslands have suggested an even higher carbon sink capacity, up to possibly one ton of carbon per hectare and year, when well-managed (Soussana et al. 2007). These observations are unexpected and yet to be fully understood, since carbon levels in agricultural soils generally reach equilibrium within 30–40 years after a change in land use practices or ambient conditions, i.e. it could be expected that permanent pastures in Europe (which in general are much older than 30–40 years) would be in equilibrium since long. Therefore, even if these measurements would be valid for European permanent pastures in general, it is yet uncertain to what extent they represent the true carbon sequestration capacity for the nearest decades. In addition, even if this would be the true, using permanent pastures for bioenergy instead of ruminant production would still in many cases offer higher GHG mitigation per area unit. For instance, using grassland for production of biomass that substitute for coal in power production results in net avoided GHG emissions of about 2.4 ton C/ha/year, whereas using biomass that substitute for oil in heat production results in net avoided emissions of some 1.8 ton C/ha/year (calculated from data in Table 4).

From a socio-economic perspective, a disadvantage of the tax scheme is that it has a regressive impact on the distribution of household disposable income—as do most consumption taxes. However, this is a general problem associated with most climate policy measures that involve imposing a cost on GHG emissions—directly through price-based mechanisms or indirectly through performance standards or technology stipulations since this cost burden is in the end carried by the consumer in the form of higher prices on many non-luxury consumer goods. Therefore, rather than constituting a categorical argument against any form of stringent climate policies, regressive effects on household income from climate policies need to be addressed and, if deemed necessary, compensated for by changes in other tax schemes, such as more progressive income taxes.

This study assumed, for simplicity, that all tax-induced changes in consumption translate into changes of food production and land use within the EU27 only. As some food is imported to the EU, GHG weighted consumption taxes would of course in reality affect food production and land use also in the regions exporting to the EU. However, for animal food products, imports and exports as share of consumption and production are, overall, relatively small, and this simplification is therefore not likely to largely affect the accuracy of the estimates of GHG emissions and land use. For cattle meat, import and export constitute about 7% and 2%, respectively, of total EU supply; for milk, export and import are more or less negligible (USDA 2008a, b). For pork and poultry, trade flows make up less than 8% of total supply in the EU27 (USDA 2008a, c).

Most of the cattle meat imported to the EU is of South American origin, dominated by Brazil whose beef export makes up about 75–80% of the EU import (USDA 2008a). South American cattle meat production is completely dominated by extensive, grazing-based systems, and intensive feedlot systems are rare. In general, these grazing-based beef cattle systems have lower productivity per area unit and generate higher methane and nitrous oxide emissions per food unit than those in the EU (Cederberg et al. 2009b). In addition, cattle production in South America is one of the factors contributing to deforestation in the Amazon (McAlpine et al. 2009). Taking into account CO_2 emissions from deforestation related to cattle meat production, total GHG emissions per unit of meat produced far exceeds those in the EU, by as much as a factor of five (Cederberg et al. 2009b). Therefore, considering the tax-induced reductions of cattle meat production outside the EU, too, the total GHG mitigation effect is likely to be higher than estimated in this study.

To the extent that reduced demand for meat from the EU is not counteracted by increased consumption elsewhere GHG weighted taxes on food in the EU would mitigate demand for meat from cattle meat exporting regions. Therefore an additional benefit outside the EU of the tax scheme is that it could help preserve biodiversity in exporting regions. Reduced demand for meat exports would bring about a mitigation of the expansion of beef cattle production into the Amazon and other pristine areas of high biodiversity in South America (e.g. the Brazilian *Cerrados*).

7 Conclusions

This study concludes that consumption taxes on animal food differentiated to the GHG emissions per food unit can be a cost-effective policy to abate agricultural GHG emissions. There are three principal arguments behind this conclusion. First, the costs of monitoring agricultural emissions are very high, which makes the option of using emission taxes at the farm level prohibitively expensive. Second, the potential for reducing agricultural GHG emissions by technical means is limited overall, which means that the only way to drastically cut emissions is to reduce production. Third, there are very large, and most importantly, biologically inherent, differences in GHG emission intensity between different categories of food.

This study estimated the potential for reducing agricultural GHG emissions with GHG weighted consumption taxes on animal food products in the EU. A tax scheme of differentiated consumption taxes on animal food equivalent to €60 per ton CO_2-eq is estimated to lower emissions from food production by approximately 32 million tons CO_2-eq, which corresponds to about 7% of current GHG emissions in EU agriculture. Taking into account the possible impact on cattle meat production in regions exporting to the EU, the GHG mitigation effect from the tax scheme is likely to be higher than this. About 80% of the estimated emission reduction is related to a decrease in ruminant (cattle and sheep) meat consumption. This is to a great extent explained by the high GHG emissions per meat unit produced.

The production of ruminant meat also requires very large areas of agricultural land. GHG weighted consumption taxes would therefore have the additional benefit of making substantial areas of land currently used for feed and pasture available for bioenergy production, which could contribute to additional GHG mitigation. If lignocellulosic bioenergy crops are grown and used to replace coal in power generation, the total emission reductions achieved are estimated to be six times higher than those associated with reductions in food production only. For a tax scheme corresponding to €60 per ton CO_2-eq, the combined GHG emission reduction in this case would amount to about 5% of total current GHG emissions in the EU27.

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Appendix

Table 7 Assumed feed rations for animal food systems in the EU27. Numbers are given for land use on average (numbers on left-hand side) and land use for marginal changes in production (numbers on right-hand side; see Section 3.1 for explanation of "average" and "marginal" production systems)

	Ruminant meat				Pork		Poultry		Dairy (dairy cows and replacement heifers)		Eggs	
	Dairy bulls and heifers		Beef cattle									
Cropland feed ex. protein concentrates[a]	65%	75%	45%	55%	75%	80%	65%	70%	68%	75%	80%	83%
Cropland-produced protein concentrates[b]					5.0%	20%	15%	30%	0%	7.5%	0%	18%
Permanent pasture	25%	25%	45%	45%					18%	18%		
By-products and residues[c]	10%	0%	10%	0%	20%	0%	20%	0%	15%	0%	20%	0%

Sources: Estimates based on data in Wirsenius (2000, 2003) and Wirsenius et al. (2010)
All numbers on dry matter basis
[a] Refers to all types of feedstuffs produced on cropland (cereal grains, hay, silage, etc) except protein-rich crops
[b] Refers to protein-rich feedstuffs produced on cropland, e.g. soybeans
[c] Refers to all types of by-products and residues from crop production (e.g. straw) and food industry (e.g. bran, oil cakes)

Table 8 Assumed yields of cropland-produced feed (excl. protein concentrates) for animal food production and of feedstock for vegetable food production in the EU27

	Ruminant meat		Pork	Poultry	Dairy	Eggs	Cereals	Other vegetable products
	Dairy bulls and heifers	Beef cattle						
Yield (ton dry matter/ha/year)	5.5	6.3	5.0	5.0	5.5	5.0	4.5	3.2

Sources: Estimates based on FAOSTAT and data in Wirsenius (2000, 2003) and Wirsenius et al. (2010). Yields of cropland-produced protein concentrates and of permanent pasture were assumed to be 2.5 and 1.6 ton dry matter per ha, respectively, for all animal food systems

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