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The impacts of the German biofuel quota on sectoral domestic production and imports of the German economy

Luisa Sievers [a,*,1], Axel Schaffer [b]

[a] Fraunhofer Institute for Systems and Innovation Research ISI, Breslauer Strasse 48, 76139 Karlsruhe, Germany
[b] Universität der Bundeswehr München, Werner-Heisenberg-Weg 39, 85577 Neubiberg, Germany

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ABSTRACT

This study analyses the impacts of the German biofuel quota on sectoral domestic production and imports of the German economy. The effects are calculated as net effects, i.e. accounting for the direct and indirect effects of both the additional demand for biofuels and the reduced demand for fossil fuels. The analysis uses an input–output model and information on quantities, production processes, import quotas etc. To calculate the impacts for the agricultural sector, which is obviously of high relevance for biofuel production, two cases are differentiated: first, and in line with classical input–output assumptions, we propose that agricultural production is not constrained by the availability of agricultural land. Thus, biofuel production is basically added to other agricultural outputs. In the second case, agricultural land is considered a limiting factor for production. As a consequence, biofuel production substitutes other agricultural outputs. The results indicate a clear increase of domestic production and a decline of net imports in the first case. In the second case gains in domestic production are smaller and net imports are, in contrast to the first case, increasing.

Contents

1. Introduction

Biofuels are seen as a way to decrease the dependency on fossil fuels in transport and to reduce the emission of greenhouse gases. In many countries, policies exist to promote the substitution of

* Corresponding author.
E-mail addresses: luisa.sievers@isi.fraunhofer.de (L. Sievers), axel.schaffer@unibw.de (A. Schaffer).
[1] Tel.: +49 721 6809446.

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Table 1
Biofuel quota in % of calorific value [5,6].

Year	Diesel	Petrol	Total
2007	4.4	1.2	
2008	4.4	2.0	
2009	4.4	2.8	5.25
2010–2014	4.4	2.8	6.25

fossil fuels with biofuels. The consequences of this substitution on production and employment have been the subject of recent academic studies [1–3]. Multi-sectoral modelling approaches (CGE models, input–output models) are used in most of these studies (compare [4]) and applied to future scenarios that vary with respect to biofuel use.

In Germany, biofuels have been promoted since 2004, and were exempted from mineral oil tax to start with. In 2006, this policy was, in line with EU policy, replaced by mandatory blending of fossil fuel with biofuel [5,6]. As illustrated in Table 1, the biofuel quota (defined as a percentage of calorific value) was increased continuously until 2010, when it reached the maximum of 6.25%. There are minimum quotas for diesel, petrol and total fuel consumption. The petroleum industry has to pay high fees if the quotas are not reached. From 2015 onwards, the quota is no longer based on the calorific value, but on the reduction of greenhouse gas emissions due to the substitution [6].

Fig. 1 illustrates the development of the production and consumption of biofuels in Germany.

This study's objective is to identify the impacts of the biofuel quota on sectoral domestic production and net imports of the German economy. Applying the input–output modelling technique, direct and indirect effects are calculated for the year 2010.[2] We ignore the step-wise introduction of biofuels and compare a setting with and without a biofuel quota.

The paper is structured as follows: Section 2 provides an overview of the relevant literature and the main hypotheses. Section 3 describes the database and methodology. The results are discussed in Section 4. Finally, the paper concludes with a summary of the main findings and policy implications in Section 5.

2. Relevant literature and main hypotheses

The economic impact of substituting fossil fuels with biofuels has been intensely discussed in the last few years. According to Allan [4] multisectoral economic models are necessary to take into account “the specific biofuels feedstock and production technology employed; the sector´s embeddedness in the rest of the economy, through its demand for local resources; and the extent to which new activity is created”.

CGE models have been applied to examine the economic impacts of biofuels for a wide range of regions, including Austria [8], Spain [9], the USA [10], Brazil [11], Argentina [12], Mozambique [13] and Tanzania [14]. The majority of these studies find a positive impact on GDP.

Input–output analyses have the same positive result for various regions of the USA [15–18], Canada [19], Brazil [20,21], Australia [1], Thailand [22], the European Union [3], Croatia [23] and Germany [2]. Obviously, a positive impact on GDP is inherent if the impact of biofuels on the economy is modelled as additional final demand for a new sector without taking into account any substitution effects (fossil fuels) or constraints (e.g. land constraint of the agricultural sector). But in many of the cited studies, these aspects are included and the net impact is still positive, although there might be sectors with reduced output.

In Germany, the economic impact of biofuels is often discussed in the context of renewable energy. Employment effects are the focus of most of these studies. Gross effects concern additional employment generated through the investment in and deployment of renewable energy. These have been estimated on a yearly basis since 2007 [24,25]. In 2013, the gross employment effects of biofuels were estimated at 25,600 jobs. This is about 7% of the total impact of renewable energies. While biofuel deployment and the related jobs have only experienced a slight increase since 2007 ($<10\%$), other renewable technologies have grown much more dynamically.

However, there are also negative economic impacts of renewable energies. First, if the biofuels substitute fossil fuels, additional investments in biofuel production might crowd out investment in fossil fuel production. Second, if biofuels are more expensive than fossil fuels, this leads to a reduced budget for other expenditures. According to Frondel et al. [26], these negative effects might dominate in the long run for the case of electricity from renewable energy. Taking into account both positive and negative impacts and the respective indirect effects yields the net effects. Increased investment activity is found to be a major driver for the positive net effect on economic growth caused by the expansion of renewable energy [27]. In Lehr et al. [28], the net impact is found to be positive and its magnitude is dependent on the export of German renewable energy technology. However, this study does not include biofuels. In the study of Duscha et al. [29], biofuels are included in the portfolio of renewable energy technologies. Their impact was not calculated separately, but the total net impact of renewable energy sources was found to be positive. The net impact of biofuels was discussed in more detail as part of the biotechnology industry [2,30] and was found to be positive. Also in Wydra's study [2], input–output analysis is applied to 3 scenarios with the time horizon 2020. The scenarios differ with respect to bioethanol diffusion (up to 7.25%) and the cost difference of biofuels compared to fossil fuels. The results show a positive impact on net production of up to 1 billion euros and an increase in employment due to bioethanol diffusion of up to 9000 jobs. The main effects occur in the agricultural sector.

The effect of biofuels (and other renewable energy sources) on local value added is derived as specific values per litre plant oil, biodiesel and bioethanol as being put forward by Hirschl et al. [31]. These specific values are then applied to exemplary municipalities which vary in size and renewable energy portfolio. Aggregated at the national level, Hirschl et al. [31] estimated that biofuels contributed 561 million euros to local value added and generated 8600 jobs in 2009. These values can neither be clearly classified as net effects (losses due to the reduced demand for fossil fuels are not considered) nor as gross effects (due to the assumption that energy plants substitute other plants and that there is no additional value added generated by the agricultural sector). Finally, the study of Heinbach et al. [32] builds on these results, but generalizes them for a modelled average municipality.

Despite the varying methods, assumptions and worldwide regions, the generally robust result in the relevant literature leads to:

Hypothesis 1. *Substituting fossil fuels with biofuels leads to a positive net effect on aggregated domestic production over all sectors.*

The sectoral distribution of output losses reflects the input structure of fossil fuel production [1]. This means the main losses occur in the petroleum production sector and the mineral oil

[2] This year is chosen for two reasons. One, it is the first year in which the full quota applies, and two, it is the year of the most recent national input–output table at time of this analysis.

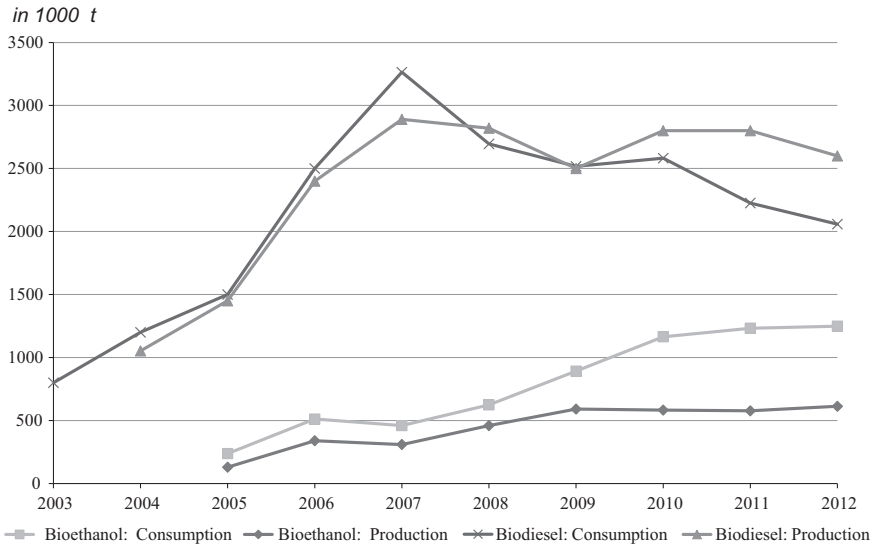

Fig. 1. Production and consumption of biofuels in Germany based on [7].

sector. In the case of Germany, the first concerns domestic production, whereas the latter concerns reduced imports.

The sector which benefits the most from the substitution of fossil fuels by biofuels is agriculture. About 75% of the energy crops used to produce biofuels are cultivated domestically, and 25% are imported. Thus, the impact on domestic agricultural production of the substitution of fossil fuels by biofuels depends strongly on how the land used to grow energy plants would have been used otherwise. This dependence is even stronger in Germany because the conversion of high-value non-agricultural land into farmland in order to grow energy plants is not permitted [33]. Thus, land to grow energy plants is limited to existing agricultural land which, in turn, can mean conflicts between the cultivation of food and of energy plants [34,35]. A similar situation applies to imports as some agricultural goods formerly produced on domestic farmland now have to be imported due to the land being used to grow energy crops. Thus, it is reasonable to assume that the domestic production of energy plants leads to additional imports of agricultural goods. At the same time, the production of biofuel leads, ceteris paribus, to a reduction of imported fossil fuels. This is in line with the political target of increasing the security of energy supply, in particular for the transport sector, where this issue is assumed to be the most relevant [36]. Import dependency on fossil fuels is generally considered more critical than dependency on other imports [37]. Although imports of biofuels are seen as a likely and desired way of reaching the blending targets, they should be in a good balance to domestic production within the European Community [36]. The absence of any discussion of how to weigh increased agricultural and biofuel imports against reduced fossil fuel imports leads to

Hypothesis 2. *Substituting fossil fuels with biofuels leads to a negative net effect on aggregated imports over all sectors.*

3. Methodological remarks

3.1. General approach

This paper focuses on calculating the economic impacts of partly substituting fossil fuels by biofuels. The reference situation of an economy without biofuels is compared to the situation after the (adhoc) introduction of an obligatory biofuel quota assuming that the total demand for fuels measured in energy units remains the same.

Based on empirical data, we propose the introduction of a blending quota of 6.04% biodiesel and 4.15% bioethanol. The mandatory blending of 6.25% of total fuel consumption (Table 1) can be reached with these amounts.[3] To calculate the direct and indirect effects of this quota, the paper applies the static input–output technique and refers to the domestic input–output table and the corresponding import matrix for the year 2010. They consist of 73 sectors and are published by the German Federal Statistical Office.

As mentioned above, economic impacts are calculated for two different scenarios.

First, we propose that agricultural production is not constrained by the availability of agricultural land. In this *unconstrained scenario*, biofuel production basically adds to other agricultural outputs and farmers generate additional revenues. This is not only in line with classical input–output analysis [38], but has also been applied in a more recent analysis of the regional economic impacts of biofuel production [4].

In the second scenario, the availability of agricultural land is considered a limiting factor for biofuel production. As a consequence, biofuel production substitutes other agricultural outputs. In this *constrained scenario,* the domestic cultivation of energy plants replaces other domestic agricultural production which, in turn, implies additional imports of agricultural products.

As the permanent sealing of land continuously reduces the availability of agricultural land, the *unconstrained scenario* seems to be rather unrealistic. However, the existence of large non-food set-aside areas for oilseed indicates that the production of biofuel is not a priori in conflict with food production and that the constrained scenario might also be too strong. However, when regarded together, the constrained and unconstrained scenario might define the lower and upper limit of the direct and indirect effects on domestic production and imports caused by the mandatory biofuel quota.

[3] BAFA [7] provides data on the consumption of fossil fuels and biofuels. We only consider blended biofuels as they are relevant for the quota. The calculated real quota differs slightly from the political quota. This is due to special arrangements for 2nd generation biofuels or the possibility to carry any over fulfilment of the quota into the following year.

3.2. Input–output model

The input–output model used here basically follows the traditional, static, open model according to the following equation

$$X = (I - A)^{-1} Y \quad (1)$$

X: n-element vector of production values
I: $n \times n$ unit matrix
A: $n \times n$ matrix of input coefficients
Y: n-element vector of final demand
n: number of sectors (the applied German IOT accounts for $n = 73$ sectors)

The partial substitution of fossil fuels by biofuels has direct and indirect effects, both of which can be accounted for using input–output analysis. In order to identify the economic impacts of the mandatory blending quota, two slightly different approaches can be applied. First, a new sector "*biofuel products*" could be introduced into the system [1]. However, integrating a new industry into the input–output table requires a detailed understanding of the input and output structure of this sector and is usually only performed by the national statistical offices. This has not yet been done. Instead, biofuels are treated as a subgroup of chemical products.

For this reason, most multisectoral impact studies of biofuel production follow the simpler final demand approach [4]. The basic idea behind this approach, which is described in more detail by Miller and Blair [39], is to account for the different input structure of the specific subgroup by treating the first round of intermediate flows as the final demand impulse. This allows the official input–output table to be applied without neglecting the different input structures of the main sector and the subgroup of specific interest. Any change in investments due to different specific investments in biofuels and fossil fuels also occur as a change in final demand.

As a consequence, the direct effect of the growing demand for biofuel crops is an increase in the production of chemical products. The indirect effects, however, are not driven by the input structure of chemical production, but by the input structure of the subgroup biofuels. Agricultural inputs, for example, are much higher for biofuel production compared to the input structure of general chemical products.

The main shortcoming of this approach is that the substitution effect is only considered in the first round of intermediate flows due to the fact that the technology matrix and thus the Leontief Inverse remain unchanged. Demand for fuels resulting from indirect effects in the next order only reflects the production structure of fossil fuels. However, in the analysed case of only moderate blending and thus limited indirect effects on fuel demand, it is reasonable to simplify by using the final demand approach.

3.3. Direct and indirect effects on domestic production and imports

3.3.1. Direct effects

Statistics on German biofuel production are provided by UFOP [40] for biodiesel and by BDBe [41] for bioethanol. The imports of biofuels are calculated as the difference between production and consumption [7]. In order to calculate the production value, we assume that producer prices for domestic and imported biofuels are the same [42].

In addition to direct sales, the biofuel industry has revenues from by-products. The most relevant by-product of biodiesel is rapeseed cake, which is used as animal feed. By-products of sugar beet-based bioethanol are vinasse and beet pulp. When producing bioethanol from crops, one output is DDGS.[4] The production value from selling rapeseed cake is calculated as follows: the value per toe as given by Neuwahl et al. [3] is increased by a factor of 1.6 and multiplied by the amount of biodiesel in toe. Using this factor leads to more realistic biodiesel production costs (whole sale price minus 15%) than just using the oil price correction factor as given in [43]. The values given by Wydra [2] for wheat- and sugar beet-based bioethanol are used to calculate the by-product output of bioethanol based on the raw material mix of 2010 [41]. In the logic of the German input–output table, these additional outputs of the German biofuel industry are assigned to animal feed production – a subgroup of the food production sector [44]. As most of the by-products used to be imported before mandatory blending was introduced, any increases in domestic production are offset by decreases in imports.

The additional demand for biofuel products is offset by a reduced demand for petroleum products. It is assumed that biofuels substitute fossil fuels according to their energy content as given by the Federation of German bioethanol industry (BDBe) [45]. The direct effect on the petroleum industry is calculated as a negative product of the substituted amounts and the fossil fuel producer prices [46,47]. All effects occur domestically, as only intermediate products for fossil fuel production are imported, but not petrol or diesel. It should be noted that price effects of the substitution are not taken into account in this study.[5]

Following this approach, the direct effects on domestic output equal the changes in domestic final demand (ΔY_0) for the sectors of petroleum products, chemical products and food products.

$$\Delta X_{\text{direct}} = \Delta Y_{0,\ \text{dom}} \quad (2)$$

The same holds for imports.

$$\Delta Imp_{\text{direct}} = \Delta Y_{0,\ imp} \quad (3)$$

An overview of the data used to derive the direct effects is given in Table A1 in the Appendix.

3.3.2. Indirect effects

The additional demand for the intermediates needed for biofuel production and the reduced demand for intermediates due to the substituted fossil fuel production are taken from the detailed statistics on German biofuel production and the national input–output table. As mentioned above, these changes in the demand for intermediate products are treated as a final demand impulse distinguishing between domestic production and imports ($\Delta Y_{1,\ \text{dom}}$ and $\Delta Y_{1,\ \text{imp}}$). Additional investments in biofuel production and reduced investments in fossil fuel production lead to an investment impulse (ΔInv_{dom} and ΔInv_{imp}). The domestic final demand impulse and the investment impulse are aggregated and multiplied by the Leontief inverse $(I-A)^{-1}$ to calculate the indirect effect on domestic sectoral output:

$$\Delta X_{\text{indirect}} = (I - A)^{-1}(\Delta Y_{1,\ \text{dom}} + \Delta Inv_{\text{dom}}) \quad (4)$$

This study not only considers the imports of intermediates for biofuel/fossil fuel production and imported investments. In addition, the indirect effects on imports account for the change in imported intermediates corresponding to the change in domestic production. This can be calculated using the import coefficient matrix (A_{imp}).

$$\Delta Imp_{\text{indirect}} = \Delta Y_{1,\text{imp}} + \Delta Inv_{\text{imp}} + A_{\text{imp}} \Delta X_{\text{indirect}} \quad (5)$$

Indirect effects do not include direct effects as the final demand approach starts with changes at the stage of intermediates for fuel production. The total impact on sectoral output and imports is thus given as the sum of direct and indirect effects.

[4] Dried distillers grains with solubles.
[5] The possible impact of the quota on the blended fuels is discussed in Sievers et al. [48].

3.4. Applied scenarios

The input structure of biofuel production indicates that a successful implementation of the mandatory quota relies strongly on agricultural inputs. This is true for the production of biodiesel, which makes use of rape seed [49], but also holds for bioethanol that largely depends on sugar beets and wheat. Detailed statistics on the production processes make it possible to calculate the quantities needed to produce one litre of biodiesel and bioethanol respectively [50]. The total agricultural input in tons can be estimated by taking into account the total number of litres needed to fulfil the mandatory quota. Multiplying this amount of raw material by the producer prices finally yields the additional demand in monetary units [41,42].

Statistics on the foreign trade in energy plants further allow differentiating domestic inputs and imports [40,51]. If net imports are negative, it is assumed that the total amount of raw material originates from domestic production; otherwise net imports equal the difference between total consumption and domestic production.

Based on this information, the value of domestic production and imports of energy plants can be derived. However, in order to calculate economic impacts, it is of further interest whether farmers cultivate energy plants in addition to or instead of other plants. This is examined by applying two scenarios: an unconstrained scenario and a constrained scenario.

In the *unconstrained scenario,* land and other production factors employed in the agricultural sector are not constrained. Thus, domestically produced energy plants are cultivated in addition to other plants, i.e. they increase the output of the agricultural sector. Agricultural imports increase by the value of imported energy plants.

At first glance, this unconstrained scenario seems rather unrealistic. However, the existence of large non-food, set-aside areas for oilseeds, the cultivation of energy plants on marginal land and the use of fallow land to grow energy plants all indicate that farmers are indeed using previously unfarmed land to grow energy crops [52].[6]

In the *constrained scenario,* we assume that land (amongst other production factors) represents a limiting factor for the agricultural sector. Thus, energy crops are cultivated at the expense of other plants. However, as no farmer is forced to cultivate energy crops, it can be reasonably assumed that, if he chooses to do so, the cultivation of energy crops must be at least as profitable as using the land for other purposes. This is in line with the findings of a recent survey of more than 640 Bavarian farmers, which found that most farmers cultivating energy crops think that the financial bonus of monetary output is indeed higher for energy plants than for food plants. Some energy crop growers see no major difference in income, but are primarily interested in diversifying their income [53]. It is therefore proposed that the output (measured in monetary units) of domestic agricultural production remains unchanged in the constrained scenario. However, due to the occurrence of by-products from growing energy crops, there is an increase in the production of animal feed (as part of the food production sector). The latter is also the case for the unconstrained scenario.

In line with the unconstrained scenario, imports increase by the value of imported energy plants. But in contrast to the unconstrained scenario, imports additionally increase by the value of other agricultural goods formerly produced on land now used for the cultivation of energy crops. Finally, the increased domestic production of animal feed is accompanied by a corresponding decrease of imports in the food production sector.

Neither scenario reflects the real situation. Instead, they describe two extremes. While the unconstrained scenario slightly overestimates the domestic economic impacts of the mandatory blending quota, the constrained scenario generally underestimates them.

4. Results

The next section presents the results of this study concerning the impact of the German biofuel quota on sectoral production and imports. The direct effects are not changed by the assumptions about constraints on the agricultural sector. This is not the case for the indirect effects or, consequently, the total economic impact that are therefore given for both scenarios.

4.1. Direct effects

Within the German quota scheme, the domestic biofuel industry (classified under NACE as part of the chemical product sector) generated revenues of 1.83 billion euros through the sale of biofuels; 0.34 billion euros were generated by the foreign biofuel industry. By-products from domestic biofuel production led to an increase of 0.49 billion euros in domestic food products and to a respective decrease of the same magnitude in imports. Substitution effects resulted in a reduction in the use of fossil fuels. As a consequence, the domestic petrol industry had a loss of revenues totalling 1.46 billion euros. In sum, the direct effects increase domestic production by 0.77 billion euros and decrease imports by 0.15 billion euros.

4.2. Final demand and investment impulses

Biofuel production relies primarily on agricultural inputs which have already been discussed above in the context of the applied scenarios. Energy plants grown domestically for German biofuel production are valued at 1.39 billion euros, and the imports of such plants (mainly rapeseed) at 0.45 billion euros.[7] Beside agriculture, several other industries contribute direct inputs to the production of biofuels, or are negatively affected by the substitution of fossil fuels. For the latter, especially the reduced imports of crude oil (0.97 billion euros) have to be mentioned. Indeed, the input structure of biofuel and fossil production is intensively discussed in the corresponding literature. This applies to the physical inputs (based on the recipes of biodiesel and bioethanol) and the monetarized values [2,3,54]. Furthermore, the share of each sector's domestic production and imports is calculated from the official input–output tables [44].

The specific investments in the domestic production of bioethanol [54] and biodiesel [3] are slightly higher than the investment values for fossil fuels which are assumed to be equivalent to the specific depreciation in the petroleum sector [44,54]. The resulting investment delta of 72 million euros increases total investment in the economy. In line with Wydra [54], the investment structure of fossil fuels and biofuels is based on the German national investment structure [44] with a weighting of 15% and 85% between investments in buildings and in machines, respectively. Shares of domestically produced and imported investments in each sector are applied [44].

The resulting changes in the final demand and the investment vectors are summarized in Tables 2 and 3 for domestic production

[6] The use of fallow land, for example, can be traced back to former regulations according to which farmers were obliged to keep a certain percentage of fallow land, which was not allowed to be used for food production, but could be used to cultivate plants for other purposes. As a consequence, about 25% of the land used for energy crops was fallow land. Though the regulation was abolished in 2010, farmers still cultivate energy plants on areas which would have been left fallow otherwise [52].

[7] In the unconstrained scenario, the domestic production of energy plants is treated as additional domestic impulse, whereas, in the constrained scenario, the complete figure of 1.84 billion euros was regarded as an increase in imports.

Table 2
Proposed final demand impulse (domestic production).

[Mill. euros 2010 p.a.]	Final demand impulse					
	Biodiesel	Ethanol	Diesel	Petrol	Investments	Total
Agriculture, forestry and fishing	1150.0	241.2	0.0	0.0	0.0	1391.2
(Agriculture, forestry and fishing constrained scenario)	(0)	(0)	(0)	(0)	(0)	(0)
Crude petroleum and natural gas	7.0	0.0	−1.9	−0.8	0.0	4.3
other Mining	0.0	0.0	−2.8	−1.1	0.1	−3.8
Coke and refined petroleum products	0.0	0.0	−49.6	−19.2	0.0	−68.9
Chemical products	65.2	11.3	−1.2	−0.5	0.0	74.9
Other manufacturing	0.0	0.0	−18.1	−7.0	27.7	2.5
Electricity, gas, steam and air conditioning supply	27.4	19.7	−11.1	−4.3	0.0	31.7
Water supply; sewerage, waste management, remediation	3.1	2.3	−0.5	−0.2	0.0	4.7
Construction	1.5	1.1	−1.8	−0.7	8.4	8.5
Wholesale and retail trade	0.0	0.0	−28.0	−10.9	5.7	−33.1
Transportation and storage	0.0	0.0	−16.9	−6.5	0.0	−23.4
Accomodation and Food Service activities	0.0	0.0	0.0	0.0	0.0	0.0
Information and communication	0.0	0.0	−1.3	−0.5	7.1	5.2
Financial and insurance activities	32.7	18.3	−4.4	−1.7	0.0	45.0
Real estate activities	0.0	0.0	−2.6	−1.0	0.3	−3.3
Professional, scientific and technical activities	0.0	0.0	−14.6	−5.7	1.0	−19.3
Administrative and support service activities	0.0	0.0	−3.1	−1.2	0.2	−4.0
Public administration, defence; compulsory social security	0.0	0.0	−1.4	−0.5	0.1	−1.9
Education	0.0	0.0	−0.2	−0.1	0.0	−0.3
Human health and social work activities	0.0	0.0	0.0	0.0	0.0	0.0
Arts, entertainment and recreation	0.0	0.0	0.0	0.0	0.3	0.3
Other service activities	0.0	0.0	−1.4	−0.5	0.0	−1.9
Activities of households	0.0	0.0	0.0	0.0	0.0	0.0
Total	1287.1	293.9	−160.9	−62.4	50.8	1408.4
(Total constrained scenario)	(137.1)	(52.7)	(−163.7)	(−63.5)	(50.9)	(17.2)

Table 3
Proposed changes of final demand and investments (imports).

[Mill. euros 2010 p.a.]	Final demand impulse					
	Biodiesel	Ethanol	Diesel	Petrol	Investments	Total
Agriculture, forestry and fishing	450.0	0.0	0.0	0.0	0.0	450.0
(Agriculture, forestry and fishing constrained scenario)	(1600)	(241.2)	(0)	(0)	(0)	(1841.2)
Crude petroleum and natural gas	98.4	0.0	−698.3	−271.0	0.0	−870.9
other Mining	0.0	0.0	−4.5	−1.7	0.0	−6.2
Coke and refined petroleum products	0.0	0.0	−57.0	−22.1	0.0	−79.2
Chemical products	22.9	4.0	−6.9	−2.7	0.0	17.3
Other manufacturing	0.0	0.0	−3.9	−1.5	20.3	14.9
Electricity, gas, steam and air conditioning supply	0.9	0.7	−0.3	−0.1	0.0	1.2
Water supply; sewerage, waste management, remediation	0.0	0.0	0.0	0.0	0.0	0.0
Construction	0.0	0.0	0.0	0.0	0.0	0.0
Wholesale and retail trade	0.0	0.0	−0.6	−0.2	0.0	−0.8
Transportation and storage	0.0	0.0	−0.7	−0.3	0.0	−1.0
Accomodation and Food Service activities	0.0	0.0	0.0	0.0	0.0	0.0
Information and communication	0.0	0.0	−0.1	−0.1	0.9	0.7
Financial and insurance activities	7.1	4.0	−0.9	−0.4	0.0	9.8
Real estate activities	0.0	0.0	0.0	0.0	0.0	0.0
Professional, scientific and technical activities	0.0	0.0	−4.4	−1.7	0.1	−6.0
Administrative and support service activities	0.0	0.0	−0.2	−0.1	0.0	−0.3
Public administration, defence; compulsory social security	0.0	0.0	0.0	0.0	0.0	0.0
Education	0.0	0.0	0.0	0.0	0.0	0.0
Human health and social work activities	0.0	0.0	0.0	0.0	0.0	0.0
Arts, entertainment and recreation	0.0	0.0	0.0	0.0	0.0	0.0
Other service activities	0.0	0.0	0.0	0.0	0.0	0.0
Activities of households	0.0	0.0	0.0	0.0	0.0	0.0
Total	579.3	8.6	−777.9	−301.9	21.3	−470.6
(Total constrained scenario)	(1729.3)	(249.8)	(−777.9)	(−301.9)	(21.3)	(920.4)

and imports, respectively.[8] The changes for the constrained scenario are given in brackets.

[8] Calculations were done for 73 economic sectors but these are grouped as classified in NACE rev 2.1 for the sake of clarity, unless they contributed substantially as a single sector to a change in output.

4.3. Economic impact including indirect effects

The total impact on domestic output was estimated for 73 economic sectors. This consists of the direct effects discussed above and the indirect effects which were derived using the aggregated final demand and investment impulse. The total impact on imports is the sum of the direct effects on imports, imported intermediates and investment goods for fuel production and the change in the imported

Table 4
Direct effects, applied impulse and total (direct and indirect) impact on domestic production and imports in the unconstrained scenario.

	Domestic production				Imports			
	Direct [Mill. euros]	Impulse [Mill. euros]	Total [Mill. euros]	Relative [%]	Direct [Mill. euros]	Impulse [Mill. euros]	Total [Mill. euros]	Relative [%]
Agriculture, forestry and fishing		1391.20	1758.52	3.52		450.00	474.05	1.86
Crude petroleum and natural gas		4.32	4.96	0.21		−870.87	−877.53	−1.33
other Mining		−3.84	7.87	0.05		−6.19	−1.95	−0.02
Food products (include by-products of biofuel production)	490.20	0.00	608.08	0.38	−490.20	0.00	−460.96	−1.06
Coke and refined petroleum products	−1388.60	−68.85	−1419.22	−2.34	0.00	−79.19	−53.48	−0.16
Chemical products (include biofuels)	1831.30	74.90	1992.52	1.28	337.60	17.25	430.36	0.63
Other manufacturing		2.54	110.40	0.01		14.89	65.71	0.01
Electricity, gas, steam and air conditioning supply		31.75	96.43	0.08		1.19	2.73	0.01
Water supply; sewerage, waste management; remediation		4.72	35.56	0.07		0.00	11.99	0.16
Construction		8.54	54.60	0.02		0.01	0.06	0.03
Wholesale and retail trade		−33.13	111.08	0.03		−0.82	4.88	0.09
Transportation and storage		−23.40	27.07	0.01		−1.02	4.43	0.01
Accomodation and food service activities		0.00	1.32	0.00		−0.02	1.27	0.02
Information and communication		5.20	28.88	0.01		0.68	6.43	0.03
Financial and insurance activities		44.99	129.56	0.05		9.80	13.87	0.12
Real estate activities		−3.34	42.16	0.01		0.00	0.04	0.01
Professional, scientific and technical activities		−19.29	62.87	0.03		−6.03	6.06	0.01
Administrative and support service activities		−4.02	198.71	0.11		−0.33	8.30	0.11
Public administration; defence; compulsory social security		−1.88	19.23	0.01		0.00	0.04	0.01
Education		−0.27	1.56	0.00		0.00	0.00	0.00
Human health and social work activities		−0.04	1.16	0.00		0.00	0.00	0.00
Arts, entertainment and recreation		0.26	2.14	0.00		0.00	0.02	0.00
Other service activities		−1.90	8.44	0.01		0.00	0.00	0.00
Activities of households		0.00	0.00	0.00		0.00	0.00	0.00
Total	932.90	1408.45	3882.36	0.08	−152.50	−470.64	−363.68	−0.04

investments and imports of intermediates related to the indirect effects on domestic production.

Direct effects, the applied impulse and the total impact on sectoral domestic production and imports are given in Table 4 for the unconstrained scenario and in Table 5 for the constrained scenario.[9] The total impact is not only given as an absolute but also as a relative change.

According to the analysis of the unconstrained scenario, blending with biofuels leads to a net increase in domestic output by about 3.88 bn euros (0.08%). The direct effects discussed are of major relevance for the change in domestic output. In addition, the agricultural sector contributes substantially in this scenario (1.76 bn euros), mainly due to the domestic production of energy plants, i.e. the first round of intermediate flows, but also due to additional indirect effects. The other sectors are of minor importance but, together, still increase domestic output by about 0.94 bn euros. This can be explained by the fact that the final demand impulse for the domestic agricultural sector triggered substantial indirect effects. Imports decrease slightly by 0.36 bn euros (0.04%) in the unconstrained scenario. The sectoral distribution shows the direct effects (imported biofuels, reduced imports of feedstock), but is dominated by indirect effects, namely the increase in imported energy plants and the decrease in crude oil imports. Indirect effects in other sectors are of minor importance, but, when aggregated, they still increase imports by 0.12 bn euros. The net effect of the biofuel quota on imports is rather small in the unconstrained scenario, because increasing and decreasing effects are almost balanced. The impact on individual sectors, however, can be substantial.

We do not differentiate between the unconstrained and the constrained scenario for direct effects. The applied impulse only differs in the allocation of the additional demand for agricultural products to domestic production and imports. The results on the total impact (Table 5) show the relevance of the constrained scenario: the difference between the two scenarios not only occurs in the domestic agricultural sector but in the economy as a whole. In the constrained scenario, the increase in domestic output (1.03 bn euros, 0.02%) is much smaller than in the unconstrained scenario. In the constrained scenario, the direct effects dominate the impact on sectoral domestic output. Unlike the unconstrained scenario, the contribution of indirect effects to changes in domestic output can be neglected. The relative change in domestic output is less than 0.1% for almost all these sector groups. Imports increase by 0.74 bn euros (0.07%) in the constrained scenario. The sectoral distribution is similar to the unconstrained scenario, but the increase in agricultural imports is much stronger. This implies that indirect effects dominate direct effects to the extent of changing the net impact from a decrease to an increase in imports.

[9] Calculations were done for 73 economic sectors but, for the sake of clarity, they are grouped as classified in NACE rev 2.1 unless they contributed substantially as a single sector to a change in output.

5. Conclusions

This study analysed the direct and indirect effects of the quota-regulated substitution of fossil fuels with biofuels on sectoral production and imports of the German economy. Input–output analysis was used as the methodology, and the data was based on statistics for the year 2010 and recent literature. Concerning our hypotheses, the results show the following:

Hypothesis 1. *Substituting fossil fuels with biofuels leads to a positive net effect on aggregated domestic production over all sectors.*

The results corroborate this hypothesis, but the effect is very small ($<0.1\%$) in relation to total domestic production. The main effects occur in the sectors: chemical products (biofuels), food products (by-products of biofuels), agricultural products (main intermediates for biofuel production), petroleum products and crude petroleum (main intermediate of fossil fuel production). The analysis of the two scenarios shows that the results are very sensitive to assumptions concerning the constraints on domestic agricultural production. Treating the domestic production of energy plants as additional (unconstrained scenario) led to

Table 5
Direct effects, applied impulse and total (direct and indirect) impact on domestic production and imports in the constrained scenario.

	Domestic production				Imports			
	Direct [Mill. euros]	Impulse [Mill. euros]	Total [Mill. euros]	Relative [%]	Direct [Mill. euros]	Impulse [Mill. euros]	Total [Mill. euros]	Relative [%]
Agriculture, forestry and fishing		0.00	0.25	0.00		1841.20	1841.32	7.63
Crude petroleum and natural gas		4.32	4.31	0.18		−870.87	−910.23	−1.38
other Mining		−3.84	1.64	0.01		−6.19	−5.33	−0.04
Food products (include by-products of biofuel production)	490.20	0.00	491.24	0.31	−490.20	0.00	−489.54	−1.13
Coke and refined petroleum products	−1388.60	−68.85	−1459.31	−2.41	0.00	−79.19	−82.71	−0.24
Chemical products (include biofuels)	1831.30	74.90	1949.01	1.26	337.60	17.25	369.65	0.54
Other manufacturing		2.54	9.87	0.00		14.89	12.41	0.00
Electricity, gas, steam and air conditioning supply		31.75	44.26	0.04		1.19	1.32	0.00
Water supply; sewerage, waste management; remediation		4.72	5.84	0.01		0.00	0.76	0.01
Construction		8.54	9.97	0.00		0.01	0.01	0.01
Wholesale and retail trade		−33.13	−31.40	−0.01		−0.82	−1.04	−0.02
Transportation and storage		−23.40	−36.47	−0.02		−1.02	−2.13	−0.01
Accomodation and food service activities		0.00	−0.01	0.00		−0.02	−0.11	0.00
Information and communication		5.20	6.77	0.00		0.68	0.94	0.00
Financial and insurance activities		44.99	54.69	0.02		9.80	10.35	0.09
Real estate activities		−3.34	−2.54	0.00		0.00	0.00	0.00
Professional, scientific and technical activities		−19.29	−14.65	−0.01		−6.03	−5.51	−0.01
Administrative and support service activities		−4.02	−3.49	0.00		−0.33	−0.08	0.00
Public administration; defence; compulsory social security		−1.88	1.19	0.00		0.00	0.00	0.00
Education		−0.27	0.06	0.00		0.00	0.00	0.00
Human health and social work activities		−0.04	0.12	0.00		0.00	0.00	0.00
Arts, entertainment and recreation		0.26	0.55	0.00		0.00	0.00	0.00
Other service activities		−1.90	−1.97	0.00		0.00	0.00	0.00
Activities of households		0.00	0.00	0.00		0.00	0.00	0.00
Total	932.90	17.25	1029.88	0.02	−152.50	920.56	740.06	0.07

substantial indirect effects on domestic production. These indirect effects were very small in the constrained scenario.

The findings of this study can be taken as a good estimation of the net impact of the policy. The method includes the indirect effects with respect to the substitution in the production process. However, the reader should keep the following aspect in mind. With respect to demand, fossil fuels and blended fuels were treated as perfect substitutes [1] so that the production recipes of all other industries remain unchanged. This means that possible additional expenditures for fuels were not included in this analysis [48] nor were impacts on oil price [55]. The additional expenditures were, however, rather small in 2010, and are expected to decline still further in the future (learning effects biofuels, rising fossil fuel prices). In principle, it would have been possible to include them by using a price model which also accounts for the indirect effects [3], or choosing the more aggregated approach of decreasing the final demand for other products [2]. In both cases, further assumptions would have been needed.

Hypothesis 2. *Substituting fossil fuels with biofuels leads to a negative net effect on aggregated imports over all sectors.*

The findings of this study do not corroborate this hypothesis. On the contrary, we found a strong decline of imports in the crude petroleum sector (main intermediate for domestic fossil fuel production) and in food products (reduced need for imports due to the by-products of biofuel production). Imports of the petroleum products sector only decline slightly as these are mainly produced domestically. On the other hand, additional imports of biofuels and agricultural products are necessary. This increase outweighs the decrease in the other sectors. However, the results on imported agricultural goods are very sensitive to assumptions made about the production limit of the domestic agricultural sector. For the unconstrained scenario (i.e. domestic production of energy plants is additional), agricultural imports rise by less than 0.5 bn euros (compared to 1.8 bn euros for the constrained scenario). Thus, for this scenario, the net impact on imports is slightly negative. The relative increase (or decrease) of imports compared to the total amount of imports is very small for both scenarios (less than 0.1%). From a political perspective, decreasing import dependency includes more aspects than just the amount of imports, such as the political stability of the exporting country, dependency on a limited number of countries and possibilities for substitution, market structure etc. With respect to these aspects, a decline in crude petroleum imports might count more than an increase in imported agricultural goods and biofuels.

In summary, it can be concluded that the German biofuel quota only has a minor impact on domestic production and imports of the German economy. There is a positive overall impact on domestic production. From a methodological point of view, input–output analysis proved to be a suitable method and the final demand approach was sufficient for this case. The analysis of the two scenarios showed that the findings are highly dependent on the assumptions made regarding the limitation of domestic agricultural production. Including empirical data on this aspect could improve the quality of this analysis. Although the constrained scenario seems to be more likely in 2010, this may not apply in the future. The declining population and demand for agricultural products, rising productivity of the agricultural sector, cultivation of energy plants on abandoned coal and lignite districts, increase of second generation biofuels – these are all aspects which reduce the competition on productive agricultural land. A clear regulation on indirect land use change could accelerate the latter two aspects and, according to our analysis, increase domestic output and decrease imports.

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Table A1
Database for calculating direct effects.

	Biodiesel	Bioethanol	Based on
Consumption [mill. l]	2532	1449	[7,40,41]
Price [€$_{2010}$/l]	0.61	0.80	[42]
Import share [%]	3	49	[7]
By-products [€$_{2010}$ / t Biofuel]	200	95.6	[2,41,43]
Substituted fossil fuel [mill. l]	2305	940	[45]
Price of substituted fossil fuel [€$_{2010}$/l]	0.434	0.413	[46,47]

Appendix

See appendix table here Table A1.

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