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Impact of changes in diet on the availability of land, energy demand, and greenhouse gas emissions of agriculture

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Abstract

Background: Recent scientific investigations have revealed a correlation between nutrition habits and the environmental impacts of agriculture. So, it is obviously worthwhile to study what effects a change in diet has on land use patterns, energy demand, and greenhouse gas emissions of agricultural production. This study calculates the amount of energy and emission savings as well as changes in land use that would result from different scenarios underlying a change in diet.

Methods: Based on the healthy eating recommendations of the German Nutrition Society, meat consumption in Austria should decrease by about 60%, and consumption of fruits and vegetables has to increase strongly.

Results: This investigation showed that compliance with healthy eating guidelines leads to lower energy demand and a decrease in greenhouse gas emissions, largely due to a decrease in livestock numbers. Furthermore, arable land and grassland no longer needed for animal feed production becomes redundant and can possibly be used for the production of raw materials for renewable energy. The scenario examination shows that in the self-sufficiency scenario and in the import/export scenario, up to 443,100 ha and about 208,800 ha, respectively, of arable land and grassland are released for non-food uses. The cumulative energy demand of agriculture is lower by up to 38%, and the greenhouse gas emissions from agriculture decrease by up to 37% in these scenarios as against the reference situation.

Conclusion: The land use patterns for the scenario demonstrate that animal feed production still takes up the largest share of agricultural land even though the extent of animal husbandry decreased considerably in the scenarios.

Keywords: diet, agriculture, energy

Introduction

Agriculture has various impacts on the environment. One of the most obvious impacts is the emission of methane [CH_4], nitrous oxide [N_2O], and other greenhouse gases from ruminant animals and manure management, the application of mineral and organic fertilizers [1], and soil management practices [2,3]. These greenhouse gas emissions contribute significantly to climate change in line with their global warming potential [1]. In addition, agriculture also contributes to emissions by the consumption of energy, both directly, in the operation and maintenance of plant and machinery used to cultivate cropland and maintain livestock housing, and indirectly, in the form of manufactured mineral fertilizers and pesticides. The level of energy consumption and greenhouse gas emissions depends on the production system, for example, whether organic or not, and on the product mix, i.e., the mix of crops and livestock. It has been shown that organic farming consumes less energy and contributes less to greenhouse gas emissions than conventional agriculture because of the abandonment of fossil-fuel-derived nitrogen and synthetic pesticides [4-11]. Besides the approach to input use, soil management practices, such as tillage, irrigation, use of cover crops [2] in cropping systems,

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and storage of slurries and manures in livestock systems, also influence greenhouse gas emissions from agriculture. In the context of choice of the cropping system, crop rotation has a strong influence on emissions. For example, adapting crop rotations to include more perennial crops, thereby avoiding use of bare and fallow land, reduces greenhouse gas emissions from agriculture by accumulating soil carbon stocks [3]. Animal husbandry is recognized to have higher energy consumption and therefore has more greenhouse gas emissions than arable agriculture. In fact, 18% of the global greenhouse gas emissions stems from livestock production, whereby CH_4 from enteric fermentation in ruminant animals is a major contributor, followed by N_2O and carbon dioxide [CO_2] [12]. The high levels of animal protein found in modern western diets does not only affect land use[a], but is also a significant driver of current levels of energy consumption and greenhouse gas emissions of agriculture [4,5,7-13]. The correlation between nutritional habits and emissions from agriculture has already been shown in other studies with different geographical foci [14,15].

The high land requirements of livestock production, coupled with a growing demand for meat in developing countries, raise the specter of shortages of arable land over the next few decades [16]. Indeed, some authors have also questioned whether it will be at all possible to feed so many animals in the future [17]. In addition, there is a growing demand for land for the production of renewable energy feedstocks [18]. As the markets for crop feedstocks for bioenergy and biofuels grow [19], arable land is bound to be reallocated to meet these new demands [19]. Demand for feedstock for bioenergy can affect food supplies in two ways: first, by diverting land to the production of non-food crops and second, by diverting food and feed crops to renewable energy uses. Both of these outcomes constrain food and feed supply, and this in turn impacts on prices [20]. The years 2007 and 2008 witnessed very significant food price rises, which especially affected the developing countries. One of the major factors for these price increases was the demand for maize for bioethanol production. Although demand for biofuel feedstocks is only one factor pushing food prices up, alongside droughts and bad harvests, biofuel production exacerbated the situation [21]. Among experts, there is an agreement that biofuels have an important role in reducing greenhouse gas emissions, and with energy prices rising and public policies supporting their use, the demand for biofuels will continue to grow. The challenge for governments is to find approaches that can accommodate the competing demands of the food and biofuel sectors. One possible future option is to make biofuels from a cellulosic feedstock which does not compete with food production [22]. Another approach is to encourage a shift to a diet with less meat intake [23]. Stehfest et al. [12] showed that land which becomes redundant because of changed nutritional habits could possibly be used for energy crop production. Table 1 gives estimates of the area which currently might be used for renewable energy feedstock production in Austria, together with a number of scenarios of land use change as modeled in this study.

Both the correlation between the choice of diet, agricultural greenhouse gas emissions, and energy consumption and the land use competition between food and energy crops have already been discussed in past publications, e.g., [12,17,24,25]. A similar work by Freyer and Weik [13] has been done for Austria. They found out that the CO_2e emissions related to a nutritional recommendation by the German Nutrition Society [DGE] are about 1,031 kg per capita and year.

Although a good deal of research has been done on these topics, only a few studies, e.g., [12], have investigated the impacts of a change in diet on agricultural greenhouse gas emissions, energy consumption, and land use in an integrated way for a whole country. The present study addresses this deficit by analyzing the impacts of a change in diet on land use, energy consumption, and the emissions of Austrian agriculture, together with the potential for producing renewable energy feedstocks using redundant land. A major aim of this work is to show the complex interactions between food demand, agriculture, emissions, and renewable energy production.

Finally, we estimate how much renewable energy feedstocks may be produced in Austria without competing with food production in the case of changed nutritional habits. This approach also makes it possible to discuss whether changed nutritional habits are an available

Table 1 Area available for renewable energy feedstock production in Austria currently

Arable land and grassland available for renewable energy feedstock production in Austria				
Baseline situation in 2006	**Estimated potential in 2020 for a national Biomass Action Plan**	**Estimated potential in a Biomass Resource Potential Study in 2020**	**Estimated potential in self-sufficiency scenario (maximum)**	**Estimated potential in import/export scenario (maximum)**
55,000 ha	1,011,000 ha	455,000 ha	443,100 ha	208,800 ha

The said available area for renewable energy feedstock production is also under a number of scenarios of land use exchange. The data come from BRAINBOWS [53] and from the authors' own calculation.

future option to limit the extent of competition between food production and renewable energy feedstock production. The results of this work may provide starting points for an integrated policy addressing the diet of the population, agriculture, and renewable energy production.

Materials and methods

The life cycle assessment [LCA] (EN ISO 14040:2006) approach was chosen to quantify the cumulative energy demand [CED] of and the related greenhouse gas emissions from the conventional agriculture in Austria. The LCA method seems to be appropriate for reaching this goal because the CED and the corresponding emissions are an integrated component of every LCA study [26].

There is no agreed standard for calculating energy balances in the context of agriculture, with various approaches documented in the literature. In terms of analyzing the energetic aspects of agro-ecosystems, a hierarchy of methods exists. The approach adopted for this study is a mechanistic, technical one, where all energy inputs are traced into an agricultural system as physical material flows [27]. The involvement of material flows shows again that the application of the EN ISO 14040:2006 method for this work is appropriate. As a method for measuring the energy demand of agriculture, CED was chosen. The CED was developed in the 1980s and has played an important part in impact assessment since the early development of LCA. Because CED aggregates all forms of energy consumed over the whole life cycle including losses, it is a sum parameter, i.e., a meaningful parameter used to quantify the primary energy demand of a system and its upstream stages. CED is derived from inventory analysis, where mass and material flows have to be known [28], so it does not depend on any assumptions and their associated uncertainties made in impact assessment [29]. CED is also an appropriate yardstick for comparing products [30] and scenarios [31,32]. According to EN ISO 14040:2006, LCA is divided into four steps: goal and scope definition, inventory analysis, impact assessment, and finally, interpretation. The approach taken in this study stops just short of a full conventional LCA, but nevertheless, it consists of a life cycle inventory analysis survey although an impact assessment is carried out for the impact categories, global warming potential and CED. The impact assessment steps of characterizing and classifying inventory results (EN ISO 14040:2006) are necessary to show the results in CO_2 equivalent and the CED [33].

Employing the LCA method on the entire Austrian agricultural system posed some difficulties because LCA methods developed for agriculture are mostly designed for use at farm level [34]. Other agricultural LCA approaches are tailored to just a single agricultural sector [35] or a single agricultural product [36,37]. Therefore, a manageable approach had to be developed to employ the LCA method on the whole of Austrian agriculture. As a result, to reduce complexity, Austrian agriculture is treated as a single average farm. This average farm cultivates all Austrian farmland, grows all demanded crops, and breeds all demanded animals. Crop rotation is determined by the current pattern of crop cultivation, both in the reference case and in the scenario analysis. As a consequence, the LCA can be thought of as being performed at the 'notional' farm level.

Methodology of energy accounting

Definition of the goal and scope for energy accounting in conventional agriculture in Austria

In line with the goal definition and principles of LCA (ISO, 2006) and following the approach taken by Hülsbergen et al. [38], the agricultural production process chain, i.e., all relevant upstream stages of agricultural production (such as the production of fertilizers and pesticides and the upstream stages of energy supply), is taken into account for current energy accounting. On the downstream side, the farm gate is treated as the system boundary. So, transporting crops from the field to the farmyard takes place within the system, but not transporting or processing beyond that point. This ensures the same system boundary for animal husbandry and crop production. The construction and maintenance of agricultural infrastructure such as farm buildings and machines are not within the system boundaries. Other inputs not taken into account are solar energy used by growing crops and energy inputs to human labor.

Figure 1 is a simplified diagram of the LCA system boundaries. The picture shows the main inputs into the Austrian agricultural production system, consisting of mineral fertilizers, organic fertilizers, pesticides, electricity, diesel fuel, thermal energy, and animal feed from industry. The stages of processing the agricultural operating resources are taken into account in the calculations. The CED of seeds is estimated as the CED used for the part of current crop production that is retained for use as seeds in the next cultivation period. In Austrian agriculture, seed retention ranges from 0.5% to 7% depending on the crop. A transport process between field and farm takes place. Cultivated crops and grass forages are brought from the field to the farm, where they are either exported off the farm or fed to livestock. The animal products accounted for are meat, milk, and eggs. The processing stages of food transport off the farm processing are not taken into account.

Life cycle inventory analysis for Austrian agriculture

A life cycle inventory analysis characterizes the juxtaposition of the quantified inputs and outputs [39] of

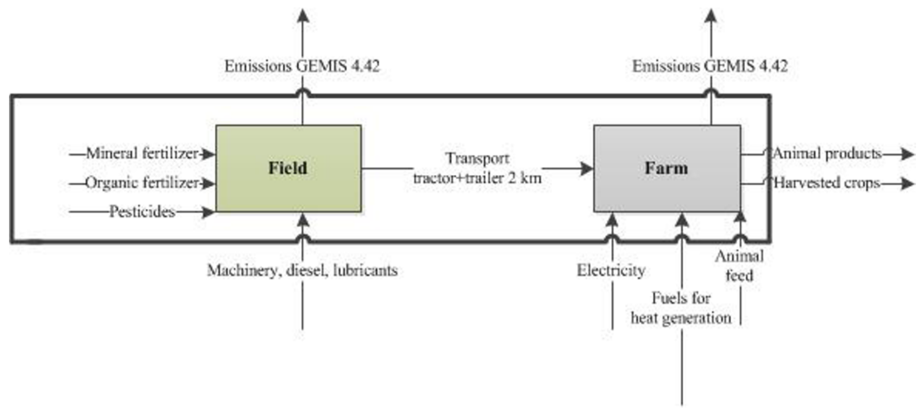

Figure 1 LCA system boundaries. The data are based on the authors' calculation.

agricultural production. In the present case, the inputs are fertilizer, pesticides, animal feed, and energy; the outputs are the emissions involved in consuming these factors of production. The software model Global Emission Model for Integrated Systems [GEMIS] (Version GEMIS Austria 4.42-2007, Institut für angewandte Ökologie e.V., Vienna, Austria) [40] was used to quantify the associated emissions and CED.

GEMIS comprises a lot of different agricultural processes including the correlation of energy demands and CO_2e emissions, describing both plant production and animal production. Consequently, GEMIS makes it possible to take all relevant agricultural processes into account, including energy demand and the associated emissions from upstream stages such as mineral fertilizer and synthetic pesticide production. Not all processes relevant to calculating the CED of Austrian agriculture were available in GEMIS for carrying out process chain analysis; so, some processes had to be modeled, and other processes had to be adapted to Austrian agricultural conditions. For adapting the processes in GEMIS, special data on fertilizer and pesticide application as well as data on the direct energy demand of Austrian agriculture had to be obtained. Data on fertilizer and pesticide application were provided by the Austrian Association for Agricultural Research. Details of the data set used and methods of data generation are described in the literature [11]. For determining the average rates of fertilizer and pesticide application in Austrian agriculture, guidelines published by the Austrian Ministry of Agriculture were used. Other data, especially concerning the direct energy consumption of agriculture, were obtained from the literature [41-46] and from stakeholder interviews. For more details on this procedure and the data that were derived, read about the study of Zessner et al. [47]. In GEMIS, a separate process exists for each agricultural product. As a first step, the CED and emissions are calculated for each agricultural product separately. As GEMIS outputs are denominated per ton of a specific product, the outcome has to be multiplied by the whole production volume determined for the baseline situation and for the scenarios. By this means, the CED and CO_2e for the whole Austrian production of a specific crop or animal product are calculated. Aggregating these results yields the entire CED and greenhouse gas emissions for the whole of Austrian agriculture.

Scenario definition and description

Scenario definition: common assumptions

Initially, it has to be clarified that the scenarios examined in this paper are retrospective. By this means, uncertainties concerning future states of drivers of change such as increasing technical efficiency, demographic changes in Austria, or developments in agricultural policy are avoided. These influencing parameters stay constant *vis-à-vis* the baseline period, i.e., the average of 2001 to 2006. As already stated, in all the scenarios the impacts on the existing conventional agricultural system of changing nutritional habits among the population of Austria are examined. The scenarios have been developed on the assumption that only conventional farming methods are used [47].

For the purposes of scenario analysis (all scenarios), it is assumed that dietary change involves the compliance of the Austrian population with the recommendations of the DGE. Today, meat consumption in Austria exceeds the levels recommended in healthy eating guidelines. According to the DGE recommendations, meat consumption of the average Austrian inhabitant would need to decrease by about 60% of today's level of 57 kg per capita per year. This will result in a shift to more plant-based nutrition, with the consumption of fruits and vegetables increasing by about 50% and 60%, respectively (for a more detailed information, read more on the study of Zessner et al. [48]).

The DGE recommendations refer to specific product groups such as fruits. To calculate the amount of food needed for the population of Austria in one year, the average recommended daily or weekly intake of a specific food product was taken. Next, the amounts of agricultural products, such as milk, eggs, cereals, and oil, needed to meet the demand for healthy nutrition were determined. To calculate total agricultural production, net food consumption was derived using correction factors for each food category. Net food consumption determines how much livestock and arable land is needed to produce all the agricultural goods in demand. Animal feed amounts were derived from the specific animal feed demand per animal category. A distinction was made between ruminant animals and monogastric animals. This calculation yielded the area of arable land and grassland needed for animal feed production [47].

The starting point of each scenario is a change in diet among the population of Austria in line with the DGE recommendations. This change in diet between the baseline situation and the scenarios is presented in Table 2.

Agricultural production has to be adjusted to these changes in commodity demand. In the case of meat consumption, it is assumed that consumption of all meats decreases to the same extent. Although common healthy eating guidelines recommend eating more white meat than red meat, this study assumes that the shares of the various sorts of meat stay the same because people would still prefer red meat. The consumption and production of alcoholic beverages are left unchanged because no commonly accepted recommendation is available from nutrition scientists. As the efficiency of agricultural production is assumed to be the same as in the baseline period, the same amount of resources is consumed in producing a given product conventionally as in the baseline situation. Agricultural production is not expanded to forest areas, and the amount of fallow land cannot increase beyond the level observed in the baseline period [47].

Table 2 Consumption of food by product categories in the baseline situation and the scenarios

Product categories	Baseline situation [kg/per capita/annum]	Scenario situation [kg/per capita/annum]
Meat	56.8	23.4
Eggs	11.8	9.5
Milk and milk products[a]	257.0	279.9
Fish	9.8	0.4
Cereals/rice/potatoes	114.6	129.7
Fruits	58.6	91.3
Vegetables	89.6	146.0
Vegetable oils	9.7	6.8
Sugar	33.0	18.3

[a]Raw milk equivalent; The data are based on the authors' own calculation which is based on the study of Zessner et al.[48].

In the import/export scenario, net imports change in proportion to the change in food and animal feed demand in Austria. An exception is made in the case of saltwater fish because it is assumed that there is no potential, in view of depleted fish stocks, to increase the supply of fish from the world's oceans. The lack of omega-3 and omega-6 fatty acids is made good with vegetable oils. In this scenario, exports stay at the same level as in the baseline situation in absolute terms. Currently, about 26,000 t of meat and 361,700 t of milk are exported per year, with most of the meat exported being beef [47]. Once the main assumptions for the scenario definition have been settled, the different scenarios and sub-scenarios examined in this work can be described.

The scenario development largely depends on the assumed self-sufficiency in agricultural production. Even in the baseline situation, Austria is already close to self-sufficiency in some agricultural goods. Self-sufficiency in grain in Austria was about 100% and self-sufficiency in potatoes, about 96% in 2005/2006; self-sufficiency in meat in Austria was about 106% and in milk, about 136% in the year 2006. Austria is much further from self-sufficiency in oil seeds (59%), fruits (69%), and vegetables (57%). Where Austria is quite close to self-sufficiency, the simplifying assumption is made that the country is 100% self-sufficient in these products. Where full self-sufficiency in agricultural goods is assumed, some consumption assumptions are also required. For example, because rice plays a role in the diet of the average Austrian and because domestic rice cultivation is not possible, in the scenario, modeling has to be replaced by other starchy foods such as potatoes and cereals. Full self-sufficiency also means that the amount of fish recommended by the DGE cannot be produced in Austria, so the Austrian population is assumed to be supplied with omega-3 and omega-6 fatty acids in the form of linseed oil, walnut oil, and rape seed oil. Again, in the full self-sufficiency scenario, tropical and subtropical fruits are replaced by domestic fruits. The substitution was done in line with the ratio of domestic fruit types actually consumed. For example, as apples have the largest share of fruit consumption in Austria, most tropical and subtropical fruits are replaced by apples [47].

In determining agricultural production, crop rotation constraints have to be taken into account. In this case, the following crop rotation constraints were assumed for conventional agriculture in Austria: the share of grains in crop rotation should be < 65%; the share of oil seeds, < 25%; the share of legumes, < 25%; and the share of root crops, < 50%. These constraints are crucial for determining the energy feedstock crops to be produced in the various scenarios [47].

Using the assumptions outlined above, the following scenarios were developed [47] (see Figure 2):

- *'Self-sufficiency' scenario*. The central assumption in this scenario is that Austria is 100% self-sufficient in agricultural goods. No agricultural products are imported or exported.
- *'Import/export' scenario*. In contrast to the self-sufficiency scenario, agricultural goods are imported and exported in the import/export scenario. Exports stay at the same level as in the baseline situation from 2001 to 2006. Imports are adapted to the new demand pattern in Austria after the change in diet. These assumptions are scenario constraints, not a market outcome.

For both the self-sufficiency scenario and the import/export scenario, the following sub-scenarios are examined. In conclusion, six sub-scenarios are calculated.

- *Sub-scenario a*. In this sub-scenario, the agricultural production is limited to food production. The production of renewable energy feedstocks is constant at the level already produced in the baseline situation (2001 to 2006).
- *Sub-scenario b*. In addition to food production, agriculture produces renewable raw materials for supplying itself with bioenergy and biofuels on released arable land and grassland. Furthermore,

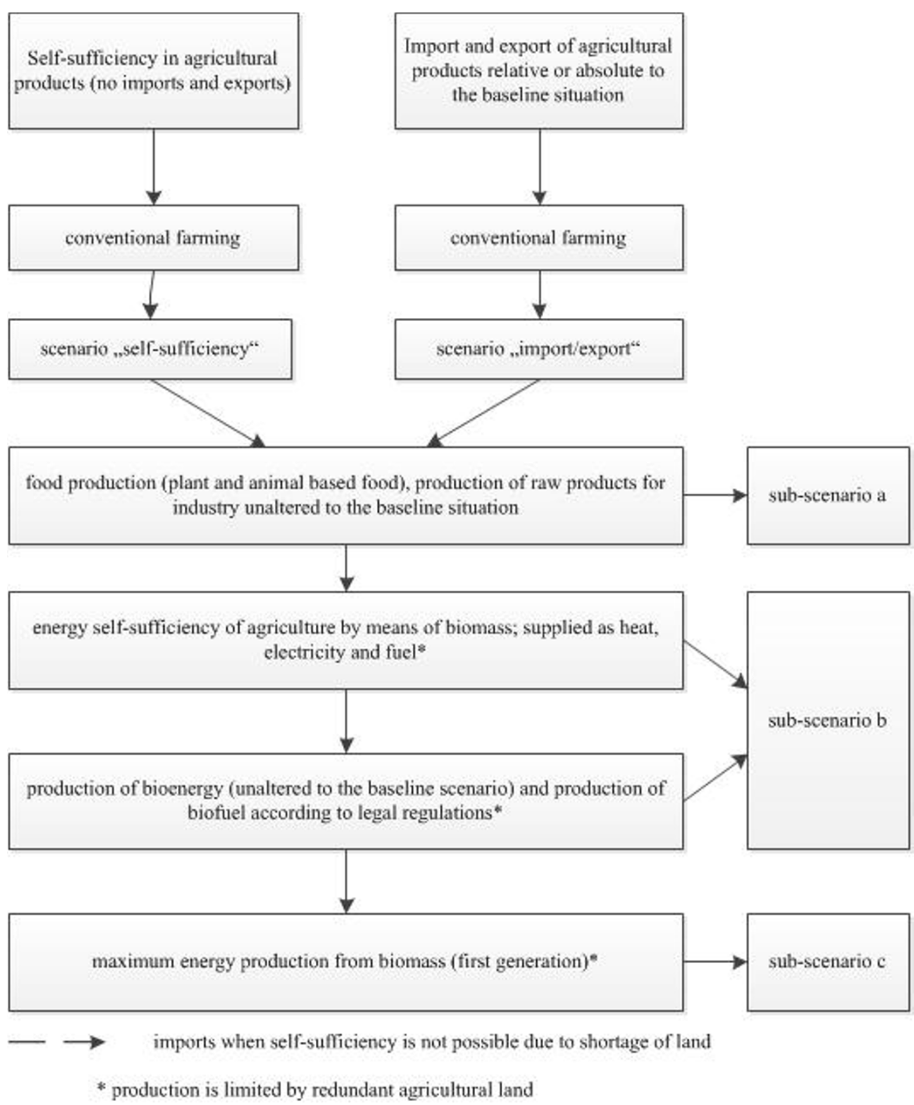

Figure 2 Scenario description. The data are from the authors' calculation which is based on the study of Zessner et al. [47].

biofuels for fulfilling the transport fuel renewable obligation as per mandate of the European Parliament [49] are produced.

- *Sub-scenario c*. This sub-scenario assumes maximum energy production from agricultural raw materials based on first generation bioenergy and biofuel technologies. The general assumption is that all the redundant agricultural land is used for energy feedstock production.

Determining the production of renewable energy feedstocks in the sub-scenarios self-sufficiency (a, b, and c) and import/export (a, b, and c)

One of the main outputs of this analysis is the quantity of renewable energy feedstocks produced under the conditions of the various sub-scenarios. The volumes produced will obviously be dependent on the area of land made available due to decreased meat production. It was assumed that where arable land and grassland are released due to falls in livestock production, this occurs evenly all over Austria. This assumption is necessary because of uncertainties over the likely real world location of the land that was released. It is assumed that this redundant grass is harvested as a feedstock for bioenergy production.

Due to the necessity of crop rotation, oilseed (rape and sunflower) cultivation cannot be expanded in any of the scenarios. The cultivation areas currently observed, 59,000 ha of which is currently used to supply biodiesel feedstocks, are retained as upper constraints. In the scenario analysis, it is assumed that any biodiesel produced is used only within agriculture.

Free grassland and silage maize are used for biogas production. There are two different technical options for the use of biogas for heat and electricity production. One option is combined heat and power generation, and the other option is to feed upgraded biogas into the natural gas grid for power generation in a large-scale gas-power station. A mix of these two technologies is also possible.

In the case of bioethanol production, i.e., to meet the feedstock requirements of the national bioethanol plant, a maize wheat ratio of 1:1 is assumed. As a result, based on average yields, 52,000 ha of wheat and 25,000 ha of maize would be needed to meet the demand.

Results

Because the baseline situation and scenario results that follow are derived from a process chain analysis carried out by means of GEMIS, it is important to show how upstream stages, such as fertilizer production, contribute to a single agricultural production process. To facilitate this, the results are presented by the agricultural sector for each scenario and also for the baseline situation.

The contribution of upstream processing stages to CO_2e and CED

As mentioned above, CED has been chosen as the most appropriate measure to quantify the energy and emission balance of Austrian agriculture in this study because it includes all primary energy used throughout the life cycle. This measure permits the contribution of upstream processing stages, such as fertilizer production, to CO_2e emissions to be estimated. Rather than try to estimate the emissions of all upstream processing, the upstream contribution to wheat production was chosen as an exemplar for the contribution of upstream production stages in general. Wheat was chosen due to its heavy reliance on mineral fertilizer production, which accounts for a large part of the upstream CO_2e contribution of conventional agricultural production. Accounting for all sources, the production of 1 t of wheat yields a CED of 676 kWh and emissions of 360 kg of CO_2e, where 31% of the CED and 27% of the CO_2e emissions are attributable to the processing stage of mineral fertilizer production. It is therefore safe to say that the CED and CO_2e emissions of agricultural products are closely related to the use of mineral fertilizers. It should be mentioned that the use of mineral fertilizers and pesticides in the scenarios stays at the same level as in the baseline situation.

CED and CO_2e emissions in the baseline situation and the scenarios

CED and CO_2e values, for both the baseline and the scenarios, are calculated for Austrian agriculture and displayed for each agricultural sector in Tables 3 and 4. In the scenarios, CED ranges from 30% to 38% lower than in the baseline situation, while CO_2e ranges from 30% to 37% lower. These headline statistics show the significant changes in energy demand and greenhouse gas emissions that would likely accompany a change to a healthier diet.

Although the CED of animal husbandry in the scenarios is nearly halved in comparison to the baseline situation, it remains the agricultural sector with the highest energy demand. Furthermore, these reductions are somewhat offset by a rise in energy demand from vegetable and fruit production, which would see an expansion in production area as a consequence of changed nutritional habits. Taken overall, the CED of Austrian agriculture shrinks in comparison to the baseline situation because less animal feed is needed. The CED of crop cultivation and grassland farming is lower in the scenario 'self-sufficiency a' than in the scenario 'import/export a' because of a difference in animal husbandry. In the scenario 'import/export a' there are more livestock to be fed due to the export of animal products. In sub-scenarios b and c, the CED of renewable energy

Table 3 CED in the baseline situation and the scenarios

	Baseline situation	Scenario self-sufficiency a	Scenario self-sufficiency b	Scenario self-sufficiency c	Scenario import/export a	Scenario import/export b	Scenario import/export c
	CED [MJ/capita]						
Crop cultivation	726	460	595	595	550	724	724
Grassland	460	143	152	220	152	169	198
Animal feed crop cultivation	363	319	325	320	290	290	290
Vegetable production	99	190	190	190	102	102	102
Fruit production	111	245	245	245	142	142	142
Animal husbandry	2,252	1,146	1,146	1,146	1,294	1,294	1,294
Sum	4,005	2,505	2,648	2,715	2,531	2,721	2,75
where the additional energy crop production is calculated as follows:							
Crop cultivation			135	0		174	0
Grassland			9	68		17	6
Sum without additional energy crop production			2,504	2,647		2,530	1,288

The data are based on the authors' own calculation.

feedstocks also needs to be included in the calculations, with sub-scenario c yielding a higher CED than b.

More specifically, the difference in CED between sub-scenarios a and b is due to the share of the CED derived from renewable energy feedstock production in sub-scenario b. In sub-scenario c, the use of grass from pasture as a renewable energy feedstock leads to a further increase in CED. An additional rise in crop cultivation in sub-scenario c is not possible because no more arable land is available.

The emission of CO_2e is closely connected with the CED of agriculture. Animal husbandry causes most of the CO_2e emissions of Austrian agriculture. Under the dietary change scenarios, CO_2e emissions fall reflecting an increased vegetable and fruit production and a decreased grassland farming and animal feed crop cultivation.

Renewable energy feedstock production leads to an additional CO_2e emission from agriculture in the sub-scenarios b and c. This additional CO_2e emission is the difference between the emissions in sub-scenarios a and b compared with b and c. Although renewable energy feedstocks are also produced on arable land in sub-scenario c, there is no increase in CO_2e emissions compared to scenario b because no further expansion of crop cultivation is possible.

Current research shows that Austrian agriculture would emit about 578 kg CO_2e per capita and year provided that nutrition is adapted to DGE recommendations. This discrepancy occurs because of taking the processing of foodstuffs into account [13]. It is difficult to compare the results from this research with other results due to differences in spatial and temporal system boundaries.

Production of renewable energy based on agricultural raw materials

In sub-scenario 'self-sufficiency c', the modeling projects 443,100 ha of renewable energy feedstock production, made up of 86,641 ha of arable land and 356,452 ha of

Table 4 CO_2e emissions in the baseline situation and the scenarios

	Baseline situation	Scenario self-sufficiency a	Scenario self-sufficiency b	Scenario self-sufficiency c	Scenario import/export a	Scenario import/export b	Scenario import/export c
	CO_2e [kg/per capita/annum]						
Crop cultivation	104	69	89	89	86	106	106
Grassland	118	39	42	61	42	47	53
Animal feed crop cultivation	62	56	56	56	50	50	50
Vegetable production	22	43	43	43	23	23	23
Fruit production	7	16	16	16	10	10	10
Animal husbandry	573	355	355	355	377	377	377
Sum	887	578	601	620	587	612	619

The data are based on the authors' own calculation.

grassland. The area of land used for renewable energy feedstock production in sub-scenario 'import/export c' is less than half of that used in sub-scenario self-sufficiency c, i.e., 208,800 ha, made up of 21,464 ha arable land and 187,360 ha of grassland. Looking at the outputs of the modeling, it is apparent that in practice, it would be all but impossible for Austrian agriculture to be self-sufficient in energy through the production of renewable energy feedstocks. However, a partial covering of CED is possible (Table 5).

Table 6 illustrates that agriculture is able to make good a part of its CED by producing renewable feedstocks for energy production. In the best case (sub-scenario self-sufficiency c), enough energy is produced from renewable feedstocks to make good more than half of the entire agricultural CED. Determining factors in the level of CED replacement in agriculture are biofuel and biogas production. With diminished biodiesel production in the sub-scenario 'import/export b,' 21% of the CED can be made good by renewable energy feedstock production. In the sub-scenario import/export c, 37% of the entire CED can be made good. By contrast, in the sub-scenario self-sufficiency c, 68% of the CED is made good by renewable energy feedstock production. As much less bioethanol is produced in the scenarios 'import/export b/c,' total energy feedstock production in these scenarios, and therefore the extent to which CED is made good, is lower than in the case of the self-sufficiency scenarios. It should be pointed out that the data in Table 6 do not take into account the energy consumed in producing renewable energy feedstocks. Consequently, the values given for a share of CED made good are likely to overestimate the actual net level of replacement. Despite this, it is obvious that significant partial agricultural self-sufficiency in energy from renewable feedstocks is possible under the given conditions.

In the sub-scenario 'self-sufficiency b,' about 521,916 ha are used for food production, with a much larger area (1,520,710 ha) used for animal feed production. About 8% of the whole cultivated agricultural area is used for renewable energy feedstock production. The picture is similar in the sub-scenario import/export b, where 461,416 ha of land are used for food production and 1,949,839 ha are used for animal feed production. Only about 10% of the entire agricultural land employed in this sub-scenario is applied for renewable energy feedstock production.

The direct energy demand of agriculture

In self-sufficiency scenario, Austrian agriculture requires about 713 GWh of fuel, 815 GWh of thermal energy, and about 134 GWh of electricity per year. These results were derived by taking the direct energy requirements (per unit of the different crop and animal enterprises), multiplying these by the observed crop production areas and livestock numbers and aggregating to the national level [50]. For the sub-scenarios self-sufficiency b and import/export b, the target is that agriculture produces enough renewable energy feedstocks on free agricultural land to make it as close to self-sufficiency as possible in biodiesel as well as heat and electricity from biogas technology. In addition, enough feedstocks (wheat and maize) have to be cultivated by agriculture annually in order to utilize the capacity of Austria's agriculture and only bioethanol plants to the fullest.

The direct energy demand of agriculture in the import/export scenario is slightly lower than in the self-sufficiency scenario. This is because of the higher proportion of imported goods. So, in import/export scenario, agriculture needs about 755 GWh of fuel, 802 GWh of thermal energy, and about 130 GWh of electricity in total per year [50]. Various factors influence the amount of direct energy needed. The ratio of imported to domestically produced agricultural products has a significant impact on direct energy consumption. A larger share of imported vegetables implies a decrease in the thermal energy needed for cultivation under glass and a lower fuel demand for machinery. Additionally, higher exports of animal products cause an increase in fuel demand for crop cultivation because more animal feed has to be produced domestically.

Consequently, there is a supply gap of 105 GWh. As a result, agriculture cannot be self-sufficient in biodiesel in the sub-scenarios nor can the additive obligation of 5.75% to fossil fuels be fulfilled [51]. The situation is different in the import/export scenario: the ratio of imports to exports not only determines the direct energy consumption, but also influences land use and consequently crop rotation. As a result of decreased land use due to imports and changes in crop rotation, rape for biodiesel production is cultivated on 154,320

Table 5 Contribution of renewable energy feedstock production to the CO_2e emissions of agriculture

	Scenario self-sufficiency b	Scenario self-sufficiency c	Scenario import/export b	Scenario import/export c
	CO_2e [kg/per capita]			
Crop cultivation	20	0	21	0
Grassland	3	19	5	6

The data are based on the authors' own calculation.

Table 6 Comparison of CED and energy production (self-sufficiency scenario and import/export scenario)

	Scenario self-sufficiency b	Scenario self-sufficiency c	Scenario import/export b	Scenario import/export c
Biodiesel [TJ]	2	2	5	5
Bioethanol [TJ]	4,862	4,862	1,366	1,366
Biogas [TJ]	3,415	10,035	3,203	6,773
Sum [TJ]	8,279	14,897	4,577	8,141
CED [TJ]	21,530	22,091	22,115	22,359
Proportion of CED made good [%]	38%	68%	21%	37%

The data are based on the authors' own calculation. TJ, terajoule.

ha. The expansion of rape cultivation is attributable to the imports of oil seeds for human nutrition. Another important fact is the import of fish, which is an important supplier of omega-3 and omega-6 fatty acids. As a result, less oil seeds are needed to meet the fatty acid needs of the Austrian population [50]. This implies a biodiesel production of 1,512 GWh. Agriculture consumes only 755 GWh of biodiesel, and consequently, 757 GWh of biodiesel is available to fulfill the additive obligation or for other uses.

In the sub-scenario self-sufficiency b, 45,143 ha grassland and in sub-scenario import/export b, about 82,000 ha grassland are used for biogas production. In the sub-scenario self-sufficiency b, silage maize is used for biogas production in addition to grassland. In all, 10,393 ha for silage maize is available for biogas production. By contrast, no land is available for silage maize production in the import/export scenario; so, more grassland has to be assigned to the production of biogas. The difference in silage maize production between the two scenarios, self-sufficiency and import/export, again reveals the impact of importing and exporting agricultural goods in Austria. In the import/export scenario, the export of meat induces more animal husbandry so more land is needed for animal feed production, and given the crop rotation constraints, it is not possible to produce more silage maize in this scenario.

In the scenario self-sufficiency b, a total of 200,000 m^3 bioethanol is produced. In the import/export scenario, the production situation for bioethanol feedstocks differs; overall, maize is grown on 6,949 ha and wheat, on 14,515 ha for bioethanol production. In all, 64,522 m^3 are produced in the import/export scenario; so, the capacity of Austria's only bioethanol production plant is not used to the fullest. The increase in meat exports and in animal husbandry necessitates more animal feed production so less land is available for the production of wheat and maize as bioethanol feedstocks.

The only difference between the scenarios self-sufficiency b and self-sufficiency c and between the scenarios import/export b and import/export c is the full usage of grassland for biogas production. In the scenario self-sufficiency c, an additional of 356,452 ha of grassland is used for biogas production. A different situation is indicated in the scenario import/export c, in which the area of grassland for biogas production is lesser than in the scenario self-sufficiency c. In the scenario import/export c, a total of 192,444 ha grassland is available for biogas production. The area of grassland available for biogas production in the scenario import/export c is smaller because of the export of animal products and the simultaneous increase in animal husbandry so that more grass is needed for animal feed. The results of the various scenarios are shown in Figure 3 of this article.

Discussion

This research has shown the extent to which the energy demand and greenhouse gas emissions of agriculture can be influenced by changes in human nutritional habits. A strong correlation between nutritional habits, resource demand, and the environmental burden of agriculture can be inferred. Although the study has Austrian agriculture as its particular focus, this correlation has already been shown in other studies with a different territorial focus [14,15,52]. The results of the present study show that a decrease in meat consumption, arising from a change in diet, causes a release of arable land. This would be a significant outcome for Austrian agriculture with its current dominance by livestock production, driven by high rates of meat consumption both in Austria and its trading partners. These results confirm the findings of other research carried out internationally [14-20,52].

It is important to examine the correlation of nutritional habits with agricultural energy demand and greenhouse gas emissions at a regional level because specific production methods and circumstances can then be taken into account. The main aim of this study was to examine how a change in diet (and concomitant release of land for renewable energy feedstock production) influences the CED and CO_2e emissions of Austrian agriculture. To do this, Austrian agricultural production was modeled as a single average farm, where all agricultural goods in demand are produced. Applying

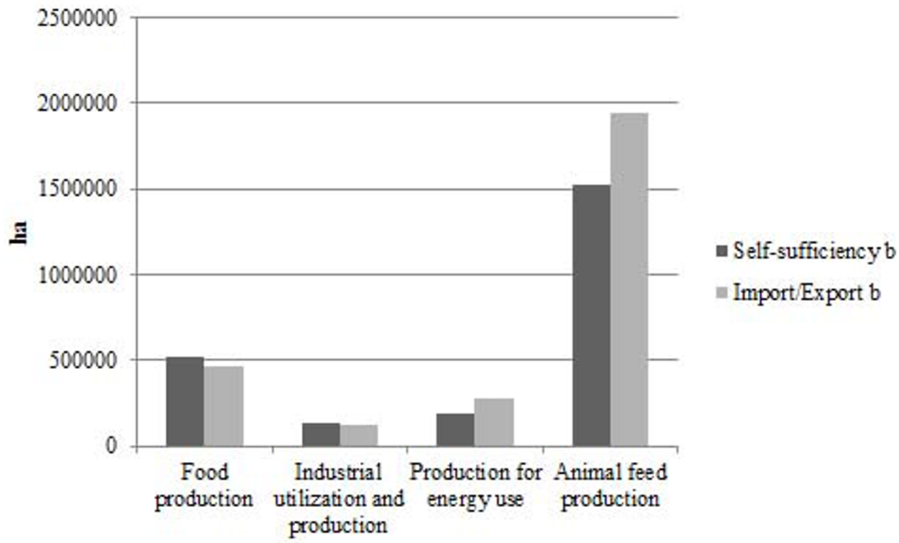

Figure 3 Agricultural land for different uses in the sub-scenarios self-sufficiency b and import/export b. The data are based on the authors' calculation.

this method involves some uncertainties because some parameters cannot be determined in detail. As a result, no statements about soil quality and soil management methods are made. As soil management influences emissions from agriculture and the demand for energy, a detailed scenario calculation for each Austrian production area would lead to results different from the 'averages' presented in this study. In some cases, the values for emissions and energy demand would be higher, for example, in intensive production areas; in other cases, they would be lower, for example, in extensive production areas. Another limitation of this study is that, for energy crop production on redundant land, no precise statements can be made about where this production is located and whether this land is in fact suitable for energy production, or even whether it would be economic to convert surplus land to these uses. Sustainable economic activity by farmers may not lead to the release of land where there are no profitable alternative uses; under these circumstances, land is likely to remain in livestock production, albeit under more extensive conditions. It is therefore a simplifying assumption of the modeling that land that is surplus to food and feed production must be diverted to renewable energy crop production and to only these uses.

Other limiting factors can be identified in the CED calculation. Agriculture receives no energy or emission credits in the sense of the LCA methodology according to ISO 14040 for producing energy crops. As a result, the emissions and energy demand of agriculture are slightly overestimated because emission and energy credits would lower the values of these parameters [52]. Regarding the energy consumption of agriculture, the aim was to examine the demand side; so, the energy input to and output from agriculture are not compared. A further change in energy demand and emissions can be induced if agricultural emissions and energy consumption abroad are calculated. System boundaries have to be set so as to reduce the amount of data that has to be analyzed to manageable proportions. This should not be taken to mean that energy demand and emission output from Austrian agriculture can be brought to zero by simply importing all goods.

BRAINBOWS estimates for Austria that in the year 2020 about 455,000 ha agricultural land could be used for renewable energy crop production [53]. This is slightly higher than the estimate in the sub-scenario self-sufficiency c, where 443,000 ha are projected to be available for renewable energy crop production. It is questionable whether the potential estimated in the study by BRAINBOWS [53] is realistic because this estimate is based on the assumption that set-aside land is used, that surplus goods which are exported at the moment are used domestically, and that demand for animal feed goes down because of the use of co-products from food and particularly biofuel processing. In addition, the development of higher yielding crops and the use of catch crops should guarantee that this potential is realized by 2020. Even if, under the assumptions made in the study by BRAINBOWS [53], a similar amount of agricultural land can be used for energy crops, a change in diet generates further potential. Another advantage of land released because of a change in diet is that this land does not compete with food production.

Conclusion

The present work has shown that change in nutritional habits can have a great influence on agricultural energy consumption and greenhouse gas emissions. Above all, eating less meat would lead to a decrease in negative agricultural environmental impacts. This research involves some uncertainties caused by the simplifications necessarily involved with treating Austrian agriculture as a single 'average' farm. As a result, it was not possible to consider the different conditions of production specific to various farming regions. Despite these uncertainties, the positive effects of reducing meat consumption and basing nutrition on plants to a greater extent on the agricultural energy and emission balance are obvious from the modeling and well attested in the literature. Furthermore, changed nutritional habits can contribute to the achievement of policy targets defined for renewable energy use through the release of redundant land, where a large part of which can be used for renewable energy crops. So, the solution to the problem of increased competition for land for bioenergy production might well be not to increase the area under cultivation in sensitive regions, not to plow up grassland for crop cultivation, nor to increase the agricultural output by applying more pesticides and fertilizers. Even under consistent agricultural production methods in Austria, changed nutritional habits make more arable land available for renewable energy crops. As a consequence, changing nutritional habits would be desirable not only because of the potential benefits that might be obtained in terms of human health, but also because of these secondary emissions and renewable energy benefits.

The novelty of this work is that the impacts of dietary choices on the availability of land for renewable energy production and the positive CED and emissions benefits are examined simultaneously. Existing studies on this topic often focus on the impact of dietary choices either on energy and emissions or on the availability of land, e.g., in the studies conducted by Carlsson-Kanyama [4], Eshel and Martin [9], Risku-Norja et al. [11], Gerbens-Leenes and Nonhebel [54], Elferink and Nonhebel [23], and Dale et al. [52]. This study merges these approaches. The results of this analysis suggest that new options for mitigating greenhouse gas emissions and reducing the use of fossil energy are feasible. A change in diet would be the first step to a more sustainable agriculture and more sustainable production of renewable energy crops. Thus, this work also demonstrates the importance of an integrated policy design, encapsulating nutrition, agriculture and renewable energy.

The assumption on arable land and grassland available for renewable energy feedstock production in the examined scenario involves an expansion compared to the baseline situation. On the other hand the scenario estimates are lower than the estimates presented in the Austrian Biomass Action Plan. In particular, the import/export scenario shows more modest results than the Biomass Action Plan. By contrast, the self-sufficiency scenario shows results quite similar to the potential estimated in a biomass resource potential study for Austria [52]. For purposes of comparison with existing studies of biomass potential in Austria, the scenario results for maximum renewable energy feedstock production were chosen. In future the role of energy production from agricultural residues will be strengthened and therefore the renewable energy production potential will increase further [55].

However, with a maximum of about 8% of agricultural land used for renewable energy crops under any scenario, the results of the study also show that most of the greater part of agricultural land will always be needed for food and feed production, even if we assume the most positive outcomes in terms of changed nutritional habits.

Endnotes

[a]Production of 1 kg of beef requires an area of 20.9 m^2, while 1 kg of cereals only requires about 1.4 m^2 of arable land [54].

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Authors' contributions
KF carried out the CED and CO_2e calculations as well as the calculation of the energy produced on the redundant land, wrote the manuscript, and was responsible for textual design of the paper. HS contributed to the underlying assumptions and the scenario definition. Furthermore, HS proofread the manuscript and gave some important evidences concerning the structure and content of the paper. All authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

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