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Marnix Brinkman [a], Jason Levin-Koopman [b], Birka Wicke [a], Lindsay Shutes [b], Marijke Kuiper [b], André Faaij [c,d], Floor van der Hilst [a,*]

[a] Copernicus Institute of Sustainable Development, Section Energy & Resources, Utrecht University, Princetonlaan 8a, 3584 CB Utrecht, the Netherlands
[b] Wageningen Economic Research, Prinses Beatrixlaan 582 – 528, 2595, BM, The Hague, the Netherlands
[c] Energy and Sustainability Research Institute, University of Groningen, Nijenborgh 6, 9747 AG Groningen, the Netherlands
[d] TNO Energy Transition. Princetonlaan 6, 3584 CB Utrecht, the Netherlands

A R T I C L E I N F O

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A B S T R A C T

The demand for biofuels is expected to increase significantly in the coming years. However, there are major concerns on the impact of increased biofuel production on food security. As biofuel affects food security in various ways, it is important to assess the impacts on the four pillars of food security, *availability, access, utilisation and stability*. The objective of this study is to ex-ante quantify impacts of biofuel production on the four pillars of food security for urban and rural households in a developing country. We illustrate this for Ghana, which proposed a 10% biodiesel and 15% ethanol mandate for 2030 and which faces food security issues. We used the computable general equilibrium (CGE) model MAGNET in combination with a household and a nutrition module to quantify 13 food security indicators. The results show that the largest food security effects of the biofuel mandate are negative impacts on food prices and import dependency. However, the projected food security impacts of the biofuel mandate in 2030 are relatively small compared to the projected food security effects of economic development in Ghana towards 2030. Our approach enables ex-ante quantification of the effects of biofuel on the four pillars of food security and the differentiation of the effects between urban and rural households. Although improvements can be made, the approach means a big step forward compared to the state-of-the-art knowledge on food security impacts of biofuel production and it could contribute to identify options to minimise negative and optimise positive food security effects.

1. Introduction

Biofuels are an attractive alternative for fossil transport fuels because of the renewable nature of the feedstocks and the potential favourable GHG emission balance compared to fossil fuels [1,2]. The combination of these benefits, with a large untapped feedstock potential [3–5], potential socio-economic benefits of rural development, increased energy access, reduced fossil fuel imports [6–9] and the possibility to benefit financially via the Clean Development Mechanism of the Kyoto Protocol [10] sparked interest in biofuel production in many developing countries [10–17]. However, in public, policy, and academic debates major question marks have been raised on the food security effects of biofuel production, particularly in developing countries. According to the definition of food security from the United Nations Food and Agriculture Organisation (FAO) food security consists of four pillars: *availability*, *access*, *utilisation,* and *stability*. Following this definition, people are considered food secure when they have year-round access to sufficient and nutritious food [18,19]. Concerns about food security impacts resulting from an increased biofuel demand are raised because of competition for land, water, labour and other resources, which could have a negative impact on production and prices of food products [15,20–24].

The rise in global food prices in the period 2007–2008 ignited the food vs fuel debate [13,25]. An increased demand for bioenergy feedstock was thought to have contributed significantly to the price spike in global food markets [26–28]. An increase in global food prices could negatively impact *access* to food, especially in food importing countries and low income (urban) households [20,29–33]. However, the direct causation between increased bioenergy production and higher food prices is hotly debated as many interlinked factors (e.g. weather, energy prices) determine food prices on a global level [25,34–46]. Also on a local level, competition for land and resources can be associated with a reduction in food security [47]. In some case studies in Africa where farmers opted to produce more cash crops, such as bioenergy feedstock,

* Corresponding author.
E-mail address: f.vanderhilst@uu.nl (F. van der Hilst).

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availability and *access* to food has decreased [23,48,49]. Furthermore, a higher dependency of households on crop production for their income makes them more vulnerable to extreme weather events that threaten food crop production, and therefore reduces *stability* [50]. In addition, there are multiple documented cases of land-grabbing, where large tracks of land are purchased by international companies to produce bioenergy feedstocks. As a result, farmers and their production were displaced and local food security was reduced [49,51,52]. As with land, in water scarce areas, competition for irrigation water can reduce food security [53]. Furthermore, the competition for water can potentially reduce the possibilities for cleaning and cooking food, which negatively impacts food security [25,53].

In contrast, also positive impacts of bioenergy production on food security have been reported. Food *availability* and *access* have also been found to increase in areas with additional bioenergy production [54,55]. Bioenergy investments can increase (fixed) employment, raise and stabilise rural income and act as a financial buffer for households. Therefore, these investments can contribute to increasing *availability* and *access* to food [20,23,32,47,54–60]. An increase in global food prices due to bioenergy production, could result in higher incomes of farmers and therefore increase food *access* for net-producers [61]. Technology spill-overs from cash crop production can also raise food crop yields, thereby increasing the food *availability* [23,62–64]. Furthermore, bioenergy can contribute to energy security and can reduce energy price volatility. This positively influences the *utilisation* and *stability* aspects of food security, as improved energy security enhances reliable storage and cooking of food [20,30,65–67].

These diverse findings in the literature on the impact of biofuels on food security demonstrate that the effects depends on the local conditions, as well as on how crops for bioenergy are produced and how the land is managed [68]. Furthermore, it illustrates that biofuel production affects food security in various ways, which emphasises the importance of assessing all four pillars of food security. The need to understand the linkage between food security and bioenergy is emphasised by the Sustainable Development Goals #2: *Zero hunger* and #7 *Clean and affordable energy* [69]. The urgent need for improved food security in developing countries combined with the projected growth in biofuel demand, underlines the importance of a better understanding and quantification of impacts of biofuel production on food security, avoiding negative impacts and finding synergies between food and fuel production.

Impacts of bioenergy on food security have mostly been quantified in studies on food *availability* and *access* [49,54,59,60,63,70–75]. Studies linking bioenergy and food security are generally based on specific case studies [23,48,49,54,55,57,59,60,63,76], which are not necessarily generalisable. These case studies often consider a single region in a country where a bioenergy feedstock plantation is established [48,49,54,55,60,63,76] and measure the food security impacts for employees or farmers [49,59,63] in that region. However, these studies do not consider the food security effects for the rest of the country or for the households not directly involved in the bioenergy project [54,60], even though they may be indirectly affected e.g. through higher food prices.

In addition, these case studies often investigate past (ex-post) performance [23,48,49,54,55,57,59,60,63], whereas ideally the potential food security impacts are assessed before (ex-ante) starting bioenergy production in an area to avoid negative impacts. The ex-ante studies that are available mostly use macroeconomic models (e.g. Refs. [70,73–75,77,78]) to determine the effect of an increased biofuel demand on the production and prices of other economic sectors and assess the food security impacts based on changes in these sectors. These effects are limited to those on *availability* and *access.* Most available ex-ante studies are on national [72,74,75,78,79] or higher aggregation levels [70,73,80–82], obscuring the large differences in food security impacts within a country [83–85]. Rural households are in general poorer, less energy secure and more tied to agriculture than urban households in the same country. This means that changes in the agricultural sector as a result of increased biofuel production affect rural and urban households differently [86]. Therefore, it is important to distinguish between various groups within a country when assessing food security impacts [38,87–91], which is not possible using highly aggregate models.

Given these knowledge gaps, we aim to ex-ante quantify impacts of biofuel production on all four pillars of food security (*availability*, *access*, *utilisation* and *stability*) for different household types in a developing country. We will illustrate this for Ghana up to 2030, a country that has seen four different proposals to introduce a biofuels mandate of up to 20% biofuels in total transport fuel[1] consumption in 2030 [10,92–94]. Ghana also faces food security issues [83,95], making it important to consider, ex-ante, the effects of a biofuel mandate on food security. To do so, we will use the macroeconomic model MAGNET to project food security impacts, including the nutritious value of food intake, for rural and urban households [96]. Using this model, we are able to make a comprehensive assessment of the food security effects of biofuel production in Ghana and show the distribution of the effects over rural and rural households.

We focus on first generation (food crop-based) biofuels in this study, because the link between biofuel production and food security is much more prominent in debates on first generation compared to second generation biofuels [97,98] and because Ghanaian biofuel policy proposals focus on first generation biofuels [93]. Furthermore, first generation biofuels can be much better represented in the economic models, as it is much more developed compared to advanced biofuels.

2. Case study description

Of the 29 million inhabitants of Ghana, 5.5% are undernourished while nearly a quarter is living below the poverty line [99,100,101]. This is significantly lower than the Sub-Saharan average of 22% undernourished [102]. There is a large variety in the degree to which under-nourishment occurs across the country, as in the Upper East region it is as high as 34% [83]. These differences reflect the income inequality between urban and rural areas, and between the northern-most regions and central and southern regions, with the richest regions having a per capita income more than four times higher than poorest regions [103]. Agriculture plays an important role in the country's economy as it provides employment for 44% of the population, and contributes 22% to the GDP [104].

Cassava, yams, plantains and rice provide nearly 60% of the consumed calories in the country (see Table 1). Two thirds of the rice is imported, while the other main crops are not traded in significant quantities [100]. Cocoa and timber are among the most important export products, after crude oil and gold [105].

About two thirds of Ghanaian land area is classified as agricultural land, which is split evenly between crop land and pastures and meadows for livestock [100] (see Table 2). Ghana's agriculture can be classified as extensive, and yield gaps are large, as is illustrated in Table 2 [106]. Low yields are mainly attributed to the low input of fertilizers, improved seeds and pest control measures [107–109]. This suggests a slight intensification of the agricultural sector may create the potential to include biofuel production without decreasing food production or expanding arable land area.

Nearly 80% of the Ghanaian population has electricity access [99], but power supply cannot always match demand [112]. The majority of households energy use is covered by traditional biomass [113]. Overall, oil and oil products are the main energy sources (50% of primary energy supply, 201 PJ) followed by fuel wood and other forms of traditional bioenergy (151 PJ); smaller shares are provided by natural gas and hydropower [113,114]. Oil products are mostly imported, despite the discovery in 2007 of the Jubilee oil field (2015 production 110 000 bbl

[1] Although diesel and gasoline are called transport fuel, these are also used for other applications such as fueling generators and as household fuel.

Table 1
Food Supply in Ghana in 2011, derived from FAOSTAT [100].

	Food supply (kcal cap^{-1} d^{-1})	Share of total per capita daily calorie intake (%)
Cassava and products	708	23.6
Yams	407	13.6
Plantains	320	10.7
Rice (milled equivalent)	323	10.8
Maize and products	222	7.4
Wheat and products	139	4.6
Sugar (raw equivalent)	106	3.5
Groundnuts (shelled eq.)	85	2.8
Palm oil	65	2.2
Groundnut oil	61	2.0
Other	564	18.8
Total	2436	100

Table 2
Overview of crop production and land use in Ghana (average 2012–2016) [100, 106,110]. Potential yield is the yield level that is already achieved under optimal conditions in the country [106].

CROP	AREA (KM^2)	PRODUCTION (KT)	YIELD (T HA^{-1})	POTENTIAL YIELD (T HA^{-1})
Cocoa	16 504	858	0.5	1
Maize	9696	1778	1.8	5.5
Cassava	8976	16 669	18.6	45
Yams	4289	7114	16.6	52
Plantains	3517	3785	10.8	38
Oilpalm[a]	3506	2370	1.3	4.4
Groundnuts	3362	429	1.3	3.5
Pulses	2633	25	0.1	2.5
Sorghum	2283	258	1.1	2
Rice	2213	597	2.7	6
Cocoyam	1983	1287	6.5	20
Millet	1639	161	1.0	2
Other crops	13 440			
Total	74 040			
Meadows and pastures	83 000			
Forest	92 800			

[a] Production and area data for 2011–2015 [106]. Production and yield data for crude palm oil. Potential yield from IIASA [111].

d^{-1}) and the presence of one of the few African refineries [115]. The refinery, which is in operation since the 1960s and works far under capacity, cannot process the oil from the Jubilee field [113]. As a consequence, crude oil is exported and Ghana has to import nearly all of its transport fuels at a cost of 2 billion USD in 2015 (or 5% of GDP) [116]. This creates an incentive to consider alternative fuel sources, in order to reduce import dependency and reduce spending of foreign currencies.

Apart from the traditional use of fuel wood, no other sources of bioenergy are used in significant quantities in the country [117]. However, there have been initiatives in the past to produce jatropha biodiesel on a large scale [7,10,60,118], but all these projects failed [7]. In addition to the jatropha plans, Ghana has seen multiple proposals to implement a biofuels mandate. The national biofuel policy (2005) already aimed to replace 20% of diesel in 2015 with jatropha-based biodiesel [10]. The 2006 Strategic National Energy Plan wanted to introduce a liquid biofuels blending target of 10% for both biodiesel and ethanol in 2020 [94]. The proposed national bioenergy policy of 2010 increased the blending mandate to 20% biodiesel and ethanol in 2030 [92]. However, none of these three policies was ever implemented in law. In the context of ECOWAS, Ghana agreed in 2011 on national blending targets for biodiesel and ethanol of 5% in 2020 and 10% and 15% in 2030 [93]. At 2014 consumption levels, this is would be equivalent to 210 ML of biodiesel and 258 ML of ethanol.

3. Methods

To ex-ante quantify the impacts of increases in biofuel production on food security in Ghana in 2030, we used the computable general equilibrium (CGE) model MAGNET [96]. CGE models are considered as a suitable method to capture the food security impacts of bioenergy, as they include competition for land and labour and the resulting effects on food production, prices and income [119]. CGE models are mostly used on national or higher aggregation level, but can be adapted to zoom in on specific regions or households [9]. MAGNET contains economic interactions of all sectors in the economy, a special household module [120] that distinguishes a rural and urban household in Ghana, and a nutrition module [121] to convert the household level food consumption to its nutritional value. The addition of these two modules to the MAGNET model enables projections of food security impacts on household level in Ghana (see section 3.1). We defined indicators for all four pillars of food security (section 3.2) and applied a scenario approach (section 3.3) to determine the effects of the biofuel mandate. While developing a tailormade national CGE could allow more sectoral detail (provided the required data are available), we use the MAGNET model because it combines additional household detail for Ghana relying on supplementary data from Breisinger et al. [122] with nutrition and biofuel modules tailormade to explore the impacts of a biofuel mandate and the impacts of agricultural policies on nutrition respectively.

3.1. MAGNET model

The Modular Applied GeNeral Equilibrium Tool MAGNET, a computable general equilibrium (CGE) model, was employed to assess the impacts of an increased biofuel demand in Ghana on food security of rural and urban households. The MAGNET model is based on the GTAP database [123] which includes 56 sectors in 140 countries and regions (see Fig. 1) and is extended to include additional commodity detail, particularly in agriculture. The MAGNET model is an extension of the GTAP model [124] and is structured such that additional features or -“modules”- can be added as needed to address a particular policy question.

The core of the model is the Social Accounting Matrix (SAM) which includes all payments and receipts through the economy in the base year. The MAGNET model is then a set of behavioural equations in production, consumption, international trade and savings which adjust the SAM in response to a change in exogenous variables. A scenario is then run over multiple periods updating the SAM for each period by the percent changes in price and quantity for all value flows. Prices are normalised to 1 in the base year to accommodate the lack of quantity data given the economywide coverage and aggregated nature of some sectors. The production structure of each sector is governed by a flexible nested Constant Elasticity of Substitution (CES) function where the exact structure and substitution elasticities can vary by sector. Labour and capital are perfectly mobile within the agricultural and non-agricultural sectors but imperfectly mobile between them. The land endowment, used exclusively for agriculture, is imperfectly mobile between agricultural sectors. Total quantities of labour and capital by region are exogenous variables in all scenarios. An endogenous agricultural land supply function allows for an increase in the quantity of agricultural land, as the average price of land increases. Factor income, private consumption, savings and taxes are allocated to urban and rural households and the government. Private consumption behaviour is governed by a Constant Difference of Elasticities (CDE) function to capture changes in demand structure when incomes increase (non-homothetic demand). To explore policy questions, a baseline is first run

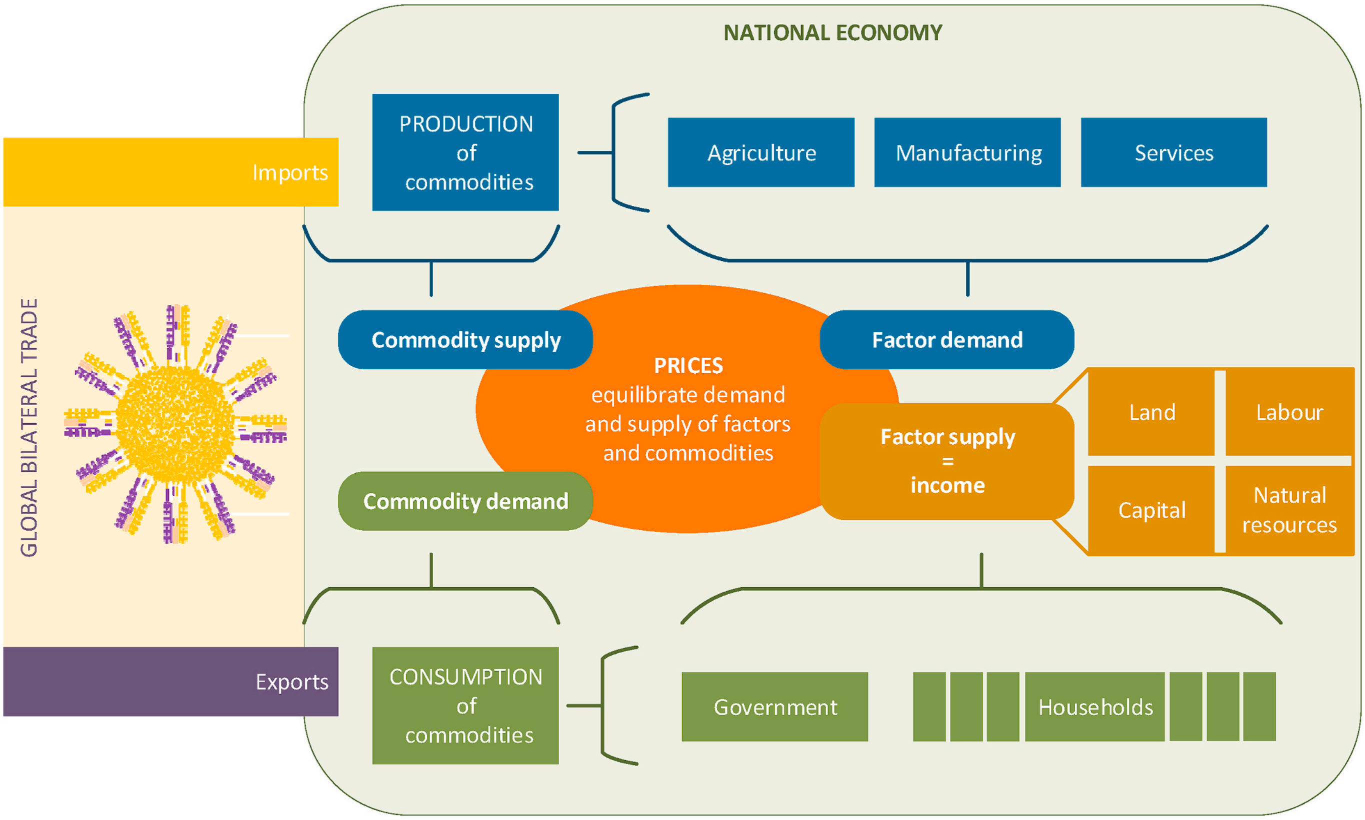

Fig. 1. Graphic representation of the MAGNET model. In this specific version two household types in Ghana are distinguished [120,125], and a nutritional module [121] is added as post analysis.

with exogenous GDP and population projections with endogenously calibrated increases in productivity of labour and other inputs. Land and feed productivity increases are set exogenous based on projections from the IMAGE model [126]. In the case of large increases in income per capita, commodity preferences in the consumption function are adjusted for the higher incomes. The ease of switching between the consumption of domestic or imported products is governed by the Armington elasticity [127]. Finally, to explore the impact of a particular policy an additional scenario is run with exogenous productivity increases, endogenous GDP and an additional policy, such as a biofuel mandate, that has not been included in the baseline. While in both the baseline and the policy scenario, the productivity of the land endowment is exogenously specified, the crop yield in unit of output per unit of land is endogenously determined as the other inputs in the crop production structure can change relative to the land input. The MAGNET model is described in detail by Woltjer et al. [97], including the addition of bioenergy sectors. In order to assess the impact on food security of rural and urban households, we used the household module as described in Kuiper et al. [120] and Kuiper and Shutes for Ghana [125], to include several household types in the model; and the nutrition module [121] to translate the food consumption per household from monetary terms to nutritional value. The relationships between the modules to assess the impacts of an increased biofuel demand on the various food security indicators for the two types of households is illustrated in Fig. 2.

The household module of MAGNET includes a rural and urban household type in Ghana. The characteristics of the two household types can be found in Table A1in the Appendix. The Social Accounting Matrix of Ghana, which is the overview of all domestic monetary flows between sectors, households, the government and abroad, was updated for the two household types based on the results of a national household survey of Ghana [103,125]. This builds on previous work of Breisinger et al. [122] who described the Social Accounting Matrix (SAM) for Ghana, made an overview of all domestic monetary flows between sectors and households, and included a rural and an urban household type. The nutritional module of MAGNET uses a post simulation-analysis to convert the percent changes in household consumption of agricultural products in value terms into the energy and nutrients they provide [121]. The module uses initial quantity and nutritional data from the FAO for the base year and updates this data with the same percent changes as the value flows related to primary agricultural products. This enabled us to calculate the effects of the biofuel mandate on the level of energy and nutrient intake by each household. The set-up and functioning of the household module and the adaptations that were made for Ghana are further explained in Kuiper and Shutes [125] and the nutrition module in Rutten et al. [121].

For the size of the biofuel mandate (i.e. the shock) we used two scenarios (see section 3.3). By running the two scenarios we examined the household level food security impacts from the increase in biofuel demand in Ghana.

3.2. Indicators

There are various indicators to measure the four pillars of food security. The FAO compiled a list of 30 food security indicators, and based on expert judgement and data availability these are monitored on national level [128]. From this list, seven indicators (for *availability, access* and *utilisation*) can be assessed at household level using the MAGNET model, and an additional four indicators can be assessed at regional or national level (see Table 3) [121,125]. Other indicators of the FAO list (e.g. road density and political stability) are generally not represented in macroeconomic models.

In addition to these indicators from the FAO list, the nutrition module of the MAGNET model includes indicators for the household level consumption per capita of food energy and three macronutrients

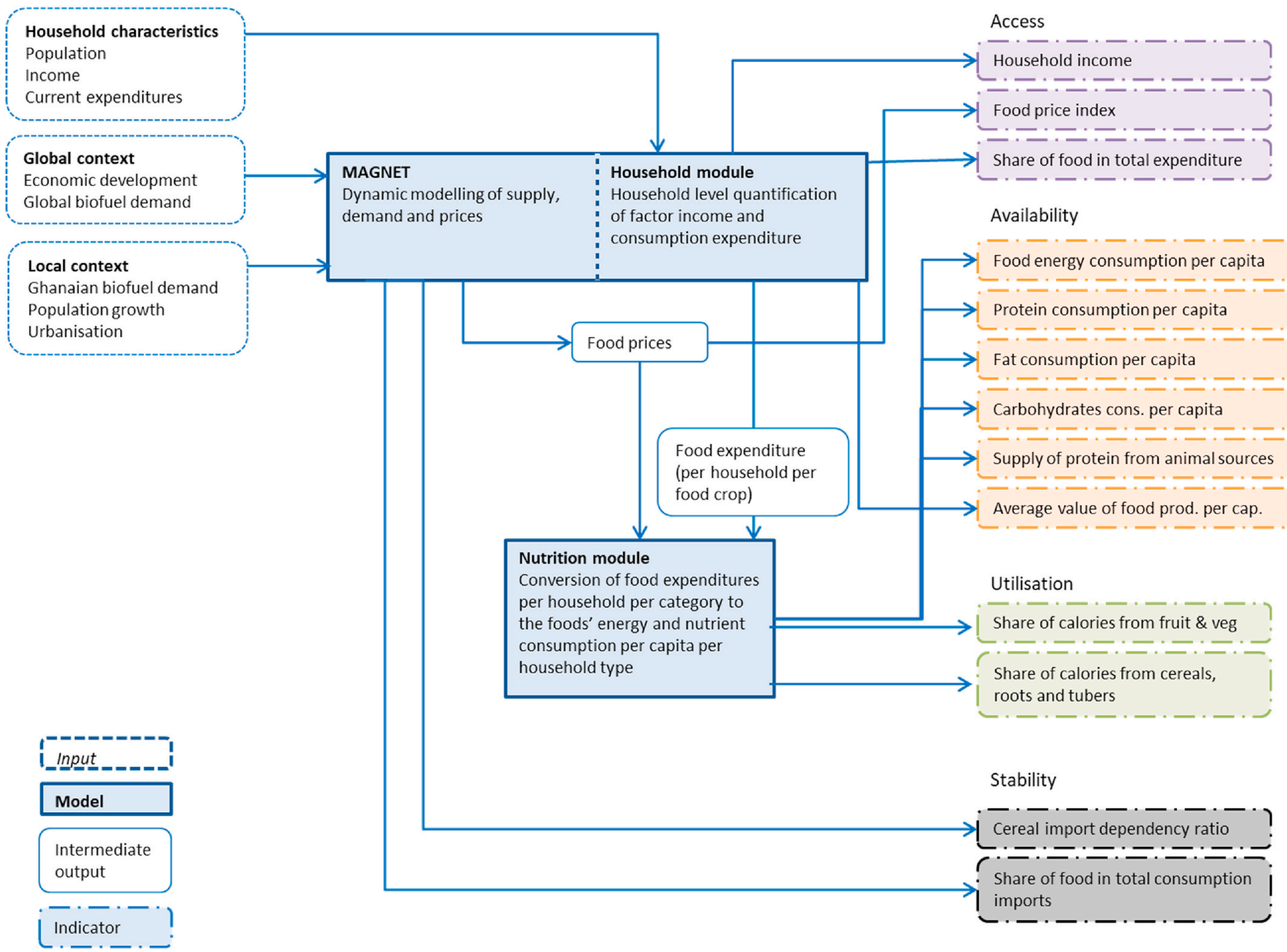

Fig. 2. Relation between the MAGNET model and the household and nutrition module to assess the effects of the biofuel mandate on each of the pillars of food security at household level. The household module integrates the urban and rural households as two separate sectors in the CGE model. Thereby, the MAGNET model can determine the household income and food consumption. The nutritional module consists of an ex-post analysis to convert the household spending on each primary agricultural product (crop or livestock) into the food energy and nutrient consumption.

(protein, fat and carbohydrates). For *utilisation,* the use indicators of dietary diversity (share of fruit and vegetables in total food consumption and share of cereals, roots and tubers in total food supply) were used. These indicators are not represented in the list of the FAO [128], as these focus on outcome indicators for utilisation (e.g. number of underweight children) which are not available in the MAGNET model. Therefore, the selected indicators mainly focus on the nutrition part of the definition of utilisation.[2]

Energy and the three macronutrients are the main constituents of food items and therefore relevant when considering food security [137]. For these four indicators a minimal food security value or threshold was defined, because not only the direction of the change matters, but also the absolute values (e.g. 1% lower consumption is less of a problem for households with a high per capita consumption, than for households at risk of under nourishment). These threshold values were determined following the dietary reference intake. This is the minimum per capita consumption that is sufficient for 97.5% of a population without dietary deficiencies [130]. When this minimum is not met, it shows the food security is insufficient.

The results on food energy or macronutrients are expressed in primary equivalents and account for primary agricultural products only. Processed foods contribute to the total food expenditure, but due to the highly heterogeneous composition of this category and the lack of accurate data on how the composition of processed foods changes in response to income changes at the household level, energy and macronutrient consumption from processed foods were too uncertain too include. The used version of the MAGNET model does not account for waste nor nutrition loss through cooking. Therefore, the consumption values represent upper limits of available energy and macro-nutrients.

The indicators were derived from the MAGNET model as follows (as is also illustrated in Fig. 2). Most indicators for *availability* were quantified in the nutrition module. The household level food consumption, expressed in monetary volumes for each food crop and animal product, was converted to the calories and macronutrients it contains in the nutrition module. Dividing the total household consumption by the total population per household type (see Table A1: in the Appendix) gave the food energy, protein, fat and carbohydrates consumption per capita. The share of protein consumption from animal sources was determined by dividing the consumption of proteins from milk, beef and other animal products per household type by the total protein consumption per household type. The average monetary value of food production per capita was calculated by summing the value of all food produced in Ghana by the total population. The indicators for food *access* were

[2] Utilisation refers to the way food, and the nutrients in it, are taken up in the body. Various aspects play a role in this, such as hygiene, food preparation and dietary diversity [127].

Table 3
Indicators of food security from the MAGNET model and the nutrition module and their relation to food security [121,125]. A plus sign indicates a positive relation to food security, a minus sign a negative relation, i.e. an increase in the indicator reflects a negative effect on food security.

Pillar	Indicator	Unit	Level	Relation to food security	
Availability	Food energy consumption per capita[a]	kcal cap^{-1} d^{-1}	Household	+	A decrease in the food energy supplied to households is a sign of reduced food security in the area. The study of Maxwell et al. [129] put the recommended daily caloric consumption in Ghana at 2900 kcal for adults.
	Protein consumption per capita[a]	g cap^{-1} d^{-1}	Household	+	Protein is a macronutrient for which the dietary reference intake[b] is 45–56 g d^{-1} [130,131]. This is sufficient for 97.5% of the population. When this minimum is not met, it shows the food security situation in the country is insufficient.
	Fat consumption per capita[a]	g cap^{-1} d^{-1}	Household	+	Fat is a macronutrient of which an average person has to consume 64 g d^{-1} [131],[c].
	Carbohydrates consumption per capita[a]	g cap^{-1} d^{-1}	Household	+	The dietary reference intake of carbohydrates is 130 g d^{-1} (60–210) [131].
	Supply of protein from animal sources (excluding fish)	g cap^{-1} d^{-1}	Household	+	A supply of animal protein indicates sufficient feed is available to raise livestock to produce food consume this [132]. As peoples first response to food security issues is to reduce animal protein consumption, this is a good indicator for food security [88].
	Average value of food production per capita (in constant prices)	USD cap^{-1}	National	+	A higher value of food produced denotes a higher availability of food in the region. As it is presented in constant prices, price effects are excluded, and this only includes production effects. This is not on household level as urban households do not produce food.
Access	Household income	USD cap^{-1} a^{-1}	Household	+	Because of the link between poverty and hunger, household income is a good indicator for access to food as increased income increases the household's potential to purchase food.
	Food price index	index	National	–	Increased food prices result in lower accessibility of food, especially for lower income households. Households with a higher income are better equipped to buffer price increases.
	Share of food in total household expenditure	%	Household	–	Increasing the share of household income allocated to food purchases means food has become less accessible and therefore food security decreases.
Utilisation	Share of calories from fruit and vegetables	%	Household	+	High quality diets are associated with higher diversity in food sources. Especially for poor people in developing countries, diet diversity can be an issue. Increasing diversity, increases the *utilisation* aspect of food security [133].
	Share of energy supply from cereals roots and tubers	%	Household	–	An increased reliance on staple crops as cereals, roots and tubers for food supply means dietary diversity and thereby food security decrease [133].
Stability	Share of food in total	%	National	–	A high share of food in total imports indicates

(continued on next page)

Table 3 (*continued*)

Pillar	Indicator	Unit	Level	Relation to food security	
	consumption imports				Ghana needs to spend a significant share of its foreign exchange income on food imports and becomes vulnerable to exchange rate risks and price increases [128].
	Cereal import dependency ratio	%	National	–	Price variations on the world market can translate to larger variation in domestic food prices endangering the food security of people. A high dependency on import makes a country more vulnerable to these price changes. Cereals are specifically determined because cereals are proportionally more consumed by poor and food-insecure people, which are impacted worst by price increases [20,33,128,134,135].

[a] Results are only presented for primary agricultural products. The heterogeneity of the nutritious value of processed foods is too large for the results to be reliable.

[b] The dietary reference intake varies between women and men, the average value that was used here was based on a weighted average (regional data from Ghana household survey) of the male and female daily reference intake.

[c] Based on the minimum food energy intake, the lower end of the suggested range of energy from fat [131] and the average energy content of consumed fat [136].

determined on household level, with the exception of the food price index, which was determined at national level. The household income for each household was the sum of the income factors land (only rural), capital, natural resources and labour (divided into skilled and unskilled, with a special category for agricultural labour). Dividing by the household population gave the per capita income. The share of food in total the household expenditure was determined by dividing the expenditure for each household on all food products by the household's total expenditure. For *utilisation,* the two indicators were determined on household level. For the share of calories from fruits and vegetables, their total consumption (in caloric value) was divided by the total food energy consumption of the household. For the cereals and roots and tubers, the sum of rice, wheat, other grains, and horticultural,[3] [4] products was used. The cereal import dependency, an indicator for *stability,* was determined by dividing the household expenditure on imported rice, wheat and other grains by the total expenditure on these products. The share of food in total consumption imports was determined by summing the food imports and dividing these by the total consumption imports.

3.3. Scenarios

To calculate the food security effects of biofuel production in Ghana in 2030, the MAGNET model was used for two scenarios, a *baseline* scenario without biofuel production and a scenario with a biofuels *mandate* [93]. Comparing the food security situation in the *mandate* scenario to the *baseline* scenario, shows the effects of biofuel production in Ghana. The *baseline* scenario included a business as usual development for the world economy (based on the Shared Socioeconomic Pathways SSP2 narrative scenario [138] and includes projections for first generation biofuel for the rest of the world) and no biofuel production in Ghana. The *mandate* scenario was based on the most recent proposed biofuels mandate for Ghana for 2030 which consists of 15% ethanol and 10% biodiesel (E15/B10) [93]. The purpose of this mandate is both economic by cutting fossil imports and social by bringing development to rural areas by local production of biofuels [93]. Therefore, it is assumed that the required biofuels are produced domestically.

The scenarios were implemented in MAGNET as targets for biofuel production in 2030 in Ghana. Population and GDP projections and are taken from KC and Lutz [139] and Dellink et al. [140] respectively. Exogenous increases in land and feed productivity were taken from the SSP2 projections from the IMAGE model [126]. Productivity increases for other economic inputs were endogenously calibrated to meet the GDP projections. Increased demand for food coupled with additional labour and capital resources and more efficient use of inputs in a growing economy encourages farmers to intensify production to meet the growing demand. This leads to leads to an endogenously calculated yield increase. Land availability increases at much slower rate than the rest of the economy and therefore becomes the relatively scarce resource. Land use is determined endogenously in the MAGNET model and assumes imperfect substitution between the various land uses [141]. The potential to expand the total agricultural area is limited and conversion from potential agricultural land to actual agricultural land becomes more expensive when closer to the total land supply [96]. The potential agricultural land in Ghana is based on a global study on land supply for agriculture [142], and accounts for land in use for other functions such as built up areas and protected nature areas.

The additional costs of biofuel compared to regular fuel were assumed to be paid by government subsidies. This means that the government spends proportionally less on other sectors, reducing amongst others, direct transfers to households. Reducing energy costs corresponds to a goal of the Ghanaian biofuel policy that focusses on combatting energy poverty. Furthermore, increased fuel prices are a

[3] Both cassava and fruits and vegetable are aggregated in this category. The category was split based on the share of food energy from cassava in the sum of all horticulture products, based on FAOSTAT food energy for Ghana [100].

[4] The low oil price of the last years made fossil fuels economically more attractive. As fuel prices are an important political topic in the country, it is unlikely biofuels will be mandated if these lead to higher fuel prices. This would mean biofuels need to be subsidised. If it would be assumed that fuel producers pay the higher costs for biofuel production, it would result in higher consumer prices, which would also lead to reduced disposable income.

serious political problem in the country, which makes it unfavourable to place the burden on fuel producers.

4. Results

4.1. Baseline scenario

The *baseline* scenario shows strong economic growth in Ghana between 2010 and 2030, with a quadrupling of the gross domestic product (GDP). In this period, labour productivity increases in the country, which results in higher production and lower agricultural prices. Demand for labour decreases in the agricultural sector by 28%, and demand for unskilled labour in services and manufacturing increases by 265% and boosts average wages. Land is a relatively scarce resource compared with other agricultural inputs and land prices increase in the country by 340%. This increase in price results in a 5% increase of total agricultural land area.

These economic developments result in a large progress in the food security of the country, as nearly all indicators show an improvement for 2030, compared to 2010 in the *baseline* scenario (see Table 4 and Fig. 3). Food *access* increases as household income increases both in urban (190%) and rural (162%) households. The higher income, combined with lower food prices, lead to a falling share of household income spent on food purchases in urban areas. In rural areas this share increases as the higher incomes lead to a switch to processed foods (increase of 435%), rather than primary agricultural products. As processed foods are relatively more expensive, the share of food expenditures in total spending increases. Despite the rise in the share spent on food in rural households, income available to spend on non-food consumption increases in absolute terms. The *availability* of food, expressed as primary agricultural food consumption per capita, grows as a result of the higher production, higher incomes and lower prices, despite an expanding population. The calorie consumption per capita increases by 17% (rural) to 34% (urban) by 2030 (see Fig. 3). In addition to this, spending on processed foods further increases and becomes 32% in urban areas and 26% in rural areas in 2030, up from 27% to 17% in 2010. This explains why the energy and nutrient consumption from primary agricultural food consumption in the urban areas is lower than in the rural areas, see Table 4. The absence of the calorie and nutrition intake of processed foods in the model results is also the reason why the energy and macronutrient intake per capita are low compared to the threshold values from Table 3 and FAOSTAT data [100], which include processed foods. In 2030, the food energy from primary agricultural food consumption is about 75% of the recommended daily caloric consumption [129].In addition, 15% (rural) to 25% (urban) of the food expenditure of households is spent on processed foods. This adds to the food energy.

In contrast to the indicators for *availability* which increase for both household types, the picture for the indicators of *utilisation* is more mixed. *Utilisation* improves as there is a higher contribution from animal products, especially in the diets of urban households and the contribution from fruit and vegetables to the energy intake increases for rural households. However, the dependency on roots, tubers and cereals remains and even increases for rural households. *Stability*, measured as the reliance on imported food, does not significantly change for the cereal dependency rate, as this remains nearly stable towards 2030. The share of food in the total consumption imports is nearly halved by 2030.

4.2. Biofuel mandate scenario

To fulfil the E15/B10 mandate, the MAGNET model projects grains (maize) to be the most important feedstock of ethanol and crude vegetable oil from oil seeds (in this case palm oil) as the major feedstock of biodiesel. The additional demand for these crops for biofuels results both in higher production and in lower consumption and export, but the ratio is very different for both feedstocks (see Fig. 4). Although total agricultural land in the country does not increase compared to the *baseline*, the land use for oil seeds production expands by 57%. The combined effect of this land expansion and a 4% yield improvement compared to the *baseline,* provides two thirds of the additional demand for oil seeds. In addition to this extra production, the demand for oil seeds for biodiesel production is met by reduced exports (27%) and by reduced consumption of oil seeds for food and other sectors (10%). In the mandate scenario, 30% of the total oil seed production is used for the production of biofuel.

The total grain production only increases slightly between the *baseline* and the *mandate* scenario, but grain consumption for food and the use in other sectors is lower compared to the *baseline*. The reduced consumption covers 95% of the demand for grains for ethanol, with the rest being provided by higher production. In the mandate scenario, 4% of the total grain production is used for the production of biofuels. Overall, the reduced consumption of grains does not lead to lower food consumption as it is compensated by other food sources. In general, the effect of the biofuel mandate is small on most of the food security indicators (see Table 4 and Fig. 5).

The higher production of oil seeds and the reduced availability of maize for food, due to the demand for biofuel production, stimulate the agricultural sector. Demand for non-skilled agricultural labour and land for feedstock production increases significantly, leading to higher prices for land and labour compared to the *baseline*. This is beneficial for rural households as their income is based on the value of their land and labour. The income from direct endowments increases as a result. As a part of the government expenditure is used for subsidising biofuel

Table 4
Household food security in Ghana in 2010 and 2030 for the *baseline* and *mandate* scenario.

Pillar	Indicator	Unit	2010		2030: baseline		2030 mandate	
			Urban	rural	urban	rural	urban	rural
Availability	Food energy consumption	(kcal cap^{-1} day $^{-1}$)[a]	1660	1892	2223	2215	2222	2215
	Protein consumption	(g cap^{-1} day $^{-1}$)[a]	35	37	48	42	48	42
	Fat consumption	(g cap^{-1} day $^{-1}$)[a]	26	37	34	40	34	40
	Carbohydrates consumption	(g cap^{-1} day $^{-1}$)[a]	321	354	432	424	432	424
	Energy supply from cereals roots and tubers	(kcal cap^{-1} day $^{-1}$)[a]	968	776	1052	1096	1051	1096
	Supply of protein from animal sources (excluding fish)	(g cap^{-1} day $^{-1}$)	4.24	2.44	6.05	2.95	6.04	2.95
	Average value of food production	(USD cap^{-1})	560[b]		834		853	
Access	Household income	(USD cap^{-1} yr^{-1})	2524	1729	7316	4532	7201	4527
	Food price index	(% change, compared to 2010)			−14.2%		−12.1%	
	Share of food in total household expenditure	(%)	19%	22%	12%	30%	12%	31%
Utilisation	Share of calories from fruit and vegetables	(%)[a]	16%	13%	16%	15%	16%	15%
	Share of energy supply from roots and tubers	(%)[a]	51%	42%	52%	47%	52%	47%
Stability	Cereal import dependency ratio	(%)	5%	4%	5%	3%	5%	3%
	Food share in total consumption imports	(%)	27%		14%		14%	

[a] Only primary agricultural products are included.
[b] In the MAGNET model, no agricultural production is assumed in the urban areas.

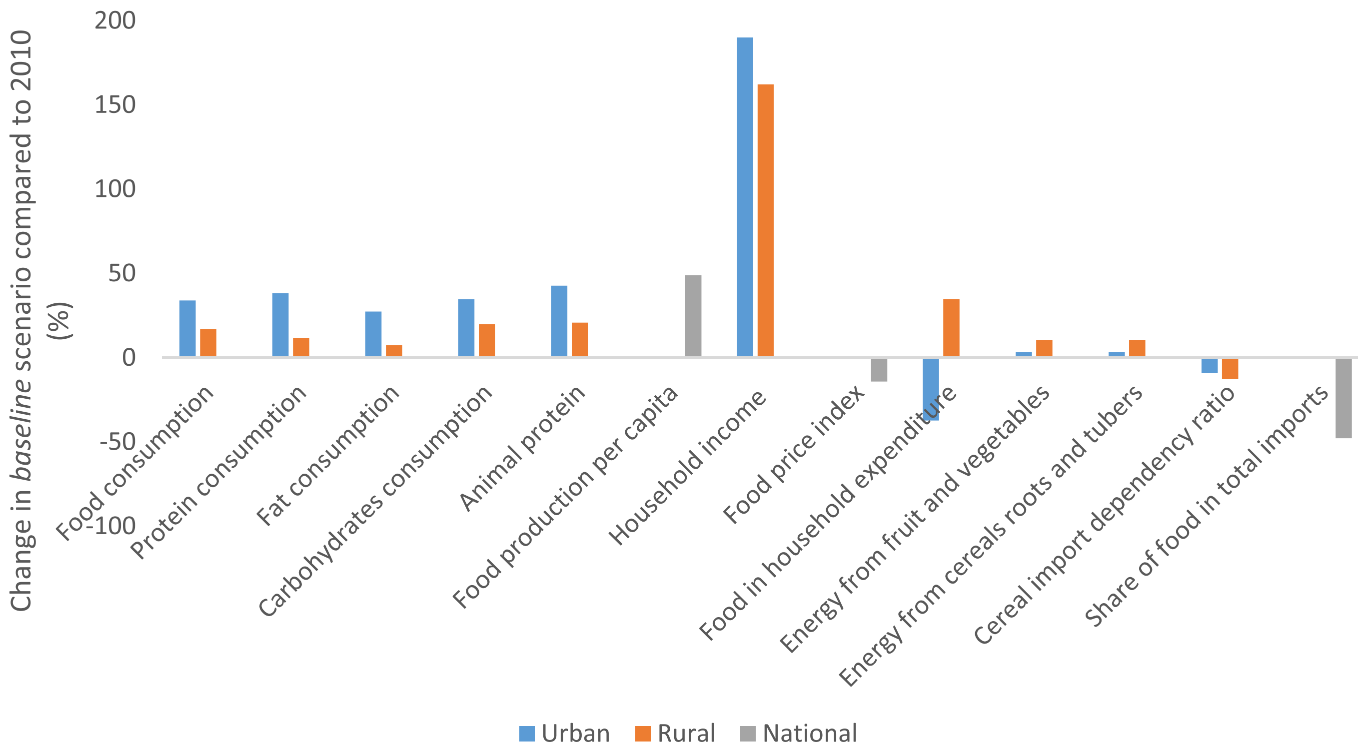

Fig. 3. Change in food security indicators between 2010 and 2030 in the *baseline* scenario (i.e. without biofuel mandate) for urban and rural households.

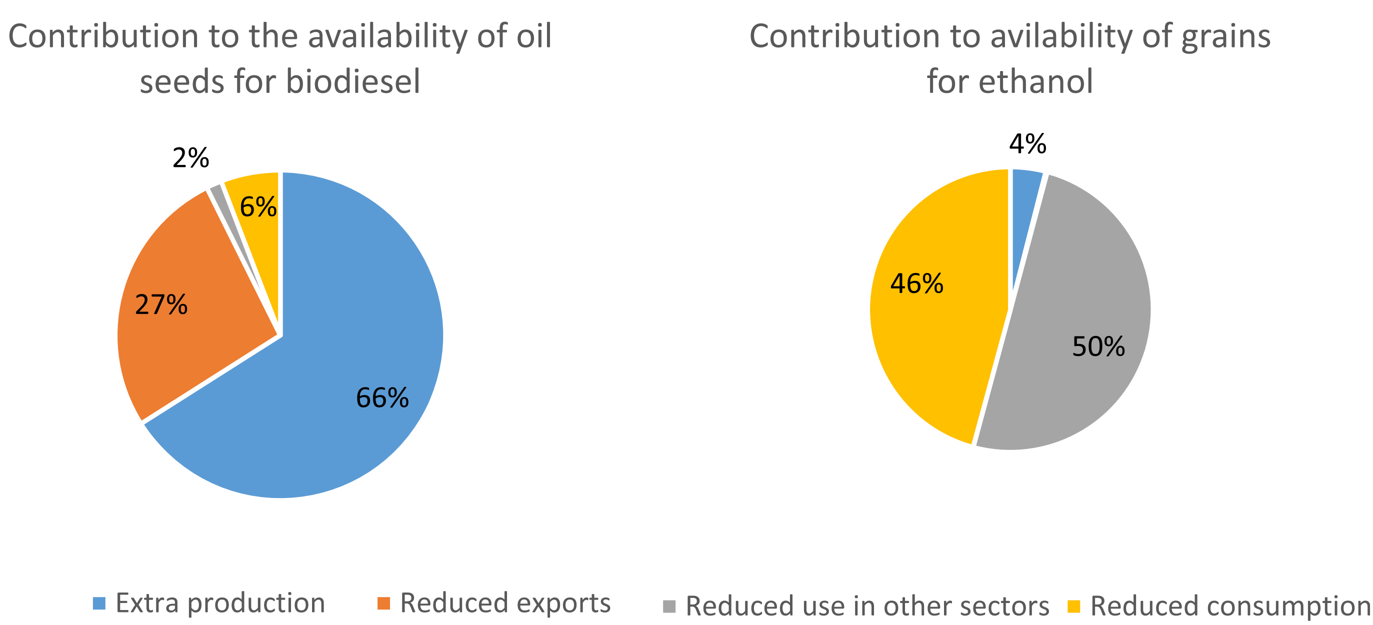

Fig. 4. Contribution of additional production, net changes in trade, and reduced consumption to cover the additional demand for oilseeds (mainly palm oil) for biodiesel (left) and grains (maize) for ethanol (right) in the *mandate* scenario.

production, government transfers to households are lowered by approximately 7% in the *mandate* scenario compared to the *baseline*[4]. This cancels out the additional income rural households obtain compared to the *baseline,* and leads to a decrease in income in urban households. This means *access* to food is reduced in most households compared to the *baseline* (see Fig. A1in the appendix). Especially since the *mandate* leads to increased food prices (+2.4%) compared to the *baseline*, although food prices are still lower compared to 2010. In the mandate scenario, the share of household income allocated to food purchases also increases, with the highest increases in the urban areas. Comparing the country average food expenditure as share of the total income (23%) in 2030 for the *mandate* scenario to current data of other countries, shows Ghana would be comparable to countries such as Mexico and China (in 2010) [143].

The *availability* pillar of food security is also affected by the biofuel mandate as calorie consumption of primary products in both household types decreases compared to the *baseline*. However, the decrease in consumption is limited to less than 1% for energy intake and for each of the macronutrients in both rural and urban households. At the same time, the diet also becomes less meat intensive, and use of fruit and

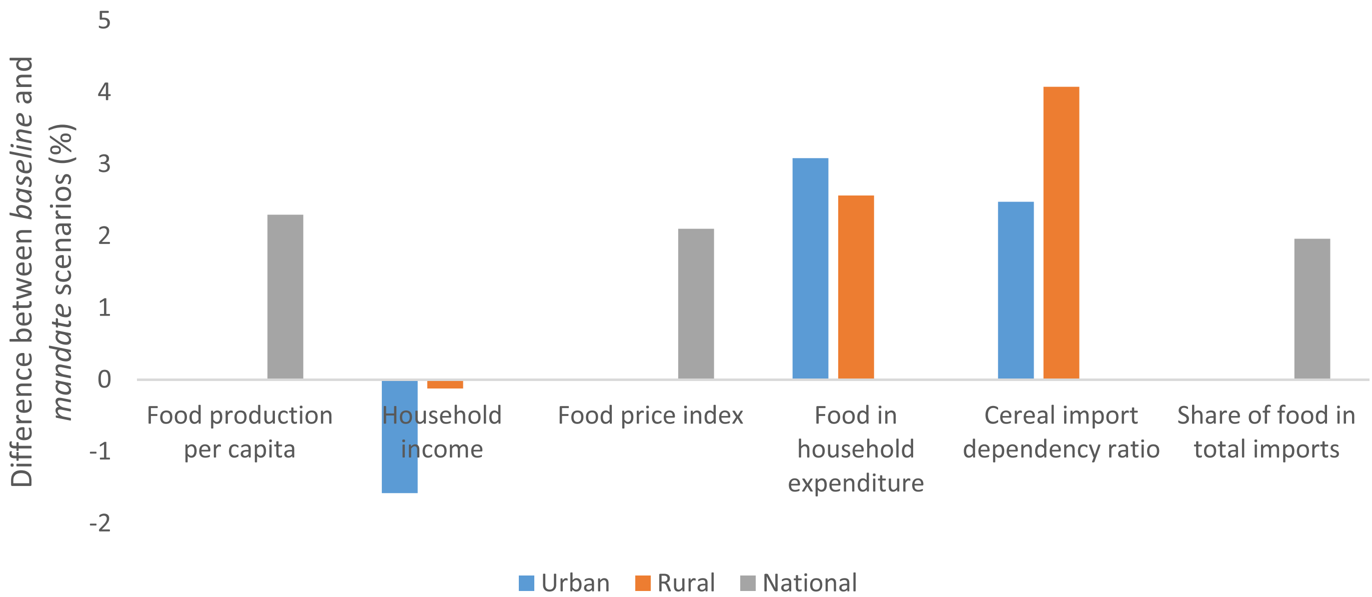

Fig. 5. Differences in food security indicators between the *baseline* and *mandate* scenario in 2030 for the urban and rural households or on national level. Differences smaller than 0.5% are not shown in this figure.

vegetables decreases slightly, affecting the *utilisation* pillar of food security as well. In addition, the use of food crops to fulfil the bioenergy mandate means a larger share of the cereals and other foods have to be imported, reducing the *stability* pillar of food security.

5. Discussion and conclusion

In this study we projected the effects of a E15/B10 biofuel mandate in Ghana in 2030 on all four pillars of food security: *availability*, *access*, *utilisation* and *stability*. The food security effects were assessed for rural and urban households. For this, we developed and demonstrated a methodological approach to enable ex-ante quantification of the impact of biofuel production on all four pillars of food security at a household level.

Overall, the projected increase in food production and consumption as a result of expected economic progress in the country far outweigh the projected impacts of a biofuel mandate on the *availability* of and *access* to food. Although the introduction of a biofuel mandate slightly decreases the food security situation in the country in 2030 compared to the 2030 baseline, it would still mean strong overall progress compared to the current (2010) situation. Previous ex-ante studies on food security impacts of biofuel for other countries [e.g. 8,80,91,120] also show that the negative food security impacts of biofuel production are relatively small compared to the baseline scenario and that the food security situation is still better compared to the starting year. Although the food security situation in 2030 with or without a biofuel mandate is projected to be better than in the starting year, this does not mean the situation is good. For our study, it is important to note that even in 2030, most *availability* indicators do not surpass the dietary reference intake threshold (see Table 3) so that food security in terms of availability remains a concern.

The pillars *food availability* and *access* are included in most previous studies on food security. In this study, nine indicators are available for these two pillars that together provide a broad picture of availability and access to food. The major aspect lacking in this study for the *availability* pillar, is a good representation of nutrients in processed foods in the MAGNET model. The heterogeneity of this compound category means that the food energy and macronutrients content could vary much more for this category than for the primary agricultural products that are included in the assessment and that are much more homogenous. As it is likely that the contribution of processed food to the overall diet will increase with economic development, this becomes increasingly important.

Ex-ante quantification of the pillars *utilisation* and *stability* is in general less comprehensive and more research is needed. In this study, *utilisation* is quantified based on the shares of staple foods and fruits and vegetables in the diet to reflect the dietary diversity. This is because more diverse diets, which are less dependent on staple foods, are considered healthier [144]. Other nutrients than the macronutrients that were used in this study (such as fibres, vitamins) are also important for healthy diets and for utilising the nutrients in the food [145]. Other aspects of *utilisation*, such as cooking and food preservation are not represented in the MAGNET model. Integration of these indicators in the model would increase the quality of the assessment. It is likely that increased energy access as a result of bioenergy expansion has positive effects on utilisation as it can help to improve food quality through better storage and preparation.

The *stability* in the *availability, access* and *utilisation* of food is in this study assessed by the share of the consumed food that is imported. This is however only one aspect of *stability*. But as can be seen from Fig. 5, it is the indicator most affected by a biofuel mandate. The *stability* in food *availability* can for example be affected by extreme weather events which are not included in the *stability* indicators of the MAGNET model. In this study, we explore a new market equilibrium with the biofuel mandate as compared to an equilibrium without the mandate. The model assumes that all markets have adjusted to the new situation. However, these assumptions are not applicable in the exploration of short term shocks to food production. For example, the period 2005–2014 showed two years in which the maize harvest was 10% lower than the previous year [100,106]. A short term decrease of 10% in availability of a staple crop could lead to food security issues in Ghana, which cannot be immediately corrected by market adjustments alone. Extreme weather events are more likely to occur with climate change [146] and as biofuels lead to a higher dependency on agriculture, the vulnerability to harvest failure increases [50].

World food prices are volatile [147] and assuming an average price for a commodity in a country neglects the variation in prices over space and time. Historical market price data from Ghana shows a variation of 50% in food prices within the country as well as over the year [148]. This intra-annual and intra-country variation in food prices is not captured in the food price index indicator [44,147], and therefore also not included in the quantification of *stability*. In addition, this indicator focusses only on the economic access to food. In developing countries, characterised by less developed distribution infrastructure, the physical access can play a role as well. For example, market access for both buyers and sellers may depend on access to a road that is blocked, leaving the people unable to reach the market to buy or sell food [149]. This type of indicators of access to food is not currently included in food security models. The variation in food *availability* can also have an impact on the *stability* in the *utilisation* pillar. If a stable supply of a specific food type is substituted by a food type with only a short seasonal, the stability in the *utilisation* pillar would decrease.

The domestic food security effects of a biofuel mandate in Ghana are relatively small, but part of the effects will spill over to other countries. This is because a large share of the oil seed feedstock for biodiesel is made possible by reduced export and a larger share of the food consumption is imported. As a result of these trade effects, the pressure on the world agricultural commodity market would increase slightly and could therefore cause indirect land use change and related food security effects outside Ghana. A cumulative effect of more countries implementing a biofuel mandate (in addition to those already included in the *baseline*) is likely to result in a larger effect on world agricultural commodity markets. The resulting price effects will probably impact low income countries disproportionately [150]. As the aim of the mandate is to cut fossil imports and stimulate rural development, we assumed domestic biofuel production. If however the biofuels would be imported, this would have a different effect in food security in Ghana and elsewhere.

The effects of biofuel mandates on all four pillars of food security also depends on how the world develops in the baseline. In this study, a SSP2 middle-of-the-road scenario was used as the baseline scenario. Using a SSP1 (sustainable) or SSP3 (fragmentation) scenario can lead to very different results, especially in Sub-Saharan Africa [151]. The population projections in SSP3 are much higher, people have a larger preference for animal products, and yield increases are limited. Together, this adds up to larger pressure on agricultural land. As SSP3 also assumes a less globalised market, the effects of a biofuel mandate in Ghana are likely to be higher. Conversely, in a SSP1 scenario with lower population growth, faster yield development, and more plant-based diets, the effects of biofuels on food security are likely to be smaller. As global developments have such a large impact on local food security, it is recommended that future studies will assess this in more detail. Furthermore, it is assumed that economic development will result in agricultural intensification trough improved access to agricultural inputs. Access to these inputs is however not solely determined by economic conditions, but also by e,g, physical access. In case agricultural intensification will be slower, the impacts of the biofuel mandate on food security are likely to be much higher.

Our approach enables the differentiation of food security effects of biofuels between urban and rural households, which is an important improvement over previous studies that only considered one aggregate household for a country. This is relevant, as rural and urban households tend to differ in their food security responses. Our results show that rural households tend to benefit more from biofuel expansion, whereas the urban population is mostly confronted with negative food security impacts. Nevertheless, overall both households are still better-off on all indicators in the mandate scenario in 2030 as compared with 2010.

In the model it is assumed that the endowments, land, labour and capital are owned by the households and the benefits of increased agricultural activity stimulated by the biofuel mandate will return to the rural households. If however the farms suppling the biomass are financed by foreign investors then the model results will overestimate benefits to the rural households from the biofuel mandate. This points to the need to take care in implementing the biofuel mandate policy in such a way that the benefits flow to the local farmers. Expanding the model to include foreign ownership of capital and land in Ghana would be a further step in clarifying the welfare benefits to rural households of the biofuel mandate policy.

Although an improvement compared to previous studies, the disaggregation in urban and rural households in this study is still crude. Further disaggregation would increase the level of detail and show better where impacts accrue and which groups in society are confronted with negative impacts. Suggestions for further disaggregation would be to include various income groups to differentiate between richer and poorer households, distinguishing between rural households with and without land ownership, or further regional disaggregation. Disaggregating to various income classes can be useful, as increased income can mitigate the effects of increased food prices. Higher prices are most likely to benefit those who own land and already have a relatively high income [152]. Further geographical disaggregation can provide additional insight as Ghana contains various agro-ecological zones, which vary in suitability to produce various crops, but also in socio-economic status, and food security situation.

Even household level assessment of food security impacts masks some differences. It assumes that within a household food is shared equally, according to the needs of each household member. However, especially in periods of food scarcity, households are confronted with an intra-household distribution question [86,153]. In sub-Saharan countries, this can be a gender issue where women are likely to be the least food secure [153]. Furthermore, as men are more likely to be employed by biofuel projects than women [56], gender inequality can be worsened by a biofuel mandate.

Regarding MAGNET it is important to state that as a computable general equilibrium model with assumptions on full employment, the model assumes that any additional taxes or subsidies push the economy from its optimal equilibrium. Therefore, by definition the additional biofuel subsidies have a net negative effect on the economy. This might not be the case, however, if government investments in biofuels were to stimulate economic growth by increasing innovation or bringing additional workers into the labour pool. This would further increase the benefits to the rural households as a result of the biofuel mandate.

Further model assumptions on the mobility of labour and capital, as well as the flexibility of the demand for specific types of food can have a significant influence on the reaction of producers and consumers to the increased demands of biofuels for agricultural products. If we assume that farmers currently engaged in a particular agricultural activity will have difficulty changing to another activity or that labour and capital will have more difficulty moving between farms, then this may decrease the flexibility in the economy and increase prices. Similarly if consumers are very rigid in their food preferences and do not adjust as easily between domestic or imported foods or between food types, then this will also contribute to a further rise in prices. However, as we are exploring a policy which will be implemented over many years, it is reasonable to assume that the economy will have time to adjust to the new demands for agricultural products.

6. Conclusions

This study has shown **it is possible to ex-ante quantify the impacts of a biofuels mandate on the four pillars of food security on household level. Although all four pillars can be assessed, *availability* and *access* are more easily and better addressed than *stability* and *utilisation*.** The trade-offs between the different pillars of food security show the importance of this analysis. In addition, as the impacts differ between the urban and rural households, it also illustrates why food security assessments preferably include different household types for which the impacts of biofuels can differ. An average number for a whole country or region does not do justice to the differences in impacts. Therefore, **further disaggregation to households in e.g. different geographical regions or different income groups, is required to assess the variability of impacts across different groups in society and which groups in society are affected most.** This can help to maximise positive socio-economic impacts and minimise negative impacts.

Food security impacts are often cited as an important (potentially negative) impact of biofuel production and a reason to oppose biofuel development. This study shows that the **projected food security effects of a biofuel mandate in Ghana are slightly negative, but limited compared to the effects of the projected economic growth of the coming years.** This means caution is needed when deciding on biofuel production in the country, and that the assessment of a biofuel mandate must be made in the context of other developments.

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Appendix

Table A1
Households characteristics of the two households in Ghana included in the MAGNET model.

Household	2010 Population (million)	**Income (USD cap^{-1} yr^{-1})**	2030 Population (million)
Urban	12.5	2524	16.3
Rural	16.3	1729	17.1

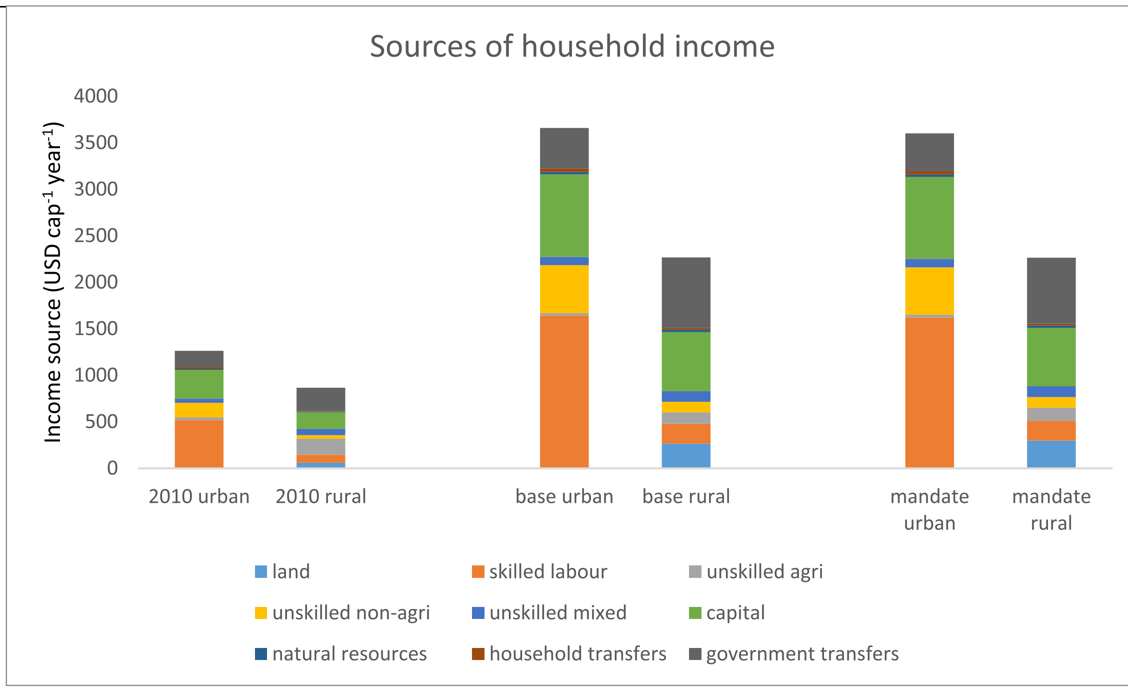

Fig. A1. Sources of household income in rural and urban areas in Ghana in 2010, and *baseline* (base) and *mandate* scenarios in 2030.

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