The effect of changing meat and milk consumption on future water and land footprints in Kenya.

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Abstract

Population growth and rising affluence increase the demand for agricultural commodities, while urbanization and globalization enlarge consumer-producer distances. The associated growth in trade in agricultural products results in increasing dependence on natural resources in the producing regions. This study assesses the impact of changing meat and milk consumption on natural resources use in Kenya, considering two socio-economic development scenarios, namely the Business As Usual (BAU) and Kenya Vision 2030 (S2030) scenarios. Two resource use indicators, water footprint and land footprint, are used to represent human appropriation of water and land resources for meat and milk production, trade and consumption in 2030. Overall meat and milk production and consumption are projected to be higher in the S2030 than in the BAU scenario. The fraction of imported meat in total meat consumption is expected to grow between 2009 and 2030 from 37% to 45% in both scenarios. The fraction of imported milk in total milk consumption will remain at 13% in the S2030 scenario but grow towards 20% in the BAU scenario.

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From 2009 to 2030, the water and land footprints of meat production will grow by 93% and 91% in BAU and by 45% and 23% in S2030. The water and land footprints of milk production will both grow by 59% in BAU and by 18% and 14% in S2030. The use of water and land for producing meat and milk in Kenya will thus grow under both scenarios, but less in S2030 than in BAU, despite the stronger growth of meat and milk consumption per capita in S2030, which can be explained by the smaller population growth in the S2030 scenario and the greater improvements in water and land productivities. The Vision 2030 strategy for improving livestock production in Kenya is of great importance to reduce the speed with which the environmental footprint of the sector will increase, but it will be insufficient to stabilize or even reduce the sector’s footprint. Besides, reducing the dependency on foreign land and water resources would require a yet more ambitious policy.

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1. Introduction

Human population has increased globally from an estimated 2.5 billion people in 1950 to the current 7 billion (UN 2013). Population growth has been most rapid in the developing world where the growth rate is spurred by high fertility rates (Spence et al. 2009). Alongside the population increase is a trend towards diets that include more highly nutritive and resource-demanding livestock products. This so called demand-driven livestock revolution (Delgado 2003) has been realized mostly in developing regions, especially in Asia. Animal source foods such as milk and meat require more freshwater than crop-based foods (Rockström et al. 2009, Mekonnen and Hoekstra 2012). Satisfying the increasing demand for animal source foods is therefore constrained by the amount of water and land resources available for agricultural production (Wirsenius et al. 2010, Stroosnijder et al. 2012).

While other countries may have a competitive advantage in other economic sectors, in sub-Saharan Africa agriculture remains the pillar of many economies and the main driver of economic growth (De Fraiture et al. 2010). Consequently, there have been repeated calls to develop and intensify agricultural production in general and the livestock sector in particular as envisioned in initiatives such as the Comprehensive Africa Agriculture Development Programme. However, agricultural intensification can have adverse effects on the environment, as has been documented for the livestock sector, particularly intensified dairy and pig production in developed regions (van der Zijpp 1999, Gerber et al. 2005). These negative outcomes of agricultural intensification agendas point to a disconnection between policies that focus on enhancing livestock production on the one hand and natural resource management on the other (Otte et al. 2012). This realization has spurred the development of scientifically sound environmental indicators that provide quantitative metrics for empirically monitoring and evaluating the environmental footprints of human consumption (Hoekstra and Wiedmann 2014, Bruckner et al. 2015). The water and land footprints are two such key indicators that are used to assess the impacts of human consumption on the appropriation of freshwater and land.

In Kenya, the national vision for development, officially referred to as Kenya Vision 2030, outlines strategies to be used by the national government to achieve middle-income status by 2030. The economic pillar of Vision 2030 aims at an annual gross domestic product (GDP) growth rate of 10% from the year 2012 to 2030, while the social pillar seeks to establish a just and equitable society living under a secure and clean environment. The political pillar aims at entrenching and nurturing a democratic system that respects the rule of law and protects the freedom of every Kenyan. Increased prosperity in Kenya as envisioned by Vision 2030 will almost certainly result in increased consumption, especially of animal source foods. The increased consumption will aggravate the pressure on the water and land resources needed to meet the growing demand.

This study aims to understand how the policies on population fertility rates, livestock production and dairy consumption, as formulated in Kenya's Vision 2030, will affect land and water resources use, both within and outside Kenya. This is achieved through the quantification and evaluation of the environmental resources demand linked to the consumption of meat and milk in Kenya projected to the year 2030, the anticipated end date of Kenya's Vision 2030 strategy.

2. Method and data

We formulated two scenarios for Kenya towards 2030: the Business as Usual (BAU) scenario, which assumes the continuation of current policies into the future, and the S2030 scenario, which assumes the full implementation of Kenya's Vision 2030 strategy. The scenarios are described in terms of changes in population, total meat and milk production, water and land use efficiency in feed production, feed conversion efficiency of animals, and consumption of meat and milk per capita. We consider total meat and milk from ruminants (cattle, sheep, goats), leaving out meat from pigs and chicken as well as meat and milk from camels. For both scenarios we use outputs from the Kenyan Threshold 21 (T21) model to obtain future estimates for population and meat and milk production. The T21 model was specifically developed to forecast the impacts of agricultural strategies and national development plans in Kenya and was made suitable to assess the impacts of implementing Kenya's Vision 2030 strategy (Züllich et al. 2015). To date, the model has been used for climate change adaptation and comprehensive national development planning in Kenya, analysis of green economy investment options, as well as for assessment of alternative national strategies for malaria eradication (Pedercini et al. 2011, Züllich et al. 2015). Consumption patterns and the usage of water and land resources are not included in the T21 model and related variables in the two scenarios are assumed as described in the following section. Based on the description of the two scenarios we estimate water and land footprints of meat and milk production, assess the economic productivities of water and land use in meat and milk production, and estimate the water footprint of meat and milk consumption, showing which parts of these footprints lie within Kenya and which parts outside the country.

2.1. Description of scenarios

Several issues are addressed in the Kenya Vision 2030 strategy. We focus here on population growth and the production and consumption of meat and milk. Table 1 shows the status of a number of relevant variables in the base year (2009) and assumed changes between the base year and 2030 under the BAU and S2030 scenarios, assuming full implementation of the policies pertinent to each scenario. Figure 1 further shows total meat and milk production, consumption and net import in 2009 and in 2030 for the two scenarios.

The BAU scenario assumes the continuation of the current trends in population, production and consumption growth up to 2030, full implementation of the currently existing legislation and no fundamental deviation from the current policies between now and 2030. Population size is estimated based on decadal national censuses and projections based on fertility rates for the year 2009 (GOK 2010c, 2012). The BAU scenario assumes similar meat and milk consumption rates as those documented by Gamba (2005) and Argwings-Kodhek et al. (2005) for Kenya today. Production parameters for meat and milk are taken from Bosire et al. (2015) for the period 2000-2012. Trade in meat and milk is quantified based on the food balance approach. Current trade is estimated based on figures for the year 2009.

The S2030 scenario assumes full realization of the Vision 2030 strategic goals. In this scenario, the population growth rate is assumed to be based on halving the fertility rate between 2009 and 2030 (GOK 2012). The scenario is further characterised by a high economic growth rate, which translates into a higher rate of consumption of animal source foods. The S2030 scenario assumes a 184% increase in total meat consumption between 2009 and 2030 and a 121% increase in total milk consumption (GOK 2010b, Alexandratos and Bruinsma 2012). In this scenario, the projected growth in production is based on an increased public investment in agriculture of up to 10% of the national budget and an average annual growth rate of at least 6% in agricultural production as outlined in the Comprehensive Africa Agriculture Development Programme (CAADP) from the African Union agreement. The overall goal of CAADP is to eliminate hunger and reduce poverty through agriculture. The S2030 scenario assumes the adoption of technologies and management practices that improve production. Trade in meat and milk is quantified based on the food balance approach.

Table 1. The status of variables in the base year (2009) and assumed changes between the base year and 2030 under the Business as Usual and S2030 scenarios.

	Base year[1] (2009)	Scenario for the year 2030[2]	
		Business as usual	S2030
		% change	% change

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Population	38,610,100	+63%	+29%
Consumption of ruminant products per capita (kg)	Meat: 17 Milk: 53	Meat: +23% Milk: +10%	Meat: +101% Milk: +77%
Production of ruminant products (tonnes)	Meat: 374,840 Milk: 1,831,870	Meat: +93% Milk: +59%	Meat: +147% Milk: +122%
Meat WF (m^3/tonne)			
Green	32,069	0%	-42%
Blue	501	0%	-38%
Total	32,570	0%	-41%
Meat LF (ha/tonne)			
Grazing	4.86	0%	-62%
Crop	0.36	0%	+105%
Total	5.22	0%	-50%
Milk WF (m^3/tonne)			
Green	1,139	0%	-47%
Blue	31	0%	-39%
Total	1,170	0%	-47%
Milk LF (ha/tonne)			
Grazing	0.17	0%	-65%
Crop	0.02	0%	+63%

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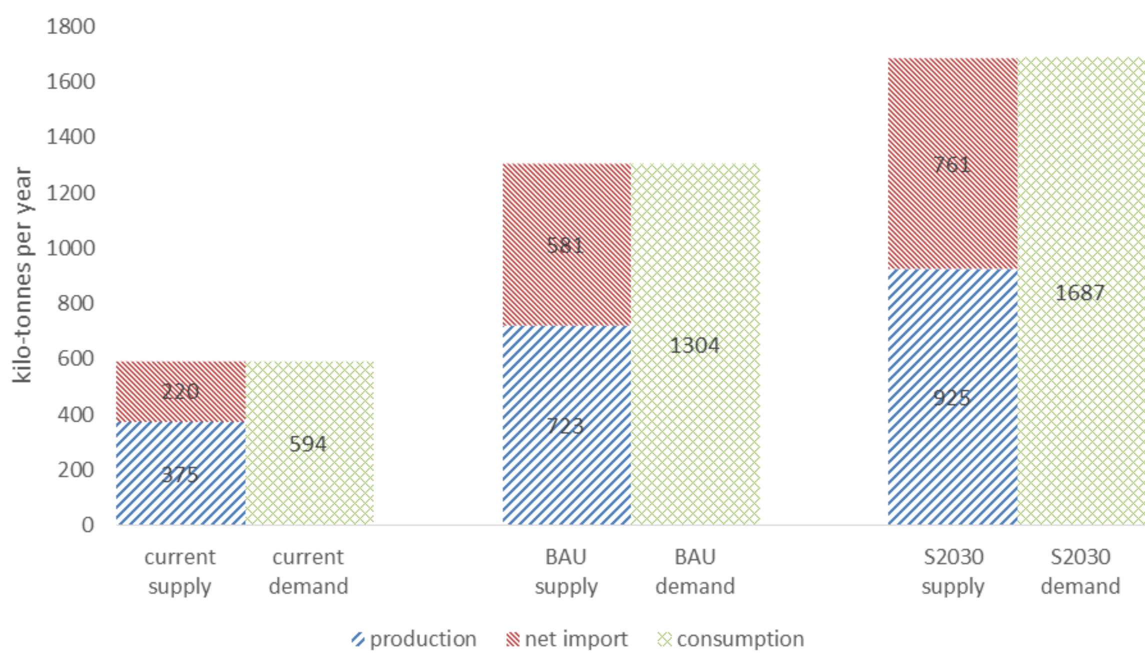
Total	0.19	0%	-49%

[1] Sources: base year data on population from (GOK 2010c); WF and LF data from (Bosire et al. 2015); consumption of meat and milk per capita from (Argwings-Kodhek et al. 2005, Gamba 2005)

[2] Sources: estimated changes of population, and total production of meat milk are taken from the output of the T21 model; changes in WF and LF per tonne of product are taken from Bosire et al., (2016); changes in consumption of meat and milk per capita from Erb et al. (2009) and (GOK 2010b), respectively.



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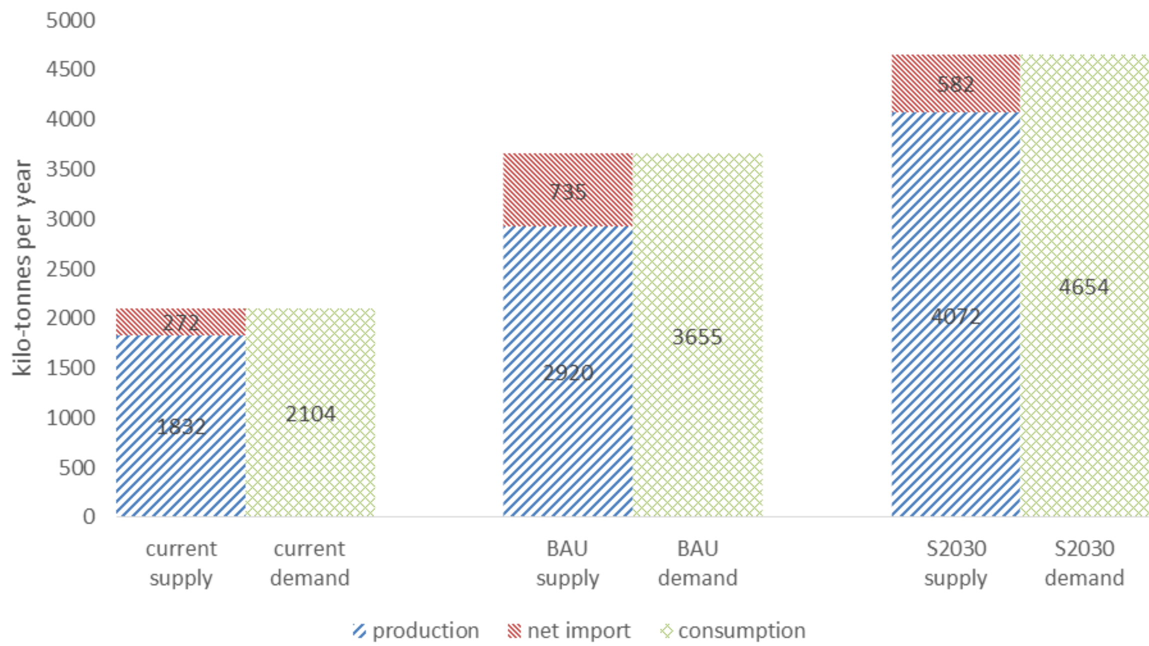

Figure 1. The production, consumption and net import of meat (upper graph) and milk (lower graph) in 2009 and in 2030 for the BAU and S2030 scenarios.

2.1.1. Population

Population growth is determined by birth and mortality rates. In the BAU scenario, population growth is presumed to continue under the current high fertility rate of 4.6 children per woman, resulting in a population growth of 63% between 2009 and 2030 (GOK 2012). The S2030 scenario is based on a reduction of the fertility rate towards 2.1 children per woman in 2030, resulting in a population growth of 29%. Achieving the lower population growth as assumed under the S2030 scenario presupposes increasing the effective contraceptive use rate from 27% under the BAU scenario to 40% under the S2030 scenario.

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2.1.2. Production of meat and milk

The agricultural sector in Kenya has seen annual growth rates varying between 0.7% and 5.3% in the 1990s (Ndung'u et al. 2011). In the BAU scenario, meat and milk production are assumed to continue growing and become 93% and 59% larger than the current production, respectively, by 2030. For the S2030 scenario we use production growth rates assuming increased budgetary allocation as described in Züllich et al. (2014). Meat and milk production under the S2030 scenario are assumed to grow between the base year and 2030 by 147% and 122%, respectively. This assumption is motivated by the second and fourth strategies in the agricultural sector improvement plan in the Vision 2030 document. The second strategy aims to increase productivity of crops and livestock while the fourth strategy focuses on preparing new lands for cultivation by strategically developing irrigable areas of arid and semi-arid lands for both crops and intensified livestock production.

For the BAU scenario we assume that the prevailing feed crop yields remain unchanged and therefore that the water and land footprints per unit of feed crop stay at their current levels. In the S2030 scenario, we assume improvements in feed crop yields according to the "good" water productivity improvement percentage in Ercin and Hoekstra (2014). The water and land footprints per unit of meat and milk associated with improved livestock productivity under technology improvements are derived from scenario S1 in Bosire et al. (2016) for the BAU scenario and from scenario S3 for the S2030 scenario. The relative distribution of production over the arid, semi-arid and humid production systems is assumed to remain the same as in the base year.

Overall, the average water and land footprints per tonne of meat and milk are lower for the S2030 than the BAU scenario (Table 1). As we assumed no technological improvements in production in the BAU scenario, there is no difference in the water and land footprints per tonne of meat and milk between the BAU scenario and base year. In S2030, however, the water footprints per tonne of meat and milk will get reduced by 41% and 47%, respectively. The land footprint per tonne of meat and milk will decrease in this scenario by 50% and 49%, respectively. However, the overall smaller land footprint of meat and milk production in the S2030 scenario is the net result of large decreases in the grazing land footprint, but very substantial increases in the cropland footprint, related to the increased fraction of feed crops in the diet of the animals in this scenario.

Due to large discrepancies in the various data sets on livestock production in the base year (2009), we use the meat and milk production values from Bosire et al. (2015) and project production to 2030 using the production growth rates from Züllich et al. (2014). The large discrepancies are brought about by the inaccuracies inherent in the country level data prior to the 2009 livestock census. The estimates from Bosire et al. (2015) are based on consistent livestock censuses by the Kenya Directorate of Resource Surveys and Remote Sensing (DRDRS) covering the period 1977 to 2012.

2.1.3. Consumption of meat and milk

For the baseline year 2009 we used the data on consumption of meat and milk from Gamba (2005) and Argwings-Kodhek et al. (2005). Since consumption of livestock products has not yet been developed in the T21 model, changes in consumption had to be determined outside the model. Per capita meat and milk consumption in the BAU scenario is assumed to grow with the same growth rates as were calculated for the period 1980-2009 (Shah and Frohberg 1980, Argwings-Kodhek et al. 2005, Gamba 2005). The growth of meat and milk consumption per capita in the S2030 scenario was estimated assuming full implementation and realization of the Vision 2030 strategy.

Total consumption of meat and milk in the BAU scenario are projected to grow by 119% and 74%, respectively (Alexandratos and Bruinsma 2012). Due to lack of country-specific projections, total meat consumption under the S2030 scenario is assumed to grow by 184% to meet the “less meat” scenario for Sub-Saharan Africa described in Erb et al. (2009). The less meat scenario has been selected because it is

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the most plausible scenario for Kenya's meat consumption into the future as opposed to the other scenarios in Erb et al. (2009) which give as high as 400% increase in per capita meat consumption. Total milk consumption in the S2030 scenario is projected to more than double, as targeted under Kenya's dairy development strategy (GOK 2010b), with an increase of 121% by 2030 relative to the base year.

2.1.4. Food balance analysis

In the Kenya Agricultural Sector Development Strategy, the government advocates self-sufficiency through maintaining a balance between demand and supply of livestock products (GOK 2010a). However, in neither of the two scenarios does the expected growth in production of meat and milk keep up with the expected growth in consumption. To understand the implications of changes in consumption and production on food self-sufficiency, we use a food balance approach (subtracting total production from total consumption) to determine required imports of meat and milk by 2030.

2.2. Assessment of water and land footprints of livestock production and consumption

The water and land footprints of livestock production in the two scenarios are estimated following the same method as in Bosire et al. (2015). The water footprint is an indicator of appropriation of freshwater, from either a production or consumption perspective (Hoekstra et al. 2011). We consider here both the blue water footprint, the consumption of blue water resources (groundwater and surface water), and the green water footprint, the consumption of green water resources (rainwater in the soil). The land footprint is defined here as the actual land used from either production or consumption point of view (Erb 2004). We will distinguish between two components in the land footprint: grazing land and cropland.

For both meat and milk, we calculate the water footprint of production and consumption as:

$$WF_{prod}[p] = P[p] \times WF_{prod}[p] \quad (1)$$

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$$WF_{cons}[p] = C[p] \times WF_{cons}[p] \qquad (2)$$

whereby *P[p]* is the production of product p in the country (tonne/yr), *C[p]* is the consumption of product p (tonne/yr), $WF_{prod}[p]$ is the average water footprint of the product produced in the country (m^3/tonne), and $WF_{cons}[p]$ is the average water footprint of the product consumed in the country. The products are meat and/or milk from cattle, sheep and goats and camel. Whereas $WF_{prod}[p]$ depends on the water footprint of production in the country (averaged over different regions and production systems), $WF_{cons}[p]$ depends on the water footprint of production in the country and on the water footprint of the production in other countries for imported products.

Similarly, we calculate the land footprint of production and consumption as:

$$LF_{prod}[p] = P[p] \times LF_{prod}[p] \qquad (3)$$

$$LF_{cons}[p] = C[p] \times LF_{cons}[p] \qquad (4)$$

The dependency of Kenya's consumption of meat and milk on domestic versus foreign freshwater and land resources is derived from the ratios of domestic production versus imports.

2.3. Assessment of economic water and land productivity of meat and milk production

Economic water and land productivities of meat production in Kenya are estimated by dividing the total value of meat production (Kshs/y) by the total water and land footprint associated with meat production, respectively, and similarly for milk production. The values of meat and milk production are derived by multiplying the unit price of meat and milk and their total production. Prices of milk and meat are assumed to be constant. Although we expect increases in milk and meat prices during the projection period, we assumed no price changes, since we are interested in comparing the two scenarios for each livestock product. Additionally, the difference in price between meat and milk is consistent with the conclusions of Syrstad (1993). The price of 1 kg of beef ranges between three to five times that of 1 kg of milk.

3. Results

3.1. Water and land footprints of meat and milk production in Kenya by 2030

Compared to the base year, the total water footprint of meat production increases by 93% in the BAU scenario and 45% in the S2030 scenario. The total water footprint of milk production increases by 59% in BAU and decreases by 18% in S2030 (Table 2). The total land footprint shows a similar trend: the total land footprint of meat production increases over the period 2009-2030 by 93% in the BAU scenario and 23% in the S2030 scenario. The total land footprint of milk production grows by 59% under the BAU scenario and by 12% in S2030.

Between 2009 and 2030, the economic value of meat production increased by 93% and 147%, whilst the economic value of milk production increased by 59% and 122% under the BAU and S2030 scenarios, respectively. Both meat and milk production had higher economic water productivity under the S2030 than the BAU scenario. Though the economic water productivity of meat production is smaller than in milk production, the water productivity in both sectors grows by more or less the same rate in the S2030 scenario. Economic water productivity of milk in 2030 is higher in S2030 (148 Kshs/m^3) than in BAU (78 Kshs/m^3) scenario. Economic land productivity grows fast (by 100%) for meat production in the S2030 scenario.

Table 2 Water and land footprints and water and land productivity of meat and milk production at present and by 2030 under the BAU and S2030 scenarios.

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	Base (2009)	BAU	S2030
WF of meat production (million m^3/year)	12,210	23,540	17,640
WF of milk production (million m^3/year)	2,140	3,420	2,520
LF of meat production (10^3 ha/year)	1,960	3,770	2,410
LF of milk production (10^3 ha/year)	350	560	400
Economic value of meat (million Kshs)	174,300	336,070	430,290
Economic value of milk (million Kshs)	167,520	267,060	372,400
Economic water productivity of meat (Kshs/m^3)	14	14	24
Economic water productivity of milk (Kshs/m^3)	78	78	148
Economic land productivity of meat (Kshs/ha)	89,080	89,080	178,240
Economic land productivity of milk (Kshs/ha)	475,540	475,540	940,850

3.2. Water and land footprints of meat and milk consumption in Kenya by 2030

The water footprint of meat consumption per capita is about 5% smaller in the S2030 scenario than in the BAU scenario despite the fact that the milk consumption per capita is more than 60% larger (Figure 2). Similarly, the water footprint of milk consumption per capita is 16% smaller in the S2030 scenario than in the BAU scenario. The land footprint of meat consumption per capita is 22% smaller in the S2030 scenario than in the BAU scenario. The largest difference in land footprint per capita is between the per capita cropland footprint for milk in the S2030 scenario and the BAU scenario. The cropland footprint in the S2030 scenario almost quadruples relative to the base year for meat consumption because of the increased use of feed crops in livestock production.

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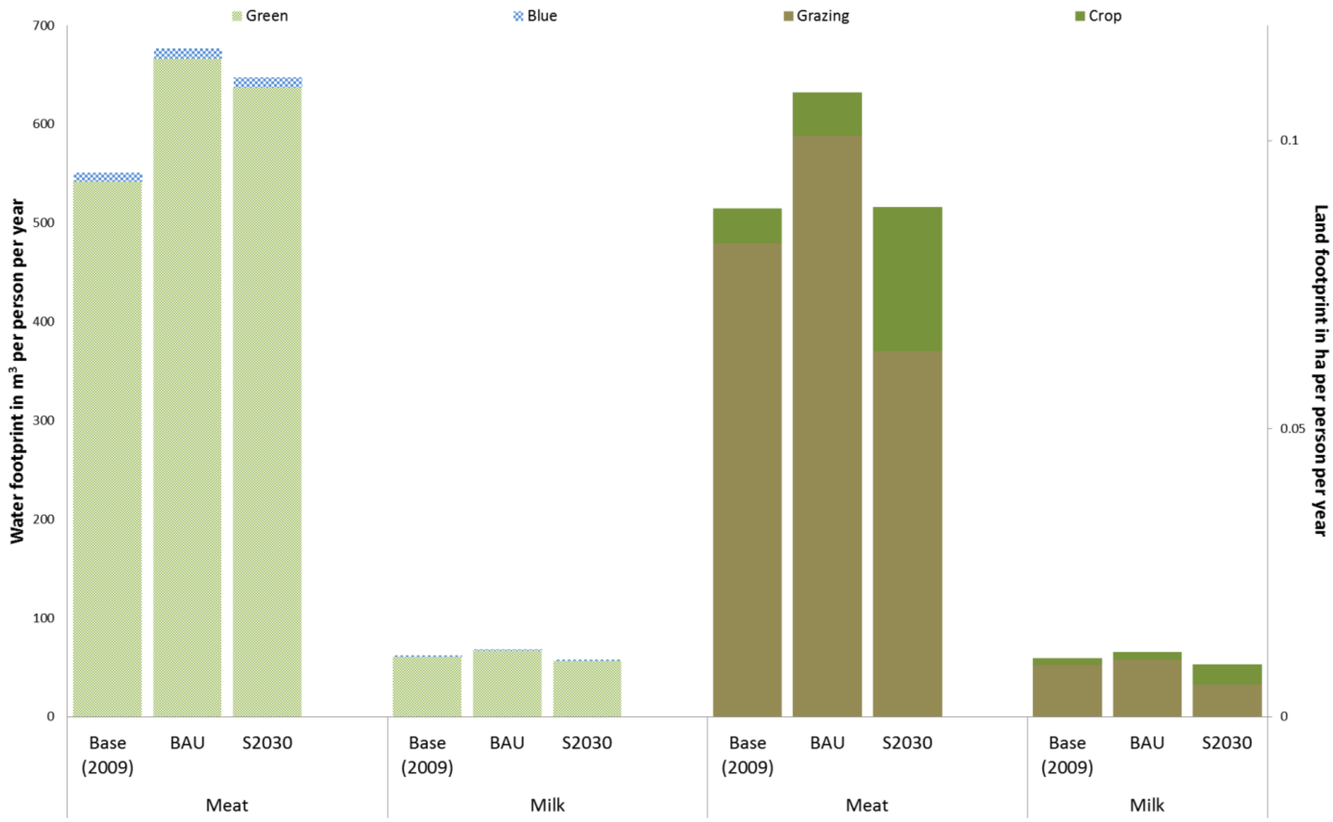

Figure 2 Water and land footprints per capita for meat and milk consumption in 2030 for the BAU and S2030 scenarios.

Table 3 shows the domestic and foreign water footprints of meat and milk consumption in Kenya under the two scenarios. The ratios of the domestic and foreign water footprints of meat consumption in the base year differ slightly from that in the BAU and S2030 scenarios. The ratios of the domestic and foreign water footprints of both meat and milk consumption in the BAU and S2030 scenarios in 2030 are similar. Under the base year (2009) there is a 43% dependence on foreign water resources to meet the meat demand as opposed to a 45% consumptive use of foreign water resources under the BAU and S2030 scenarios. Consumption of milk however shows greater dependence on foreign water resources under the BAU scenario (20%) than under the S2030 scenario (12%).

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Table 4 shows the domestic and foreign land footprints of meat and milk consumption in Kenya under the two scenarios. In both scenarios, the foreign land dependence of meat consumption marginally grows from 43% in the base year to 45% in 2030. Milk consumption relies more strongly on domestic land resources, both in the base year and the future, although the foreign land dependence will grow in both scenarios.

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Table 3 Domestic and foreign water footprints of meat and milk consumption in 2030 under the BAU and S2030 scenarios.

Water footprint	Total water footprint of consumption (10^6 m^3/year)			Domestic water footprint of consumption (10^6 m^3/year)			Foreign water footprint of consumption (10^6 m^3/year)			Domestic water dependence of consumption (%)			Foreign water dependence of consumption (%)		
	Base (2009)	**BAU**	**S2030**	**Base (2009)**	**BAU**	**S2030**	**Base (2009)**	**BAU**	**S2030**	**Base (2009)**	**BAU**	**S2030**	**Base (2009)**	**BAU**	**S2030**
Meat															
Green	20,920	41,830	31,640	12,020	23,180	17,360	8,900	18,650	14,280	57	55	55	43	45	45
Blue	330	650	530	190	360	290	140	290	240	57	55	55	43	45	45
Total	**21,250**	**42,480**	**32,170**	**12,210**	**23,540**	**17,650**	**9,040**	**18,940**	**14,520**	**57**	**55**	**55**	**43**	**45**	**45**
Milk															
Green	2,330	4,170	2,790	2,090	3,330	2,440	240	840	350	90	80	88	10	20	12
Blue	70	110	90	60	90	80	10	20	10	90	80	88	10	20	12
Total	**2,400**	**4,280**	**2,880**	**2,150**	**3,420**	**2,520**	**250**	**860**	**360**	**90**	**80**	**88**	**10**	**20**	**12**

Table 4 Domestic and foreign land footprints of meat and milk consumption in 2030 under the BAU and S2030 scenarios.

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Land footprint	**Total land footprint of consumption (10^3 ha/year)**			**Domestic land footprint of consumption (10^3 ha/year)**			**Foreign land footprint of consumption (10^3 ha/year)**			**Domestic land dependence of consumption (%)**			**Foreign land dependence of consumption (%)**		
	Base (2009)	**BAU**	**S2030**	**Base (2009)**	**BAU**	**S2030**	**Base (2009)**	**BAU**	**S2030**	**Base (2009)**	**BAU**	**S2030**	**Base (2009)**	**BAU**	**S2030**
Meat															
Grazing	3,170	6,330	3,150	1,820	3,510	1,720	1,350	2,820	1,430	57	55	55	43	45	45
Crop	240	470	1,240	140	260	680	100	210	560	57	55	55	43	45	45
Total	**3,410**	**6,800**	**4,390**	**1,960**	**3,770**	**2,400**	**1,450**	**3,030**	**1,990**	**57**	**55**	**55**	**43**	**45**	**45**
Milk															
Grazing	345	620	280	310	500	250	35	120	30	90	80	88	10	20	12
Crop	45	80	170	40	60	150	5	20	20	90	80	88	10	20	12
Total	**390**	**700**	**450**	**350**	**560**	**400**	**40**	**140**	**50**	**90**	**80**	**88**	**10**	**20**	**12**

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4. Discussion

4.1. Population growth under the BAU and S2030 scenarios

An important challenge is the combination of population growth and increasing affluence. The future size of Kenya's population will inevitably affect the ability of Kenya to feed itself (Schell et al. 2007). The available resources make it difficult to meet the self-sufficiency target. The main cause of population growth is that the average birth rate in Kenya remains high whilst the average mortality rate has dropped due to implementation of the Millennium Development Goals (GOK 2013). If Kenya is to achieve the Vision 2030 goal of an increase in income with associated increase in meat and milk consumption per capita, a more stringent demographic policy would be required than assumed in the S2030 scenario. This can be achieved if the birth rate is further lowered, commensurate with the reduced mortality rates.

4.2. Consumption changes under the two scenarios

Globally, consumption of meat and milk has grown since the 1970s, albeit at rates that vary across countries (Alexandratos and Bruinsma 2012). Meat consumption in the developing regions has grown at a slightly faster rate (average rate of 5.1% per annum over the period 1979-1997) than milk consumption (about 3.6 % per annum over the same period). However, between 1997 and 2007, the growth rate in meat consumption in these countries decreased to 2.9% per annum (Alexandratos and Bruinsma 2012). The demand for meat in Kenya, in particular, is assumed to be rising at an unprecedented rate (GOK 2010a), though various studies that focus on changes in meat consumption suggest that it may not be growing at the perceived high rate (Alexandratos and Bruinsma 2012). One possible explanation for this discrepancy is that the growth in the middle class segment of Kenya's population may be pushing the

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perceived increase in demand. However, when averaged over all the income segments, the fast increase in demand is no longer apparent.

4.3. Production changes under the two scenarios

The increased consumption must be met by increased production or imports. An increase in production often forms a critical component of efforts to alleviate poverty. Indeed, agriculture-led growth in Africa is currently more than twice as effective in reducing poverty as growth led by industry (Conceição et al. 2016). The key to sustaining and enhancing growth in agricultural performance in Kenya will most likely lie in increasing smallholder productivity and investing in developing non-farm activities (IFAD, 2013).

Improvements in the livestock sector are contingent upon the production of sufficient quantities of compounded livestock feeds. Increasing livestock productivity should therefore also entail concurrently increasing productivity in the crop sector, increasing feed crop quality and decreasing water and land demand per unit of feed. In Kenya, maize is the major component of compounded livestock feeds, as well as the main staple food. Maize productivity is unfortunately declining in many parts of Kenya despite the rising demand, due to widespread land subdivision, land degradation through soil erosion and other factors (Jones and Thornton 2009, Maitima et al. 2009). To meet both the food and feed demands in Kenya, it will thus be necessary for farmers to be supported to increase productivity of cereals higher than the levels envisioned in Kenya's Vision 2030 strategy and Agricultural Sector Development Strategy. Realizing the potential for large-scale production of feed crops such as maize and wheat may lie in using the less exploited areas like Turkana and Tana River, where farmers may be able to use their excess produce to make animal feed and where land subdivision is still relatively less extreme.

4.4. Options to attain food self sufficiency

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Meeting the food balance deficit can be achieved either through import or through increasing the productivity of both crops and livestock. A country may decide to import goods or services that are either essential to the country's economic well-being or products that are highly sought after by the citizens but are not sufficiently available in the domestic market. Additionally, a country may decide to import products that can be produced at a relatively low cost or more efficiently by another country, and therefore are sold at lower prices. In both cases, meeting the deficit through imports will require that the source areas are able to produce surpluses and that the country requiring the product is able to purchase the commodities (Bourguignon and Morrisson 1990). It is noteworthy, that some countries are able to produce surplus dairy and meat (such as Brazil, India and New Zealand) which are, in some instances, imported into Africa (Herrero et al. 2014). Currently, Kenya imports very low quantities of milk which is mainly in powder form (EADD 2008). However, meat imports in the form of live animals, are already equivalent to around 40% of the total demand. The trend of increasing import of meat is continued under the two scenarios, which also show an increase in milk imports. To ensure that Kenya is able to purchase the shortfall in internal supply, there will be a need for Kenya's income level to grow in tandem with the growth in deficit level.

Another option is to further increase domestic livestock production. In Africa, currently ranked as the continent with the lowest productivity per animal and therefore least productive in terms of livestock production in the world, there is still a large potential to improve productivity (Tittonell and Giller 2013). In Kenya, under both scenarios, there is a need to import meat and milk. Even with increased productivity under the S2030 scenario, there is still a need to import about 13% of milk and 45% of meat. Therefore, productivity will need to improve even faster than under the ambitious high productivity scenario S2030. However, several processes may diminish the likelihood of substantially enhancing livestock productivity. These include high population density associated with reduced fallow periods and land use intensification and the very limited level of successful non-farm diversification options to farmers that are forced off their farms (Headey and Jayne 2014).

4.5. Water and land footprint associated with the two scenarios

This study has shown that in Kenya, both meat and milk production are mainly dominated by grazing land and green water footprints, which have lower opportunity costs compared to cropland and blue water, especially in the arid and semi-arid regions. However, crop land footprints and blue water footprints are increasing under both scenarios, an increase related to the increasing use of feed crops. The increase in the proportion of compounded and supplemental feeds in livestock diet is associated with increases in meat and milk yields (Herrero et al. 2013). Supplying this increased proportion of compounded and supplemental feeds translates into an increased crop land footprint, with the potential to increase the competition for arable land for producing food crops. In the S2030 scenario, with a relatively high proportion of feed crops in the livestock diets, the risk of this type of conflict is higher than in the BAU scenario. In terms of the water footprint of meat and milk production, increasing the production of maize through irrigation in arid and semi-arid areas, which is also partly used as livestock feed, would increase the blue water footprint in both crop and livestock production. These production systems in Kenya are already blue water scarce (Hoekstra et al. 2012) and so increasing the use of irrigation would further elevate this scarcity and escalate the ongoing conflicts caused by water scarcity.

An alternative to way of achieving greater food security in Kenya that has not yet received adequate attention in governmental policies yet is to promote crop-based protein sources instead of animal-based protein sources. Since the former have a much smaller water and land footprint per unit of protein than the latter (Erb et al. 2012, Mekonnen and Hoekstra 2012), this offers a perspective on reducing the environmental footprint of a population through the diet (Steinfeld and Gerber 2010, Hoekstra 2014). Policies that aim to influence diets could thus supplement policies that aim to increase productivity.

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4.6. Economic water and land footprint associated with the two scenarios

The total economic value of meat and milk production in Kenya in the base year is valued in this study at 342 billion Kenya shillings, an estimate which does not vary greatly from the estimate by Behnke and Muthami (2011). However, the main contribution to this economic value in this study is meat production as opposed to milk production as in Behnke and Muthami (2011). This apparent discrepancy in the economic estimates is caused by the difference in the data sources used to obtain the two estimates. Under the projections in the BAU and S2030 scenarios, the economic value of livestock products in Kenya is set to be, respectively, 78% and 136% larger than the 2009 levels, mainly due to increase in production as price has been assumed to remain constant for this analysis.

The economic water productivity of milk is much higher than that of meat, both in the base year and in both scenarios (Table 2). This implies that milk production in Kenya generates higher value per unit of water used compared to meat production. The same is observed for the economic land productivity of milk versus meat. This observation may suggest that it would be more economically sound to shift to or increase milk production and reduce meat production in Kenya and probably focus on importing the latter. However, in reality this is much more complex due to the varied agro-economic conditions in the production systems in Kenya. It would be possible to shift to specialization in milk production for farmers in the highland areas of the country because of favourable climatic and soil conditions. In the arid and semi-arid lands though, low and widely variable rainfall and land degradation make livestock rearing for meat environmentally more appropriate (mainly green water and grazing land used) in comparison to milk production.

4.7. Limitations

Underlying the S2030 scenario is the assumption that the necessary investments will be undertaken, and that policies will be successfully implemented. We however are cognizant of several issues that may introduce some bias into the outcomes of the projections used in this study. Firstly, completely missing is a consistent database on projections for consumption of livestock products in Kenya. Secondly, policy options for meat production and consumption are generally very limited. This hampers the use of such models as the T21 model and therefore limits our capacity to reliably project likely future consumption related to the two products. Additionally, reliable estimates on the total production estimates for meat production are scanty and inconsistent. There is more information pertaining to milk production and consumption in Kenya, mainly as an outcome of higher investment in the dairy sector in the more humid highland regions. Finally, we have not included the possible effects (negative and/or positive) of climate change in our long term meat and milk productions projections. The T21 model does not currently account for such factors, but we recognize that our results could change if we were to account for the potential impacts of climate change in our projections.

In this study, our milk and meat production estimates are aggregated over three production systems in Kenya. Each system has a varying range of conditions, bio-physical and socio-economic, that favour the production of either meat or milk and plausible changes may be expected to show different trends per production system. Future research could focus on trends that differentiate amongst the type of production systems of meat and milk production and additionally include effects of both climate change on projected longer term patterns.

5. Conclusion

If the budget for agriculture is increased to meet the recommendations of the Comprehensive Africa Agriculture Development Programme, meat and milk production in Kenya in 2030 can be expected to grow 1.5 to 2 times faster than if the budgets are maintained at their current levels. However, this magnitude of increase in production is not sufficient to meet the projected growth in demand for these two products, and diminishes the self-sufficiency aimed for in Kenya’s policy strategy. It may be possible to achieve the self-sufficiency target in meat and milk production under a more modest increase in population numbers than that forecasted by the S2030 scenario. The projected growth in population and in meat and milk production under the two scenarios does not match the growth in consumption, leading to a widening of the gap between local supply and demand for these two products.

In order to meet meat demand, it may be worthwhile considering import of meat from the neighbouring countries or increasing production in the humid production system where the economic costs of production may be lower, but where the competition with food demand will be greater. Because meat has lower economic water and land productivities than milk, it may be worthwhile for Kenya to consider importing meat and enhancing milk production, especially in the humid systems, to meet the increased demand.

Strategies that focus on increasing livestock and crop productivity lead to lowered water and land footprints per unit of production, which creates room for increased production. However, land and water resources in Kenya are already scarce and overexploited in some places. Besides, climate change may adversely impact on the availability of water resources in the future.

The results of this study show that the amount of water and land for producing meat and milk in Kenya will grow under both scenarios considered, but less in S2030 than in BAU, despite the stronger growth of meat and milk consumption per capita in S2030. This can be explained by the smaller population growth in S2030 and the greater improvements in water and land productivities in S2030. The Vision 2030 strategy for improving livestock production in Kenya is of great importance to reduce the speed with which the environmental footprint of the sector will increase, but it will be insufficient to stabilize or even reduce the sector's footprint. Besides, reducing the dependency on foreign land and water resources would require a yet more ambitious policy.

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Conflict of Interest Statement

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I, Caroline Bosire as corresponding author, submit that there is no conflict of interest associated with the submission of the manuscript titled **“The effect of changing meat and milk consumption on future water and land footprints in Kenya”** to the Journal Food Security.

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