

Substituting beans for beef as a contribution toward US climate change targets

Helen Harwatt¹ · Joan Sabaté¹ · Gidon Eshel^{2,3} ·
Sam Soret¹ · William Ripple⁴

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Abstract Shifting dietary patterns for environmental benefits has long been advocated. In relation to mitigating climate change, the debate has been more recent, with a growing interest from policy makers, academics, and society. Many researchers have highlighted the need for changes to food consumption in order to achieve the required greenhouse gas (GHG) reductions. So far, food consumption has not been anchored in climate change policy to the same extent as energy production and usage, nor has it been considered within the context of achieving GHG targets to a level where tangible outputs are available. Here, we address those issues by performing a relatively simple analysis that considers the extent to which one food exchange could contribute to achieving GHG reduction targets in the United States (US). We use the targeted reduction for 2020 as a reference and apply published Life Cycle Assessment data on GHG emissions to beans and beef consumed in the US. We calculate the difference in GHGs resulting from the replacement of beef with beans in terms of both calories and protein. Our results demonstrate that substituting one food for another, beans for beef, could achieve approximately 46 to 74% of the reductions needed to meet the 2020 GHG target for the US. In turn, this shift would free up 42% of US cropland (692,918 km²). While not currently recognized as a climate policy option, the “beans for beef” scenario offers significant climate change mitigation and other environmental benefits, illustrating the high potential of animal to plant food shifts.

✉ Helen Harwatt
hharwatt@gmail.com

¹ Loma Linda University, Loma Linda, CA, USA

² Physics Department, Bard College, Annandale-on-Hudson, New York, USA

³ Present address: Radcliffe Inst. for Advanced Study, Harvard, USA

⁴ Department of Forest Ecosystems and Society, Oregon State University, Corvallis, OR, USA

1 Introduction

Climate change is one of the defining public issues of our time, threatening crop yield in some regions, reducing access to water, increasing human toll due to weather extremes, and increasing the spread of infectious disease among a myriad of other, mostly adverse, effects (Stern 2007; Blanco et al. 2014). The Copenhagen Accord and Paris Agreement acknowledge that limiting global mean temperature rise to ≤ 2 °C above pre-industrial levels requires deep cuts in global greenhouse gas (GHG) emissions (UNEP 2011; UNFCCC 2015). Additionally, the Paris Agreement states that efforts to limit warming to no more than 1.5 °C are needed to significantly reduce the risks and impacts of climate change (UNFCCC 2015), requiring deeper cuts in global GHGs. Currently, climate change policy largely focuses on reducing carbon dioxide (CO₂) emissions, the dominant anthropogenic GHG (Solomon et al. 2007). Yet realizing ≤ 2 °C warming also requires major reductions in non-CO₂ GHG emissions (primarily methane (CH₄) and nitrous oxide (N₂O)) (Stehfest et al. 2009; Popp et al. 2010; Bajzelj et al. 2014; Blanco et al. 2014), especially in the near term (Ripple et al. 2014; Pierrehumbert and Eshel 2015). Globally, livestock farming accounts for ~15% of total anthropogenic GHG emissions (Gerber et al. 2013) and is the primary anthropogenic source of CH₄ and N₂O emissions, producing around 50 and 60%, respectively (Smith et al. 2007). This is particularly significant given that on a mass basis, CH₄ and N₂O have 25 and 298 times the centennial-mean global warming potential of CO₂ (Myhre et al. 2013). In addition, CH₄ has a much shorter atmospheric lifetime than CO₂ (9–12 years), enhancing its near-term prominence (Myhre et al. 2013) and highlighting the importance of early focus on livestock.

Livestock accounts for up to half of the technical GHG mitigation potential of the agriculture, forestry, and land-use sectors (Herrero et al. 2016). Yet even the most technologically possible GHG reductions (32%) are outpaced by increasing demand for meat (Gerber et al. 2013). In addition, due to adoption constraints, costs and numerous trade-offs only 10% of the livestock-related technical GHG mitigation potential is viable (Herrero et al. 2016). Without significant dietary shifts, food-related GHG emissions in 2050 would constitute half of the total emissions budget imposed by the 2 °C target (Springmann et al. 2016). Hedenus et al. (2014) have shown that food-related emissions could exceed the full emissions budget by as early as 2070. Hence, a dietary shift away from livestock products is most likely required in addition to technological reduction of agricultural GHG emissions (Hertwich et al. 2010; Popp et al. 2010; Bajzelj et al. 2014; Hedenus et al. 2014).

Modifying diets for environmental benefits has long been advocated (Gussow and Clancy 1986) and has been enjoying considerable attention recently (Stehfest et al. 2009; Scarborough et al. 2014; Green et al. 2015; Machovina et al. 2015; Lamb et al. 2016; Springmann et al. 2016). Despite this growing interest, so far, dietary choices have not been as central in climate change discourse as energy production and usage (Stehfest et al. 2009; Bailey et al. 2014; Bajzelj et al. 2014). The analysis presented here seeks to specifically assess the potential contribution of simple dietary changes toward achieving the US GHG emissions target for 2020, which we use as a reference. To keep the analysis tractable, we consider replacing one item, beef, the highest GHG emitting food item (Nijdam et al. 2012; Eshel et al. 2014), with beans, a lower GHG intensity food (Nijdam et al. 2012). This work is novel in that no other analysis has placed potential diet changes in the context of meeting country-wide GHG reduction targets.

2 Methods

The US President’s Climate Change Plan sets out to reduce net US GHG emissions by 17% below 2005 levels (6438 million metric tons, mmt, of CO₂ equivalent, denoted CO₂e) by the year 2020 (EOP 2013). This target requires net 2020 GHG levels to remain below 5344 mmt CO₂e, a 7% reduction from current net emissions of 5791 mmt CO₂e (EPA 2015) (as the most recent data available, we refer to 2013 levels as “current emissions”).

This analysis is based on replacing beef consumption with beans. Beef is the most GHG-intensive food item, with emissions ranging from 9 to 129 kg CO₂e/kg, whereas comparatively legumes result in 1–2 kg CO₂e/kg (Nijdam et al. 2012). In addition, legumes are a high protein food currently consumed at levels well below the US government’s dietary recommendations (USDA 2012c; Moore and Thompson 2015). Legumes are therefore a natural option for substantially reducing GHG emissions while improving nutrition. We calculate the net emission change by taking the averted beef emissions and subtracting the emissions associated with producing the legume replacement. We use emission factors from US Life Cycle Assessments (LCA) of 40.2 kg CO₂e/kg beef and 0.8 kg CO₂e/kg beans (Nijdam et al. 2012). The beef LCA reflects typical US beef production, Midwestern feedlot finishing of range-weaned calves (Pelletier et al. 2010). Live to retail weight loss is accounted for, using a factor of 2.7 (Nijdam et al. 2012). As a sensitivity analysis, we also use a global average from Nijdam et al. (2012), of 25.5 kg CO₂e/kg beef and 1.1 kg CO₂e/kg beans, derived from a review of 52 LCA studies of meat and its alternatives (Nijdam et al. 2012). Because beef emission estimates vary widely, we use their geometric mean. The 52 LCAs included CO₂e emissions from the cultivation/farming process and transportation to retail. Additionally, the beef LCAs include direct and indirect N₂O emissions from feed production, CH₄ from enteric fermentation, N₂O and CH₄ from manure management, and carbon (C) emissions due to the slaughter process. GHGs from the production of farm machinery, changes in soil C emissions, and emissions related to land use change are not considered here. For both beans and beef, the bulk (>90%) of emissions occur during production (Nijdam et al. 2012). We consider the mass necessary to fully replace both kcals and protein delivered by beef with beans, using nutritional information for both beef (USDA 2015a) and beans (USDA 2015b), and report each separately. Beef provides 332 kcals and 14.4 g protein per 100 g of raw weight (USDA 2015a), and raw beans’ corresponding values per 100 g are 341 kcals and 21.6 g protein (USDA 2015b) (we use raw weights because the emissions data apply to the retail level). The corresponding moisture content of the raw weights of beef and beans is 54 and 11%, respectively. The caloric equivalence ratio of substituting beans for beef is 0.97 (332 beef kcals divided by 341 bean kcals), and the protein mass ratio is 0.66 (14.4 g beef protein divided by 21.6 g bean protein). Consequently, we derive energy (kcal) and protein equivalence emissions factors using:

- US emissions, energy equivalence: 40.2 kg CO₂e/kg—(0.8 kg CO₂e/kg × 0.97) = 39.4 kg CO₂e/kg
- US emissions, protein equivalence: 40.2 kg CO₂e/kg—(0.8 kg CO₂e/kg × 0.66) = 39.7 kg CO₂e/kg
- Global emissions, energy equivalence: 25.5 kg CO₂e/kg—(1.1 kg CO₂e/kg × 0.97) = 24.4 kg CO₂e/kg
- Global emissions, protein equivalence: 25.5 kg CO₂e/kg—(1.1 kg CO₂e/kg × 0.66) = 24.8 kg CO₂e/kg

We next use US beef consumption data (USDA 2012b), converting carcass to retail weights following Nijdam et al. (2012). Finally, we obtain emission savings due to substituting beans for beef in the energy and protein equivalence by applying the above factors to US annual beef consumption, 8.4 mmt. We report results using both US specific and global GHG emission factors for beef and beans. As the US is a net exporter of beans (USDA 2012c) and beef (USDA 2012a), we assume that the consumption amounts in this analysis are relevant to the US GHG inventory and hence our “beans for beef” scenario is appropriate for considering as part of US GHG reduction efforts. We treat the envisioned dietary change in isolation, quantifying its effect as the only emission reduction measure implemented toward the 2020 target. We do not consider land use changes associated with converting pasture and cropland from beef into beans.

3 Results and discussion

Substituting beans for beef in the US diet would reduce CO₂e emissions by 334 mmt, accomplishing 75% of the 2020 reduction target. Using global emissions factors, the figures reduce to 209 mmt CO₂e and 47%, respectively (Table 1), due to large differences between US and global emissions factors (Fig. 1). The results are almost identical when conserving either protein mass or energy (Table 1).

Our findings demonstrate that substituting plant sourced foods for animal sourced foods can play an important role in climate change mitigation. While substituting beans for beef does not entirely satisfy the US GHG reduction targets, it could be combined with mitigation efforts for other major emitters such as power generation or transportation. While our estimate represents the upper bound, given the sizable contribution to the GHG reduction target, a lower level of uptake, i.e., less than 100%, would still provide an important contribution.

The example analyzed is particularly impactful for mitigating near-term global temperature rise (Rockstrom et al. 2009; Ripple et al. 2014). Radiative forcing in the short-term, i.e., over the next several decades, will be dominated by CH₄ due to its relatively short atmospheric lifetime (~9 years) in comparison to CO₂ (~100 years) and its much higher global warming potential (Myhre et al. 2013). Because we replace beef, a high CH₄ source, with beans, a relatively much lower CH₄ source, the expected resultant decline in radiative forcing and decline in decadal scale warming will be greater than that expected from current policies,

Table 1 Actual CO₂e reduction and percent of the US 2020 CO₂e target achieved by substituting beans for beef in the calorie and protein mass equivalence

Scenario	Beans for beef: energy equivalent		Beans for beef: protein mass equivalent	
	% contribution to 2020 US climate change target	CO ₂ e reduction (million metric tons)	% contribution to 2020 US climate change target	CO ₂ e reduction (million metric tons)
US specific LCA emissions factors	74	332	75	334
Global LCA emissions factors	46	206	47	209

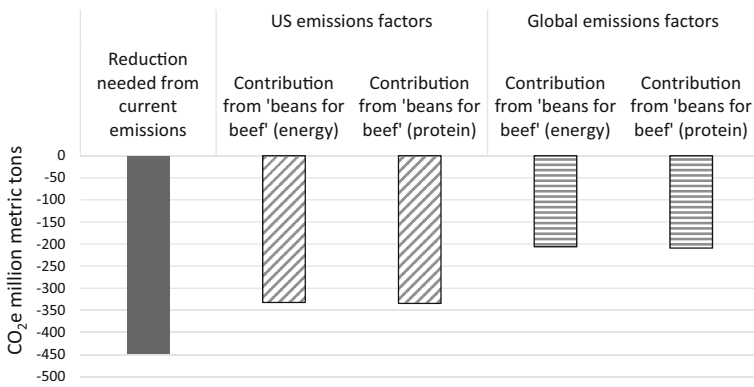


Fig. 1 Greenhouse gas reductions. CO₂e reductions needed to achieve US climate change targets set for 2020 (*solid box*), in comparison to the CO₂e reductions achieved from substituting beans for beef, by energy equivalence and protein weight equivalence using US emission factors (*diagonally hatched boxes*) and global emission factors (*horizontally hatched boxes*)

which focus almost exclusively on reducing CO₂ emissions (Pierrehumbert and Eshel 2015). However, to meet long-term GHG reduction targets, significant reductions of both CO₂ and non-CO₂ emissions are required (Blanco et al. 2014).

Although the goal of our analysis is to assess the potential of conceptually simple food substitutions to contribute to climate change goals, the resultant shifts—requiring societal level behavior change (Popp et al. 2010; Green et al. 2015)—are non-trivial and unprecedented at the national level. Policy innovation and experimentation, and economic incentives (Ripple et al. 2014) will likely be required to propel such shifts (Bajzelj et al. 2014). While a national substitution of beans for beef would be socially demanding, a strong willingness to make dietary changes for environmental improvements, including eliminating red meat, has been demonstrated (Bailey et al. 2014). For example, in 2014, Ipsos MORI (Market & Opinion Research International) conducted an online survey of at least 1000 individual consumers from each of the following countries: Brazil, China, France, Germany, India, Italy, Japan, Poland, Russia, South Africa, the UK, and the US (Bailey et al. 2014). Among those aware of the climate impact of meat, 44% were likely to reduce their meat consumption and 15% had already reduced their meat consumption. A public survey conducted by the UK government revealed that from over 3000 participants, 85% stated that they will or maybe will change their diets for environmental improvements, and 53% were willing to give up red meat (DEFRA 2011). Furthermore, consumer acceptance could possibly be increased by plant-based beef analogs (Hoek et al. 2011; Bailey et al. 2014) that have become more palatable, available and accepted, now being regularly availed by a third of US consumers (Mintel 2015). Because these meat analogs have very similar GHG emissions to the beans used in our analysis (Nijdam et al. 2012), if beef is replaced by meat analogs, we expect similar GHG reductions to those presented for replacing beef with beans. To further ease the implementation of such a policy, increasing awareness of the impacts food choices have on climate change and also on the urgency and importance of reducing the impacts of climate change are likely to be crucial (Stern 2007; Ripple et al. 2014; Bailey et al. 2014). Recent findings have demonstrated that people who are the most aware of the related climate impacts have a greater likeliness of having already reduced their meat consumption and a greater likeliness of reducing meat consumption in the future (Bailey et al. 2014). Highlighting the human health benefits related to such a policy could increase consumer interest (Stehfest et al. 2009; Bailey et al. 2014), particularly as health benefits have been a strong motivator for consumers purchasing meat analog products (Sadler 2004).

To provide further context to the analysis, replacing daily calories from beef could be achieved with 188 g (0.8 of a cup) of cooked black beans, which 87% of Americans currently consume below recommended levels (Moore and Thompson 2015). This shift will also reduce chronic disease burdens including heart disease, diabetes, and some meat-related cancers (Bouvard et al. 2015; Orlich et al. 2013) and increase dietary fiber intake, currently also below recommended or protective levels (Anderson et al. 2009; Orlich et al. 2013).

The GHG targets assessed here are less demanding in comparison to those recommended to stabilize global temperature increase below 2 °C (Gupta et al. 2007; UNEP 2011; UNFCCC 2015). We analyze beef-to-beans in this analysis purely as an illustration of the substantial emission reduction potential of a conceptually simple dietary shift. Future assessments could compare more stringent GHG reductions or sweeping dietary shifts.

The actual emission reduction needed to meet the 2020 target depends on the considered baseline emissions. For example, if we instead use the 2020 forecast (6206 mmt CO₂e) (USDS 2010), as the baseline, and estimate beef consumption for 2020 by applying current per capita consumption (8,428,000 metric tons for 308,745,538 people) to the projected 2020 US population (334,503,000 people) (USCB 2014), we get 9.1 mmt of beef (27.3 kg cap⁻¹ × 334,503,000 people). Inputting these figures into the methodology of section 2 changes our estimated contribution to meeting the 2020 target from 46–74 to 26–42%.

Given the focus on GHG reduction targets, the current analysis included GHG emissions as the sole environmental metric. A more comprehensive assessment would include the likely very significant impacts of substituting beans for beef on other resource use. For example, using the mean for US specific land-use factors from a published meta-analysis for beef (86.5 m²/kg) and beans (4.4 m²/kg) (Nijdam et al. 2012), substituting beans for beef in the US on a calorie equivalent basis will spare 692,918 km² of land, as an upper bound estimate. This land area is equivalent to 42% of cropland in the contiguous US, which is 1,650,745 km² (USDA 2011), and roughly 1.6 times the surface area of California. This type of land sparing is particularly relevant to climate change goals given the potential for enhancing carbon sequestration, which will likely augment GHG reductions (Lamb et al. 2016). By removing cattle from rangelands and pastures, the beef-to-beans shift would also benefit woody plant recruitment and biodiversity (Mishra et al. 2003; Pelletier and Tyedmers 2010; Phalan et al. 2011; Batchelor et al. 2015; Lamb et al. 2016), and substantially reduce water needs (Marlow et al. 2015), an increasingly important conservation issue under climate change (IPCC 2007; Cisneros et al. 2014). Beyond calories and protein, and the general health co-benefits mentioned above, our analysis did not rigorously account for any health and/or nutritional factors related to substituting “beans for beef.” Future assessments could usefully include such health factors in an integrated assessment with environmental factors (Stehfest et al. 2009; Sabate et al. 2014; Green et al. 2015; Springmann et al. 2016).

While some have argued that there are climate and environmental benefits associated with livestock production in certain locales and practices (de Oliveira Silva et al. 2016; Teague et al. 2016), others have forcefully demonstrated the factual inconsistencies in these arguments (Beschta et al. 2013; Briske et al. 2013; Carter et al. 2014; Phalan et al. 2016).

One of the key strategies for effective climate change mitigation is informing, educating, and persuading individuals about what they can do (Stern 2007). Dietary shift is ideal in this respect as it ascribes a pivotal role to personal choice in achieving GHG reduction targets. Further strategies will likely prove necessary to assist consumer choice regarding dietary shifts, including gaining support from the food service industry and retail markets.

4 Conclusions

Key traits position livestock production as a prime target for climate policy. The significant contribution to global GHGs, the dominance of short-lived methane, and thus the relatively immediate impact compel dietary shifts away from livestock products as important tools for mitigating anthropogenic climate change and particularly for avoiding near-term global temperature rise. We further demonstrate this through our analysis, showing the significant GHG reductions deliverable through simple food substitutions such as “beans for beef,” meeting up to 74% of the reductions needed to reach the 2020 GHG target for the US. Additional benefits include the sparing of 692,918 km², equivalent to 42% of US cropland.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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