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Submitted via email to [*fsispetitions@usda.gov*](mailto:fsispetitions@usda.gov)

FSIS Docket Clerk
Food Safety and Inspection Service
U.S. Department of Agriculture
Room 2534 South Building
1400 Independence Ave., S.W.
Washington, D.C. 20250

Re: Comment in Support of the Environmental Working Group's Petition to Prohibit "Climate-Friendly" Claims on Beef Products

To Whom It May Concern,

On behalf of the Animal Legal Defense Fund (ALDF), a national nonprofit organization with a mission to protect the lives and advance the interests of animals through the legal system, we respectfully submit this comment in support of the Environmental Working Group's (EWG) petition to prohibit the use of "climate-friendly" claims or similar claims on beef products, or in the alternative, to require independent third-party verification of such claims, as well as to require a numerical carbon disclosure whenever such claims are made on beef product packaging.[1]

The production of beef is by far the most carbon-intensive method of production for any food source. There is no credible evidence suggesting that beef production is, or can be, "climate-friendly" at scale. Empirical research further confirms how misleading such a label claim would be, as consumers routinely underestimate the climate cost of conventional beef production and severely underestimate the cost of "climate-friendly" beef production.[2] In short, "climate-friendly" beef claims are inherently misleading, and the Food Safety and Inspection Service (FSIS) can and should prohibit them.

[1] Ex. 1, Petition from Env't Working Grp., to Food Safety & Inspection Serv. (July 11, 2023) [hereinafter "EWG Petition"].
[2] Ex. 2, Report by Dr. Adam Feltz & Dr. Silke Feltz (2023) [hereinafter "Feltz Report"]; *see infra* I.C.

Background

After a year of record heatwaves, floods, and wildfires,[3] the tremendous human and economic cost of the climate crisis is more pronounced than ever. The climate emergency has led consumers to demand more sustainable, environmentally friendly products.[4] A recent study by researchers at the University of Oklahoma (the Feltz Report) found that 95.2% of participants would choose climate-friendly products if given the option.[5] Consumer Reports surveys have confirmed that environmental concerns are important to food shoppers, and that consumers understand various—and vague—claims as carrying environmental meaning.[6] A national survey conducted by the Johns Hopkins Bloomberg School of Public Health's Center for a Livable Future similarly found that eight out of ten respondents expressed concern about environmental problems

[3] *See* Seth Borenstein, *Here's How Hot and Extreme the Summer Has Been, and it's Only Halfway Over*, AP NEWS (July 31, 2023), https://apnews.com/article/heat-wave-flood-wildfire-smoke-climate-change-c36078efbcba515a4c67b7d9d0bbb9fd [https://perma.cc/M8NL-URRL]; Seth Borenstein, *Summer of Record-breaking Heat Paints Story of a Warming World, Scientists Say*, PBS (July 22, 2023), https://www.pbs.org/newshour/science/summer-of-record-breaking-heat-paints-story-of-a-warming-world-scientists-say [https://perma.cc/T9MT-9K2E]; Alejandra Borunda, *What's the Connection Between Climate Change and Hurricanes?*, NPR (Aug. 30, 2023), https://www.npr.org/2023/08/30/1196865225/whats-the-connection-between-climate-change-and-hurricanes [https://perma.cc/2XP6-HMY4]; Jon Haworth, *2023 set to be hottest year on record: United Nations*, ABC NEWS (Nov. 30, 2023), https://abcnews.go.com/International/2023-set-hottest-year-record-united-nations/story?id=105268460 [https://perma.cc/GP3H-E3DU]; Joe Hernandez, *With Florida Ocean Temperatures Topping 100, Experts Warn of Damage to Marine Life*, NPR (July 26, 2023), https://www.npr.org/2023/07/26/1190218132/florida-ocean-temperatures-101-marine-life-damage [https://perma.cc/5B2H-8BGB]; Sarah Kaplan, *Floods, Fires and Deadly Heat are the Alarm Bells of a Planet on the Brink*, WASH. POST (July 12, 2023), https://www.washingtonpost.com/climate-environment/2023/07/12/climate-change-flooding-heat-wave-continue/ [https://perma.cc/Y7DG-X772]; Andrea Thompson, *Here Are the Stunning Heat Records Set So Far This Summer*, SCI. AM. (July 27, 2023), https://www.scientificamerican.com/article/here-are-the-stunning-heat-records-set-so-far-this-summer1/ [https://perma.cc/2QHY-CQNK]; Raymond Zhong, *Warming Set the Stage for Canada's Record Fires, Study Finds,* N.Y. TIMES (Aug. 22, 2023), https://www.nytimes.com/2023/08/22/climate/canada-wildfires-climate-change.html [https://perma.cc/ESZ8-Z3UX].

[4] *See* Amy Emmert, *The Rise of the Eco-friendly Consumer*, STRATEGY+BUS. (July 8, 2021), https://www.strategy-business.com/article/The-rise-of-the-eco-friendly-consumer [https://perma.cc/FS24-26XF].

[5] Ex. 2, Feltz Report.

[6] CONSUMER REPS. NAT'L RSCH. CTR., NATURAL FOODS LABELS SURVEY, 2015 NATURALLY-REPRESENTATIVE PHONE SURVEY (2016), available at https://www.foodpolitics.com/wp-content/uploads/Consumer-Reports-Natural-Food-Labels-Survey-Report.pdf [https://perma.cc/4SY3-P7VY].

caused by factory farms.[7] Consumers are also willing to pay more for products that are better for the climate.[8]

As consumer demand for environmentally friendly products has increased, so too have misleading "greenwashing" claims.[9] In the last decade, this has been especially true in the meat and dairy industry. As evidence mounted and heightened public awareness increased regarding the climate costs of industrial animal agriculture,[10] companies like JBS, the largest meat producer in the world, disseminated misleading "net zero" claims that were purely aspirational.[11] Similarly, restaurants like Chipotle and McDonald's have capitalized on dubious "sustainable" claims.[12]

Nowhere is the greenwashing of food production more misleading than in the beef industry. The production of meat from cows is unavoidably climate-intensive and is by no reasonable metric "climate-friendly."[13] Despite this, FSIS recently approved the first beef product label containing a "climate-friendly" claim.[14] The claim has been approved for products sold under Tyson's new

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7 JOHNS HOPKINS CTR. FOR A LIVABLE FUTURE, NATIONAL SURVEY ON CONCENTRATED ANIMAL FEEDING OPERATIONS (CAFOS) (2019), available at https://clf.jhsph.edu/sites/default/files/2019-12/CAFO-moratorium-survey-results.pdf [https://perma.cc/7AGC-44R6].

8 *See* Ex. 2, Feltz Report (finding that 65.6% of respondents were willing to pay more for climate-friendly products); *Majority of US Consumers Say They Will Pay More for Sustainable Products*, SUSTAINABLE BRANDS (Aug. 29, 2022), https://sustainablebrands.com/read/marketing-and-comms/majority-of-us-consumers-say-they-will-pay-more-for-sustainable-products [https://perma.cc/7TYD-RBMF]; *Recent Study Reveals More Than a Third of Global Consumers Are Willing to Pay More for Sustainability as Demand Grows for Environmentally-Friendly Alternatives*, BUS. WIRE (Oct. 14, 2021), https://www.businesswire.com/news/home/20211014005090/en/Recent-Study-Reveals-More-Than-a-Third-of-Global-Consumers-Are-Willing-to-Pay-More-for-Sustainability-as-Demand-Grows-for-Environmentally-Friendly-Alternatives; *see also* Yvonne Feucht & Katrin Zander, *Consumers' Willingness to Pay for Climate-Friendly Food in European Countries*, PROCS. IN SYS. DYNAMICS & INNOVATION IN FOOD NETWORKS (2017) (finding that "consumers were willing to pay a price premium for climate-friendly labelled food in all study countries").

9 *See Greenwashing: What Your Clients Should Avoid*, AM. BAR ASS'N (Apr. 5, 2019), https://www.americanbar.org/groups/gpsolo/publications/gp_solo/2011/september/greenwshing_what_your_clients_should_avoid/ (Noting that "[t]here is no doubt that eco-friendly products have an edge in our eco-conscious society. . . . Put simply—green is good for business.").

10 *See* Caroline Christen, *Investigation: How the Meat Industry is Climate-Washing its Polluting Business Model*, DESMOG (July 18, 2021), https://www.desmog.com/2021/07/18/investigation-meat-industry-greenwash-climatewash/ [https://perma.cc/4KMH-7TBW]; Zahra Hirji, *Report Suggests 'Rampant' Greenwashing in Food Sector*, BLOOMBERG (Mar. 20, 2023), https://www.bloomberg.com/news/articles/2023-03-20/report-suggests-rampant-greenwashing-in-food-sector#xj4y7vzkg [https://perma.cc/YUQ4-XKD9]; *see also infra* I.A.

11 *National Advertising Review Board Recommends JBS Discontinue "Net Zero" Emissions by 2040 Claims*, BETTER BUS. BUREAU (June 20, 2023), https://bbbprograms.org/media-center/dd/narb-jbs-net-zero-emissions [https://perma.cc/EH7Y-69BU].

12 *National Advertising Division Finds Certain Sustainability Claims for Chipotle Mexican Grill Supported; Recommends Modification of Others*, BETTER BUS. BUREAU (Mar. 15, 2022), https://bbbprograms.org/media-center/dd/chipotle-sustainability-claims [https://perma.cc/B8VH-VGVH].

13 *See infra* I.A.

14 Krista Garver, *Tyson Creates Climate Smart Beef Program, First Beef Product to Earn USDA "Climate-Friendly" Label*, FOOD INDUS. EXEC. (Mar. 21, 2023), https://foodindustryexecutive.com/2023/03/tyson-creates-climate-smart-beef-program-first-beef-product-to-earn-usda-climate-friendly-label/ [https://perma.cc/LD2C-3BE6].

"Brazen Beef" product line, for which the company claims a ten percent reduction in greenhouse gas (GHG) emissions compared to conventionally produced beef.[15]

In response to FSIS's approval of the Brazen label, numerous press outlets criticized the move given that beef is inherently unfriendly to the climate.[16] On July 11, 2023, EWG submitted a petition urging FSIS to prohibit the use "climate-friendly" and analogous claims on beef products, or in the alternative, to require independent third-party verification of such claims as well as to require a numerical carbon disclosure whenever such claims are made on beef product packaging.[17]

I. "Climate-friendly" beef claims are inherently misleading.

The production of slaughter-based meat from cows emits more GHG emissions than the production of any other food source, and not by a narrow margin.[18] Beef production generates "more than twice the emissions of the next most polluting food, lamb."[19] Even methods of beef production with reduced emissions still emit far more GHGs than any other food source. There is no credible evidence to support the claim that beef production—even production with ten percent lower emissions—is "climate friendly."

Consumers consistently underestimate the climate cost of conventionally raised beef.[20] What's more, the Feltz study shows they are even worse at estimating the emissions associated with "climate-friendly" beef.[21] Given this evidence, and the fact that "climate-friendly" beef is still far

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[15] John Magsam, *Tyson's Brazen Beef Now Available*, ARK. DEMOCRAT GAZETTE (July 3, 2023), https://www.arkansasonline.com/news/2023/jul/03/tysons-brazen-beef-now-available/ [https://perma.cc/Y3QX-3AXR].

[16] *See, e.g.*, Brian Kateman, *'Climate-Friendly' Meat Is a Myth*, TIME (Sep. 8, 2023), https://time.com/6311793/climate-friendly-meat-myth/ [https://perma.cc/S4H3-ZBFR]; Kenny Torrella, *"Climate-friendly" beef could land in a meat aisle near you. Don't fall for it.*, VOX (Sep. 8, 2023), https://www.vox.com/future-perfect/2023/9/8/23863100/tyson-climate-friendly-beef-burger-usda [https://perma.cc/6NKH-M29R]; Jan Dutkiewicz & Matthew Hayek, *The B.S. Behind the USDA's New "Climate-Friendly Beef" Label*, NEW REPUBLIC (Sep. 5, 2023), https://newrepublic.com/article/175337/bs-behind-usdas-new-climate-friendly-beef-label [https://perma.cc/UR4S-G82H].

[17] Ex. 1, EWG Petition.

[18] *See* Xiaoming Xu et al., *Global greenhouse gas emissions from animal-based foods are twice those of plant-based foods*, 2 NATURE FOOD 724 (2021).

[19] David Vetter, *Got Beef? Here's What Your Hamburger is Doing to the Climate*, FORBES (Oct. 5, 2020), https://www.forbes.com/sites/davidrvetter/2020/10/05/got-beef-heres-what-your-hamburger-is-doing-to-the-climate/?sh=1c92587d5206 [https://perma.cc/9FMG-MWWH].

[20] *See* Ex. 2, Feltz Report; Ex. 3, Christina Hartmann et al., *Consumers' evaluation of the environmental friendliness, healthiness and naturalness of meat, meat substitutes, and other protein-rich foods*, 97 FOOD QUALITY & PREFERENCE 104486 (2022) (finding beef entrecote's "environmental friendliness was greatly overestimated by consumers"); *see also* Christina Hartmann & Michael Siegrist, *Consumer perception and behaviour regarding sustainable protein consumption: A systematic review*, 61 TRENDS FOOD SCI. & TECH. 11 (2017) (finding that consumer awareness of true environmental impact of animal-based meat production is low).

[21] *See* Ex. 2, Feltz Report.

more damaging to the climate than any other food production process, "climate-friendly" claims for beef products are inherently misleading and should be prohibited.

A. Beef is the least climate-friendly protein source.

Every year, approximately 9.78 billion chickens, turkeys, and ducks,[22] 38.1 million cows,[23] and 125 million pigs[24] are raised and slaughtered for food in the United States. Ninety-nine percent of all animal-based meat products sold in the United States are raised in confined animal feeding operations (CAFOs).[25] These facilities are large, industrial operations in which animals are confined (often indoors) in highly dense, disease-inducing enclosures where they live in their own waste.[26] In addition to the many animal welfare harms of modern animal agriculture, animal farming also uses disproportionate environmental resources and causes extreme and severe environmental degradation.[27]

Animal agriculture is a leading driver of the climate crisis. This is due both to the emissions released and the resources consumed.

Animal agriculture is the number one source of methane emissions in the United States.

Conservative estimates show that, between the meat and dairy industries, 7.1 gigatons of GHGs are emitted annually, representing 14.5% of all human-made GHG emissions.[28] Meat production accounts for the majority of all food production GHG emissions.[29] Animal agriculture is

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22 USDA, NAT'L AGRIC. STAT. SERV., POULTRY SLAUGHTER 2022 SUMMARY (2023), available at https://downloads.usda.library.cornell.edu/usda-esmis/files/pg15bd88s/m613p944x/ht24xx05j/pslaan23.pdf [https://perma.cc/QX3D-98C2].
23 USDA, NAT'L AGRIC. STAT. SERV., LIVESTOCK SLAUGHTER 2022 SUMMARY (2023), available at https://downloads.usda.library.cornell.edu/usda-esmis/files/r207tp32d/8p58qs65g/g445dv089/lsan0423.pdf [https://perma.cc/V5AK-3ZPD].
24 *Id.*
25 Jacy Reese Anthis, *US Factory Farming Estimates*, SENTIENCE INST. (Apr. 11, 2019), https://www.sentienceinstitute.org/us-factory-farming-estimates [https://perma.cc/RHK9-R9A6].
26 Aysha Akhtar, *I Studied Factory Farms for Years. Visiting One was far Worse Than I Imagined*, SALON (Apr. 20, 2019), https://www.salon.com/2019/04/20/i-studied-factory-farms-for-years-visiting-one-was-far-worse-than-i-imagined/ [https://perma.cc/3XZA-CMUG].
27 CARRIE HRIBAR, NAT'L ASSOC. OF LOCAL BDS. OF HEALTH, UNDERSTANDING CONCENTRATED ANIMAL FEEDING OPERATIONS AND THEIR IMPACTS ON COMMUNITIES 10 (2010), available at https://www.cdc.gov/nceh/ehs/docs/understanding_cafos_nalboh.pdf [https://perma.cc/L6PP-HX43]; *see also* Gidon Eshel et al., *Land, Irrigation Water, Greenhouse Gas, and Reactive Nitrogen Burdens of Meat, Eggs, and Dairy Production in the United States*, 111(33) PNAS 11,996 (2014).
28 Pierre J. Gerber et al., *Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities.* ROME: FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, (2013), available at http://www.fao.org/docrep/018/i3437e/i3437e.pdf
29 Xu et al., *supra* note 18.

the number one source of methane emissions in the United States, methane being a potent GHG with eighty times the warming effect of carbon dioxide.[30]

Beef production stands out as the most climate-injurious form of animal agriculture. Meat from cows is the "no. 1 agricultural source of greenhouse gases worldwide."[31] Each gram of protein from beef emits nearly ten times more GHGs than chicken, and over twenty-five times more than from soy.[32]

Animal agriculture is environmentally resource-intensive, worsening biodiversity loss, pollution, and water scarcity.

Meat requires more land, water, and energy than any other source of protein.[33] Animal farming currently occupies more than a third of the world's habitable land area,[34] is responsible for thirty percent of current global biodiversity loss,[35] and accounts for twenty perfect of global freshwater use.[36] Despite its colossal environmental impact, meat and dairy provide a mere eighteen percent of calories consumed,[37] making its production incredibly inefficient. Scientists have cited reducing meat consumption in high-income countries like the United States as a prerequisite to keeping below a global temperature rise that will cause systems collapse, mass extinctions, fatal heat waves, drought and famine, water shortages and flooded cities.[38] However, global meat consumption is projected to double from 2000 to 2050.[39]

Beef is also far more resource-intensive than any other animal protein. For every calorie, beef requires twenty-eight times more land, six times more fertilizer, and eleven times more water

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30 *See Methane Emissions are Driving Climate Change. Here's How to Reduce Them*, UNITED NATIONS ENV'T PROGRAMME (Aug. 20, 2021), https://www.unep.org/news-and-stories/story/methane-emissions-are-driving-climate-change-heres-how-reduce-them [https://perma.cc/GYK3-HECX]; *Agriculture and Aquaculture: Food for Thought*, U.S. ENV'T PROT. AGENCY (Oct. 2020), https://www.epa.gov/snep/agriculture-and-aquaculture-food-thought#:~:text=Methane%20is%20More%20Potent%20than%20CO2%3F&text=than%20CO2%20on%20a%20100,of%20methane%20gas%20per%20year [https://perma.cc/7CTB-5JDT].

31 Amy Quinton, *Cows and Climate Change: Making Cattle More Sustainable*, UC DAVIS (June 27, 2019), https://www.ucdavis.edu/food/news/making-cattle-more-sustainable [https://perma.cc/48CD-5PTK].

32 Joseph Poore & Thomas Nemecek, *Reducing food's environmental impacts through producers and consumers.* 360 SCI. 987 (2018).

33 Ex. 4, David Pimentel & Marcia Pimentel *Sustainability of meat-based and plant-based diets and the environment*, 78 THE AM. J. OF CLINICAL NUTRITION 660 (2003).

34 *Land Use in Agriculture by the numbers*, U.N. FOOD & AGRIC. ORG. (May 7, 2020), https://www.fao.org/sustainability/news/detail/en/c/1274219/ [https://perma.cc/7BRS-72M2].

35 Ex. 5, Henk Westhoek et al., *Food choices, health and environment: Effects of cutting Europe's meat and dairy intake*, 26 GLOBAL ENV'T CHANGE 196 (2014).

36 UNITED NATIONS FOOD & AGRIC. ORG., WATER USE OF LIVESTOCK PRODUCTION SYSTEMS AND SUPPLY CHAINS–GUIDELINES FOR ASSESSMENT (2018), available at https://www.fao.org/3/ca5685en/ca5685en.pdf.

37 Poore & Nemecek, *supra* note 32.

38 Michael A. Clark et al., *Global food system emissions could preclude achieving the 1.5° and 2°C climate change targets*, 370 SCI. 705 (2020).

39 UNITED NATIONS FOOD & AGRIC. ORG., WORLD AGRICULTURE: TOWARDS 2030/2050. PROSPECTS FOR FOOD, NUTRITION, AGRICULTURE AND MAJOR COMMODITY GROUPS71 (2006).

than the average of all other sources of animal protein.[40] As beef consumption increases, the need for more land for feed crop or pasture risks encroachment upon important carbon storage reservoirs like grasslands and tropical rainforests.[41] As a key driver of the climate crisis, beef is the very antithesis of a "climate-friendly" food.

B. The least climate-intensive methods of beef production are still worse for the planet than the production of any other protein source.

Even beef production managed to reduce its emissions by 10%—enough for a "climate-friendly" label according to FSIS[42]—beef remains significantly worse for the environment than any other food. Beef is more than twice as carbon intensive as lamb, the next highest-emitting food,[43] meaning beef produced with 10% fewer emissions still far surpasses the emissions of any other food.

Additionally, scientists are skeptical about the efficacy of "regenerative farming practices" like those cited on Tyson's website as responsible for Brazen Beef's lower emissions,[44] such as pasture rotation, planting cover crops, and reduced tillage in meaningfully sequestering carbon.[45] Far from a proven solution to beef's devastating impacts, these management practices may be just as detrimental to plants, soils, water, and the climate as conventional grazing systems.[46] Even if they offset some of the emissions associated with beef production, these techniques fall far short of the carbon storage capacity of native ecosystems that pre-existed pasture-raised beef production.[47] Instead, a shift to farming more efficient forms of protein than meat and dairy can free up land to

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[40] Ex. 6, Gidon Eshel, *Land, irrigation water, greenhouse gas, and reactive nitrogen burdens of meat, eggs, and dairy production in the United States.* 111 PROCS. NAT'L ACAD. SCIS. 11996 (2014).

[41] Brian Machovina et al., *Biodiversity conservation: The key is reducing meat consumption*, 536 SCI. TOTAL ENV'T 419 (2015) ("Livestock production is the single largest driver of habitat loss, and both livestock and feedstock production are increasing in developing tropical countries where the majority of biological diversity resides . . . The projected land base required by 2050 to support livestock production in several megadiverse countries exceeds 30–50% of their current agricultural areas.")

[42] See Krista Garver, *Tyson Creates Climate Smart Beef Program, First Beef Product to Earn USDA "Climate-Friendly" Label*, FOOD INDUS. EXEC. (Mar. 21, 2023), https://foodindustryexecutive.com/2023/03/tyson-creates-climate-smart-beef-program-first-beef-product-to-earn-usda-climate-friendly-label/ [https://perma.cc/LD2C-3BE6].

[43] Poore & Nemecek, *supra* note 32.

[44] *Our Process*, BRAZEN BEEF, https://brazenmeats.com/our-process/ [https://perma.cc/C8AH-7AWK].

[45] *See* TARA GARNETT, ET AL., FOOD CLIMATE RSCH. NETWORK, GRAZED AND CONFUSED?: RUMINATING ON CATTLE, GRAZING SYSTEMS, METHANE, NITROUS OXIDE, THE SOIL CARBON SEQUESTRATION QUESTION-AND WHAT IT ALL MEANS FOR GREENHOUSE GAS EMISSIONS (2017) ("Regenerative grazing, applied well and by motivated farmers, could well benefit soils, build organic carbon matter and as such perhaps help sequester some carbon. However the overall gains are likely to be modest, are not exclusive to rotational practices, and will be time limited – and the problem of the other greenhouse gases, methane and nitrous oxide – do not go away."); David S. Powlson et al. *Limited potential of no-till agriculture for climate change mitigation*. 4 NATURE CLIMATE CHANGE 678 (2014).

[46] Ex. 7, John Carter et al., *Holistic Management: Misinformation on the Science of Grazed Ecosystems*. INT. J. BIODIVERSITY. 1 (2014).

[47] Poore & Nemecek, *supra* note 32.

support ecosystems capable of absorbing up to seventy-five percent more carbon than so-called "regenerative" cattle farming.[48]

Moreover, a focus on carbon emissions does not address the other environmental impacts of beef, including on water use, water pollution, and deforestation. Even though most cows are confined to CAFOs, cattle grazing already occupies a whopping forty-one percent of all land in the U.S.[49] Transitioning the nearly forty million cows that are slaughtered each year to pasture would require 270% more land.[50] There simply is not enough land to scale these "regenerative" farming practices. The facts make it clear that addressing climate change demands a reduction in the consumption of beef, not its endorsement as a "climate-friendly" source of food.

C. Consumers do not understand the climate cost of conventionally raised or "climate friendly" beef.

There remains a disconnect between what the research shows and what consumers understand about the outsized impact that meat production, particularly beef, has on the environment. Studies consistently find consumers lack awareness of the true climate cost associated with animal-based meat.[51] According one consumer study: "The belief that 'eating less meat is better for the environment,' which is strongly supported by many climate and environmental researchers, is at an all-time low."[52] Another survey of students in the U.S. indicates less than ten percent of people associate meat with climate change.[53] As expected, consumers also severely underestimate the GHG emissions of conventional beef. In a study conducted by researchers at Duke University and the University of Technology Sydney, participants estimated that a serving of beef produced twice the GHG emissions of a serving of corn, when in reality a serving of beef produces *fifty times* the emissions of a serving of corn.[54] Consistent with these findings, participants in the Feltz study

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[48] Jessica Scott-Reid, *The fallacy of "climate friendly" beef*, TRUTHDIG (2023), https://www.truthdig.com/articles/the-fallacy-of-climate-friendly-beef/ [https://perma.cc/FB4E-PXUK].
[49] Ex. 8, James S. Drouillard *Current situation and future trends for beef production in the United States of America — A review*, 31(7) ASIAN-AUSTRALAS J. ANIMAL SCI. 1007 (2018).
[50] Ex. 9, Matthew N. Hayek & Rachael D. Garrett, *Nationwide shift to grass-fed beef requires larger cattle population* 13 ENV'T. RES. LETTERS 084005 (2018).
[51] *See, e.g.*, Ex. 3, Hartmann et al. (finding beef entrecote's "environmental friendliness was greatly overestimated by consumers"); Laura Wellesley et al., *Changing climate, changing diets: Pathways to Lower Meat Consumption*. CHATHAM HOUSE REP. (2015), available at https://www.chathamhouse.org/sites/default/files/publications/research/CHHJ3820%20Diet%20and%20climate%20change%2018.11.15_WEB_NEW.pdf [https://perma.cc/87EK-PBBZ] (finding low awareness of the impact of meat production and consumption on climate change); Hartmann & Siegrist, *supra* note 20 (finding the same); Jennie I. Macdiarmid, et al., *Eating like there's no tomorrow: Public awareness of the environmental impact of food and reluctance to eat less meat as part of a sustainable diet.* 96 APPETITE 487 (2006) (finding the same).
[52] JAYSON L. LUSK & SAM POLZIN, COLL. OF AGRIC., PURDUE UNIV., CONSUMER FOOD INSIGHTS: REPORT FOR THE CENTER FOR FOOD DEMAND ANALYSIS AND SUSTAINABILITY (2022), https://ag.purdue.edu/cfdas/wp-content/uploads/2022/05/Report_04-2022.pdf [https://perma.cc/A6YV-UBQ8].
[53] Heather B. Truelove & Craig Parks *Perceptions of behaviors that cause and mitigate global warming and intentions to perform these behaviors*. 32 J. ENV'T. PSYCHOL. 246 (2012).
[54] Ex. 10, Adrian R. Camilleri et al., *Consumers underestimate the emissions associated with food but are aided by labels*, 9 NATURE CLIMATE CHANGE 53 (2019).

significantly underestimated the carbon emissions of conventionally raised beef—even when using a conservative estimate of its actual emissions.[55]

Research further suggests consumers are even worse at estimating the climate cost of beef labeled as "climate-friendly." Worse than simply underestimating the emissions for conventional beef, participants in the Feltz study also overestimated the percentage reduction in emissions associated with "climate-friendly" beef. Participants underestimated the GHG emissions of "climate-friendly" beef by 175% more than for conventionally raised beef.[56] That is, participants were nearly twice as bad at guessing the actual GHG emissions associated with "climate-friendly" labelled beef as those associated with conventionally raised beef. Empirical evidence thus confirms that consumers underestimate the true climate cost of beef—and further, that a "climate-friendly" label compounds this miscalculation. This is true even when the label defines "climate-friendly" as a "10% greenhouse gas reduction."[57]

D. "Climate-friendly" beef claims inevitably mislead consumers.

Commercial speech is "inherently misleading" if it will "inevitably [] be misleading to consumers."[58] Inherently misleading speech is outside the protection of the First Amendment entirely,[59] and potentially misleading speech may be regulated or banned under the test from *Central Hudson*.[60] In the context of regulating health supplements claims, the D.C. Circuit has implied that a claim is inherently misleading if no "credible evidence" supports it.[61] The D.C. Circuit further stated that it sees "no problem with the FDA imposing an outright ban on a claim where evidence in support of the claim is qualitatively weaker than evidence against the claim"[62] or "where evidence in support of a claim is outweighed by evidence against the claim."[63] The evidence that beef in general and Brazen-labeled beef in particular is not "climate-friendly" far outweighs any evidence of its climate-friendliness and therefore such claims can and should be prohibited.

The plain meaning of "climate-friendly" suggests that a product is good for the climate. Consumers understand this and show strong preferences for climate-friendly products.[64] However,

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[55] Ex. 2, Feltz Report.
[56] *Id.*
[57] *See* Ex. 2, Feltz Report; Ex. 11, Brazen Beef Label.
[58] *1-800-411-Pain Referral Serv., LLC v. Otto*, 744 F.3d 1045, 1056 (8th Cir. 2014) (quoting *Bates v. State Bar of Ariz.*, 433 U.S. 350, 372 (1977)).
[59] *Pearson v. Shalala*, 164 F.3d 650, 655 (D.C. Cir. 1999).
[60] *Id.* (citing *Cent. Hudson Gas & Elec. Corp. v. Pub. Serv. Comm'n of N.Y.*, 447 U.S. 557, 566 (1980)).
[61] *Cf. Pearson*, 164 F.3d at 659 (implying that when "credible evidence" supports a claim it may not be absolutely prohibited as "inherently misleading").
[62] *Id.* at 659 n.10.
[63] *Id.* at 659. The D.C. Circuit has also voiced support for complete bans on claims "when there was almost no qualitative evidence in support of the claim and where the government provided empirical evidence proving that the public would still be deceived even if the claim was qualified by a disclaimer. *Whitaker v. Thompson*, 248 F. Supp. 2d 1, 10-11 (D.D.C. 2002) (citing *Pearson*, 164 F.3d at 659-60).
[64] *See* Ex. 2, Feltz Report (finding that 95.2% of participants would choose climate-friendly products compared to alternatives).

consumers often struggle to identify which foods are in fact climate-friendly.[65] As the Feltz Report demonstrates, consumers are alright at ranking products relatively (e.g., most people understand that tofu is less carbon intensive than beef) but consumers significantly underestimate just how bad red meat production is for the climate.[66]

Given this confluence of consumer interest and relative lack of understanding, labeling claims about the climate impact of food (particularly red meat) are particularly important and ripe for misleading people. The Feltz Report further confirmed this, as participants underestimated the GHG emissions of Brazen Beef significantly more than they underestimated the GHG emissions of conventionally raised beef.[67] Clearly, the "10% fewer emissions" disclaimer on the label was insufficient to correct consumer confusion. In fact, consumers overestimated the reduction in GHG emissions by at least fifteen percent from their baseline estimate of conventionally raised beef (which participants already underestimated).[68] Participants in the study equated the climate cost of Brazen Beef to that of chicken production, placing it lower in absolute terms than the emissions from pork production.[69] In reality, both chicken and pork production release far fewer GHG emissions than "climate-friendly" beef.[70] This research shows that people are unaware of the climate cost of beef, and that "climate-friendly" beef label claims simply increase consumer confusion. The results held across a generic "climate-friendly" or "low carbon" beef label as well as when participants were showed Brazen's specific product packaging.[71]

There is no credible evidence that suggests any form of beef production is even close to the carbon intensity of other protein production methods—including all other meat and poultry products. Research demonstrates that consumers are confused by these claims, thinking that the GHG emissions from "climate-friendly" beef are the same or lower than other meat or poultry products. The addition of such label claims increases the error of estimation, meaning consumers are less informed and more likely to be misled because of these claims. For all the foregoing reasons, "climate-friendly" beef claims are inherently misleading and should be prohibited.

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65 *See* IPSOS, THE TRUTH ABOUT CLIMATE FRIENDLY EATING: REVEALING THE DANISH EATING HABITS & PERCEPTIONS ON CLIMATE FRIENDLY FOODS (Nov. 2022), available at https://www.ipsos.com/sites/default/files/ct/publication/documents/2022-12/Climate%20friendly%20eating_Final%20Report.pdf [https://perma.cc/XW4B-ACH8] (finding a number of misunderstandings among consumers as to which food options had more of a climate impact); Yvonne Feucht & Katrin Zander, *Consumers' attitudes on carbon footprint labelling: Results of the SUSDIET project* 39 (Johann Heinrich von Thünen Inst., Working Paper No. 78, 2017), available at https://www.econstor.eu/bitstream/10419/173086/1/1009605887.pdf ("The interviews showed that people often miss a concrete idea what climate-friendly food means").

66 *See* Ex. 2, Feltz Report; *see also* Ex. 3, Hartmann et al.; Ex. 10, Camilleri et al.

67 Ex. 2, Feltz Report.

68 *See id.*

69 *See id.*

70 *See id.*; *supra* I.A.

71 *See* Ex. 2, Feltz Report.

II. FSIS must, at minimum, require third-party verification and numerical carbon footprint disclosures for any "climate-friendly" beef label claim.

ALDF also supports EWG's alternative ask, that FSIS require third-party verification for "climate-friendly" and similar claims, and that such claims be accompanied by a numerical carbon disclosure on the label. Third-party verification can improve the reliability and trustworthiness of GHG emissions claims, and emissions disclosures have been shown to improve consumer understanding of the carbon cost of food choices.

Third-party verification is particularly necessary given the lack of transparency of "climate-friendly" or "low-carbon" claims made by beef producers. When a reporter asked the United States Department of Agriculture ("USDA") and Tyson about how the agency and the company substantiate Brazen's emissions reduction claim, they received no answers.[72] Tyson claims it is able to achieve these emissions reductions through "healthy soil" practices like reduced tillage and pasture rotation, as well as monitoring individual "cattle performance" at the feedlot.[73] Similarly, Tyson's Climate-Smart Beef Program uses a lot of buzzwords like using "data to pinpoint areas of improvement" without specifying what data it is using, what improvements it is making, and how any of that effects GHG emissions.[74]

More generally, academic experts remain skeptical of carbon claims made by food companies.[75] Quantified claims about carbon sequestered in soil, such as the tilling methods claims made by Tyson, are suspect given that different regions have different soil types and reliable baseline data often does not exist as a basis for making numerical claims.[76] As the American Society of Agronomy wrote in a letter to the USDA, "the scientific community currently lacks consensus" on the best approaches to measure soil carbon sequestration.[77]

The lack of scientific consensus on how to measure the types of emissions reductions beef producers are alleging means that USDA should require concrete substantiation from companies to ensure that consumers are not misled or that represented claims are not unsubstantiated. Instead, USDA defers almost entirely to producers. FSIS Guidelines for animal welfare and environmental

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[72] *See* Arielle Samuelson, *The Mystery of Climate-Friendly Beef*, HEATED (May 25, 2023), https://heated.world/p/the-mystery-of-climate-friendly-beef [https://perma.cc/4PBD-3SZT].
[73] *Our Process*, BRAZEN BEEF, https://brazenmeats.com/our-process/ [https://perma.cc/C8AH-7AWK].
[74] *See Our Path to Climate-Smart Beef*, TYSON, https://www.tysonfoods.com/climate-smart-beef-program [https://perma.cc/RQ56-KZP9].
[75] *See, e.g.*, DAVID J. HAYES ET AL., STANFORD L. SCH. L. & POL'Y LAB, DATA PROGRESS NEEDED FOR CLIMATE-SMART AGRICULTURE (2023), available at https://law.stanford.edu/wp-content/uploads/2023/04/Final-Climate-Smart-Agriculture-Report.pdf.
[76] The problems with measurement and monitoring have

> eliminated or severely limited the availability of reliable baseline data against which changes in soil concentrations due to good soil management practices can be measured and monitored. Unmoored from baseline conditions, subsequent soil carbon sampling activities using traditional methods arguably offer only random data points that cannot support meaningful conclusions about sequestered carbon quantities or trends.

See id. at 13.
[77] Letter from Am. Soc'y of Agronomy et al., to Terry Crosby, Chief, Nat. Res. Conservation Servs., U.S. Dep't of Agric. (Dec. 21, 2022), available at https://www.regulations.gov/comment/NRCS-2022-0015-0451.

stewardship claims allow producers to self-define key terms.[78] Producers seeking label approval need only provide the agency with a written description of what the term means to them and how their practices align with this definition.[79] The agency does little-to-nothing to verify whether these self-attestations are true, or whether the self-definitions align with consumer understanding.[80] Mandatory third-party certification by independent (i.e., non-industry) certifiers of GHG emissions claims will improve transparency for consumers and facilitate more robust, trustworthy claims.

Numerical carbon disclosure labels can also address the informational asymmetry and provide clarity to consumers. Researchers at Duke University and the University of Technology Sydney designed a label that included a red-to-screen scale and expressed GHG emissions in terms of equivalent light-bulb minutes.[81] They found that the emissions labels improved consumer awareness—when tested, the group presented with emissions labels were more accurate at estimating the difference in GHG units between beef and vegetable soup compared to a control group.[82] This kind of comparison to a neutral unit that consumers better understand (i.e., lightbulb hours) is useful as it allows more direct understanding as well as improved comparisons across food choices. A label with such an emissions disclosure is less likely to mislead consumers than a mere statement that the product is "climate-friendly."[83]

Furthermore, third-party verification and numerical carbon disclosures can help offset the trend of setting artificially high baselines to make a product look "low-carbon" or "climate-friendly" by comparison. As EWG demonstrated in an April 2023 petition, USDA's low-carbon beef standards are so low that a product could qualify and label itself as "low-carbon" despite producing *more* carbon emissions than are produced by average beef production in the U.S. or Canada.[84]

Conclusion

For all the foregoing reasons, ALDF strongly supports EWG's petition and urges FSIS to prohibit the use "climate-friendly" or similar claims on beef products. "Climate-friendly" beef claims are inherently misleading, as cow meat is the least climate friendly means of protein production. Consumers care about what food they purchase, including its effect on the environment. Prohibiting

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78 *See* FSIS, LABELING GUIDELINE ON DOCUMENTATION NEEDED TO SUBSTANTIATE ANIMAL RAISING CLAIMS FOR LABEL SUBMISSIONS (2019), https://www.fsis.usda.gov/sites/default/files/media_file/2021-02/RaisingClaims.pdf.
79 *See id.*
80 A petition for rulemaking by the Animal Welfare Institute alleged that of twenty-five claims reviewed, twenty lacked any records of pre-approval materials at all, and the remaining five were supported by "as little as a one-sentence statement." Petition for Rulemaking from Animal Welfare Inst. to FSIS (May 2014), available at https://www.fsis.usda.gov/sites/default/files/media_file/2020-08/Petition-AWI-Labeling-0514.pdf.
81 Ex. 10, Camilleri et al.
82 *See id.*
83 As the Feltz Report demonstrates, disclaimers that compare one type of beef to another do not help consumers and can actually increase confusion. *See* Ex. 2, Feltz Report.
84 *See* Ex. 12, Petition from Env't Working Grp., to Food Safety & Inspection Serv. (Apr. 27, 2023). As the petition explains, the average emissions from beef production are 21.3 kilograms of carbon dioxide equivalents per kilogram of carcass weight in the U.S. and 19 kilograms in Canada. *Id.* To meet USDA's "low carbon" beef standard, beef production must reduce emissions by ten percent compared to a 26.3 kilograms baseline. *Id.*

the use of climate-friendly claims on beef product labels is necessary to further the statutory mandates of the Federal Meat Inspection Act.[85] ALDF further supports EWG's urging FSIS to, if the agency refuses to prohibit "climate-friendly" or "low-carbon" claims, require third-party verification and numerical label disclosures. These requirements would be the bare minimum to help ensure that consumers are not grossly misled by assertions of environmental-friendliness from the most GHG-emitting production process of all food choices.

Sincerely,

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[85] 21 U.S.C. § 607(d) ("No article subject to this subchapter shall be sold or offered for sale by any person, firm, or corporation, in commerce, under any name or other marking or labeling which is false or misleading, or in any container of a misleading form or size, but established trade names and other marking and labeling and containers which are not false or misleading and which are approved by the Secretary are permitted.").

Exhibit List

Exhibit	Item
1	Petition from Env't Working Grp., to Food Safety & Inspection Serv. (July 11, 2023).
2	Report by Dr. Adam Feltz & Dr. Silke Feltz (2023).
3	Christina Hartmann et al., *Consumers' evaluation of the environmental friendliness, healthiness and naturalness of meat, meat substitutes, and other protein-rich foods*, 97 FOOD QUALITY & PREFERENCE 104486 (2022).
4	David Pimentel & Marcia Pimentel *Sustainability of meat-based and plant-based diets and the environment*, 78 THE AM. J. OF CLINICAL NUTRITION 660s (2003).
5	Henk Westhoek et al., *Food choices, health and environment: Effects of cutting Europe's meat and dairy intake*, 26 GLOBAL ENVIRONMENTAL CHANGE 196 (2014).
6	Gidon Eshel, *Land, irrigation water, greenhouse gas, and reactive nitrogen burdens of meat, eggs, and dairy production in the United States.* 111 PROCS. NAT'L ACAD. SCIS. 11996 (2014).
7	John Carter et al.., *Holistic Management: Misinformation on the Science of Grazed Ecosystems.* INT. J. OF BIODIVERSITY. 1 (2014).
8	James S. Drouillard *Current situation and future trends for beef production in the United States of America — A review*, 31 ASIAN-AUSTRALAS J. ANIMAL SCI. 1007 (2018).
9	Matthew N. Hayek & Rachael D. Garrett, *Nationwide shift to grass-fed beef requires larger cattle population* 13 ENV'T. RES. LETTERS 084005 (2018).
10	Adrian R. Camilleri et al., *Consumers underestimate the emissions associated with food but are aided by labels*, 9 NATURE CLIMATE CHANGE 53 (2019).
11	Brazen Beef Label.
12	Petition from Env't Working Grp., to Food Safety & Inspection Serv. (Apr. 27, 2023).

Exhibit 1

July 11, 2023

FSIS Docket Clerk
Department of Agriculture
Food Safety and Inspection Service
Room 2534 South Building
1400 Independence Avenue, S.W.
Washington, DC 20250-3700

Re: Petition to Prohibit "Climate-Friendly" Claims on Beef Products

The Environmental Working Group respectfully submits this petition to the U.S. Department of Agriculture (USDA) to:

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- Prohibit "climate-friendly" claims or similar claims on beef products.
- Require third-party verification for "climate-friendly" and similar claims.
- Require a numerical on-pack carbon disclosure when such claims are made.

Thank you for your consideration of this petition. Replies and other communication can be directed to sfaber@ewg.org.

Sincerely,

Scott Faber[1]
Environmental Working Group
1250 I Street N.W., Suite 1000
Washington, D.C. 20005

[1] Scott Faber is Senior Vice President for Government Affairs for the Environmental Working Group.

Summary

We urge the U.S. Department of Agriculture to reject misleading climate-related food marketing and labeling, such as "climate-friendly" claims on beef products, and to modernize the USDA's verification system to require independent third-party verification of such claims. We further urge the USDA to require a numerical carbon disclosure whenever such claims are made.

Allowing misleading climate claims, including "climate-friendly" claims on beef products, or allowing climate claims without sufficient verification and an accompanying numerical carbon disclosure, violates federal laws which prohibit false and misleading claims.

About the Petitioner

The **Environmental Working Group** (EWG) is a public interest, nonprofit, non-partisan organization, with offices in Washington, D.C., Sacramento, California, and Minneapolis, Minnesota. EWG aims to empower people to live healthier lives in a healthier environment, and for over two decades, it has worked to protect human health and the environment through breakthrough research and education, encouraging consumer choice and civic action.

Full Statement of the Action Requested

Pursuant to 5 U.S.C. 553 (e), 7 CFR § 1.28, and 9 C.F.R. § 392.5, the Petitioner requests that the USDA agency the Food Safety and Inspection Service (FSIS) take the following actions:

1) Prohibit "climate-friendly" claims or similar claims on beef products;
2) Require independent third-party verification of any climate claims; and
3) Require a numerical carbon disclosure whenever such claims are made.

Basis for the Action Requested

A. Climate-Friendly Beef Claims Are Inherently Misleading

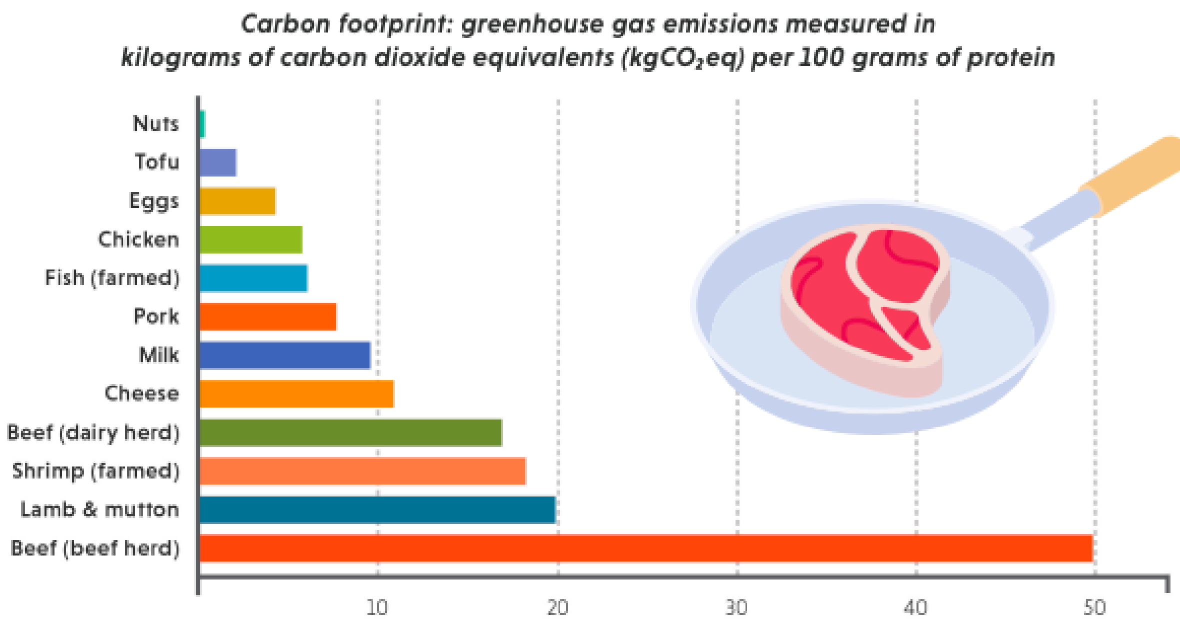
There is no such thing as "climate-friendly" beef. In fact, no food choice results in more greenhouse gas emissions than beef.[2] However, many consumers viewing "climate-friendly" claims, like those made by Brazen Beef,[3] are likely to assume that buying beef bearing such a label will help reduce greenhouse gas emissions.

[2] Xiaoming Xu et al., *Global Greenhouse Gas Emissions From Animal-Based Foods are Twice Those of Plant-Based Foods*, Nature Food 724 (2021), https://www.nature.com/articles/s43016-021-00358-x.

[3] Brazen Meats, https://brazenmeats.com/ (retrieved on July 4, 2023).

Even the beef that meets the "Low-Carbon" beef standard recently approved by the USDA still results in more greenhouse gas emissions than any other food choice, including any other meat or poultry. Making matters worse, beef meeting the USDA's "Low-Carbon" beef standard would still result in more emissions than much of the other beef produced in the U.S. or Canada.[4]

By any measure, consuming beef is a bad choice for the climate. Per gram of protein, beef production results in approximately nine times more greenhouse gas emissions than poultry, six-and-a-half times more than pork, and 25 times more than soybeans.[5]



Source: EWG analysis of GHG data based on global averages of all production types.[6]

[4] To meet USDA's "Low-Carbon" beef standard, beef production must reduce emissions by 10% of 26.3 kilograms of carbon dioxide equivalents per kilogram of carcass weight. Matt Reynolds, *Is There Really Such a Thing as Low-Carbon Beef?*, Wired (Jan. 17, 2022), https://www.wired.com/story/low-carbon-beef/. However, a recent study of beef production in the U.S. found beef production resulted, on average, 21.3 kilograms of carbon dioxide equivalents per kilogram of carcass weight. *Id.* (citing C. Alan Rotz, *Environmental Footprints of Beef Cattle Production in the United States*, 169 Agricultural Systems 1 (2019), https://www.sciencedirect.com/science/article/pii/S0308521X18305675). In Canada, the average is approximately 19 kilograms of carbon dioxide equivalents per kilogram of carcass weight. *Id.* (quoting Karen Beauchemin, an expert on cattle nutrition at Canada's Department of Agriculture and Agri-Food).

[5] *Id.* (citing J. Poore & T. Nemecek, *Reducing Food's Environmental Impacts Through Producers and Consumers*, 360 Science J. 987 (2018), https://www.science.org/doi/abs/10.1126/science.aaq0216), https://www.wired.com/story/low-carbon-beef/.

[6] Environmental Working Group, *EWG's Quick Tips For Reducing Your Diet's Climate Footprint* (2022), https://www.ewg.org/sites/default/files/2022-04/EWG_TipSheet_Meat-Climate_C02.pdf.

B. Many Carbon Claims Are Inherently Misleading

Consumers are deeply confused by similar carbon claims, including but not limited to Climate-Friendly, Net-Zero, Carbon-Neutral, Carbon-Negative, Climate-Neutral, Net-Zero Carbon, Climate-Positive, and Carbon-Positive. Many of these claims are already appearing on products subject to USDA regulation, such as:

Studies show that consumers are often misled by claims like those being made by Brazen Beef. Most consumers believe these claims reflect reductions in actual greenhouse gas emissions, not offsets of these emissions through changes in farming practices.[7] When consumers are told that claims could be made by reliance on offsets in lieu of actual emissions reductions, most consumers report feeling misled.[8]

Experts have found the lack of standard definitions for terms like "climate-friendly," "net-zero," and "carbon-neutral" contributes to consumer confusion. In the absence of such guidelines, consumers report wanting more information, including verification measures.[9]

[7] The Advertising Standards Authority (ASA) found through a survey that in making [carbon neutral and net zero] claims, businesses were not believed to be taking an offsetting-first approach – instead, they were believed to have been reducing their absolute emissions in-house. Sarah George, *Consumers Confused Over Net-Zero Claims in Ads, ASA Warns*, Edie (Oct. 20, 2022), https://www.edie.net/consumers-confused-over-net-zero-claims-in-ads-asa-warns/ (citing Advert. Standards Auth., *Environmental Claims in Advertising: Qualitative Research Report*, Jigsaw Research (Oct. 2022)).

[8] *Id.* When the ASA explained that brands could technically claim carbon neutrality by offsetting alone, a majority said that they would feel misled.

[9] *Id.* The ASA found that members of the public would like more information on offsetting and emissions reductions, with accompanying time frames, from the brands that they shop with.

C. Brazen Beef's "Climate-Friendly" Claims Are Misleading

Brazen Beef's claims "our greenhouse gas emissions are already down 10%." In support of this claim, Brazen claims to have "built a model that backs it up":[10]

> We worked with researchers, technical experts, and suppliers to track and reduce emissions from pasture to production as compared to emissions for conventional beef. Animals chosen for the program are raised with emissions reduction practices in mind. Before being fully accepted into the program, the emissions of each animal are evaluated to ensure they meet the base emissions and program qualification.[11]

Brazen Beef says it relies on "innovative, reliable farmers who raise crops using agricultural practices that can help reduce GHG emissions," citing changes in tillage, the adoption of cover crops, and better nutrient management.[12] Its ranchers, Brazen Beef says, must also "undergo a qualification process" but can also "customize the practices based on individualized needs," including practices such as pasture rotation.[13]

Brazen Beef's ranchers must meet the criteria of Tyson's Climate-Smart Beef Program, which includes an auditing process and data sharing that is "used in a model that estimates GHG emissions."[14] Tyson's Climate-Smart Beef Program also says it aims to "work with enrolled producers…to integrate environmentally responsible agricultural practices."[15]

Neither Brazen or Tyson identifies the farmers or ranchers adopting these practices, names the practices that have been adopted, or produces data demonstrating that these practices have reduced the nitrous oxide emissions caused by fertilizing animal feed or the methane emissions caused by animals and their manure.

Neither Brazen or Tyson describes how these practices have been "customized" or the effect these changes have had on GHG emissions. While Tyson claims to work with Adams Land & Cattle, the Nebraska feedlot operator provides no information on the steps taken to reduce emissions from animals and their waste, or steps taken to require change in nutrient management by animal feed suppliers.[16] The model "that backs it up" is unavailable to the public.

To verify these claims, Tyson contends that the company "can now track beef emissions at the individual animal level" and that the data is collected and verified through third-party auditors, such as Where Foods Comes From, Inc. However, no information on data collection or verification is publicly available from Where Food Comes From.[17]

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[10] Brazen Beef, https://brazenmeats.com/our-process/, (retrieved on July 4, 2023).
[11] *Id.*
[12] *Id.*
[13] *Id.*
[14] *Id.*
[15] Tyson Foods, Climate-Smart Beef Program, https://www.tysonfoods.com/climate-smart-beef-program, (retrieved on July 4, 2023).
[16] Adams Land and Cattle, https://www.adamslandandcattle.com/programs/brazenbeef/ (retrieved on July 4, 2023).
[17] Where Food Comes From, https://www.wherefoodcomesfrom.com/verification, (retrieved on July 4, 2023).

D. Carbon Claims Should Be Subject to Third-Party Verification

Experts agree that the USDA currently lacks reliable measurement, monitoring, reporting, and verification protocols, or MMRV protocols, to accurately predict the GHG impacts of different farm stewardship practices. However, neither Brazen nor Tyson address the uncertain GHG benefits associated with better pasture management or practices like conservation tillage and cover crops.

In addition, consumers, non-governmental organizations, and academics do not have access to the data supporting these protocols, sowing doubt with regard to promised environmental benefits.[18]

One recent report from Stanford researchers concluded, "Simply put, the lack of practical and scientifically sound approaches for confirming specified practices generates claimed benefits, and the lack of access to confirmatory data poses major systemic impediments to rewarding farmers and ranchers for deploying climate-smart practices."[19]

Companies making carbon claims often rely on models that do not provide a "sound basis for quantifying or monetizing increases in carbon sequestration in soils or decreases in methane and nitrous oxide emissions."[20] In particular, measuring and monitoring soil carbon presents unique challenges, as different regions have widely different soil types, and carbon concentration can vary significantly within a particular field.

These limitations, the Stanford report explains,

> have eliminated or severely limited the availability of reliable baseline data against which changes in soil concentrations due to good soil management practices can be measured and monitored. Unmoored from baseline conditions, subsequent soil carbon sampling activities using traditional methods arguably offer only random data points that cannot support meaningful conclusions about sequestered carbon quantities or trends.[21]

In comments recently submitted to the USDA, the American Society of Agronomy concluded that "the scientific community currently lacks consensus" on the best approaches to measure soil carbon sequestration, citing the need for better data.[22] Similar concerns have been raised regarding USDA protocols to assess reductions in nitrous oxide[23] and methane emissions.[24]

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[18] Kim Novick, et al., *The Science Needed for Robust, Scalable, and Credible Nature-Based Climate Solutions in the United States,* (Ind. Univ. O'Neill School of Public and Environmental Affairs, 2022), https://scholarworks.iu.edu/dspace/handle/2022/28264.

[19] David J. Hayes et al., *Data Progress Need for Climate-Smart Agriculture*, Stanford Law School, Law and Policy Lab, (Apr. 2023) [Hereinafter "Stanford Report"].

[20] *Id.*

[21] Stanford Report, *supra* note 15, at 13.

[22] American Society of Agronomy et al., *Comment Letter on Request for Public Input About Implementation of the Inflation Reduction Act Funding* (2022).

[23] Stanford Report, *supra* note 15, at 9.

[24] *Id.*

More data is needed from a more representative set of samples to quantify the benefits of climate-smart practices, whether implemented alone or in combination with other practices.[25] Nitrous oxide emissions in particular vary significantly, and efforts to increase soil carbon can result in increases in nitrous oxide emissions.[26]

Consumers assume that companies' carbon claims have been verified by an independent third party. However, the USDA relies on affidavits by farmers and food companies that are not subject to verification by the USDA or a qualified third-party.[27] In other words, the USDA currently relies upon the honor system. Proposals to "strongly encourage" farmers to use third-party audits, as the USDA recently proposed for animal raising claims, are not sufficient to earn the trust of consumers or to ensure company accountability.

Fortunately, third-party verification is familiar to the USDA. For example, qualified third parties must certify that organic food meets USDA standards. Experts have identified measurement and monitoring protocols that feature sampling and analytical tools designed to measure changes in carbon, methane, or nitrous oxide levels.[28] The USDA recognizes that better measurement, monitoring, and verification tools are badly needed to support carbon claims. Among others, the USDA has identified[29] the following barriers to the use of carbon claims:

- The lack of standard definitions of climate-smart commodities;
- The lack of clear standards for the measurement of climate benefits; and
- The potential for double counting of benefits.

The USDA recognizes that the effects of climate-smart practices vary depending upon the location, landscape position, methods of installation, and type of activity.[30] To address these uncertainties, the USDA is currently creating a "learning network" to incorporate the lessons learned from individual projects. One of the purposes of the program is to "learn from different approaches in deploying climate-smart practices [and in] innovation in greenhouse gas quantification, monitoring, and verification."[31]

Congress also provided $300 million in the Inflation Reduction Act (IRA) to "quantify" and "monitor and track" emissions by collecting "field-based data" to measure the benefits of climate-smart practices funded by the IRA.[32]

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[25] Novick, *supra* note 14 at 9.
[26] *Id.*
[27] Under FSIS Guidelines, the only documentation needed to support such climate-smart claims are written descriptions from the farmers explaining how their process supports their claim. Food Safety and Inspection Service, *Animal Raising Claims Labeling Guidelines Update*, (Sep. 2021), PowerPoint. https://www.fsis.usda.gov/sites/default/files/media_file/2021-09/Animal-Raising-Claims-labeling-and-Non-GMO-slides-2021-09-01.pdf.
[28] Stanford Report, *supra* note 15, at 6.
[29] USDA, *Programmatic Environmental Assessment for Climate-Smart Commodities*, (Aug. 26, 2022), https://www.usda.gov/sites/default/files/documents/partnerships-climate-smart-commodities-pea.pdf (last visited on Apr. 4, 2023).
[30] *Supra note 33,* at 34.
[31] USDA, *Partnerships for Climate-Smart Commodities FAQs*, (Jan. 2023) https://www.usda.gov/climate-solutions/climate-smart-commodities/faqs.
[32] Inflation Reduction Act of 2022 § 21001(a)(1)(B)(iii), 136 Stat. 1818.

E. Any Carbon Claim Should Be Accompanied by a Numerical Disclosure

To avoid consumer confusion and address uncertainties in measurement, any carbon claims, including "climate-friendly" claims, should be accompanied by an on-pack numerical carbon disclosure.

On-pack numerical disclosures are based upon complex Life Cycle Assessments (LCAs),[33] which should be carefully reviewed and approved by both the USDA and the Environmental Protection Agency. Different types of LCAs include ISO Compliant,[34] PEF Compliant,[35] and Screening LCAs.[36]

Legal Basis for Requested Action

U.S. citizens have the right to petition the government to add, amend, or repeal rules under the First Amendment of the U.S. Constitution and the Administrative Procedures Act (5 U.S.C. 553(e)) and may petition to amend USDA rules under 7 CFR 1.28 and 9 CFR 392.5.
Under this authority, the petitioner requests that the Secretary of Agriculture require third-party verification of carbon claims, including the "climate-friendly" claim being made by Brazen Beef, and require a numerical carbon disclosure when such claims are made.

Requiring third-party verification and a numerical carbon disclosure are permitted under the *Central Hudson* test. Under the *Central Hudson* test, a four-part assessment is used to determine to what extent commercial speech is protected by the First Amendment.[37]

First, the court must determine whether the speech in question is protected commercial speech. Protected commercial speech must "concern lawful activity and not be misleading."[38] Second, the USDA must show it has a substantial interest in controlling the speech. Protecting consumers from fraud, deception, and coercion are substantial state interests.[39] Third, the USDA must show that the regulation directly advances the government's stated substantial interest.[40]

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[33] Eco Matters, *What is an LCA Process?*, https://www.ecomatters.nl/services/lca-epd/life-cycle-assessment/ (last visited Apr. 23, 2023).

[34] An ISO-Compliant LCA follows all the steps recommended by ISO standards 14040 and 14044 and is grounded in a detailed LCA report. Quantis, *Guidelines for Credible, Science-driven Environmental Footprint Claims*, (2022), https://25337892.fs1.hubspotusercontent-eu1.net/hubfs/25337892/environmental-footprint-claims-guidance-reportquantis2022.pdf.

[35] *Id.*

[36] *Id.*

[37] The four-part test under *Central Hudson* is (1) whether the speech is protected at all, (2) whether the government has a substantial interest in controlling the speech, (3) whether the regulation advances the substantial government interest, and (4) whether the government's regulation is necessary to serve that substantial interest.

[38] Mackenzie Battle & Cydnee Bence, *How Does the First Amendment Apply to Food and Supplement Labels*, Ctr. for Agric. & Food Sys., (citing *Central Hudson*, 447 U.S. at 564), https://labelsunwrapped.org/wp-content/uploads/2021/06/First-Amendment-Food-Labeling-Issue-r5.pdf.

[39] *Id.* (citing *Edenfield v. Fane* at 768; *Rubin v. Coors Brewing Co*., 514 U.S. 476, 484 (1995).

[40] *Id.* (citing *Central Hudson*, 447 U.S. at 565).

Finally, the scope of the regulation must be necessary to serve the government's interest, that is, the government must ensure that the law does not "burden substantially more speech than necessary."[41] The government need not use the *least* restrictive means.[42] The government must show a "fit between the legislature's ends and the means chosen to accomplish those ends, a fit that is not necessarily perfect, but reasonable."[43]

Requiring a mandatory numerical carbon disclosure when carbon claims are made is permitted under the *Zauderer* test. Under *Zauderer v. Office of Disciplinary Counsel of Supreme Court of Ohio*, commercial speech that is not *false* or *deceptive* and does not concern unlawful activities may be restricted only in the service of a substantial governmental interest, and only through means that directly advance that interest.[44]

Where an action compels disclosure of "purely factual and uncontroversial information," the law need only be "reasonably related to the [government's] interest in preventing deception of consumers to pass under the First Amendment."[45] Regulators and courts can require businesses to disclose undisputedly factual and ideologically neutral information about their products, such as a numerical carbon label.

Under *American Meat Institute v. USDA,*[46] the D.C. Circuit held that *Zauderer* applies to "factual and uncontroversial" disclosure mandated by the government for *any purpose*.[47] By promoting "the robust and free flow of accurate information," factual disclosure mandates further the interests protected by the commercial speech doctrine.[48] In particular, the court found that a compelled disclosure must be "purely factual and uncontroversial."

Like the facts disclosed in the *American Meat Institute* case, which conveyed facts that are "directly informative of intrinsic characteristics of the product," the disclosure we propose is not one-sided,[49] nor does a numerical carbon disclosure convey messages that are biased against or are expressly contrary to a corporation's views.[50]

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[41] *Id.* (citing *Board of Trustees of State University of New York v. Fox*, 492 U.S. 469, 478 (1989)).

[42] *Id.*(citing *Board of Trustees of State University of New York v. Fox*, 492 U.S. 469, 479(1989)).

[43] *Id.* (citing *Board of Trustees of State University of New York v. Fox*, 492 U.S. 469, 478 (1989)). At 480 (quoting *Posadas de Puerto Rico Assoc. v. Tourism Co. of Puerto Rico*, 478 U.S. 328, 341 (1986), overruled by *44 Liquormart, Inc. v. Rhode Island*, 517 U.S. 484 (1996) (internal quotations omitted)).

[44] *Zauderer v. Office of Disc. Counsel*, 471 U.S. 626, 637–638.

[45] *Id.* at 651.

[46] *Am. Meat. Inst. v. U.S. Dep't of Agric.*, 760 F.3d 18 (D.C. Cir. 2014) (en banc).

[47] *Id.* at 22.

[48] *Id.* (quoting *AMI*, 760 F.3d at 29 (quoting *Nat'l e;ec. Mfrs. Ass'n v. Sorrel*, 272 F.3d 104, 114 (2d Cir. 2001)).

[49] *AMI*, 760 F.3d at 24–25 (citing *Nat'l Ass'n of Mfrs. v. NLRB*, 717 F.3d at 958, describing one party's argument that disclosures were "one-sided…favoring unionization").

[50] *AMI*, 760 F.3d at 25 ("*Zauderer* does not leave the state "free to require corporations to carry the messages of third parties, where the messages themselves are biased against or are biased against or are expressly contrary to the corporation's views." (citing *Pacific Gas & Electric Co. v. Public Utilities Commission*, 475 U.S. 1, 15–16 n.12, 106 S. Ct. 903,89 L. Ed. 2d 1(1986)).

Exhibit 2

Report on "Climate Friendly" Beef Study

Dr. Adam Feltz
Dr. Silke Feltz

Executive Summary

The results of this survey found that participants were overall sensitive to products labelled "climate friendly," "low carbon," and "10% greenhouse gas reduction" and would choose, pay for, and trust those products more than other products. Participants were overall better than chance at identifying products with the highest and lowest carbon footprints. However, consistent with previous research, participants substantially underestimated the greenhouse gas (GHG) emissions from beef products. Participants exhibited a greater error in estimation for the GHG emissions of Brazen Beef, as well as beef labelled "climate friendly," and "low carbon," than for conventional beef. The results of this study suggest that consumer misunderstanding of the climate impacts of beef products is exacerbated when beef products have labels with "10% greenhouse gas reduction," "climate friendly," or "low carbon" claims.

Background

Previous research has explored whether consumers are knowledgeable about and can estimate the amount of GHG emissions common food products produce. On average, people are not very good at estimating the GHG emissions from animal-based products and are particularly bad at estimating the GHG emissions from beef products. One systematic review of the literature concerning environmental impacts of food concluded that "there is very low consumer awareness that meat has a large environmental impact" (Hartmann & Siegrist, 2017, p. 22). Other work has attempted to quantify that low awareness. For example, out of 20 consumer products including meats, fruits, cheeses, and plant-based products, consumers ranked beef steaks as the 10th highest product for emitting GHGs. However, in that list, beef emitted the most GHGs (Hartmann, Furtwaengler, & Siegrist, 2022).

While consumers tend to underestimate the GHG emissions of beef products, food labels have been shown to influence perceptions, actions, and understanding of food products. In general, people can understand simple descriptive and visual information, especially if that information is presented on the front of the package (Campos, Doxey, & Hammond, 2011). Other work suggests some elements of food labeling can influence perceptions of GHG emissions. For example, simple "red light, yellow light, green light" principal display panel labeling can influence perceptions of whether a product is a high, medium, or low GHG emitter (respectively) and can influence buying choices (Arrazat et al., 2023; Edenbrandt & Lagerkvist, 2021). Similar labeling that gives a scale from green (low emitter) to red (high emitter) had similar effects and made people more accurate in the GHG emission estimates (Camilleri, Larrick, Hossain, & Patino-Echeverri, 2019).

While there is some evidence that some features of labels can increase consumer understanding of products, not all labeling increased understanding. In general, as the computational complexity of the task increases (e.g., conversions, comparisons, calories per 100g to calories per gram), understanding decreases (Cowburn & Stockley, 2005). Interpreting relative reductions can be one of these kinds of tasks (e.g., 30% lower GHG emissions, "low fat"). In general, people tend to be poor at understanding what these kinds of descriptions of reductions mean (Oostenbach, Slits, Robinson, & Sacks, 2019). There is good a priori reason to suspect that the same principles apply in to GHG reductions for beef. People already tend to misunderstand the amount of GHG emissions for beef. But people attend to labeling information, especially as that information occurs on the principal display panel. Some labeling conventions might be used to help alleviate misunderstanding of GHG emissions (e.g., traffic light labels). However, labels that use claims such as "percent less than" are likely to not be understood very well. As such, "percent less than" claims are likely not to alleviate misunderstandings of a product's GHG emissions and have the potential to exacerbate that misunderstanding.

Survey

There was good theoretical reason to suspect that Brazen Beef's labeling would not alleviate and might exacerbate misunderstanding of GHG emissions. We set out to provide empirical support that Brazen Beef's labeling would not alleviate and might exacerbate misunderstandings about GHG emissions. Specifically, we had the following research questions:

- Do consumers value "climate friendly"/"low carbon" claims?
- Do consumers understand "climate friendly"/"low carbon" claims?
- Do consumers understand Brazen Beef's label?
- Can consumers accurately estimate the greenhouse gas emissions of "climate friendly" beef compared to other products?

We created an online survey hosted on Qualtrics and recruited participants from CloudResearch. CloudResearch is an online participant recruitment service. Evidence suggests samples taken from that service are acceptable and often as good as other samples (Douglas, Ewell, & Brauer, 2023). 200 participants were recruited and we employed standard quality control measures on the data (Dominik, 2019). We excluded 2 participants for failing a comprehension check question. 12 participants were excluded for "speeding" through the survey. Speeding means answering the survey too quickly and is an indication of inattentiveness. Using accepted practice, we excluded 5% of the sample for going too fast (faster than 322 seconds). 186 participants remained for the analyses. Age ranged from 18-78 with a mean of 40.3. 51% of the sample was female.

Values Results

We first asked if people valued about climate-friendly products by asking the six questions in the table below. Participants could respond on a scale from 1-6 with 1 = very unlikely and 6 = very likely. The means indicated that participants strongly valued climate-friendly products. Each response was significantly different ($p = .05$ or less) from indifference (indifference mean value would be 3.5). The overall effect was strong (an average *Cohen's d* = .75, typically characterized as a large effect meaning that preferences were on average 0.75 standard deviations higher than indifference). We also calculated percentages of individuals who had scores higher than indifference. The following table shows the proportion of participants that responded with a number greater than 3.5. This means these respondents were more likely than not to agree with the statement (e.g., *more* likely to choose a product labeled as "climate-friendly").

Values Question	Mean	SD of Mean	p	% > 3.5
With all else equal between two products, how likely are you to choose the product labeled "climate friendly"?	5.58	1.17	< .01	95
With all else equal between two products, how likely are you to choose the product labeled "low carbon"?	5.36	1.26	< .01	91
How likely are you to pay more for a product labeled "climate friendly"?	4.12	1.83	< .01	66
How likely are you to pay more for a product labeled "low carbon"?	3.76	1.79	.05	57
How likely are you to trust a label that says that the product is "climate friendly"?	4.83	1.41	< .01	87
How likely are you to trust a label that says that the product is "low carbon"?	4.58	1.52	< .01	84

These results suggest that on average, people cared about climate friendly products. They would be much more likely to choose a climate-friendly product, would pay more for a climate friendly product, and trust a climate friendly product.

Understanding Climate Friendly Products

The second part of our survey aimed to determine if participants could identify products by which had the highest and lowest carbon footprints. We asked participants the following two questions.

1. Of the following, which product has the highest carbon footprint?
2. Of the following which product has the lowest carbon footprint?

Participants were given a list of items that included "climate friendly" beef, beef, pork, chicken, and tofu. Participants were also allowed to answer that they did not know. The following table provides the number of times each response was selected for each question:

	Highest Footprint	% of total	Lowest Footprint	% of total
Climate friendly beef	5	3	27	15
Beef	140	75	0	0
Pork	12	7	1	1
Chicken	4	2	11	6
Tofu	5	3	108	58
I don't know	20	11	39	21

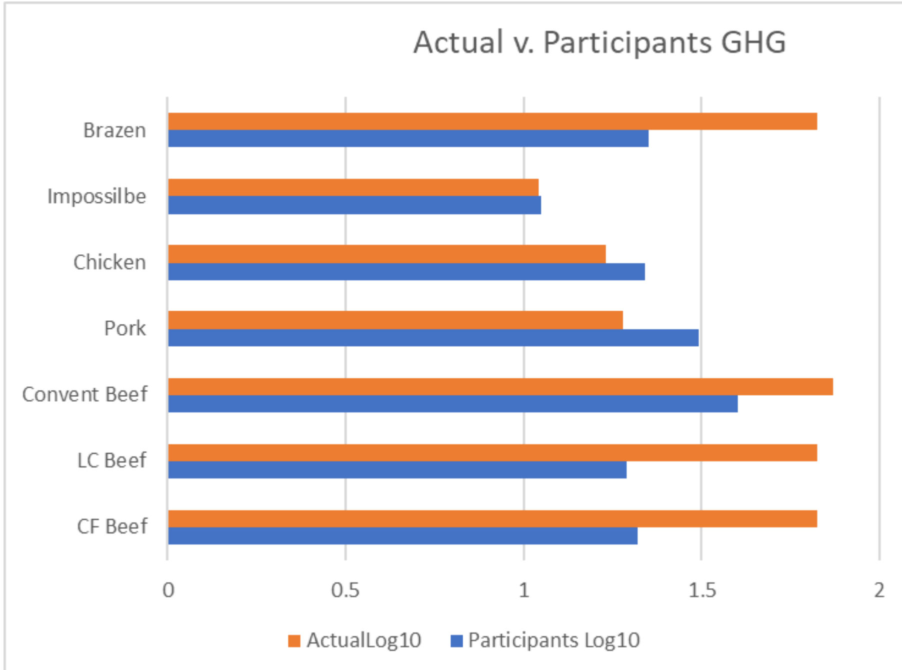
Participants largely were correct in identifying that beef had the highest carbon footprint, but a full 25% of participants either did not know or answered incorrectly. A similar pattern emerged from the lowest carbon footprint data. Most participants could identify that tofu had the smallest footprint. However, 42% of the participants answered incorrectly or I don't know with 15% of participants selecting climate friendly beef as having the lowest carbon footprint. These data suggest that there is moderate to substantial confusion about products GHG emissions and how they compare to climate friendly beef.

We also asked two questions about how confident participants were that the understood “climate friendly” and “low carbon” meant on food labels. One a 6-point scale (1 = not confident, 6 = very confident), participants were weakly confident with mean values of 4.8 (SD = 1.51) and 4.46 (SD = 1.63) respectively. These values were weakly or not significantly correlated with giving correct responses to identifying the product with the highest or lowest carbon footprint (rs = - .05 - .18, ps = .02-.98).

Emissions Estimates

The last part of our survey asked participants to quantify the GHG emissions of products. It is very difficult for the average person to understand units for GHGs (e.g., 1 kg CO_2e per unit of mass). One method to help people make those estimates is to ask them how many tomatoes one would have to grow to emit the same amount of GHGs (1 tomato = 0.32 kg CO_2e (Camilleri et al., 2019). Our focus was estimates of GHG emissions for Brazen Beef, so participants were presented with the image below and asked how many tomatoes would be equivalent to 1kg of Brazen Beef.

We also asked for estimates of other products including 1 kg of conventionally raised beef, 1kg of “climate friendly” beef, 1kg of “low carbon” beef, 1kg of conventionally raised, 1kg of conventionally raised chicken, and 1kg of Plant-Based Impossible Beef. There tends to be substantial positive skew in GHG estimates using units like tomatoes. To help correct for that positive skew, all data were transformed using the log10 of values given by participants (Camilleri et al., 2019). We then compared those estimates with the log10 values for the best mid-point estimate of the actual GHG emissions of those products. These values are graph in the figure below.



Consistent with previous research, people tended to underestimate the GHG emissions for beef products. To evaluate estimates of GHG emissions from participants of the various products, we compared the log10 values against each other. Doing so, we found that estimates for Brazen Beef were not reliably different from the GHG estimates for low carbon beef, climate friendly beef, or chicken. GHG estimates for Brazen Beef were lower than for pork and conventional beef, and higher than those for Impossible Beef. To test the differences of differences, we calculated difference scores of the log10 of the estimate values and the actual values. These results suggest that people underestimate the GHG of climate friendly, low carbon, and Brazen Beef more than people underestimate the GHG of conventional beef—and this difference is statistically significant (see Tables below for statistical analyses).

Conclusions

Our studies suggest that "low carbon" and "climate friendly" beef labels, including Brazen Beef's "10% greenhouse gas reduction" label, will increase underestimates of GHG emissions of those products. This finding is consistent with broader research concerning estimates of products' GHG. Additionally, our data, along with others, indicate that many people care about GHG emissions and are therefore likely to have positive attitudes towards those products and might be more motivated to buy those products. Alternative labeling practices exist that would allow the average consumer to have a better understanding of the GHG of products (e.g., the traffic light approach discussed above). Hence, not only does Brazen Beef's labeling conventions increase misunderstanding, there are alternative methods to communicate GHG emission levels that facilitate better understanding.

adam ~~Hf~~ Silke Feltz

More detailed analyses of the GHG emission estimates data

Analyses of the misunderstandings of GHG estimates.

Repeated Measures ANOVA—this estimates if there is an overall difference among misunderstandings of GHG estimates for the products. The unit of analysis was the difference score between the actual and estimate GHG emissions for each product. The difference score used the following formulate: Actual log10 value (minus) estimated log10 value = difference score. The difference scores were then averaged across all participants. Given this formula, a negative value would indicate an underestimation and a positive value would indicate an overestimation. A significant difference between difference scores would indicate greater misunderstanding of one product compared to the other product. Note: one participant in the study did not fill out the GHG estimates. There were significant overall differences ($F(6, 1104) = 254.96$, $p < .01$, $\eta^2 = .58$.

Mean Difference Scores for Products

	N	Mean	SD
Climate Friendly Beef	185	-0.52	0.82
Low Carbon Beef	185	-0.54	0.83
Conventional Beef	185	-0.267	0.83
Pork	185	0.20	0.79
Chicken	185	0.1	0.75
Impossible Beef	185	0.01	0.73
Brazen Beef	185	-0.48	0.74

Post Hoc Tests—These tests were designed to gauge whether the GHG estimates of some products were worse than the estimates for other products (e.g., were people more wrong about Brazen Beef GHG emissions than conventional beef GHG emissions—was there a significant "difference of the differences."). These tests use a conservative Holm correction because of multiple comparisons. This correction is applied to help control for Type I errors (i.e., falsely detecting a difference between values). The two products being compared in any analysis are the products listed in the first two columns. The statistical analysis for that comparison is presented in the row of the product in the second column. So, for example, the second row in the table compares Climate Friendly Beef and Low Carbon beef, finding a mean difference of -0.03 meaning that low carbon beef's estimate is -.03 lower than Climate friendly beef, but that difference is not statistically significant (p_{holm} = .37). The Cohen's d value is an estimate of the magnitude of the different in standard deviation units.

		Mean Difference	**SE**	**t**	**Cohen's d**	**p_{holm}**
Climate Friendly Beef Difference	Low Carbon Beef Difference	-0.025	0.028	-0.902	-0.032	0.367
	Conventional Beef Difference	0.249	0.028	8.924	0.317	< .001
	Pork Difference	0.717	0.028	25.734	0.913	< .001
	Chicken Difference	0.619	0.028	22.224	0.789	< .001
	Impossible Beef Difference	0.526	0.028	18.878	0.670	< .001
	Brazen Beef Difference	0.038	0.028	1.363	0.048	0.346
Low Carbon Beef Difference	Conventional Beef Difference	0.274	0.028	9.826	0.349	< .001
	Pork Difference	0.742	0.028	26.635	0.945	< .001
	Chicken Difference	0.644	0.028	23.126	0.821	< .001
	Impossible Beef Difference	0.551	0.028	19.780	0.702	< .001
	Brazen Beef Difference	0.063	0.028	2.264	0.080	0.071
Conventional Beef Difference	Pork Difference	0.468	0.028	16.809	0.596	< .001
	Chicken Difference	0.371	0.028	13.300	0.472	< .001
	Impossible Beef Difference	0.277	0.028	9.954	0.353	< .001
	Brazen Beef Difference	-0.211	0.028	-7.562	-0.268	< .001
Pork Difference	Chicken Difference	-0.098	0.028	-3.509	-0.125	0.002
	Impossible Beef Difference	-0.191	0.028	-6.855	-0.243	< .001
	Brazen Beef Difference	-0.679	0.028	-24.371	-0.865	< .001

		Mean Difference	SE	t	Cohen's d	p_{holm}
Chicken Difference	Impossible Beef Difference	-0.093	0.028	-3.346	-0.119	0.003
	Brazen Beef Difference	-0.581	0.028	-20.862	-0.740	< .001
Impossible Beef Difference	Brazen Beef Difference	-0.488	0.028	-17.516	-0.621	< .001

Analyses of differences in GHG emissions estimates

The final set of analyses was designed to see if there were differences among participants GHG estimates of products. There were overall differences in estimates ($F(6. 1104) = 73.5$, $p < .01$, $\eta^2 = .29$.

The mean log10 values of each product are displayed in the following table.

Descriptives

	N	Mean	SD
Climate Friendly Beef	185	1.315	0.821
Low Carbon Beef	185	1.290	0.827
Conventional Beef	185	1.594	0.827
Pork	185	1.482	0.790
Chicken	185	1.334	0.753
Impossible Beef	185	1.051	0.733
Brazen Beef	185	1.353	0.739

Post Hoc Tests

We then tested pairwise differences among the products using the same statistical methods noted above.

		Mean Difference	SE	t	Cohen's d	p_{holm}
Climate Friendly Beef Difference	Low Carbon Beef Difference	0.025	0.028	0.902	0.032	1.000
	Conventional Beef Difference	-0.279	0.028	-10.001	-0.355	< .001
	Pork Difference	-0.167	0.028	-5.992	-0.213	< .001
	Chicken Difference	-0.019	0.028	-0.689	-0.024	1.000
	Impossible Beef Difference	0.264	0.028	9.477	0.336	< .001
	Brazen Beef Difference	-0.038	0.028	-1.363	-0.048	0.693
Low Carbon Beef Difference	Conventional Beef Difference	-0.304	0.028	-10.903	-0.387	< .001
	Pork Difference	-0.192	0.028	-6.894	-0.245	< .001
	Chicken Difference	-0.044	0.028	-1.590	-0.056	0.560
	Impossible Beef Difference	0.239	0.028	8.576	0.304	< .001
	Brazen Beef Difference	-0.063	0.028	-2.264	-0.080	0.142
Conventional Beef Difference	Pork Difference	0.112	0.028	4.009	0.142	< .001
	Chicken Difference	0.259	0.028	9.313	0.330	< .001
	Impossible Beef Difference	0.543	0.028	19.478	0.691	< .001
	Brazen Beef Difference	0.241	0.028	8.638	0.306	< .001
Pork Difference	Chicken Difference	0.148	0.028	5.304	0.188	< .001

We then tested pairwise differences among the products using the same statistical methods noted above.

		Mean Difference	SE	t	Cohen's d	p_{holm}
Chicken Difference	Impossible Beef Difference	0.431	0.028	15.470	0.549	< .001
	Brazen Beef Difference	0.129	0.028	4.630	0.164	< .001
	Impossible Beef Difference	0.283	0.028	10.166	0.361	< .001
	Brazen Beef Difference	-0.019	0.028	-0.674	-0.024	1.000
Impossible Beef Difference	Brazen Beef Difference	-0.302	0.028	-10.840	-0.385	< .001

Note. P-value adjusted for comparing a family of 21

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Education

Florida State University	Ph.D., Philosophy, August 2008
Northern Illinois University	M.A., Philosophy, May 2004
University of South Carolina	B.A., Philosophy, December 1998

Employment and appointments

University of Oklahoma	Associate Professor of Psychology, 2018-present
Michigan Technological University	Associate Professor of Psychology and Applied Ethics, 2017-2018
	Assistant Professor of Psychology and Applied Ethics 2013-2017
Schreiner University	Assistant Professor of Philosophy and Interdisciplinary Studies (tenure track), 2008-2013
Max-Planck Institute for Human Development Center for Adaptive Behavior and Cognition	Visiting Research Scientist, July 2009-May 2012
RiskLiteracy.org	Co-founder and co-managing director (2012-present)

Research and Teaching Interests

Areas of Specialization	Psychology of Philosophical Judgment & Intuition, Applied Ethics, Philosophy of Mind
Areas of Competence	Ethics, Philosophy of Psychology

Grants and Consulting

1. 2021-2026. Co-Principal Investigator for DISES: Conservation incentives and the socio-spatial dynamics of water sustainability. National Science Foundation. $1,596,980.
2. 2022-2025. Co-Principal Investigator for SC-CASC (USGS): What makes climate science products useful? Exploring how stakeholders use, understand, and feel about them. $449,485.
3. 2023-2024. Co-Principal Investigator for Kirkpatrick Foundation: Animal wellbeing and the Oklahoma/Great Plains perspective – Research in support of strategy. $25,000
4. 2021-2024. Co-Principal Investigator for *EFRI E3P: Tuning Catalyst Design to Recycle Mixed Polymer Streams*. National Science Foundation. $1,999,987.
5. 2021-2023. Senior personnel for Carbon-free H2 Production and Storage (CHEPS). Big Ideas Challenge, University of Oklahoma. $150,000.
6. 2020-2021. Principal Investigator for *Understanding Rodeos: Education, Policy, and Attitudes Concerning Animals in Entertainment*. UCLA Law School Animal Law and Small Grants Program. $3,230.
7. 2017-2018. $20,500 Grant. Title: *Risk Communication with Partners: Your Guide to Resources and Recommendations* (Oct 2017-Oct 2018). Principal Investigator Edward T. Cokely, with Co-principal Investigators Rocio Garcia-Retamero & Adam Feltz, and Co-investigator Dafina Petrova. Funded by Medscape, USA (Medscape ID #: SF232838).
8. 2017 – 2018. WebMD & Medscape Risk Literacy Continuing Medical Education Educational Partnership (External Consultants Edward Cokely, Rocio Garcia-Retamero, Adam Feltz, & Dafina Petrova) for *"Risk Communication With Patients: Your Guide to Resources and Recommendations."* Project Director Haleh Kadkhoda of MedScape Education. Funded by Pfizer Foundation Grant ($209,500).
9. 2017-2018 Co-Principal Investigator for *Understanding Consumer Literacy about Milk*, UCLA Law School Animal Law and Policy Small Grants Program, $4,470.
10. 2016-2018. Principal Investigator for *The Outcome Evaluation of Positive Peer Group for American Indians with Substance Use Related Offense,* Portage Health Foundation, Research Excellence Fund, $58,111.
11. 2017-2020. Principal Investigator for *Knowing What You Eat: Measuring the Effectiveness of Educational Interventions on Animal Consumption*. Animal Charity Evaluators, $11,385.
12. 2010-2012. Recipient and Co-Primary Investigator of $200,000 *A Science of Virtue* grant from Arete Initiative at the University of Chicago.
13. 2011. $14,600 Survey Research Support (October 2010-October 2011). Title: Influences of Affect on Philosophical Intuitions (Time-Sharing Proposal ID TESS-0090). Edward T. Cokely, Adam Feltz, and Mirta Galesic. Time-Sharing Experiments in Social Sciences funded by the Social, Behavioral, and Economic Sciences Directorate of the NSF.

Book Publications

1. Feltz A., & Cokely, E.T. (under contract) *Diversity and Disagreement: From Fundamental Biases to Ethical Interactions*. Palgrave Macmillan.

Article Publications

1. Holt, J., Bui, D., Chau, H., Wang, K., Trevisi, L., Jerdy, A, Lobban, L., Crossley, S., Feltz, A., (in press). Development of an objective measure of knowledge of plastic recycling: The outcomes of plastic recycling knowledge scale (OPRKS). *Journal of Environmental Psychology.*
2. Cho, J., Cokely, E., Ramasubramanian, M., Allan, J., Feltz, A., Garcia-Retamero, R. (in press). Numeracy does not polarize climate change judgments: Numerate people are more knowledgeable and knowledge is power. *Decision*.
3. Hoang, U., Feltz, S., Offer-Westort, T., & Feltz, A. (2023). Willingness to consume fewer animal products: A latent profile analysis. *Anthrozoös, 36,* 641-663.
4. Feltz, A., Caton, J., Cogley, Z., Engel, M., Feltz, S., Ilea, R., Johns, S., Offer-Westort, T., & Tuvel, R., (2023). Using Food Frequency Questionnaires to Measure Traits: A Case Study of Human Consumption of Animal Products. *Psychology of Human-Animal Intergroup Relations, 2,* 1-22.
5. Feltz, A., Caton, J., Cogley, Z., Engel, M., Feltz, S., Ilea, R., Johns, S., Offer-Westort, T., & Tuvel, R., (2022). Educational interventions and animal consumption: Results from lab and field studies. *Appetite, 173,* 105981.
6. Tanner, B., & Feltz, A. (2022). Comparing effects of default nudges and informing on recycled water decisions. *Journal of Experimental Psychology: Applied, 28,* 399-411.
7. Feltz, A., Caton, J., Cogley, Z., Engel, M., Feltz, S., Ilea, R., Johnson, S., & Offer-Westort, T., (2022). Developing an Objective Measure of Knowledge of Factory Farming. *Philosophical Psychology,* 1-26. *DOI: 10.1080/09515089.2022.2056436*
8. Feltz, A., Tanner, B., Hoang, G., Holt., H., Asif, M. (2022). Free Will and Skilled Decision Theory. In T. Nadelhoffer, & Mondoe, A. (Eds.). *Advances in Experimental Philosophy of Free Will and Moral Responsibility (*pp. 185-202). London: Bloomsbury.
9. Vucetich, J,., Damania, R., Cushman, S., Macdonald, E., Burnham, D., Offer-Westort, T., Bruskotter, J., Feltz, A., van Eeden, L., & MacDonald, D. (2021). Minimally NonAnthropocentric Economics: What is it, is it necessary, and can it avert the biodiversity crisis? *BioScience, 71, 861-873.*
10. Feltz, A., Cokely, E.T., & Tanner, B. (2021). The Free Will and Punishment Scale: Efficient measurement and predictive validity across diverse and nationally representative adult samples. *Consciousness and Cognition, 95,* 103215.
11. Mahmoud-Elhaj, D., Tanner, B., Sabatini, D., & Feltz, A. (2020). Measuring objective knowledge of potable recycled water. *Journal of Community Psychology, 48,* 2033-2052.
12. Offer-Westort, T., Feltz, A., Bruskotter, J., & Vucetich, J. (2020). What is an endangered species?: Judgments about acceptable risk. *Environmental Research Letters, 15,* 014010.
13. Earp, B. D., Demaree-Cotton, J., Dunn, M., Dranseika, V., Everett, J. A. C., Feltz,

A., Geller, G., Hannikainen, I. R., Jansen, L., Knobe, J., Kolak, J., Latham, S., Lerner, A., May, J., Mercurio, M., Mihailov, E., Rodriguez-Arias, D., Rodriguez Lopez, B., Savulescu, J., Sheehan, M., Strohminger, N., Sugarman, J., Tabb, K., & Tobia, K. (2020). Experimental philosophical bioethics. *AJOB Empirical Bioethics, 11,* 30-33.
14. Feltz, S. & Feltz, A. (2019). Consumer accuracy at identifying plant-based and dairy-based milk products. *Food Ethics, 4,* 85-112.
15. Feltz, S., & Feltz, A. (2019). The Knowledge of Animals as Food Scale. *Human-Animal Interaction Bulletin*, 7, 19-45.
16. Feltz, A., & Cokely, E.T. (2019) Extraversion and compatibilist intuitions: A ten-year retrospective and meta-analysis. *Philosophical Psychology*, *32,* 388-403.
17. Cokely, E. T., Feltz, A., Ghazal, S., Allan, J., Petrova, D., & Garcia-Retamero, R. (2018). Skilled Decision Theory: From intelligence to numeracy and expertise. In A. Ericsson, R. Hoffman, A. Kozbelt, & A. Williams (Eds.), *Cambridge Handbook of Expertise and Expert Performance* (pp. 476-505). Cambridge: Cambridge University Press.
18. Brown, L., Feltz, A., & Wallace, C. (2018). Lab exercises for a discrete structures course: exploring logic and relational algebra with Alloy. In P*roceedings of the 23rd Annual ACM Conference on Innovation and Technology in Computer Science Education (ITiCSE 2018)* (pp. 135-140). New York: ACM.
19. Garcia-Retamero, R., Petrova, D., Feltz, A., & Cokely, E.T. (2017). Measuring Graph Literacy: A systematic review and a meta-analysis. *Encyclopedia of Health and Risk Message Design and Processing*. Cambridge University Press.
20. Feltz, A., & Cokely, E.T. (2017). Informing ethical decision making. In K. Rommelfanger & L.S. Johnson (Eds.) *Handbook of Neuroethics* (pp. 304-318). New York: Routledge.
21. Feltz, A., & May, J. (2017). The means/side-effect distinction in moral cognition: A meta-analysis. *Cognition, 166,* 314-327.
22. Feltz, A. (2017). Folk intuitions. In M. Griffith, N. Levy, & K. Timpe (eds) *The Routledge Companion to Free Will* (pp. 468-576). New York: Routledge.
23. Feltz, A., & Cokely, E. T. (2016). Personality and philosophical bias. In J. Sytsma & W. Buckwalter (Eds.), *A Companion to Experimental Philosophy* (pp. 578-589). New York: Wiley-Blackwell.
24. Feltz, A. (2016). Surrogate financial decision making: Lessons from applied experimental philosophy. *The Spanish Journal of Psychology, 19, doi: 10.1017/sjp.2016.54* .
25. Feltz, A., Cokely, E. T., & Nelson, B. (2016). Experimental philosophy needs to matter: Reply to Andow and Cova. *Philosophical Psychology, 29*, 567-569.
26. Feltz, A. (2015). Experimental philosophy of actual and counterfactual free will intuitions. *Consciousness and Cognition, 36,* 113-130.
27. Feltz, A. (2015). Everyday attitudes about euthanasia and the slippery slope argument. In M. Cholbi & J. Varelius (Eds.), *New Directions in the Ethics of Assisted Suicide* (pp. 217-237). New York: Springer.
28. Feltz, A., & Millan, M. (2015). An error theory for compatibilist intuitions. *Philosophical Psychology, 28,* 529-555.
29. Feltz, A. (2015). Ethical information transparency and sexually transmitted diseases. *Current HIV Research, 13,* 421-431.

30. Cokely, E.T., & Feltz, A. (2014). Expert Intuition. In L. Osbeck & B. Held (Eds.) *Rational Intuition* (pp. 213-238). Cambridge: Cambridge University Press.
31. Feltz, A., & Cova, F. (2014). Moral responsibility and free will: A meta-analysis. *Consciousness and Cognition, 30,* 234-246.
32. Feltz, A., & Cokely, E.T. (2014). The terror or 'terrorists': An investigation in experimental applied ethics. *Behavioral Sciences of Terrorism and Political Aggression, 6,* 195-211.
33. Feltz, A., & Cokely, E.T. (2013). Predicting philosophical disagreement. *Philosophy Compass, 8/10*, 978-989.
34. Feltz. A., & Cokely, E.T. (2013). Virtue or consequences: The folk against Pure Evaluational Internalism. *Philosophical Psychology, 26,* 702-717.
35. Feltz, A. (2013). Pereboom and premises: Asking the right questions in the experimental philosophy of free will. *Consciousness and Cognition, 22,* 54-63.
36. Feltz, A., & Samayoa, S. (2012). Heuristics and life-sustaining treatments. *Journal of Bioethical Inquiry, 9,* 443-455.
37. Feltz, A., & Abt, T. (2012). Claims about surrogate decision-making accuracy require empirical evidence. *The American Journal of Bioethics, 12,* 41-43.
38. Feltz, A., & Cokely, E.T. (2012). The virtues of ignorance. *The Review of Philosophy and Psychology, 3,* 335-350.
39. Feltz, A., Harris, M., & Perez, A. (2012). Perspective in intentional action attribution. *Philosophical Psychology, 25*, 673-687.
40. Feltz, A., Perez, A., & Harris, M. (2012). Free will, causes, and decisions: Individual differences in written reports. *The Journal of Consciousness Studies, 19*, 166-189.
41. Feltz, A., & Cokely, E.T. (2012). The Philosophical Personality Argument. *Philosophical Studies, 161,* 227-246.
42. Cokely, E.T., & Feltz, A. (2011). Virtue in business: Morally better, praiseworthy, trustworthy, and more satisfying. *Journal of Organizational Moral Psychology, 2,* 13-26.
43. Schulz, E., Cokely, E.T., & Feltz, A. (2011). Persistent bias in expert judgments about free will and moral responsibility: A test of the Expertise Defense. *Consciousness and Cognition, 20*, 1722-1731.
44. Feltz, A., & Cokely, E.T. (2011). Individual Differences in Theory-of-Mind Judgments: Order Effects and Side Effects. *Philosophical Psychology, 24,* 343-355.
45. Miller, J., & Feltz, A. (2011). Frankfurt and the folk: An Empirical Investigation. *Consciousness and Cognition, 20,* 401-414.
46. Feltz, A., & Zarpentine, C. (2010). Do you know more when it matters less? *Philosophical Psychology, 23*, 683-706.
47. Feltz, A., Harris, M., & Perez, A. (2010). Actor-observer differences in intentional action intuitions. In S. Ohlsson & R. Catrambone (Eds.), *Proceedings of the 32nd Annual Conference of the Cognitive Science Society* (pp. 2560-2565). Austin, TX: Cognitive Science Society.
48. Cokely, E. T., & Feltz, A. (2010). Questioning the free will comprehension question. In S. Ohlsson & R. Catrambone (Eds.), *Proceedings of the 32nd Annual Conference of the Cognitive Science Society* (pp. 2440-2445). Austin, TX: Cognitive Science Society.
49. Feltz, A., & Bishop, M. (2010). The proper role of intuitions in epistemology. In

M. Milkowski & K. Talmont-Kaminski (Eds.), *Beyond Description: Normativity in Naturalised Philosophy* (pp. 101-122). London: College Publications.

50. Cokely, E. T., & Feltz, A. (2010). Adaptive diversity and misbelief. *Behavioral and Brain Sciences, 32,* 526.
51. Livengood, J., Sytsma, J, Feltz, A., Scheines, R., & Machery, E. (2010). Philosophical temperament. *Philosophical Psychology, 23,* 313-330.
52. Feltz, A. (2009). Experimental philosophy. *Analyse & Kritik, 31*, 201-219.
53. Feltz, A., & Cokely, E.T. (2009). Do Judgments about Freedom and Responsibility Depend on Who You Are? Personality Differences in Intuitions about Compatibilism and Incompatibilism. *Consciousness and Cognition, 18,* 342-350. (Target Article)
54. Cokely, E.T., & Feltz, A. (2009). Adaptive variation in judgment and philosophical intuition. *Consciousness and Cognition, 18,* 355-357.
55. Cokely, E.T., & Feltz, A. (2009). Individual differences, judgment biases, and Theory-of-Mind: Deconstructing the intentional action side effect asymmetry. *Journal of Research in Personality, 43,* 18-24.
56. Feltz, A., Cokely, E.T., & Nadelhoffer, T. (2009). Natural compatibilism v. natural incompatibilism. *Mind & Language, 24,* 1-23.
57. Feltz, A. (2008). Problems with the appeal to intuition in epistemology. *Philosophical Explorations, 11,* 131-141.
58. Nadelhoffer, T., & Feltz, A. (2008). The actor-observer bias and moral intuitions: Adding fuel to Sinnott-Armstrong's fire. *Neuroethics, 1, 1*33-144.
59. Feltz, A., & Cokely, E. T. (2008). The fragmented folk: More evidence of stable individual differences in moral judgments and folk intuitions. In B. C. Love, K. McRae & V. M. Sloutsky (Eds.), *Proceedings of the 30th Annual Conference of the Cognitive Science Society* (pp. 1771-1776). Austin, TX: Cognitive Science Society.
60. Nadelhoffer, T., & Feltz, A. (2007). Folk intuitions, slippery slopes, and necessary fictions: An essay on Saul Smilansky's free will illusionism. *Midwest Studies in Philosophy, 31*, 202-213.
61. Feltz, A. (2007). Knowledge, moral praise, and moral side effects. *Journal of Theoretical and Philosophical Psychology, 27*, 123-126.
62. Feltz, A. (2007). The Knobe effect: A brief overview. *The Journal of Mind and Behavior, 28,* 265-277.
63. Feltz, A., & Cokely, E.T. (2007). An anomaly in intentional action ascriptions: More evidence of folk diversity. In D.S. McNamara & J.G. Trafton (Eds.), *Proceedings of the 29th Annual Cognitive Science Society* (p. 1748). Austin, TX: Cognitive Science Society.

Reviews

1. Feltz, S. & Feltz , A. (2016). Michael Bishop, *The Good Life: Integrating the Philosophy and Psychology of Well-being*. *Philosophical Psychology, 29,* 1253-1255.
2. Feltz, A. (2015). Christina Miller, *Moral Character*. *Philosophical Psychology, 28,* 1079-1082.

3. Feltz, A. (2009). Joshua Knobe and Shaun Nichols, *Experimental Philosophy*. *Polish Journal of Philosophy, 3,* 131-136.

Invited Presentations

1. "Ethical Risk Communication" University of Oklahoma, Spring 2018
2. "Informed, Ethical Decision Making"
   North Carolina State University, Spring 2016
   Tulane University, Spring 2016
3. "Ethical Information Transparency and Informed Decision Making" University Of Leeds, UK, Spring 2015.
4. "Philosophical Bias and Applied Experimental Philosophy" Northern Michigan University, Spring, 2014.
5. "Ethical Decision Making" Michigan Technological University, Houghton, MI, Spring 2013
6. "Predicting Philosophical Bias"
   University of Central Florida, Summer, 2012.
   University of California Merced, Spring 2013.
7. "Philosophical Dilemmas, Philosophical Personality, and Philosophy in Action" Experiments in Ethical Dilemmas University of London, London, Spring 2012.
8. "Persistent Bias in Philosophical Intuitions" Max Planck Institute for Human Development, Adaptive Behavior and Cognition Group, Berlin, Summer 2011.
9. "Heuristics of Virtue" A Science of Virtue Symposium, University of Chicago, Spring 2011.

Refereed Presentations

1. Cho. J., Cokely, E.T., Ramasubramanian, M., Allan, J.N., Feltz, A., & Garcia-Retamero, R. (2023, Nov.). Do Numeracy Skills Polarize Climate Change Judgments?. Spoken presentation at the 64th annual meeting of the Psychonomic Society. San Francisco, CA.
2. Cho. J., Cokely, E.T., Baldwin, A., Feltz, A., & Garcia-Retamero, R. (2023, Nov.). Why are Numerate People Less Susceptible to Misinformation? A test of the *Knowledge is Power* Account. Poster presented at the 44th annual conference of the Society for Judgment and Decision Making. San Francisco, CA.
3. Cho. J., Baldwin, A., Cokely, E.T., Feltz, A., & Garcia-Retamero, R. (2023, Nov.). Do Numerate People Know that Knowledge is Power?. Poster presented at the 44th annual conference of the Society for Judgment and Decision Making. San Francisco, CA.
4. Mahmoud-Elhaj, D., Tanner, B., Hoang, U., Fetlz, A. (December, 2022). *Identifying disparities in interventions to increase public acceptance of reuse water*. Poster presented at the Oklahoma Governor's Water Conference, 2022, Midwest City, OK.
5. Mahmoud-Elhaj, D., Tanner, B., Hoang, U., Holt, J., Asif, M., Feltz, A. (November, 2022). *Nudges increase disparities in recycled water acceptance.* Poster presented at the Annual Conference of the Society for Judgement and

Decision-Making, 2022, San Diego, CA.

6. Mahmoud-Elhaj, D., Tanner, B., Hoang, U., Fetlz, A. (December, 2022). *Identifying disparities in interventions to increase public acceptance of reuse water*. Poster presented at the OU International WaTER Conference, 2022, Norman, OK.
7. Hoang, U., Tanner, B., Mahmoud-Elhaj, D., Feltz, A. (December, 2022). *Trust as a Predictor of Acceptance of Recycled Water*. Poster presented at the Oklahoma Governor's Water Conference, 2022, Midwest City, OK.
8. Hoang, U., Tanner, B., Mahmoud-Elhaj, D., Holt, J., Asif, M., Feltz, A. (November, 2022). *Increase in Trust Level as a Result of Education: A Case Study in Water Reuse*. Poster presented at the Annual Conference of the Society for Judgment and Decision Making, 2022, San Diego, CA.
9. Hoang, U., Tanner, B., Mahmoud-Elhaj, D., Feltz, A. (September, 2022). *Trust as a Predictor of Acceptance of Recycled Water*. Poster presented at the OU International WaTER Conference, 2022, Norman, OK.
10. Hoang, U., Feltz, A., Tanner, B., Sabatini, D., Chamberlain, J., Rainbolt-Forbes, E., & Nijhawan, A. (February, 2022). *Generalized Trust and Intentions to Use Indirect Potable Reuse*. Poster presented at the Annual Conference of the Society for Judgment and Decision Making, 2021.
11. Holt, J. R. & Feltz, A. (August, 2021) Predicting Consumer Intentions to Recycle Multilayer Films. Poster presented at virtual Emerging Frontiers in Research and Innovation Teams Workshop.
12. Holt, J. R., Tanner, B., Asif, M., Hoang, G., Mahmoud-Eljah, D., & Feltz, A. (February, 2022) Development of a Plastic Recycling Knowledge Scale. Poster presented at annual conference for the Society of Judgement and Decision Making, 2022
13. Holt, J. R., Asif, M., Hoang, G., Mahmoud-Elhaj, D., Tanner, B., & Feltz, A. (November, 2022) Plastic Recycling Risk Literacy. Poster presented at annual conference for the Society of Judgment and Decision Making, 2022, San Diego, CA
14. Asif, M., Tanner, B., Holt, J., Hoang, G., Mahmoud-Elhaj, D., & Feltz, A. (2022). *Effects of Education and Framing on Preference to Write a Do-Not-Resuscitate Order*. Poster presented at the annual conference of the Society for Judgement and Decision-Making, 2022, San Diego, CA.
15. Asif, M., Tanner, B., Holt, J., Hoang, G., Mahmoud-Elhaj, D., & Feltz, A. (2022). *Development of an Objective Do-Not-Resuscitate Order Knowledge Scale*. Poster presented at the annual conference of the Society for Judgement and Decision-Making, 2022.
16. Tanner, B. Hoang, G., Mahmoud-Elhaj, D., Sabatini, D., Chamberlain, J., & Feltz, A. (December, 2022). Providing Information that Matters: An Empirical Investigation of the Impact of Different Areas of Educational Content on Recycled Water Knowledge and Acceptance. Oral presentation given at the Oklahoma Governor's Water Conference and Research Symposium, 2022, Midwest City, OK
17. Tanner, B., Hoang, G., Muhammad, A., Holt, J., Mahmoud-Elhaj, D., Sabatini, D., Chamberlain, J., & Feltz, A. (November, 2022). An Empirical Examination of Deeper Indicators of Choice Architecture Effectiveness. Poster presented at the annual conference of the Society for Judgement and Decision Making, 2022

18. Tanner, B., Hoang, G., Mahmoud-Elhaj, D., Asif, M., Holt, J., Sabatini, D., & Feltz, A. (October, 2022). Skilled Decisions vs. Shallow Choice: An Empirical Comparison of Effects of Nudges and Education on Recycled Water Acceptance. Oral presentation given at the ARMADILLO 2022 Conference, Stephenville, TX
19. Tanner, B., Hoang, G., Mahmoud-Elhaj, D., Asif, M., Holt, J., Sabatini, D., Chamberlain, J., & Feltz, A. (November, 2022). *An Empirical Examination of Deeper Indicators of Choice Architecture Effectiveness*. Poster accepted for presentation at the annual conference of the Society for Judgement and Decision Making, 2022, San Diego, CA
20. "Animal Production Consumption: Measurement and Education" German Institute for Economic Research (DIW), Berlin, Germany. Fall 2019.
21. "Applied ethics and animal consumption" 42nd Midsouth Philosophy Conference, Memphis, TN, Spring 2018.
22. "Know what you eat: Experimental Philosophy and Animal Ethics" 41st Midsouth Philosophy Conference, Memphis, TN. Spring 2017.
23. "The Means/Side-effect distinction in moral cognition: A meta-analysis" 41st Midsouth Philosophy Conference, Memphis, TN. Spring 2017.
24. "Measures of Agency" American Philosophical Association Central Meeting, Kansas City, MO, Spring 2017.
25. "Free will and Punishment: Measuring the Major Factors of Free Will Attitudes" 40th Midsouth Philosophy Conference, Memphis, TN. Spring 2016.
26. "The Knowledge of Brain Death Scale" poster presentation at the 36th Annual Society for Judgment and Decision Making conference, Chicago, IL, Fall 2015.
27. "Applied Experimental Philosophy: Death" 39th Annual Midsouth Philosophy Conference, Memphis, TN. Spring 2015.
28. "Moral Responsibility and Free Will: A Meta-analysis" The American Philosophical Association Central Division Meeting, Chicago, IL, Spring 2014.
29. "Experimental Philosophy of Actual and Counterfactual Free Will Intuitions" 38th Mid-South Philosophy Conference, Memphis, TN, Spring 2014.
30. "Free Will, Religion, and Fate: A Mediation Analysis" 37th Mid-South Philosophy Conference, Memphis, TN. Spring 2013.
31. "Most Folk are not Compatibilists." Northwest Philosophy Conference, Oregon State, Fall 2012.
32. "Pereboom and premises: Asking the right questions in the experimental philosophy of free will" 36th Annual Midsouth Philosophy Conference, Memphis, Spring 2012.
33. "Heuristics, Life-Sustaining Treatments, and Paternalism" Central Division of the American Philosophical Association, Minneapolis, Spring 2011.
34. "A Test of the Expertise Defense: Persistent Bias in Expert Judgments about Free Will and Moral Responsibility"
    - 35th Annual Midsouth Philosophy Conference, Memphis, Spring 2011
    - Southern Society for Philosophy and Psychology Annual Conference, New Orleans, Spring 2011.
35. "Heuristics, Life-Sustaining Treatments, and Paternalism" 35th Annual Midsouth Philosophy Conference, Memphis, Spring 2011
36. "The Philosophical Importance of Individual Differences" Experimental Philosophy Workshop, University of Wroclaw, Poland, Summer 2010.
37. "Actor-Observer Differences in Intentional Action Intuitions" 34th Annual

Mid-South Philosophy Conference, Memphis, Spring 2010.

- 34th Annual Midsouth Philosophy Conference, Memphis, Spring 2010.
- 32nd Annual Cognitive Science Society Conference, Portland, Oregon, Summer 2010.

38. "The Philosophical Heritability Argument" at the 61st Northwest Philosophy Conference, Fall 2009.
39. "Frankfurt and the Folk: An Experimental Investigation of Frankfurt-Style Cases" at the 33rd Annual Mid-South Philosophy Conference, Spring 2009.
40. "Predicting Moral Judgment and Folk Intuitions" at the annual meeting of the Society for Judgment and Decision Making, Fall 2008.
41. "Individual Differences and the 'Truth' about Right and Wrong: Predicting Variation in Meta-Ethics and Moral Judgments"
    - The 33rd Annual Mid-South Philosophy Conference, Spring 2009.
    - First Annual Interdisciplinary Approaches to Philosophy Conference, University of South Alabama, Spring 2009.
42. "The Actor-Observer Bias and Moral Intuitions: Adding Fuel to Sinnott-Armstrong's Fire" Southern Society of Philosophy and Psychology, Spring 2008.
43. "Do You Know More When It Matters Less?"
    - The 32nd Annual Mid-South Philosophy Conference, Spring 2008.
    - Southern Society of Philosophy And Psychology, Spring 2008
44. "Folk Intuitions, Slippery Slopes, and Necessary Fictions: An Essay on Saul Smilansky's Free Will Illusionism," the Inland Northwest Philosophy Conference Spring 2006.
45. "What is Intuition's Place in Epistemological Inquiry?" Southern Society of Philosophy and Psychology Conference, Spring 2005.
46. Comments on John Bickle's "Real Revolution in Neuro-science: Tool Development" 40th Midsouth Philosophy Conference, Memphis, TN. Spring, 2106.
47. Comments on Robert Barnard's "Expertise as Philosophical Reliablism." Mid-South Philosophy Conference, Memphis, Spring 2013.
48. Comments on Jeffery Englehardt's "The Problem of Second Effects" Midsouth Philosophy Conference, Memphis, Spring 2012.
49. Comments on Matt Drabek's "Feedback Bias in the Social Sciences: The Case of Paraphilia" 35th Annual Mid-South Philosophy Conference, Spring, 2011.
50. Comments on Walter Riker's "Must Corporations Obey the Spirit of the Law?" 35th Annual Mid-South Philosophy Conference, Spring, 2011.
51. Comments on Kathleen Voh's "Lay Beliefs In Free Will" at the Werkmeister Conference on Experimental Philosophy, Florida State University, Spring 2010.
52. Comments on Christopher Zarpentine's "Taking Diversity Seriously" at the 61st Annual Northwest Philosophy Conference, Fall 2009.
53. Comments on Joseph Ulatowski's "Two Senses of 'Ought' in Forrester's Paradox" at the 33rd Annual Mid-South Philosophy Conference, Spring 2009.
54. Comments on Adam Cureton's "Moral Intuitions about Large Numbers" at the Southern Society for Philosophy and Psychology's annual meeting, Spring 2009.
55. Comments on Adrian Patten's "Are the Rationality Wars Just?: A Look at the Question of Human Rationality," The 31st Annual Mid-South Philosophy Conference, Spring 2007.

56. Comments on Stacey Swain, Joshua Alexander, and Jonathan Weinberg's "The Instability of Philosophical Intuitions: Running Hot and Cold on Truetemp," The First Annual On-line Philosophy Conference, Spring 2006.
57. Comments on Jacob Canton's "The Trolley Problem in 3D". 41st Midsouth Philosophy Conference, Memphis, TN. Spring 2017

Editorial Service

Journal of Experimental Psychology: Applied	Editorial Board
Human-Animal Interaction Bulletin	Editorial Board
Psychology of Human-Animal Intergroup Relations	Editorial Board

Silke Feltz

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EDUCATION

Michigan Technological University
Ph.D., Rhetoric, Theory & Culture, August 2019
Dissertation: "Because We Have Chosen a Life of Peace: A Quantitative and Qualitative Study of Vegan Food Narratives"

Otto-Friedrich-Universität Bamberg, Germany
First Bavarian Staatsexamen (Teaching Certification in English and German), Spring 2002

Otto-Friedrich-Universität Bamberg, Germany
M.A., English and German, Fall 2001

RESEARCH & TEACHING INTERESTS

Research Focus	Pedagogy, Food Ethics
Creative Focus	Poetry
Areas of Specialization	Composition and Developmental Writing, Technical Communication, ESL, German
Areas of Competence	English and German literature, Communication Studies (Public Speaking, Writing & Research)

EMPLOYMENT

University of Oklahoma	Senior Assistant Director in First-Year Composition, Fall 2023-Present
University of Oklahoma	Director in First-Year Composition, Fall 2021-Fall 2023
University of Oklahoma	Assistant Teaching Professor/Lecturer, 2020-Present

University of Oklahoma	Instructor, 2018-2020
Michigan Technological University, MI	Composition Program Graduate Coordinator, 2016-2018
Michigan Technological University, MI	Instructor, 2014-2018
Schreiner University, TX	Instructor, Fall 2009-2014
Schreiner University, TX	Adjunct Instructor, Fall 2008-Spring 2009
Tallahassee Community College, FL	Adjunct Instructor, Fall 2007-Spring 2008
Kishwaukee College, FL	Adjunct Instructor, Fall 2003-Spring 2004
University of South Carolina, SC	Teaching Assistant, Fall 1998-Spring 1999
Otto-Friedrich-Universität Bamberg, Germany	Adjunct Instructor (German as a Second Language), Summer 1997

PUBLICATIONS

Peer-Reviewed Articles

1. Tweedale, K. and Feltz, S. (forthcoming). Inviting Empathy: A Feminist Approach to Community-Engaged Learning. *Journal of Community Engagement and Scholarship*. 2023.

2. Hoang, U., Feltz, S., Offer-Westort, T., & Feltz, A. (2023). Willingness to consume fewer animal products: A latent profile analysis. *Anthrozoös, 36,* 641-663.

3. *Feltz, A., Caton, J., Cogley, Z., Engel, M., Feltz, S., Ilea, R., Johns, S., Offer-Westort, T., & Tuvel, R., (2023). Using Food Frequency Questionnaires to Measure Traits: A Case Study of Human Consumption of Animal Products. Psychology of Human-Animal Intergroup Relations, 2, 1-22.*

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6. Seigel, M.; Chase, J.; Herder, W.; Feltz, S.; Kitalong, K. S.; Romney, A.; and Tweedale, K.. (2020). Monstrous Composition: Reanimating the Lecture in First-Year Writing Instruction. *College Composition and Communication*. Volume 71 Number 4. Pgs. 643-671.

7. Feltz, S. & Feltz, A. (2019). Consumer accuracy at identifying plant-based and dairy-based milk products. *Food Ethics, 4,* 85-112.

8. Feltz, S., & Feltz, A. (2019). The Knowledge of Animals as Food Scale. *Human-Animal Interaction Bulletin*, 7, 19-45.
   .

Book Chapters

1. *Feltz, S. (2023). Becoming Vegan: A Mixed-Methods Study of Vegan Identities.* The Rhetorical Construction of Vegetarianism. London and New York: Routledge. Pg. 45-62.

2. Feltz, A. and Feltz, S (2021). Psychology and Vegan Studies. *The Routledge Handbook of Vegan Studies*. London and New York: Routledge.

Online Articles

1. Feltz, S. (2018). My Hive. In: *Activist History Review. The Future Is Another Country. December Issue.*

Book Reviews

1. Feltz, S. (2019). Review: Chimpanzee rights. *Metapsychology Online Reviews*. Ethics 23 (29). http://metapsychology.net/poc/view_doc.php?type=book&id=8296&cn=135&fbclid=IwAR1Kw0aG5EaCviPEciguODcyef_l9VYZkNyWz_nFIGMDI0HPTe0d4eQ1P_A

2. Feltz, S. (2018). Review: The Oxford handbook of food ethics. *Metapsychology Online Reviews.* Ethics 22 (28). http://metapsychology.mentalhelp.net/poc/view_doc.php?type=book&id=8108&cn=135

3. Feltz, S. (2017). Review: Personalities on the plate*. Metapsychology Online Reviews.* Ethics 21 (40). http://metapsychology.mentalhelp.net/poc/view_doc.php?type=book&id=7950&cn=135

4. Feltz, S. & Feltz, A. (October 2016). The good life: Unifying the philosophy and psychology of well-being*. Philosophical Psychology* 29 (8). 1253-1255.

Poetry

1. Feltz, S. (2024). 3 am. In: Poem Alone. https://poemalone.blogspot.com/

2. Feltz, S. (2023). Apology. In: Literary Cocktail, Fall Issue. https://www.literarycocktailmagazine.com/

3. Feltz, S. (2023). Pretend Revenge Poem. In: Backwards Trajectory. https://backwardstrajectory.com/

4. Feltz, S. (2023). The Moth. In: Literary Veganism. https://www.litvegan.net/2023/08/poetry-by-silke-feltz.html

5. Feltz, S. (2023). Canada Day. In: Oddballmagazine. https://oddballmagazine.com/poem-by-silke-feltz/

6. Feltz, S. (2023). The Man Who Does Not Read His Poem. In: Eighteen Seventy. Writing from the Fringe. https://eighteenseventy.poetry.blog/2023/05/17/the-man-who-doesnt-read-his-poem-silke-feltz/

7. Feltz, S. (2023). Dear Ukraine. In: Dear Ukraine Project. https://dearukrainepoem.com/responses

8. Feltz, S. (2023). What If? In: Literary Veganism: An Online Journal. https://www.litvegan.net/2023/02/poetry-by-silke-feltz.html

9. Feltz, S. (2022). Selkie Sorrow Part II. In" Mockingheart Review. https://mockingheartreview.com/volume-7-issue-3/silke-feltz/

10. Feltz, S. (2022). Inadequate Lover. In: Brief Wilderness: The Space Between. https://briefwilderness.com/2022/08/13/inadequate-lover-by-dr-silke-feltz/

11. Feltz, S. (2022). How to touch an elephant. In: Literary Veganism: An Online Journal. https://www.litvegan.net/2022/07/poetry-by-silke-feltz.html?fbclid=IwAR1YDJlaSBGdyKfwjTVYVfZ5M0i_dI5JJeo_3pOF4FnMgAMWhE081gienqo

12. Feltz, S. (2021). Dear Vaccine (contributor). University of Kent.

13. Feltz, S. (2020). rockstar. revisited. In: *Writers: Craft & Context*. Vol 1 No 1. https://journals.shareok.org/writersccjournal/article/view/6/8

14. Feltz, S. (2020). Daughter of India. In: *Writers: Craft & Context*. https://journals.shareok.org/writersccjournal/article/view/6/8

15. Feltz, S. (2020). We Left Texas on Cinco de Mayo. In: *Writers: Craft & Context.* *https://journals.shareok.org/writersccjournal/article/view/6/8*

16. Feltz, S. (2018). Your Maybe Forever Goodbye. In: *Peeking Cat Poetry's Anthology*. Ed.: Sam Rose.

17. Feltz, S. (2018). The Youngest Warrior of Maharashdra. In: *Postcard Poems and Prose.*

18. Feltz, S. (2017). One Elbi. In: *Child Owlet Literary Magazine*.

19. Feltz, S. (2017). I Wish You Well. In: *Child Owlet Literary Magazine*.

20. Feltz, S. (2017). These Grounds. In: *Child Owlet Literary Magazine*.

21. Feltz, S. (2016). Nameless. In: *Drunk Monkeys*. http://www.drunkmonkeys.us/poetry/2016/5/13/poetry-nameless-silke-feltz

21.Feltz, S. (2016). Swimming Lesson. In *Drift: Narratives from the Upper Peninsula (pp. 14-15).* Houghton, Michigan: Michigan Technological University.

22. Feltz, S. (2016). Defeat. In *Drift: Narratives from the Upper Peninsula (pp. 17).* Houghton, Michigan: Michigan Technological University.

Website Manager:

www.animaliq.org

TALKS & PRESENTATIONS

Invited Talks

1. “Skilled Decisions and Animal Consumption.” With Adam Feltz. March 9, 2023 at the Southern Society for Philosophy and Psychology in Louisville, Kentucky.

2. “Balancing beneficence and autonomy in agriculture with a warming world.” June 27, 2022 at the American Society of Animal Science in Oklahoma City, Oklahoma.

3. “Effectively working with a community partner.” March 3, 2022 at the University of North Texas in Denton, TX. (Zoom)

4. “Humanitarian knitting: a rhetorical intervention.” March 3, 2022 at the University of North Texas in Denton, TX (Zoom).

5. “Milk labeling and consumer confusion.” With Adam Feltz. February 2019 at UCLA Law School in Los Angeles, California.

6. “Webinar: The Texas Language Consortium.” April 2014 at Associated Colleges of the South in Kerrville, Texas.

7. “Shared Academics Seminar: The Texas Language Consortium.” June 2013 at National Institute for Technology in Liberal Education Shared Academics Seminar.

8. “The Texas Language Consortium.” April 2013 at National Institute for Technology in Liberal Education Symposium, April 2013 in Atlanta, Georgia.

9. “Poetry Reading: women warriors.” November 2010 at California State University Fullerton Creative Writing Workshop in Fullerton, California.

10. “Foreign language learning.” June 2010 at Schulkolleg Dr. Rampitsch in Nürnberg, Germany.

Peer-Reviewed Talks and Presentations

1. “The Effectiveness of Animal Ethics Education” MIdsouth Philosophy Conference, Memphis, TN, March 2023 (co-presenter with Adam Feltz)

2. “Doing Hope in a Seemingly Hopeless State: Engaging First-Year Writing Students through Service Learning.” February 2023 at the Conference on College Composition and Communication in Chicago. (co-presenter with Jennifer Chancellor)

3. “Does Humane Education Change Knowledge, Attitudes, and Behaviors?” Animal Advocacy Conference: Insights from the Social Sciences. University of Kent, Summer 2021. (co-presenter with Adam Feltz)

4. “Education’s Impact on Knowledge, Attitudes, and Behaviors Involving Animals.” International Society for Anthropology and Zoology. Summer 2021. (co-presenter with Adam Feltz)

5. “Animal Food Consumption: Measurement and Education.” October 2019 at Deutsches Institut fuer Wirtschaftsforschung (DIW) in Berlin, Germany. (co-presenter with Adam Feltz)

6. “How to Engage in Moral Education: Skilled Decision Making.” March 2019 at Midsouth Philosophy Conference in Memphis, Tennessee. (co-presenter with Adam Feltz)

7. “Keeping It Real: Performance Pedagogy and Empathy Building in the Writing Classroom.” March 2019 at Conference on College Composition and Communication in Pittsburgh, Pennsylvania.

8. “Applied Ethics and Animal Consumption.” March 2018 at Midsouth Philosophy Conference in Memphis, Tennessee. (co-presenter with Dr. Adam Feltz)

9. “Monstrous Composition: Reanimating the Lecture in First-Year Writing Instruction.” March 2018 at Conference on College Composition and Communication in Kansas, Missouri. (co-presenter with the first-year writing team of Dr. Marika Seigel)

10. “Embodied Making and Empathy in the Technical Communication Classroom.” March 2018 at American Teachers of Technical Writing in Kansas City, Kansas. (co-presenter with Dr. Kimberly Tweedale)

11. “Shared perspectives on finding perspective on the tenure track.” April 2017 at Southern States Communication Association in Greenville, South Carolina.

12. “Expanding the moral horizon through rhetorical ecologies.” April 2017 at Southern States Communication Association/Philosophy and Ethics Interest Group in Greenville, South Carolina.

13. “Know what you eat: Experimental philosophy and animal ethics.” March 2017 at Midsouth Philosophy Conference in Memphis, Tennessee.

14. “Personalizing the standard: Approaches to first-year composition.” October 2016 at Michigan College English Association in Warren, Michigan.

15. “Communication as conscience: Animal rights in a nonideal world.” April 2016 at Southern States Communication Association in Austin, Texas.

16. “’So, I’m not a good writer:’ Using peer conferences to scaffold competence and confidence.” April 2016 at Michigan Developmental Education Consortium, April 2016 in Bay City, Michigan.

17. “Moral schizophrenia and intersectionality.” February 2016 at Midsouth Philosophy Conference in Memphis, Tennessee.

18. “*Stammtisch* approaches to crafting, networking, pedagogy, and community outreach.” April 2015 at Southern States Communication Association in Tampa, Florida.

19. “*Le Petit Prince*: A big idea for a small liberal arts campus.” November 2014 at American Council on the Teaching of Foreign Languages in San Antonio, Texas.

20. “Classroom of the future.” April 2014 at Southern States Communication Association in New Orleans, Louisiana.

21. “Teaching beyond Schreiner: The Texas Language Consortium.” October 2013 at Rocky Mountain Modern Language Association in Vancouver, Washington.

22. “Gallows voices: Surviving the battle of Berlin.” September 2012 at West Virginia University Colloquium on Humor in Literature and Film in Morgantown, West Virginia.

23. “Poetry Reading: ½ a lifetime.” March 2012 at Conference of College Teachers of English, in Fort Worth, Texas.

24. “Poetry Reading: Women warriors.” April 2011 at Popular Culture Symposium in San Antonio, Texas.

25. “Poetry Reading: Liebestänze.” April 2010 at California State University Fullerton Creative Writing and Composition Conference in Fullerton, California.

26. “Extreme Makeovers in the Writing Center: Mixing the materials.” March 2010 at Conference of College Teachers of English in Texas.

Poster Presentations

1. “Food risk literacy: Knowledge of animal product consumption.” November 2019 at Society of Judgment and Decision Making in Montreal, Canada.

2. “Food risk literacy: Results from studies of milk product literacy.” November 2018 at Society of Judgment and Decision Making in New Orleans, Louisiana.

3. “Layered literacies, service learning, and knitting: A new approach to community advocacy and workplace readiness.” April 2016 at Association of Teachers of Technical Writing in Houston, Texas.

Paper Commentaries

1. Comment on Donnie Smith’s paper, “Certain Assertions.” March 2023 at MIdsouth Philosophy Conference in Memphis, TN.

2. Comment on Travis Hreno’s paper, “The liberty enhancing effects of jury nullification.” March 2019 at Midsouth Philosophy Conference in Memphis, Tennessee.

3. Comment on Emily Tilton’s paper, “Against a ban on breast implants: A feminist
4. approach.” March 2018 at Midsouth Philosophy Conference in Memphis, Tennessee.

5. Comment on Alicia Hall’s paper, “Theory building for health-related quality of life research.” March 2017 at Midsouth Philosophy Conference in Memphis, Tennessee.

6. Comment on Daniel Doviak’s paper, “Claims, Reasons, and Degrees of Fairness.” February 2016 at Midsouth Philosophy Conference in Memphis, Tennessee.

University, Departmental & Community Talks

1. “Navigating the rhetoric of oppression and resistance in a deep red state.” Invited guest lecture. July 2023 at Gymnasium Pegnitz in Pegnitz, Germany.

2. “Living in the U.S.: An immigrant’s perspective.” Invited guest lecture. July 2023 at Gymnasium Pegnitz in Pegnitz, Germany.

3. “Food for thought: Psychological Factors Involved in Animal Product Consumption.” Invited guest lecture. July 2023 at Gymnasium Pegnitz in Pegnitz, Germany.

4. “Veganism as a social problem.” Invited guest lecture. November 2018 at the University of Oklahoma in Norman, Oklahoma.

5. “Humanitarian Knitting & Wellness.” Invited guest lecture. October 2018 at the University of Oklahoma in Norman, Oklahoma.

6. “*StreetKnits* cowl knitting workshop.” March 2018 at Michigan Tech in Houghton, Michigan. This workshop was held for faculty and graduate students at Michigan Tech.

7. “Lunch & Learn: All about going vegan.” March 2018 at Michigan Technological University in Hoghton, Michigan. Invited talk. This talk offered the Michigan Tech community an introduction and overview of veganism.

8. “StreetKnits: Helping the homeless one stitch at a time.” January 2018 at Houghton Rotary Club in Houghton, Michigan. Invited talk. This talk gave an overview of the *StreetKnits* project and discussed food insecurity on college campuses in America.

9. “Knitting and wellness.” August 2017 at Ojibwa Community Library in Baraga, Michigan. Invited talk. This talk gave an overview of the *StreetKnits* project and discussed the connections of knitting and well-being to Native Americans.

10. “Poetry reading.” March 2017 at Bluffs Nursing Home in Houghton, Michigan. Invited talk. This poetry reading was based on my own creative writing projects.

11. “Poetry Reading: From Goethe to slam poetry.” January 2017 at Bluffs Nursing Home in Houghton, Michigan. Invited talk. This poetry reading offered an overview of some of the most prominent German voice throughout time.

12. “Slaughter, art, and tofu: The rhetorical ecologies of the pig.” October 2016 at Rhetoric, Theory, and Culture Graduate Student Colloquium at Michigan Tech in Houghton, Michigan.

13. “Lunch & Learn: Knitting and Mindfulness.” October 2016 at Michigan Tech in Houghton, Michigan. Invited talk about the connections between knitting and well-being, humanitarian knitting, and community building at Michigan Tech.

14. “The Sexual Politics of Meat Slideshow” by Carol Adams. October 2016 at Michigan Tech in Houghton, Michigan. This inter-campus event between Michigan Tech and Northern Michigan raised an awareness about the rhetoric of veganism.

15. “*StreetKnits* sock knitting workshop.” March 2016 at Michigan Tech in Houghton, Michigan.This workshop was held for faculty and graduate students at Michigan Tech.

16. “*StreetKnits* hat knitting workshop.” November 2015 at Michigan Tech in Houghton, Michigan. This workshop was held for faculty and graduate students at Michigan Tech.

WORKSHOPS

1. Invited to a WPA workshop on *AI And Academic Integrity in First-Year Composition* at Macmillan in New York City, New York in November 2023.

2. Accepted and participated in the week-long “Human-Animal-Studies Summer Institute” at the University of Illinois in Urbana-Champagne in July 2018.

GRANTS

1. 2020-2022 Co-Principal Investigator for Understanding Rodeos, UCLA Law School Animal Law and Policy Small Grants Program, $ 3,230 (with Adam Feltz)

2. 2017-2018 Co-Principal Investigator for *Understanding Consumer Literacy about Milk*, UCLA Law School Animal Law and Policy Small Grants Program, $4,470 (with Adam Feltz)

3. Co-PI for *Knowing What You Eat: Measuring the Effectiveness of Educational Interventions on Animal Consumption.* Animal Charity Evaluators, $11,385. August 2017-May 2019 (with Adam Feltz, Syd Johnson, Mylan Engel, Ramona Ilea, Jacob Caton, and Carol Adams)

4. VegFund Grant, Carol Adams *The Sexual Politics of Meat* Lecture at MTU and NMU, Summer 2016 ($150)

AWARDS & HONORS

1. FYC Faculty Excellence in Teaching Award, Fall 2021
   The FYC awards committee at OU votes for the winner of this award after nominated faculty submits a teaching/reflection package.

2. Teaching Recognition, "Exceptional Average of 7 Dimensions," Spring 2018, Michigan Technological University.
   This recognition is based on student evaluations at Michigan Tech. Among all teaching faculty, my teaching fell under the "Top 10 %."

3. Excellence in Teaching Award, Spring 2018
   The Humanities Department nominated me for this award.

4. Teaching Recognition, "Exceptional Average of 7 Dimensions," Spring 2017, Michigan Technological University.
   This recognition is based on student evaluations at Michigan Tech. Among all teaching faculty, my teaching fell under the "Top 10 %."

5. Schreiner University Summer Fellows Institute, Spring 2013
   Two faculty members from each department were selected as representatives of excellent teaching. This honor entailed monetary recognition and a week-long workshop on pedagogy which resulted in several university-wide talks and cross-campus collaborations.

6. Fulbright Travel Grant, Summer 1998
   The Fulbright Travel Grant covered my flight and provided me with start-up money when I studied abroad as an exchange student. It also entailed a weekend workshop in Bremen that prepared me for living abroad.

COMMUNITY OUTREACH

2023-Present: Poetic Justice

Poetic Justice is a nonprofit in Oklahoma that helps incarcerated women reflect on their trauma through poetry workshops.

2013-Present: Founder of *StreetKnits*

StreetKnits is an international humanitarian knitting charity that provides knitwear to the homeless. Moreover, *StreetKnits* pairs up with technical communication students in Texas, Florida, Michigan, and Oklahoma and raises awareness for homelessness while serving as a client in the academic classroom. Since 2020, StreetKnits found its physical home as a maker space at the University of Oklahoma (www.streetknits2013.weebly.com).

COURSES TAUGHT

Otto-Friedrich-Universität Bamberg, Germany:

German Style Variations
German Vocabulary Expansion

University of South Carolina, SC:

Elementary German I and II

Kishwaukee College, IL:

English Composition and Rhetoric
English Composition and Literature
Elementary German

Tallahassee Community College, FL:

English Composition and Rhetoric

Schreiner University, TX:

English Composition and Rhetoric
English Composition and Literature
Developmental Writing
Technical Communication
English Studies for Teachers
Elementary German I and II (face-to-face and online)
Intermediate German I and II (face-to-face and online)

Michigan Technological University, MI:

English Composition
Technical Communication (online)
German 1A (face-to-face and online)

Intermediate Pronunciation (ESL)
Advanced Listening and Speaking (ESL)
Advanced Pronunciation (ESL)
Advanced Vocabulary (ESL)
Advanced Reading (ESL)
Transitional Listening and Speaking (ESL)
Academic Support (ESL)

University of Oklahoma, OK:

ENGL 1113: Principles of Composition I
ENGL 1213: Principles of Composition II
ENGL 1913: Writing in the Health Professions
HR 5203: Graduate Research & Writing

SERVICE

August 2023-Present: Senior Assistant Director of the FYC team at the University of Oklahoma

August 2021-2023: Assistant Director of the FYC team at the University of Oklahoma

August 2022 - Present: Member of the Online Teaching Committee (FYC)

January 2021 - Present: Poetry Reviewer for *Writers: Craft & Context*

April 2021-Present: Reviewer for *Philosophy & Psychology*

July 2021-Present: Member of Committee A (FYC)

2020-Present: Member of the Celebration of Writing Committee, First-Year Writing Program (FYC)

2020-2022: Member of the Professional Development Workshops Committee (FYC)

Jan 2021-May 2021: Member of the Editorial Board of *The South Oval Review,* the undergraduate journal launched in OU's FYC program

2019-2020: Chair of the Archives Committee, First-Year Writing Program at the University of Oklahoma

2018-2019: Member of the Archives Committee, First-Year Writing Program at the University of Oklahoma

2016-2018: Co-Founding Editor of the undergraduate research journal, *The Portage Review* at Michigan Tech

2016-2017: Co-Founder of the Graduate Student Mentorship Program at Michigan Tech

2012-2014: Co-Advisor of the English Creative Writing Group at Schreiner University

2011-2014: Director of Monday Night Fiction at Schreiner University

2010-2011: Co-Director of Monday Night Fiction at Schreiner University

2010-2014: Member of the Allied Advance Program at Schreiner University

2009-2014: Co-Advisor of Delta Phi Epsilon at Schreiner University

2009-2012: Co-Advisor of Sigma Tau Delta at Schreiner University

2009-2014: Founder & Faculty Advisor of the German Stammtisch at Schreiner University

2009-2011: Founder of the English Composition Group at Schreiner University

2009-2010: Secretary of AAUW at Schreiner University

2003-2004: Member of the International Committee at Kishwaukee College

2003-2004: Founder of the German Stammtisch at Kishwaukee College

MEMBERSHIPS

2017-Present: Conference on College Composition and Communication

2016-2018: Association of Teachers of Technical Writing

2018-present: Affiliate member of the Women's and Gender Studies Faculty at the University of Oklahoma

LANGUAGES

German, native speaker
English, fluent

REFERENCES

Dr. Syd Johnson
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Exhibit 3

Food Quality and Preference 97 (2022) 104486

Contents lists available at ScienceDirect

Food Quality and Preference

journal homepage: www.elsevier.com/locate/foodqual

Consumers' evaluation of the environmental friendliness, healthiness and naturalness of meat, meat substitutes, and other protein-rich foods

Christina Hartmann *, Patricia Furtwaengler, Michael Siegrist

ETH Zurich, Department Health Science and Technology (D-HEST), Consumer Behaviour, Switzerland

ARTICLE INFO

Keywords:
Meat replacements
Naturalness
Healthiness
Meat substitutes
Environmental friendliness

ABSTRACT

In an attempt to move consumers toward a more sustainable and healthy diet, meat substitute products have flooded the market. However, consumers tend to be conservative about new food products and technologies that are supposed to replace traditional ones. Thus, it is important to evaluate whether consumers see the benefits of consuming these new products compared to the traditional meat products they are intended to replace. This online study examined how study participants from the German-speaking region of Switzerland (N = 534) assessed the environmental friendliness, healthiness and naturalness of 20 protein-rich foods, including meat, fish, cheese and a diverse set of meat substitutes. The study also aimed to determine how well subjective consumer evaluations corresponded with objective evaluations based on life cycle assessments and nutrient profiling. Results show that most participants did not assume that meat substitutes are automatically healthier and more environmentally friendly just because they are meat-free. Participants did not evaluate meat substitute products as more environmentally friendly than meat or consider them a healthier option. Compared to traditional foods like meat, fish and cheese, meat substitutes were also evaluated as less natural. Furthermore, strong correlations were found between participants' perceptions of environmental friendliness, naturalness and healthiness, although objective evaluations of these attributes did not correlate. Consumers' generally negative impression of meat substitute products compared to meat remains a challenge for industry and public health as well as the establishment of more sustainable diets.

1. Introduction

There has been growing awareness among stakeholders and consumers of the major issues concerning highly industrialized and conventional meat production systems, which constitute most of the global meat production (Hartmann & Siegrist, 2020). Not only animal welfare and public health concerns (e.g., zoonotic diseases, cardiovascular diseases), but in particular, food security (e.g., high need for grains) and environmental concerns (e.g., depletion of natural resources, environmental pollution) are the focus of attention (Faucitano, Martelli, Nannoni, & Widowski, 2017; Kumar et al., 2017; Poore & Nemecek, 2018; Rohrmann et al., 2013). In order to provide the growing world population with protein sources and at the same time limit the burden caused by the mass production of animal protein (Jungbluth, Itten, & Schori, 2012; Poore & Nemecek, 2018), researchers are searching for alternative protein sources for human nutrition (He, Evans, Liu, & Shao, 2020). As alternatives to conventional meat products, meat substitutes and alternative protein sources have been steadily growing in importance over the last few years.

Meat substitutes comprise many products, including the subcategories tofu/seitan/tempeh, vegetable-based processed products like falafel, cultured meat and novel meat analogues that resemble meat as closely as possible in terms of texture, taste and appearance. Meat substitutes are not necessarily based only on plant material, and some of these products contain animal protein, such as milk, egg or insect components, in addition to plant-based components. However, the majority of products in Switzerland, where the present study was conducted, are plant-based or based on mycoprotein and fungi (Herrmann & Bolliger, 2021). There are other protein-rich plant- and animal-based foods that might be consumed as alternatives to meat (e.g., legumes, fish, egg and cheese), but following Hoek et al. (2011, p. 666), they are not considered meat substitutes in the present study.

Just as global meat consumption per capita is on the rise, meat alternatives across Europe are also increasing (Statista, 2020). In recent

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years, the variety of and access to meat substitutes have steadily increased. According to data from the market agency Nielsen, in 2020 alone, more than 150 new items were introduced in the Swiss market (+22.5%). However, the best-selling product subgroup in Switzerland is still tofu/tempeh/seitan followed by meat analogues steak/cutlet-like products and the fastest-growing product group, meat-like burgers (Herrmann & Bolliger, 2021). Although there has been rapid growth in the meat substitutes section, and consumers at least are becoming interested in these products, meat substitutes are still niche products with a market share of 2.3% in Switzerland (Herrmann & Bolliger, 2021). In fact, the vast majority of consumers never eat meat substitutes, and their expenditure for traditional meat products far outweighs that for meat substitutes not only in Switzerland but also across Europe (Michel, Knaapila, Hartmann, & Siegrist, 2021; Statista, 2020; Van Loo, Caputo, & Lusk, 2020).

The major target group for meat analogues is meat eaters who want to reduce or eliminate their meat intake. These products aim to provide a similar sensory and meal experience as meat, requiring less of a change of preference or eating habits (Siegrist & Hartmann, 2019). The hurdles for meat eaters to switch from traditional meat to the vegetarian alternative should actually be low. However, the majority of consumers, who are meat eaters, seem to have a negative view of meat substitutes. When asked to think about meat alternatives in a free association task, study participants came up with somewhat negative evaluations and associations, while associations with meat were mostly positive (Michel, Hartmann, & Siegrist, 2021). Only those who regularly consume meat alternatives seem to see additional benefits of these products, such as higher environmental friendliness and better nutritional value (Götze & Brunner, 2021; Hagmann, Siegrist, & Hartmann, 2019; Onwezen, Bouwman, Reinders, & Dagevos, 2021; Weinrich, 2018). The average consumer seems to question the environmental superiority and healthiness of meat alternatives (Graça, Calheiros, & Oliveira, 2015; Hoek et al., 2011; Michel, Hartmann, et al., 2021). Such negative attitudes prevent widespread acceptance of these products (He et al., 2020; Michel, Hartmann, et al., 2021; Michel, Knaapila, et al., 2021; Onwezen et al., 2021). Thus, understanding consumer perceptions of meat substitutes and meat regarding the central product attributes of healthiness and environmental friendliness is key to move consumers toward increased acceptance.

In the discourse about meat substitutes, it is not only environmental friendliness and health benefits that play a role. Because of the processing and technology involved, many meat substitutes are industrialized products, which might be considered as a disadvantage. Such industrial advances and novel foods and food technologies are needed not only to provide safe, edible and nutritious food but also to make sustainable developments in the food system (Sadler et al., 2021; Siegrist & Hartmann, 2020a). However, among consumers and some researchers, there seems to be the notion that food processing is always negative, and only minimally processed foods are "natural" and thus healthy foods (Monteiro et al., 2018; Sadler et al., 2021). Therefore, there seems to be a trade-off between sustainable developments and the absence of processing and human interference. Consequently, at this point, a better understanding of how consumers evaluate such substitute products compared to traditional ones regarding naturalness is key. Therefore, another focus of the present research was to assess the perceived naturalness of meat substitute products and compare it to other protein-rich products in order to explore whether a lack of perceived naturalness might be another barrier to wider acceptance of meat substitute products.

1.1. Perceived environmental friendliness of protein-rich products

Several studies have concluded that knowledge regarding environmentally friendly food consumption is low among the general population (Hartmann, Lazzarini, Funk, & Siegrist, 2021; Hartmann & Siegrist, 2017; Peschel, Grebitus, Steiner, & Veeman, 2016; Siegrist, Visschers, & Hartmann, 2015). Compared to experts, consumers are more likely to underestimate the high environmental footprint of meat production and consumption (de Boer & Aiking, 2011; Hartmann & Siegrist, 2017). Although consumers' perceptions of the environmental impacts of certain foods have changed slightly in the past few years (Bryant & Sanctorum, 2021; Siegrist et al., 2015), most consumers are still not fully aware of the impact of meat consumption (Siegrist & Hartmann, 2019).

Regarding meat substitutes, several studies found that substitutes have a lower environmental impact than meat (Smetana, Mathys, Knoch, & Heinz, 2015; Van Huis et al., 2013), although there are differences between different types of products and factors; for example, the transportation system can increase environmental impact (Smetana et al., 2015). However, consumers seem to overestimate the environmental impact of meat substitutes, meaning that they may be perceived as less environmentally friendly than they are. In a Swiss panel study of the consumption of meat and meat substitutes, participants mistakenly believed that the environmental impact of soy-based meat substitutes was as high as that of conventionally produced meat (Siegrist & Hartmann, 2019). In a study by Michel, Hartmann, et al. (2021) with German consumers, higher environmental friendliness was attributed to tofu, vegetarian sausage and nuggets compared to steak and wiener sausages; however, the difference was very small and suggests that consumers are not fully aware of the substantial difference in environmental impact between these products. In contrast, in a (Lazzarini, Zimmermann, Visschers, & Siegrist, 2016) sorting-task study, Swiss consumers correctly evaluated minced meat substitutes as more environmentally friendly than many of the meat products evaluated in the study but incorrectly evaluated organic chicken breast and organic pork strips as more environmentally friendly than tofu or falafel.

These reviewed studies suggest that consumers seem to have misconceptions or are uncertain about the environmental friendliness of meat and meat substitutes. In most of these studies, consumers evaluated generic products that are not sold in the supermarket and were broadly described without pictures. Additionally, the range of alternative meat products tested in the previous studies was limited. Thus, in the present study, consumers' evaluation of the environmental friendliness of a diverse set of meat, meat substitute products and foods that might be eaten as alternatives to meat was investigated.

1.2. Perceived healthiness of protein-rich products

From a nutritional point of view, meat is a food source of high nutrient density; however, the average meat consumption in Switzerland is 52 kg per capita, which exceeds the official recommendations of two to three portions per week (Chatelan et al., 2017; Swiss Society for Nutrition, 2020). Even more meat is consumed in other European countries, such as Germany, Italy and Spain, and outside Europe in countries like the United States (OECD, 2021; Statista, 2021). High consumption of red meat and meat products is associated with an elevated risk of mortality, however (Godfray et al., 2018; Rohrmann et al., 2013). Meat substitutes are often marketed as healthy alternatives to meat. However, only a few researchers have addressed the question of how nutritionally valuable meat alternatives are (e.g. Bohrer, 2019; Petersen, Hartmann, & Hirsch, 2021). Bohrer (2019) concluded that the macronutrient composition of many meat substitute products is similar to that of the traditional meat products the substitutes simulate. Petersen et al. (2021) found, on average, higher "nutrients to limit" (salt, fat, sugar, sodium) in red meat products and poultry than in meat substitutes. Some substitute products are even fortified with vitamins (e.g., vitamin B12) or contain added fiber to improve their nutritional value (Zhang et al., 2021). The nutrient composition of meat substitute products can vary considerably (Bohrer, 2019), and researchers are concerned that consumption of processed plant-based foods high in fat, salt and sugar might shift dietary behavior in an unfavorable direction (Macdiarmid, 2021). For this reason, an objective measure was used in the present study to evaluate the nutrient profile of the tested products (i.e., Ofcom/Food Standards Agency [FSA]) and compared to participants' perception of the healthiness of the products.

Regarding consumers' healthiness evaluation of meat and meat substitutes, previous research results are inconclusive. The most consistent finding is that consumers evaluate meat as an indispensable part of a healthy diet (Verbeke, Pérez-Cueto, Barcellos, Krystallis, & Grunert, 2010) and are convinced meat eaters consume more meat and are not willing to reduce their meat intake or substitute meat with alternatives (Hartmann & Siegrist, 2020; Piazza et al., 2015; Rothgerber, 2013). However, consumers seem to differentiate between different meat types in their evaluation. For example, in one study, participants considered beef healthful when unprocessed and lean (Van Wezemael, Verbeke, de Barcellos, Scholderer, & Perez-Cueto, 2010), and in another study, they evaluated chicken filet, lamb filet and beef entrecote as healthier than pork strips, ham and bacon cubes (Lazzarini et al., 2016). However, in the latter study, participants also considered some meats to be healthier than a minced meat substitute product, and only tofu received a somewhat positive evaluation. In contrast, researchers also showed that study participants evaluated a menu containing a vegetarian schnitzel (described in written form) as healthier than one containing a pork schnitzel (Hartmann, Ruby, Schmidt, & Siegrist, 2018). This leads to the question of how consumers evaluate different kinds of meat substitute products (e.g., vegetable-based processed products, meat analogues, tofu) compared to meat or dairy products like cheese. On one hand, this perception influences societal acceptance of these products and with it, their spread within the food and supply system. On the other hand, the perception has consequences for eating behavior at the individual level, mostly in the sense that a reduction in meat consumption cannot be achieved with these substitute products when consumers evaluate the products negatively. To the best of our knowledge, thus far, no study has investigated this aspect with a large range of diverse protein-rich food products based on a consumer survey and real food products available in the supermarket.

1.3. Perceived naturalness of protein-rich products

Consumers' desire for natural food products has emerged in recent decades and is accompanied by an increasing number of products carrying the claim "natural" on the package (Cao & Yan, 2016). However, there is no universal definition of food naturalness. A systematic review of consumers' conceptualization of food naturalness suggested that the following three aspects are relevant: 1) the way a food was grown (food origin), 2) how a food was produced (what technology and ingredients have been used) and 3) the properties of the final product (Román, Sánchez-Siles, & Siegrist, 2017). Accordingly, consumers associate with food naturalness that the product is minimally processed, does not contain artificial ingredients, was organically produced and is not based on a genetically modified organism (Román et al., 2017). Foods that are considered natural are perceived to be healthier, tastier and better for the environment (Román et al., 2017). In other words, naturalness evokes almost exclusively positive emotions in Western consumers and is a desired product attribute; perceived minimal degree of processing is key for perceived naturalness.

This "natural is better heuristic" or mental shortcut to evaluate foods is not necessarily based on rational arguments. Many foods produced with technology are considered natural by consumers (e.g., cheese), while others produced without technology are considered unnatural (e.g., misshapen carrots; (Hagen, 2021; Powell, Jones, & Consedine, 2019). Similarly, unnatural entities (e.g., medicine) can be good for human health and are considered progressive, while natural entities (e.g., toxic mushrooms) can be dangerous for humans. Technological processes like food processing, including chemical and physical changes, mixing entities and adding or removing something from the product, can have an impact on naturalness perception (Evans, de Challemaison, & Cox, 2010; Rozin, 2005). Except cultured meat (e.g. Bryant, Anderson, Asher, Green, & Gasteratos, 2019; Siegrist & Hartmann, 2020b; Siegrist, Sütterlin, & Hartmann, 2018), the perceived naturalness of meat substitutes was rarely assessed in previous research. In one study, vegetarian sausage and nuggets were evaluated as somewhat artificial, while steak and wiener sausage were evaluated as natural products (Michel, Hartmann, et al., 2021). Moreover, steak was evaluated as much more natural than wiener sausage or chicken nuggets, which is probably due to the perceived degree of processing. Perceived unnaturalness might lead to product rejection, and consequently, the importance of naturalness has implications for product choice. Seemingly unnatural food products are less accepted by the public (Román et al., 2017), and unnaturalness might be regarded as a shortcoming of meat substitutes that leads to lower acceptance (Hartmann & Siegrist, 2017).

1.4. Study objectives

Previous studies have investigated the public's awareness of the impact of food on the environment (e.g. de Boer, Schösler, & Aiking, 2014; Lea & Worsley, 2008; Siegrist et al., 2015); however, they did not differentiate between different types of protein sources. The present study builds on a previous study in which environmental friendliness and healthiness were assessed, but the number of included meat substitute products was much smaller, and perceived naturalness was not assessed (Lazzarini et al., 2016). Following on from this previous study, the present study was designed to answer three complementary research questions.

First, the aim was to answer the question of how well consumers evaluate the environmental friendliness and healthiness of meat, meat substitutes and other protein-rich products. To determine this, participants' subjective perceptions were compared to objective measures of environmental friendliness (evaluated using the life cycle assessment) and healthiness (assessed using nutrient profiling).

Second, the aim was to determine how consumers perceived the naturalness of meat, meat substitutes and other protein-rich products. Perceived naturalness is an important driver for positive food product evaluations (Román et al., 2017), so participants were asked to evaluate the perceived naturalness of food products. Food naturalness is a consumer-driven attribute that cannot be objectively measured; therefore, no objective measures of naturalness were included.

Third, the aim was to answer the question of whether perceived naturalness, healthiness and environmental friendliness are intercorrelated. Previous studies have observed a relationship between environmental friendliness and naturalness perception (Verhoog, Matze, Van Bueren, & Baars, 2003) and sustainability and healthiness perception (Lazzarini et al., 2016). However, to the best of our knowledge, no study has explored the interplay between participants' perceptions of these three attributes for meat, meat substitutes and other protein-rich products. The present study fills this research gap.

2. Methods

Data collection took place via an online survey in April and May 2020 in the German-speaking region of Switzerland. Consumers' evaluations of the naturalness, environmental friendliness and healthiness of 20 high-protein food products were assessed. Sociodemographic variables (age, gender, education and region of residence), knowledge of the environmental friendliness of foods and frequency of consumption of meat and meat alternatives were also measured.

2.1. Participants

Study participants were recruited from the internet panel of a commercial provider of sampling services (Respondi AG) and received a small compensation for their participation. Respondents who did not complete the survey ($n = 21$), those who did not indicate their gender ($n = 3$) and those whose total survey duration was less than half of the median of the total survey duration, which indicated that they did not answer the questions seriously (n = 24), were excluded from the study. Another respondent was excluded for giving identical answers to all food evaluation questions (straightlining). Quota samples were used, with the quota variables gender (50% men) and age (an equal number of participants per age group). The final sample consisted of 534 respondents. The mean age was 45.6 years (*SD* = 14.5, range 20–71 years) and 50.2% were female. Participants' education levels were categorized as follows: low, 3.9% (primary and lower secondary school); middle, 65.2% (secondary school, vocational education and senior high school) and high, 30.8% (higher vocational education, university and above). Of all participants, 30.5% lived in an urban area, 26.4% in suburbs and 43.2% in a rural area.

The frequency at which participants consumed food from five categories (meat, fish, cheese, legumes and meat alternatives) was assessed. Responses were given on a 6-point scale with the following options: "several times a day," "once a day," "several times a week," "several times a month," "several times a year" and "more rarely/never." Around 9% of the participants reported that they ate meat several times per year, less often or never. However, the majority (52%) reported that they ate meat several times per week, and 22% reported that they ate meat daily. With regard to the frequency of consumption of meat substitutes, 46% indicated that they never ate these products, while 14% reported that they ate them several times per week or more often.

Participants' knowledge of the environmental friendliness of foods was tested (Hartmann et al., 2021) to rule out that the present sample was particularly knowledgeable or uninformed in this domain. The observed mean value in the sample was 8.49 (*SD* = 3.47, range 0–16), which corresponds well to the observed mean value in a previous Swiss sample (Hartmann et al., 2021).

2.2. Product stimuli

The environmental friendliness of protein products varies greatly (Aiking, 2011), which makes them particularly interesting study objects. High-protein food products were used in the present study, including a broad range of plant-based meat substitutes, different types of meat and meat products in different shapes and textures, cheese, fish and tofu. The food products differed not only in product category but also in the presence or absence of an organic label and in their country of origin. These factors were varied because previous research revealed that they were the main predictors of a product's perceived environmental friendliness (Lazzarini et al., 2016). To ensure that participants had some familiarity with the products, they were obtained from the two main grocery store chains in Switzerland. To minimize the effort study participants needed to make, we limited the number of different products to 20.

For each product evaluation, participants were shown a picture of the food product and information regarding ingredients, production method (organic or conventional) and country of origin (Fig. 1, or for a list of all products, please see the Supplementary Material). Participants were asked to indicate on a slider how environmentally friendly, natural and healthy they considered the products, from not at all (0) to totally (1 0 0). Only the extreme points of the slider were verbally anchored. The terms environmentally friendly, natural and healthy were not further specified, leaving the meaning open to interpretation by participants. The order of products was randomized between participants.

2.3. Life cycle assessment

The environmental friendliness of products was determined using life cycle assessment (LCA) data. The life cycle assessment is an established tool used to evaluate environmental impacts induced by all stages of the life cycle of a product, process or service. Different methods can be applied when using this tool (Roy et al., 2009). In the present study, the 2013 Swiss ecological scarcity method was used, which aggregates a broad range of environmental impacts (*water resources, energy resources, mineral resources, land use, global warming, ozone layer depletion, main air pollutants and particulate matter, carcinogenic substances into air, heavy metals into air, water pollutants, persistent organic pollutants into water, heavy metals into water, pesticides into soil, heavy metals into soil, radioactive substances into air, radioactive substances into water, noise, non-radioactive waste to deposit* and *radioactive waste to deposit)* into an easily comparable one-score impact value measured in Ecopoints (EPs) per unit of quantity (Frischknecht & Büsser Knöpfel, 2013; Jungbluth et al., 2020). The environmental impacts of pollutant emissions and resource extraction are taken into account and are evaluated in relation to politically defined environmental protection goals and aims. The more the pollutant emissions and resource extractions exceed environmental protection goals, the higher the EP score. Thus, the higher the EP score for a specific food, the more damaging it is assumed to be to the

Fig. 1. Example of a presented product – Sausage (Cervelat). Information about ingredients, country of origin and production method was provided. Participants had to indicate how environmentally friendly, natural and healthy they considered the product. [Product information translated for publication]

environment. The LCAs for products used in the present study were conducted by the Swiss sustainability consulting company ESU Service Ltd (http://esu-services.ch/). Furthermore, estimations of EPs are usually based on the weight of food items (EPs per kilogram). This approach was applied in the present study during the main analysis. EP scores were further calculated per protein content, and as the results did not vary compared to EPs per kilogram, the scores per protein content were not included in the present manuscript.

2.4. Nutrient profiling

Nutrient profiling allows researchers to appraise and classify food products based on the healthiness of their nutritional composition (World Health Organization (WHO), 2020). Different nutrient profiling standards have been developed, such as the Ofcom/FSA nutrient profiling model (Food Standards Agency, 2011). This model has been well validated and has a good reputation (Rayner, 2017); thus, the model served as the objective measure of healthiness for the products in the present study. To objectively assess the healthiness of the 20 products, the Ofcom/FSA nutrient profile was calculated for each product based on its nutrient content per 100 g. The final nutrient profile value was composed of 0–10 A points, which were assigned for each unhealthy aspect (namely, for the amount of energy, saturated fatty acids, total sugar and sodium) and 0–5C points, which were assigned for each healthy aspect (i.e., for the content of fruits, vegetables and nuts, fiber and protein). This resulted in a maximum of 40 A points and 15C points. For the final calculation, the C points were subtracted from the A points, provided that fewer than 11 A points were scored. If this criterion was not met, then positive points for protein could not be subtracted from the A score. The possible final nutrient profiling scores ranged from 15 to 40, with lower scores representing a greater level of healthiness. Foods scoring 4 points or more were considered less healthy (Food Standards Agency, 2011). The information needed for calculations was retrieved from product packages and the Swiss food composition database (Swiss Federal Food Safety and Veterinary Office, 2020).

2.5. Statistical analyses

Data can be analyzed using respondents as the unit of analysis or by using products as the unit of analysis (i.e., aggregated data). We present results from the latter analysis. Aggregated data with the products as the unit of analysis addressed the similarity of subjective and objective product evaluations. This was done by calculating the mean evaluation scores for each food product. Subsequently, products were ranked according to their mean values. This procedure was carried out for participants' evaluations of the environmental friendliness, naturalness and healthiness of products. Objectively determined environmental friendliness (based on LCA data) and healthiness (based on nutrient profiling) were also ranked. To determine whether a healthier product was automatically regarded as more natural and more environmentally friendly and vice versa, the relationship between participants' perceptions of environmental friendliness, naturalness and healthiness were displayed visually in scatterplots with corresponding product-moment correlation coefficients.

All statistical analyses were performed using the SPSS Statistics software package version 26 (SPSS Inc., Chicago, IL).

3. Results

3.1. Perceived environmental friendliness of the food products

The correlational analysis of the food products' mean subjective environmental friendliness scores (participants' self-reported evaluations) and objective environmental friendliness scores (LCA-based EP/kg) was not statistically significant ($r =$ 0.20, $p = .405$). A visual inspection of the scatterplot in Fig. 2 suggests that participants generally seemed to underestimate the environmental impact of animal-based products and overestimate the environmental impact of meat substitutes. For instance, beef entrecote had the highest objective environmental impact (EP/kg) of all tested products; however, its environmental friendliness was greatly overestimated by consumers. A burger made from pea protein (Beyond Meat©) and a vegetarian sausage were mistakenly evaluated as less environmentally friendly than beef entrecote, although they received considerably fewer Ecopoints.

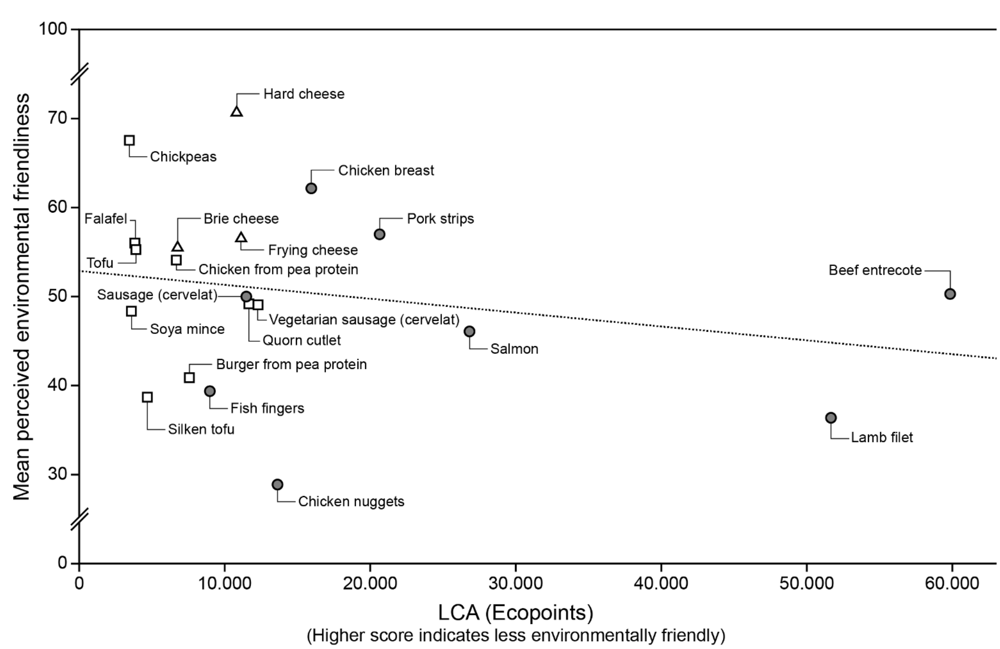

Fig. 2. Objective evaluation of the environmental friendliness of food products based on the LCA (Ecopoints) plotted against respondents' perception of the environmental friendliness of each product. No significant correlation was observed. Consumers seemed to underestimate the environmental impact of meat and meat products and overestimate the environmental impact of meat substitutes. Black dot: Meat and fish, triangle: cheese, square: meat substitutes.

Specifically, chicken breast ($M = 62.22$, $SD = 24.27$) was perceived, on average, as the most environmentally friendly meat type, followed by pork strips ($M = 56.95$, $SD = 25.56$). Chicken, pork, beef and meat sausage were also perceived as more environmentally friendly than most of the meat substitute products like Quorn cutlet, vegetarian sausage, soya mince and burger from pea protein. In fact, soya mince (ranked second), falafel (ranked third), tofu (ranked fourth), silken tofu (ranked fifth) and "chicken" made from pea protein (ranked sixth) were the most environmentally friendly options based on Ecopoints. However, consumers ranked these products much lower (14th, 6th, 8th, 18th and 9th, respectively) and thus, as having a higher environmental impact than meat. The largest discrepancy between the subjective and objective measures was 13 spots in the ranking, and this was observed for chicken breast, pork strips and silken tofu. Notably, based on LCA data, processed meat products (meat sausage, chicken nuggets) received the lowest number of Ecopoints out of all meat products, followed by chicken breast. However, compared to the meat-free alternatives, processed meat products have a much higher environmental impact, of course. Data for all products are summarized in Table 1.

3.2. Perceived healthiness of food products

No significant correlation ($r =$ 0.24, $p = .299$) was observed between scores for perceived healthiness (participants' self-reported evaluations) and objective healthiness as measured by nutrient profiling (nutrient profile scores). An inspection of the scatterplot in Fig. 3 highlights a strong discrepancy between participants' evaluations and the objective evaluations. In fact, the nutrient profile scores were similar for most meat products and meat substitutes, such as tofu, falafel, "chicken" made from pea protein, soya mince and Quorn cutlet (Table 2). However, consumers evaluated all animal-based products (except for fish fingers and chicken nuggets) as healthier than meat substitutes. Chickpeas were correctly identified as the healthiest product, and meat-based and vegetarian sausages (cervelat) were also correctly identified as less healthy by participants.

3.3. Perceived naturalness of food products

Regarding participants' perceptions of the naturalness of meat and meat substitutes, similar patterns as for healthfulness and environmental friendliness were observed. Unprocessed meat products (ranked 3rd, 4th and 5th), hard cheese (ranked 1st) and chickpeas (ranked 2nd) were perceived as the most natural products, much more natural than meat analogues (ranked 13th, 14th, 16th, 18th and 19th), tofu (ranked 9th) and falafel (ranked 10th). Data for all foods are displayed in Table 3.

3.4. Intercorrelations among perceived environmental friendliness, naturalness and healthiness

The scatterplot matrix in Fig. 4 shows intercorrelations between the objective and subjective evaluations of the perceived environmental friendliness, healthiness and naturalness of food products. Clearly, perceived healthiness, perceived environmental friendliness and perceived naturalness were strongly intercorrelated ($r = 0.72$–0.91, $p < .001$), while objective measures of these product attributes were not significantly statistically correlated. Some products (i.e., chicken breast, Gruyere cheese and chickpeas) were rated consistently positively for all three properties, while chicken nuggets were awarded low values for perceived environmental friendliness, naturalness and healthiness.

4. Discussion

An overarching goal of the present study was to find out how consumers evaluate vegetarian protein-rich products in relation to animal-based protein-rich products in three important product dimensions: environmental friendliness, healthiness and naturalness. Results showed that consumers evaluate traditional meat products more positively than their meat-free counterparts. These results held for all three assessed product dimensions. Furthermore, participants' evaluations of the perceived environmental friendliness and healthiness for most of the 20 food products differed substantially from the objective evaluations (LCA data and nutrient profiling). Accordingly, participants seemed to underestimate the negative environmental impact of meat products and overestimate the environmental impact of meat substitutes. Similarly,

Table 1
Food product characteristics and subjective and objective environmental friendliness of products.

Product	Food group[a]	Country of origin	Organic	Environmental friendliness			
				Consumer perception			Objective measure
				Rank[c]	*M*	*SD*	Rank[d] basedon EPs/kg from LCA
Gruyere cheese	D	CH	Yes	1	70.73	21.37	10
Chickpeas	S	IT	Yes	2	67.49	21.87	1
Chicken breast	M	CH	Yes	3	62.22	24.27	16
Pork strips	M	CH	Yes	4	56.95	25.56	17
Frying cheese	D	CH	No	5	56.64	23.46	11
Falafel	S	CH[b]	No	6	55.91	22.54	3
Brie	D	FR	No	7	55.58	21.14	7
Tofu	S	CH[b]	Yes	8	55.16	25.27	4
Chicken from pea protein	S	CH	No	9	54.11	24.93	6
Beef entrecote	M	CH	No	10	50.34	26.95	20
Sausage (cervelat)	M	CH	Yes	11	49.86	23.41	12
Quorn cutlet	S	GB	No	12	49.11	24.46	13
Vegetarian sausage (cervelat)	S	CH	No	13	49.00	23.90	14
Soya mince	S	CH[b]	No	14	48.23	24.96	2
Salmon	F	NO	No	15	46.13	24.82	18
Burger from pea protein	S	US	No	16	40.89	26.77	8
Fish fingers	F	PL	No	17	39.26	22.37	9
Silken tofu	S	US[b]	No	18	38.59	25.83	5
Lamb filet	M	NZ	No	19	36.34	26.81	19
Chicken nuggets	M	BR	No	20	28.89	22.54	15

Note. Products are ordered according to subjective evaluation from best to worst. EPs: Ecopoints from the life cycle assessment (LCA)[a]Food groups: M = Meat; F = Fish; D = Dairy; S = Substitute
[b]Only the country of processing is known.
[c]Ranking is based on mean perceptions.
[d]Ranking is based on LCA outcomes per kilogram.

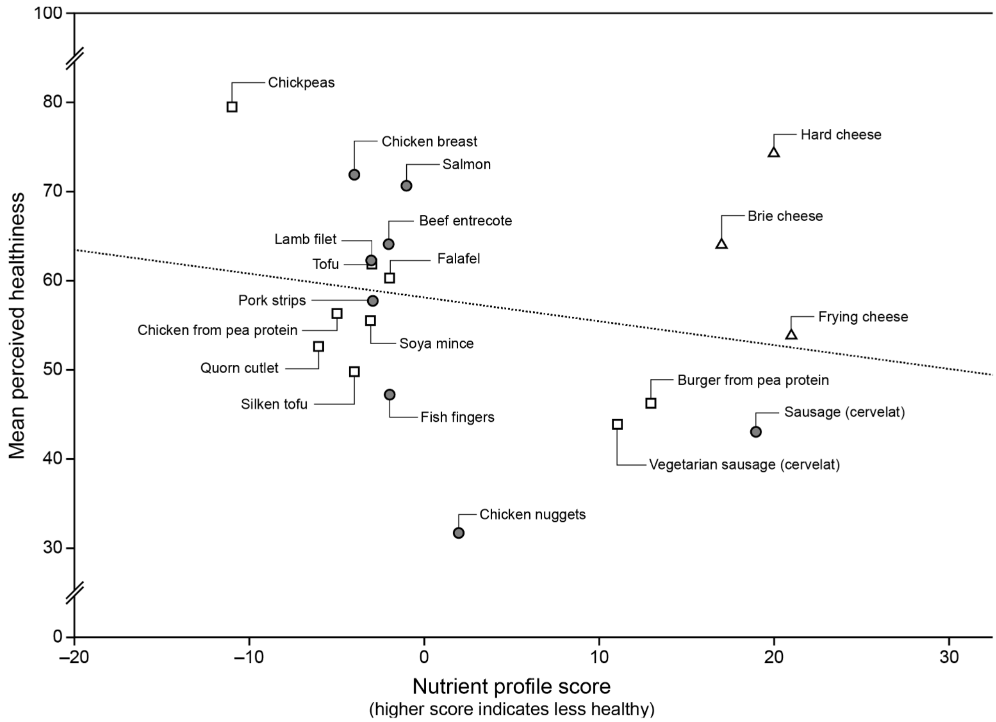

Fig. 3. Objective evaluation of the healthiness of food products based on nutrient profiling plotted against respondents' perception of the healthiness of each product. No significant correlation was observed. Consumers evaluated most meat products as healthier than the alternatives. Black dot: Meat and fish, triangle: cheese, square: meat alternatives.

Table 2
Subjective and objective healthiness evaluation of the tested food products.

Product	Healthiness Consumer perception Rank[c]	*M*	*SD*	Nutrient profiling (NP) Rank[d]	NP score
Chickpeas	1	79.62	18.93	1	–11
Gruyere cheese	2	74.37	20.07	19	20
Chicken breast	3	71.95	21.58	4.5	–4
Salmon	4	70.76	22.44	13	–1
Beef entrecote	5	64.17	23.19	11	–2
Brie	6	64.06	20.54	18	19
Lamb filet	7	62.38	23.87	7.5	–3
Tofu	8	61.94	24.35	7.5	–3
Falafel	9	60.33	23.25	11	–2
Pork strips	10	57.83	24.78	7.5	–3
Chicken from pea protein	11	56.37	25.60	3	–5
Soya mince	12	55.46	25.38	7.5	–3
Frying cheese	13	53.91	23.41	20	21
Quorn cutlet	14	52.57	24.77	2	–6
Silken tofu	15	49.75	25.03	4.5	–4
Fish fingers	16	47.26	23.20	11	–2
Burger from pea protein	17	46.37	25.54	16	13
Vegetarian sausage (cervelat)	18	44.02	25.00	15	11
Sausage (cervelat)	19	43.00	24.10	17	17
Chicken nuggets	20	31.78	22.33	14	2

Note. Products are ordered according to subjective evaluation from best to worst.

meat substitutes were evaluated as less healthy than meat products by participants, although from an objective point of view, differences between products were small. Strong correlations were observed between participants' product evaluations across the three dimensions of perceived healthiness, environmental friendliness, and naturalness, which indicated that in consumers' minds, these three factors are interrelated.

Table 3
Subjective naturalness perception of the tested food products.

Product	Naturalness Consumer perception Rank[c]	*M*	*SD*
Gruyere cheese	1	80.88	17.65
Chickpeas	2	79.42	19.93
Chicken breast	3	74.07	22.52
Pork strips	4	71.14	23.69
Beef entrecote	5	70.41	23.99
Brie	6	69.94	20.48
Salmon	7	67.16	23.90
Lamb filet	8	66.81	25.29
Tofu	9	59.44	25.78
Falafel	10	56.75	23.58
Frying cheese	11	55.26	24.23
Sausage (cervelat)	12	51.29	24.94
Soya mince	13	49.83	27.16
Chicken from pea protein	14	48.47	27.88
Fish fingers	15	45.74	23.84
Quorn cutlet	16	45.70	26.04
Silken tofu	17	43.10	25.52
Burger from pea protein	18	37.88	26.66
Vegetarian sausage (cervelat)	19	36.82	26.09
Chicken nuggets	20	32.29	22.59

Note. Products are ordered according to subjective evaluation from best to worst.

4.1. Relationship among perceived environmental friendliness, healthfulness and naturalness

In accordance with previous research (Lazzarini et al., 2016), a positive correlation between perceived environmental friendliness and healthiness indicates that consumers relate the two dimensions to each other. A positive evaluation of meats' healthfulness could be the driver in the impression formation process for positive evaluations of environmental friendliness or vice versa. It might be that a halo effect misleads consumers to generalize from one perceived positive product attribute to another, unknown attribute. In reality, LCA-based

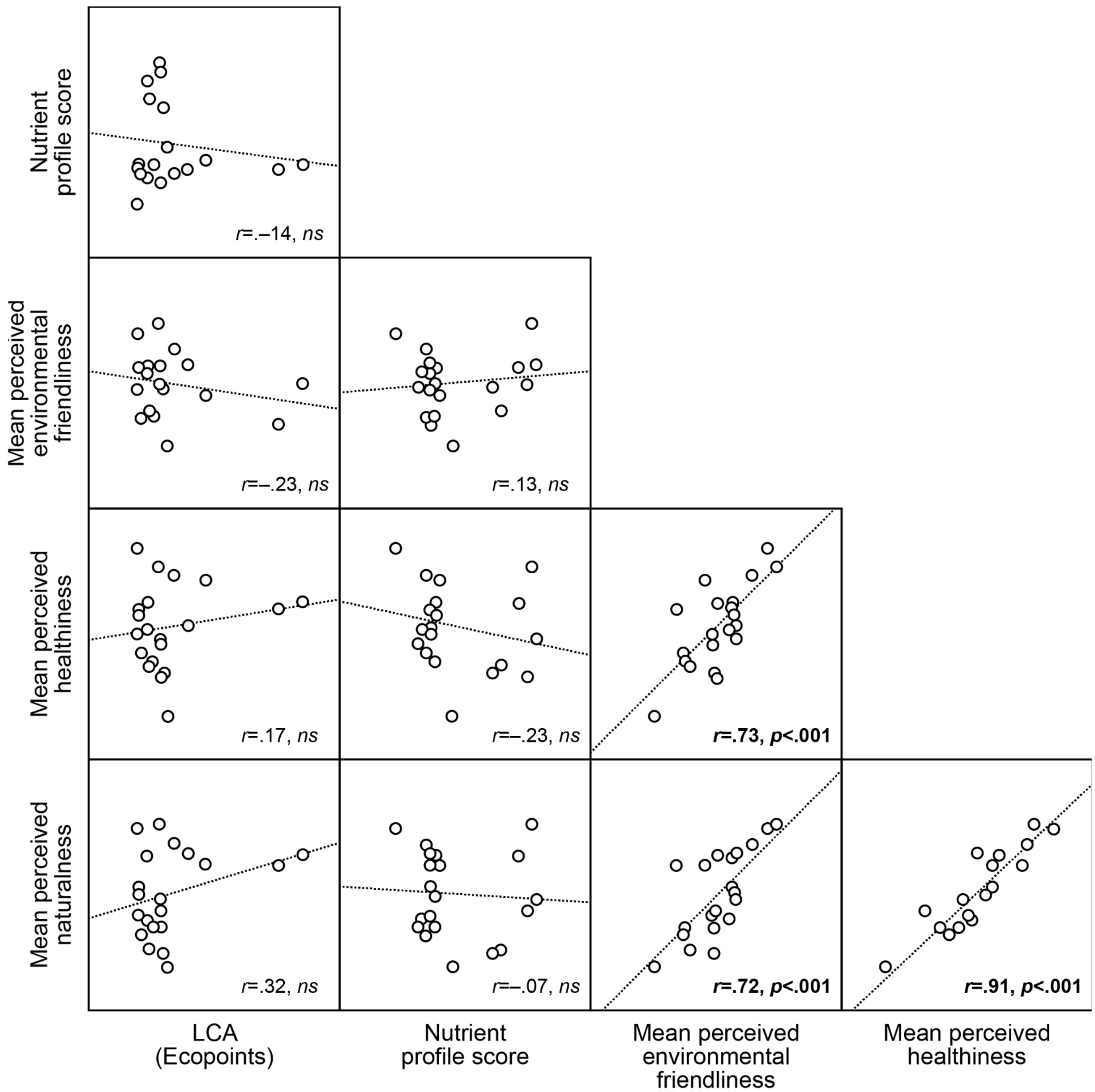

Fig. 4. Scatterplot matrix of objective and subjective evaluations of products' environmental friendliness, healthiness and naturalness.

evaluations and nutrient profiling were not correlated, which suggests that environmentally friendly products did not necessarily have a good nutrient profile, and healthy products were not necessarily environmentally friendly. Additionally, perceived naturalness is often correlated with positive evaluations of other product attributes. Products considered natural are often evaluated as being healthy and tasty (Román et al., 2017; Siipi, 2012). Results suggest that participants might have applied the same heuristic to the tested products.

4.2. Consumer perceptions of the environmental friendliness of food products

Consumer perception of the environmental friendliness of the products was not correlated with the objective evaluation based on LCA data (indicated by Ecopoints). Thus, many participants were unable to accurately assess the environmental friendliness of the presented products. The largest difference between participants' evaluations and Ecopoint values was observed for non-organic soy-based products (silken tofu and soya mince) and the meat types chicken breast, pork strips and beef entrecote. Beef entrecote was the product with the highest Ecopoints by far, but participants evaluated alternative products such as vegetarian sausage, Quorn cutlet and beyond meat burger as less environmentally friendly than beef. Generally speaking, the environmental friendliness of the animal-based products was strongly overestimated, and the meat substitute products were perceived as much less environmentally friendly than they are. This finding supports previous findings that consumers are not good at evaluating products' environmental friendliness and not only consider meat as environmentally friendly as meat substitutes as in Siegrist and Hartmann's (2019) study, but even tend to consider meat to be superior to meat-free alternatives.

Participants seemed to have misconceptions about the importance of certain factors and lacked knowledge when evaluating the environmental friendliness of products. The LCA results show that ruminant meat production (beef entrecote and lamb filet) had the highest impact on the environment; the products' Ecopoints were three to four times higher than for non-ruminant meat (chicken breast and pork strips). The main factors that lead to the high impact of ruminant meat are high greenhouse gas emissions and excessive land use (Stehfest et al., 2009).

However, the huge differences in the environmental impacts between various animal species on meat production were not reflected in participants' evaluations. Thus, there seems to be little awareness of the difference between ruminants and other meats, and consumers likely do not consider animal species when evaluating the environmental impact of meat products. Consumers seem to rely on other factors, such as country of origin and organic label (Lazzarini et al., 2016). In fact, the lamb filet was imported from New Zealand, and the beef entrecote originated from Switzerland. These two products do not differ much in terms of environmental impact in relation to other meat products. However, the subjective evaluation of lamb filet was much more negative than that of beef. All products evaluated as less environmentally friendly by consumers were imported from another country (primarily overseas), but this has a much lower impact compared to the food product category (e.g., tofu versus beef; (Nemecek, Jungbluth, i Canals, & Schenck, 2016). Thus, it is likely that for some products, participants put too much weight on the country of origin and rated Swiss products more positively than products from other countries. This "home country is best" effect has been shown in previous research with Swiss consumers but with other food products (Lazzarini, Visschers, & Siegrist, 2017).

Lastly, consumers often mistakenly use the organic label as a universal indicator of environmental friendliness (Camilleri, Larrick, Hossain, & Patino-Echeverri, 2019; Lazzarini et al., 2016). However, whether a product is produced organically or conventionally has only a marginal impact on the environment (Nemecek et al., 2016). For instance, transport via airplane multiplies the environmental footprint of meat products much more than production system factors (Jungbluth, Tietje, & Scholz, 2000; Nemecek et al., 2016). Products evaluated as the most environmentally friendly were all organically grown. Particularly striking is the difference between conventional silken tofu, which was rated environmentally unfriendly, and organic tofu, which was evaluated much more positively. Other factors such as animal species or meat-free are much more relevant but seem to be neglected by consumers.

4.3. Consumer perceptions of the healthiness of the food products

Meat substitute products were evaluated more negatively by participants than meat products. The substitutes were perceived as unhealthier than meat, although there was little difference between the meat and the meat substitutes based on nutrient profiling. In previous studies, correlations between perceived healthiness and nutrient profiling have been found (Bucher, Müller, & Siegrist, 2015; Lazzarini et al., 2016), but in the present study, participants' evaluation of products' healthiness was not correlated with the more objective nutrient profiling data. Different kinds of familiar foods, such as mayonnaise, chocolate and pasta (Bucher et al., 2015), and a range of protein-rich foods, such as different types of cheese and meat (Lazzarini et al., 2016), were included in previous research. Thus, it is possible that the range of products presented in this study posed additional challenges for participants with respect to their evaluations.

Based on nutrient profiling, there were no notably large differences between the meat products and the meat substitutes. Only two meat substitute products (burger from pea protein and vegetarian sausage) received a higher number of points during the nutrient profiling (more points were awarded for less healthy products), because they contained considerable saturated fat and salt. For these products, the objective and subjective evaluations matched very well.

When consumers evaluate the healthiness of a product, aspects such as packaging design, front-of-package labels, product ingredients, product category, origin of the product and sensory features are taken into account (Plasek, Lakner, & Temesi, 2020). Thus, many factors can be relevant for the somewhat negative healthiness image of meat substitutes. It is likely that the apparent degree of processing might be a crucial factor. In fact, almost all processed foods, vegetarian and non-vegetarian, were evaluated as unhealthier than the unprocessed foods. Consumers may believe that healthy foods must be natural and unprocessed, which might have led to the described misconception. Consequently, unprocessed animal-based protein products were systematically evaluated as healthier than meat substitutes. Processed meat, namely, chicken nuggets and sausage (cervelat), however, also received a negative subjective evaluation.

4.4. The impact of the "natural is better heuristic"

Results suggest that, on average, meat substitutes are perceived as unnatural in comparison to other protein-rich products. Products like vegetarian sausage, a burger from pea protein, silken tofu and Quorn cutlet were evaluated as unnatural, while more traditional foods and meats like chicken breast, pork strips, beef entrecote, cheese and fish were perceived as more natural. It is likely that the lack of perceived naturalness is based on the perceived degree of processing. For instance, chicken breast and chicken nuggets were judged completely differently by participants. Chicken breast received the best evaluation out of all the meat products in all three dimensions, while chicken nuggets received the worst. However, the differences between the two products lay only in their country of origin and degree of processing. In fact, technological food processing and food additives have a negative image among many consumers (Bearth, Cousin, & Siegrist, 2014), and consumers link longer ingredients lists with less natural food products (Román et al., 2017). Despite a lack of perceived naturalness for meat substitutes considering the average, individual responses ranged from the minimum score of 0 to the maximum score of 100. Thus, they were not perceived as inevitably unnatural by all participants. Additionally, consumers differ in their preference for naturalness, and some might value other product characteristics (e.g., convenience) as more important. Nevertheless, meat substitutes might fall into the category of processed or highly processed foods for consumers. Thus, the alternatives might be considered unnatural and less desirable, tasty, healthy, and environmentally friendly. These findings pose a challenge to the promotion of meat substitute products, as the lack of perceived naturalness of meat substitutes likely lowers their acceptance (Román et al., 2017).

4.5. Limitations

The nutrient profiling method neglects some aspects of evaluating the healthiness of food products. For example, the healthiness of products is influenced by the amount consumed, the cooking method and the seasoning added (e.g., adding salt and oil to raw meat), but the nutrient profiling calculations were based only on the characteristics of the product when bought in an unprepared/raw state. Although some products like sausages, nuggets and falafel were already seasoned, others were not (e.g., meat and "chicken" made from pea protein). This may have impacted the nutrient profile scores. Preparing these products increases their fat and salt content, which would have a negative impact on nutrient profiling. Thus, the objective healthiness values of meat products could have been underestimated in this study. Finally, nutrient profiling should not be interpreted as dietary advice, because a healthy diet is influenced by many factors, including the combination of foods within a dish (Rayner, 2017).

It was not assessed whether study participants were willing to buy and eat the products tested in the study. For instance, chickpeas were evaluated as healthy, natural and environmentally friendly; however, chickpea consumption in Switzerland is low (Chatelan et al., 2017). Gruyere hard cheese was evaluated very positively in all three dimensions and is a strongly beloved traditional Swiss food. Chicken nuggets were rated negatively in all three dimensions, yet they still seem to be a popular product among consumers. Thus, positive, or negative evaluations of the three dimensions do not necessarily imply that consumers are (un)willing to frequently buy and consume the corresponding product. Other product attributes, most importantly taste and liking, were not assessed in the study.

Data collection took part during the first wave of the COVID-19 outbreak. Given the higher proportion of home consumption and panic buying during that time, food sales increased in the domestic sector. Peoples' consumption habits might have been affected by the situation. However, consumers attitudes towards food products do not fluctuate that much over shorter time periods and there is no reason to belief that consumers attitudes towards meat substitute products drastically changed in a negative direction in that time.

4.6. Implications and further directions

Consumers in different European countries tend to evaluate some meat substitute products similarly, but there are also differences in tastiness expectations (Michel, Knaapila, et al., 2021). Cultural differences, different consumption patterns and varying attitudes toward meat consumption are expected to lead to differing assessments in other parts of the world. It would be especially interesting to repeat this study in developing countries, where meat consumption is still strongly on the rise (Godfray et al., 2018). Additionally, we tested only 20 products to avoid placing a burden on the study participants, but many more products are available on the market: not only meat substitutes but also vegan alternatives to milk, cheese and other animal-based products such as fish. The findings of the present study suggested research opportunities for such product options.

The reduction of dairy product consumption is another effort in the attempt to move away from carbon-intensive diets that are high in animal protein, especially those associated with production of ruminant livestock (Climate Change Committee, 2020). However, some people might consume cheese and other dairy products instead of meat. Three cheese variations (hard cheese, brie cheese, frying cheese) were included in the present study. The results showed that Swiss consumers distinguish between these types of cheese when it comes to perceived healthiness, naturalness, and environmental friendliness. In line with previous findings, hard cheese was perceived as the most environmentally friendly, healthy and natural product (Lazzarini et al., 2016). These misconceptions might occur around dairy products in general, and in a future study, a broader diary product range could be tested, and which product attributes consumers consider when evaluating dairy products could be investigated.

In the present study, the nutrient profiles of most of the tested meat substitute products were similar or better than those of meat. However, two alternatives from the subcategory meat analogues also performed worse. High consumption of such products seems to carry additional pitfalls. Even if it can be assumed that their production has a lower environmental impact, and animal welfare is not an issue, it seems counterproductive in the pursuit of a more sustainable and healthy diet. The risk of just having a new "vehicle for high fat, sugar and salt foods" may not be unfounded (Macdiarmid, 2021, p. 5). Healthy eating is often named as a motive for a shift to a meat-reduced or plant-based diet (Hagmann et al., 2019), which might not be achieved with certain types of alternative products. It is a task of the food industry to optimize the nutritional profiles of these products.

5. Conclusion

Thanks to new food technologies and resources, the possibilities for meeting humanity's protein requirements are constantly growing. However, consumers tend to be conservative about new food products and technologies that are supposed to replace traditional ones (Siegrist & Hartmann, 2020a). Thus, the consumer perspective is indispensable to achieve the goal of developing more sustainable food production systems and consumption patterns. It is essential to evaluate whether consumers see the benefits of buying and consuming technologically processed meat substitute products intended to replace traditional meat products. However, the present study showed that most consumers do not assume that meat substitutes are automatically healthier and more environmentally friendly just because they are meat-free. On average, the environmental impact of meat substitute products was overestimated, and they were mainly perceived as less environmentally friendly than meat products. At the same time, meat substitute products were perceived as unhealthier and less natural than meat. The present results showed that in consumers' minds, naturalness goes hand in hand with environmental friendliness and healthiness, which is not necessarily the case based on objective assessment.

It does not seem justified to assume that meat substitute products are inherently healthier because they are plant-based and meat-free. The nutritional and sensory qualities of meat replacement products can vary considerably. However, consumers seem to have a somewhat negative impression of these products in general. Consumers not only might have negative attitudes toward these products (Michel, Hartmann, et al., 2021) but also seem to question their nutritional and environmental benefits and seemingly have no trust in these novel solutions to decrease the environmental impact of one's diet. This remains a challenge for industry and public health as well as the establishment of more sustainable food systems.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodqual.2021.104486.

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Exhibit 4

Sustainability of meat-based and plant-based diets and the environment[1–3]

David Pimentel and Marcia Pimentel

ABSTRACT Worldwide, an estimated 2 billion people live primarily on a meat-based diet, while an estimated 4 billion live primarily on a plant-based diet. The US food production system uses about 50% of the total US land area, 80% of the fresh water, and 17% of the fossil energy used in the country. The heavy dependence on fossil energy suggests that the US food system, whether meat-based or plant-based, is not sustainable. The use of land and energy resources devoted to an average meat-based diet compared with a lactoovovegetarian (plant-based) diet is analyzed in this report. In both diets, the daily quantity of calories consumed are kept constant at about 3533 kcal per person. The meat-based food system requires more energy, land, and water resources than the lactoovovegetarian diet. In this limited sense, the lactoovovegetarian diet is more sustainable than the average American meat-based diet. *Am J Clin Nutr* 2003;78(suppl):660S–3S.

KEY WORDS Meat-based diet, plant-based diet, environment, natural resources, fossil, energy, fuel

INTRODUCTION

Worldwide, an estimated 2 billion people live primarily on a meat-based diet, while an estimated 4 billion live primarily on a plant-based diet. The shortages of cropland, fresh water, and energy resources require most of the 4 billion people to live on a plant-based diet. The World Health Organization recently reported that more than 3 billion people are malnourished (1, 2). This is the largest number and proportion of malnourished people ever recorded in history. In large measure, the food shortage and malnourishment problem is primarily related to rapid population growth in the world plus the declining per capita availability of land, water, and energy resources (3).

Like the world population, the US population continues to grow rapidly. The US population doubled in the past 60 y and is projected to double again in the next 70 y (4) (**Figure 1**). The US food production system uses about 50% of the total US land area, approximately 80% of the fresh water, and 17% of the fossil energy used in the country (3). The heavy dependence on fossil energy suggests that the US food system, whether meat-based or plant-based, is not sustainable. The use of land and energy resources devoted to an average meat-based diet compared with a lactoovovegetarian (plant-based) diet is analyzed in this report. In both diets, the daily quantity of calories consumed was kept constant at about 3533 kcal per person.

LACTOOVOVEGETARIAN DIET

The lactoovovegetarian diet was selected for this analysis because most vegetarians are on this or some modified version of this diet. In addition, the American Heart Association reported that the lactoovovegetarian diet enables individuals to meet basic nutrient needs (5).

A comparison of the calorie and food consumption of a lactoovovegetarian diet and a meat-based diet is provided in **Table 1**. In the lactoovovegetarian diet, the meat and fish calories were replaced by proportionately increasing most other foods consumed in Table 1 in the vegetarian diet except sugar and sweeteners, fats, and vegetable oils. The total weight of food consumed was slightly higher (1002 kg per year) in the lactoovovegetarian diet than in the meat-based diet (995 kg per year). The most food calories consumed in both diets were associated with food grains, and the second largest amount of calories consumed was from sugar and sweeteners.

The amount of feed grains used to produce the animal products (milk and eggs) consumed in the lactoovovegetarian diet was about half (450 kg) the amount of feed grains fed to the livestock (816 kg) to produce the animal products consumed in the meat-based diet (Table 1). This is expected because of the relatively large amount of animal products consumed in the meat-based diet (7). Less than 0.4 ha of cropland was used to produce the food for the vegetarian-based diet, whereas about 0.5 ha of cropland was used in the meat-based diet (8). This reflects the larger amount of land needed to produce the meat-based diet (Table 1).

The major fossil energy inputs for grain, vegetable, and forage production include fertilizers, agricultural machinery, fuel, irrigation, and pesticides (8, 9). The energy inputs vary according to the crops being grown (10). When these inputs are balanced against their energy and protein content, grains and some legumes, such as soybeans, are produced more efficiently in terms of energy inputs than vegetables, fruits, and animal products (8). In the United States, the average protein yield from a grain crop such as corn is 720 kg/ha (10). To produce 1 kcal of plant protein requires an input of about 2.2 kcal of fossil energy (10).

MEAT-BASED DIET

The meat-based diet differs from the vegetarian diet in that 124 kg of meat and 20.3 kg of fish are consumed per year (Table 1). Note that the number of calories is the same for both diets because the vegetarian foods consumed were proportionately

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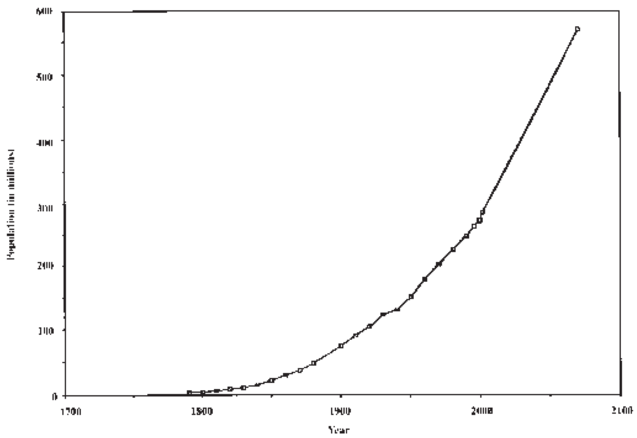

FIGURE 1. Projection of US population growth in the next 70 y (4).

increased to make sure that both diets contained the same number of calories. The total calories in the meat and fish consumed per day was 480 kcal. The foods in the meat-based diet providing the most calories were food grains and sugar and sweeteners—similar to the lactoovovegetarian diet.

In the United States, more than 9 billion livestock are maintained to supply the animal protein consumed each year (11). This livestock population on average outweighs the US human population by about 5 times. Some livestock, such as poultry and hogs, consume only grains, whereas dairy cattle, beef cattle, and lambs consume both grains and forage. At present, the US livestock population consumes more than 7 times as much grain as is consumed directly by the entire American population (11). The amount of grains fed to US livestock is sufficient to feed about 840 million people who follow a plant-based diet (7). From the US livestock population, a total of about 8 million tons (metric) of animal protein is produced annually. With an average distribution assumed, this protein is sufficient to supply about 77 g of animal protein daily per American. With the addition of about 35 g of available plant protein consumed per person, a total of 112 g of protein is available per capita in the United States per day (11). Note that the recommended daily allowance (RDA) for adults per day is 56 g of protein from a mixed diet. Therefore, based on these data, each American consumes about twice the RDA for protein. Americans on average are eating too much and are consuming about 1000 kcal in excess per day per capita (12, 13). The protein consumed per day on the lactoovovegetarian diet is 89 g per day. This is significantly lower than the 112 g for the meat-based diet but still much higher than the RDA of 56 g per day.

About 124 kg of meat is eaten per American per year (6). Of the meat eaten, beef amounts to 44 kg, pork 31 kg, poultry 48 kg, and other meats 1 kg. Additional animal protein is obtained from the consumption of milk, eggs, and fish. For every 1 kg of high-quality animal protein produced, livestock are fed about 6 kg of plant protein. In the conversion of plant protein to animal protein, there are 2 principal inputs or costs: 1) the direct costs of production of the harvest animal, including its feed; and 2) the indirect costs for maintaining the breeding herds.

Fossil energy is expended in livestock production systems (**Table 2**). For example, broiler chicken production is the most efficient, with an input of 4 kcal of fossil energy for each 1 kcal of broiler protein produced. The broiler system is primarily dependent on grain. Turkey, also a grain-fed system, is next in efficiency, with a ratio of 10:1. Milk production, based on a mixture of two-thirds grain and one-third forage, is relatively efficient, with a ratio of 14:1. Both pork and egg production also depend on grain. Pork production has a ratio of 14:1, whereas egg production has a 39:1 ratio.

The 2 livestock systems depending most heavily on forage but also using significant amounts of grain are the beef and lamb production systems (**Table 3**). The beef system has a ratio of 40:1, while the lamb has the highest, with a ratio of 57:1 (Table 2). If these animals were fed on only good-quality pasture, the energy inputs could be reduced by about half.

The average fossil energy input for all the animal protein production systems studied is 25 kcal fossil energy input per 1 kcal of protein produced (Table 2). This energy input is more than 11 times

TABLE 1
Per capita food consumption, energy, and protein of foods of a meat-based compared with a lactoovovegetarian diet in the United States

Food	Meat-based diet[1]	Energy	Protein	Lactoovovegetarian diet[2]	Energy	Protein
	kg	*kcal*	*g*	*kg*	*kcal*	*g*
Food grain	114	849	24.9	152	1132	33.2
Pulses (legumes)	4.3	40	2.0	7.5	70	4.5
Vegetables	239	147	6.6	286	155	8.8
Oil crops	6	71	3.0	8	95	4.0
Fruit	109	122	1.4	112	122	1.9
Meat	124	452	41.1	0	0	0
Fish	20.3	28	4.7	0	0	0
Dairy products	256	385	22.5	307.1	473	30.0
Eggs	14.5	55	4.2	19.2	73	5.6
Vegetable oils	24	548	0.2	25	570	0.2
Animal fats	6.7	127	0.1	6.7	127	0.1
Sugar and sweeteners	74	686	0.2	74	686	0.2
Nuts	3.1	23	0.6	4.0	30	0.8
Total	994.9	3533	111.5	1001.5	3533	89.3
Feed grains[3]	816.0	—	—	450.0	—	—

[1] Data from FAOSTAT (6).
[2] Estimated.
[3] Feed grains are cereal grains fed to livestock.

TABLE 2
Animal production in the United States and the fossil energy required to produce 1 kcal of animal protein

Livestock and animal products	Production volume[1]	Ratio of energy input to protein output[2]
	10^6	*kcal*
Lamb	7	57:1
Beef cattle	74	40:1
Eggs	77 000	39:1
Swine	60	14:1
Dairy (milk)	13	14:1
Turkeys	273	10:1
Broilers	8000	4:1

[1] Data from US Department of Agriculture (11).
[2] Data from Pimentel (9).

greater than that for grain protein production, which is about 2.2 kcal of fossil energy input per 1 kcal of plant protein produced (**Table 4**). This is for corn and assumes 9% protein in the corn. Animal protein is a complete protein based on its amino acid profile and has about 1.4 times the biological value of grain protein (8).

LAND RESOURCES

More than 99.2% of US food is produced on land, while < 0.8% comes from oceans and other aquatic ecosystems. The continued use and productivity of the land is a growing concern because of the rapid rate of soil erosion and degradation throughout the United States and the world. Each year about 90% of US cropland loses soil at a rate 13 times above the sustainable rate of 1 ton/ha/y (28). Also, US pastures and rangelands are losing soil at an average of 6 tons/ha/y. About 60% of United States pastureland is being overgrazed and is subject to accelerated erosion.

The concern about high rates of soil erosion in the United States and the world is evident when it is understood that it takes approximately 500 y to replace 25 mm (1 in) of lost soil (28). Clearly, a farmer cannot wait for the replacement of 25 mm of soil. Commercial fertilizers can replace some nutrient loss resulting from soil erosion, but this requires large inputs of fossil energy.

WATER RESOURCES

Agricultural production, including livestock production, consumes more fresh water than any other activity in the United States. Western agricultural irrigation accounts for 85% of the fresh water consumed (29). The water required to produce various foods and forage crops ranges from 500 to 2000 L of water per kilogram of crop produced. For instance, a hectare of US corn transpires more than 5 million L of water during the 3-mo growing season. If irrigation is required, more than 10 million L of water must be applied. Even with 800–1000 mm of annual rainfall in the US Corn Belt, corn usually suffers from lack of water in late July, when the corn is growing the most.

Producing 1 kg of animal protein requires about 100 times more water than producing 1 kg of grain protein (8). Livestock directly uses only 1.3% of the total water used in agriculture. However, when the water required for forage and grain production is included, the water requirements for livestock production dramatically increase. For example, producing 1 kg of fresh beef may require about 13 kg of grain and 30 kg of hay (17). This much forage and grain requires about 100 000 L of water to produce the 100 kg of hay, and 5400 L for the 4 kg of grain. On rangeland for forage production, more than 200 000 L of water are needed to produce 1 kg of beef (30). Animals vary in the amounts of water required for their production. In contrast to beef, 1 kg of broiler can be produced with about 2.3 kg of grain requiring approximately 3500 L of water.

TABLE 3
Grain and forage inputs per kilogram of animal product produced

Livestock	Grain[1]	Forage[2]
	kg	*kg*
Lamb	21	30
Beef cattle	13	30
Eggs	11	—
Swine	5.9	—
Turkeys	3.8	—
Broilers	2.3	—
Dairy (milk)	0.7	1

[1] Data from US Department of Agriculture (11).
[2] Data from Morrison (14) and Heitschmidt et al (15).

TABLE 4
Energy inputs and costs of corn production per hectare in the United States

Inputs	Quantity	Energy	Cost
		kcal 1000	*$*
Labor (h)[1]	11.4 (16)[2]	462	114.00[3]
Machinery (kg)	55 (8)	1018 (17)	103.21 (18)
Diesel (L)	42.2 (19, 20)	481 (17)	8.87 (21)
Gasoline (L)	32.4 (19, 20)	328 (17)	9.40 (21)
Nitrogen (kg)	144.6 (22)	2688 (23)	89.65 (21)
Phosphorus (kg)	62.8 (22)	260 (23)	34.54 (21)
Potassium (kg)	54.9 (22)	179 (23)	17.02 (21)
Lime (kg)	699 (22)	220 (17)	139.80 (16)
Seeds (kg)	21 (8)	520 (17)	74.81 (24)
Irrigation (cm)	33.7 (25)	320 (17)	123.00
Herbicides (kg)	3.2 (22)	320 (17)	64.00[4]
Insecticides (kg)	0.92 (22)	92 (17)	18.40[4]
Electricity (kWh)	13.2 (19, 20)	34 (17)	2.38[5]
Transportation (kg)[6]	151	125 (17)	45.30[7]
Total (kg yield)	7965 (27)	7047[8]	844.38

[1] It is assumed that a person works 2000 h/y and uses an average of 8100 L oil equivalents/y.
[2] Reference.
[3] It is assumed that farm labor is paid $10/h.
[4] It is assumed that herbicide and insecticide prices are $20/kg.
[5] The price of electricity is $0.07/kWh (26).
[6] Goods transported include machinery, fuels, and seeds that were shipped an estimated 1000 km.
[7] Transport was estimated to cost $0.30/kg.
[8] Ratio of kcal input to output = 1:4.07.

CONCLUSION

Both the meat-based average American diet and the lactoovovegetarian diet require significant quantities of nonrenewable fossil energy to produce. Thus, both food systems are not sustainable in the long term based on heavy fossil energy requirements. However, the meat-based diet requires more energy, land, and water resources than the lactoovovegetarian diet. In this limited sense, the lactoovovegetarian diet is more sustainable than the average American meat-based diet.

The major threat to future survival and to US natural resources is rapid population growth. The US population of 285 million is projected to double to 570 million in the next 70 y, which will place greater stress on the already-limited supply of energy, land, and water resources. These vital resources will have to be divided among ever greater numbers of people.

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Exhibit 5

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Food choices, health and environment: Effects of cutting Europe's meat and dairy intake

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ABSTRACT

Western diets are characterised by a high intake of meat, dairy products and eggs, causing an intake of saturated fat and red meat in quantities that exceed dietary recommendations. The associated livestock production requires large areas of land and lead to high nitrogen and greenhouse gas emission levels. Although several studies have examined the potential impact of dietary changes on greenhouse gas emissions and land use, those on health, the agricultural system and other environmental aspects (such as nitrogen emissions) have only been studied to a limited extent. By using biophysical models and methods, we examined the large-scale consequences in the European Union of replacing 25–50% of animal-derived foods with plant-based foods on a dietary energy basis, assuming corresponding changes in production. We tested the effects of these alternative diets and found that halving the consumption of meat, dairy products and eggs in the European Union would achieve a 40% reduction in nitrogen emissions, 25–40% reduction in greenhouse gas emissions and 23% per capita less use of cropland for food production. In addition, the dietary changes would also lower health risks. The European Union would become a net exporter of cereals, while the use of soymeal would be reduced by 75%. The nitrogen use efficiency (NUE) of the food system would increase from the current 18% to between 41% and 47%, depending on choices made regarding land use. As agriculture is the major source of nitrogen pollution, this is expected to result in a significant improvement in both air and water quality in the EU. The resulting 40% reduction in the intake of saturated fat would lead to a reduction in cardiovascular mortality. These diet-led changes in food production patterns would have a large economic impact on livestock farmers and associated supply-chain actors, such as the feed industry and meat-processing sector.

1. Introduction

Western diets are characterised by a high intake of animal products, which leads to an intake of saturated fats and red meats that is above dietary recommendations (Linseisen et al., 2009; Ocké et al., 2009; Pan et al., 2012). The consumption of meat, dairy and eggs is increasing, worldwide (FAO, 2006; Kearney, 2010), and this will aggravate the environmental impact related to livestock production (Bouwman et al., 2013; Godfray et al., 2010; Steinfeld et al., 2006; Thornton, 2010). Concerns about animal welfare, reactive nitrogen and greenhouse gas emissions have stimulated public debate in Europe about eating less meat and dairy products (Deckers, 2010a,b; Deemer and Lobao, 2011; Freibauer et al., 2011; Garnett, 2011; Krystallis et al., 2012). This debate draws on a growing consensus in the scientific community about changing 'western' diets possibly having a positive outcome for both human health and the environment (Friel et al., 2009; Godfray et al., 2010; Hawkesworth et al., 2010). There have been numerous life-cycle

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analyses (de Vries and de Boer, 2010; Nijdam et al., 2012; Weiss and Leip, 2012; Leip et al., 2013), input–output analyses (Tukker et al., 2011) and global assessments (Popp et al., 2010; Stehfest et al., 2013, 2009) of the environmental impact related to meat and dairy consumption and dietary changes. However, these studies do not address the implications for the structure of regional agriculture, even though the expected resource use and environmental impacts of change will manifest themselves the most on that scale. Against this background, the central question being addressed in this article is that of what the consequences would be for the environment and human health if consumers in an affluent world region were to replace part of their consumption of meat, dairy produce and eggs with plant-based foods? This question was explored with a focus on the 27 EU Member States (EU27), a region with a high per-capita intake of animal protein, compared with many other parts of the world.

2. Method and data

2.1. Overview

For this study, a large number of calculation steps were taken to arrive at the final estimates (Fig. S1). To investigate the consequences of dietary change based on reductions in the consumption of meat, dairy and eggs, we developed six alternative diets for the EU27. These diets consist of a 25% or 50% reduction in the consumption of beef, dairy, pig meat, poultry and eggs, which is being compensated by a higher intake of cereals (Table 1, S1). This article only presents the results for the alternative diets with a 50% reduction; those for the 25% reduction option are presented in the supplementary material. We assumed that a reduction in the consumption of meat, dairy and eggs would have a proportional effect on EU livestock production. Fewer livestock would mean a lower demand for feed, including forage (mostly grass and forage maize). The alternative diets therefore would result in opportunities to change the use of some of the land that is currently needed for feeding animals. We explored two scenarios for land that would be affected by such production changes: a greening world and a high prices world. We assessed the effects on greenhouse gas and reactive nitrogen emissions, land use, the use of mineral fertilisers and manure, and on N deposition in Europe. We did not apply a specific time period in the implementation of the alternative diets and land-use scenarios. Furthermore, we only used biophysical models and data to quantify the environmental effects, and only assessed the direct environmental effects on agriculture within the EU. Effects in other regions or other parts of the food chain (e.g. processing, transport, production of mineral fertilisers) were not quantified.

2.2. Alternative diets

We used statistics as compiled by the Food and Agriculture Organization of the United Nations to determine the quantity of commodities used by each EU Member State's food system in 2007 (FAO, 2010). These data represent the national supply. The commodities were aggregated into 12 major commodity groups. However, not all food is consumed, as certain parts are not edible (e.g. bones, peelings) and losses occur during processing, and in retail and preparation (FAO, 2010). Information about these food commodity losses were obtained from the literature (Kantor et al., 1997; Quested and Johnson, 2009). In an alternative approach to determining food losses, we compared FAO supply data with results from national studies that monitor actual food intake (Elmadfa, 2009). The two approaches yielded similar estimates on the relationship between supply and intake. This study is based on data on food commodities as they enter the post-farm food chain. These commodities are consumed both in their basic form (such as eggs or sugar), as well as in processed foods (for example, in bakery products). A 50% reduction diet would cause both forms of consumption to decrease.

The alternative diets that were examined showed contrasting effects of ruminant and monogastric livestock production on resource use and the environment. The production of pig meat, poultry meat and eggs is based almost entirely on cereals and soybean meal, while Europe's grasslands are a major source of feed in the production of beef and dairy. In addition, the literature on life-cycle assessments of food products consistently shows that monogastric meats have smaller carbon and nitrogen footprints than beef (Leip et al., 2013; Lesschen et al., 2011; Weiss and Leip, 2012). The 50% level of reduction was chosen for two reasons. It was expected that, under a 50% reduction in livestock production, most permanent grasslands and domestic by-products would still be used in the agricultural system. With regard to dietary composition, we expect that a 50% reduction in the consumption of livestock products would stay reasonably well within public health guidelines on the intake of proteins, micro-nutrients and vitamins. Maintaining a 50% share of livestock products in the human diet would accommodate a variation in diets among the population, as currently not all individual diets are well-balanced. If the average intake of proteins, iron and vitamins would just match dietary guidelines, there is a risk of deficiency on an individual level (Elmadfa, 2009; Mensink et al., 2013). These considerations, however, certainly do not imply that larger reductions would not be possible.

We assumed that the reduced intake of meat, dairy and eggs would be compensated by an increase in cereals, on the basis of food calorie intake. If the protein intake would drop below the recommended level, pulses (which are high in protein) were added to the scenario diet. The calculations were carried out for each EU Member State and aggregated to the EU27 level. Reductions in consumption were not uniformly applied, but varied per country. In countries with currently low rates of meat and dairy consumption, a lower reduction was assumed, with higher reduction rates for other countries. Consumption levels of sheep and goat meat were maintained at current levels in our alternative diets, because of their role in conserving extensive grasslands in their present state, as these often have both a high biodiversity and

Table 1
Evaluated alternative human diets and corresponding livestock production.

Alternative diet	Human consumption	Livestock production
Reference	Present situation	Present situation
Reference–BF[a]	Present situation	Present situation
50% beef and dairy[b]	Reduction of 50% in beef and dairy consumption	Reduction of 50% in cattle (in the number of animals)
50% pig and poultry	Reduction of 50% in pig meat, poultry and egg consumption	Reduction of 50% in pig and poultry production (in the number of animals)
50% all meat and dairy	Reduction of 50% in all meat, dairy and egg consumption	Reduction of 50% in cattle, pig and poultry production (in the number of animals)

[a] BF = balanced (nitrogen) fertilisation: fertilisation according to crop requirements/recommendation.
[b] The supplementary material also includes the results for three variants of a 25% reduction in consumption: beef and dairy; pig and poultry; and all meats and dairy.

cultural value (Paracchini et al., 2008). Sheep and goats depend on these extensive grasslands to a relatively larger degree than do beef and dairy cows (Lesschen et al., 2011). Furthermore, also fish consumption was assumed to remain on current levels. FAO data on consumption were also used for quantifying the intake of saturated fats, calories and proteins (Westhoek et al., 2011).

2.3. Livestock production, feed use and land use

The assumption was made that a reduction in the EU consumption of meat, dairy and eggs would have a proportional effect on EU livestock production, as fewer livestock require less feed. Data on current feed use were derived from the CAPRI model (Lesschen et al., 2011; Weiss and Leip, 2012; Leip et al., 2013). Calculations were done on a country level and subsequently aggregated to EU27 level (Lesschen et al., 2011). A proportional reduction was applied over the four main feed components (protein-rich feeds, energy-rich cereals, roughage, and forage maize). These reductions were based on the energy content of the different feeds and adjusted, where needed, to compensate for either too high or too low N (protein) content in total feed. All calculations were done per animal category and per country. The amounts in domestic by-products used as feed from, for example, oil and beer production, were kept at a current level. Thus, imports (such as soybean meal) were reduced more than proportionally. For the ‘roughage’ component, production was assumed to primarily take place on permanent grassland, therefore reducing the need for arable land or temporary grassland for this purpose.

2.4. Land-use scenarios

The substantial change in the demand for feed under our alternative diet scenarios would results in a net reduction in the amount of land needed for the European food system, thus opening up opportunities for land to be used for other purposes. We examined the effects of an alternative use of this land, according to two contrasting land-use scenarios: *high prices* and *greening*. The *high prices* scenario assumes a high global demand for food and an agricultural sector that is geared to produce (and export) as much cereal as possible. This means that cropland that is presently used for forage (e.g. maize), temporary grassland and some fertilised permanent grassland, but which would no longer be needed for feed production, could be converted into arable land for cereal production. The *greening* scenario assumes that arable land previously used in the production of animal feed (e.g. wheat and maize) and temporary grassland is converted to perennial bio-energy crops, such as canary reed grass, switchgrass, miscanthus, and poplar or willow, depending on the location. All permanent grassland is assumed to be maintained and N fertilisation to be reduced to a level commensurate with the lower required production level, in turn resulting in lower N emission levels and an increase in biodiversity.

2.5. Nitrogen cycle and greenhouse gas emissions

The changes in livestock numbers, feed and land use were fed into the MITERRA-Europe model. MITERRA-Europe is an environmental impact assessment model that calculates emissions of N, such as N_2O, NH_3, NO_x and NO_3, and greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), on a deterministic and annual basis using emission and leaching factors (Lesschen et al., 2009; Velthof et al., 2009). MITERRA-Europe is partly based on data from the CAPRI (Common Agricultural Policy Regionalised Impact) (Britz and Witzke, 2012) and GAINS (GHG-Air pollution INteraction and Synergies) (Klimont and Brink, 2004) models, supplemented with an N leaching module, a soil carbon module and a module on mitigation measures. Input data consist of activity data (e.g. on livestock numbers, crop areas), spatial environmental data (e.g. on soil and climate) and emission factors (IPCC and GAINS). The model includes measures to mitigate greenhouse gas and NH_3 emissions, as well as NO_3 leaching.

The reference year is 2004, which is the base year currently used by the CAPRI model. All the statistical input data are based on three-year averages over the 2003–2005 period. The main input data for the MITERRA-Europe model are on crop areas, animal numbers and feed use, on NUTS-2 (county or provincial) level. Data on crop areas and feed use were taken directly from the CAPRI model and are based on Eurostat statistics. Data on animal populations relate to countries and were obtained from the GAINS model. Livestock populations were distributed over the NUTS-2 regions according to CAPRI livestock data. Data on annual N fertiliser consumption were collected from statistical data from the Food and Agriculture Organization (FAO, 2010).

2.6. N flows

Country-specific N livestock excretion rates were obtained from the GAINS model (Klimont and Brink, 2004). The total manure N production was calculated on the NUTS 2 level, using the number of animals and the N excretion per animal, then correcting for N losses in housing and storage. Manure was distributed over arable crop fields and grasslands according to Velthof et al. (2009), taking into account the maximum manure application of 170 kg N ha^{-1} from the Nitrates Directive, or a higher application for countries that had been granted a derogation. Mineral N fertiliser was distributed over crops relative to their N demand, taking account of the amount of applied manure and grazing manure and their respective fertiliser equivalents (Velthof et al., 2009). The N demand was calculated as the total N content of the crop (harvested part plus crop residue), multiplied by a crop-specific uptake factor, set at 1.0 for grass and perennial bio-energy crops and 1.1 and 1.25 for cereals and other arable crops, respectively (Velthof et al., 2009). The quantities of mineral fertiliser needed under the alternative diet scenarios were not only compared to the present use, but also to the quantities that would be needed under a balanced N fertilisation (BF) scenario (Oenema et al., 2007; Velthof et al., 2009). Balanced N fertilisation means that N fertilisation equals the uptake by the plant during growth, corrected by the crop-specific uptake factor. This approach was justified as the input of animal manure was reduced under the alternative diets. In order to sustain arable production, an increase in mineral fertiliser may therefore be needed. Further N input includes biological N fixation, which was estimated as a function of land use and crop type (legumes), and N deposition that was derived on NUTS 2 level, from the European Monitoring and Evaluation Programme (EMEP).

NH_3 emissions from livestock manure occur during housing, manure storage, after application to the soil, and from pastures. Country-specific emission factors and estimates of the efficiency of ammonia abatement measures were taken from the GAINS model (Klimont and Brink, 2004). N_2O emissions from agriculture consist of emissions from manure storage and agricultural soils. The latter consist of (i) direct soil emissions after the application of mineral fertiliser and animal manure, and indirect emissions from crop residues, (ii) emissions from urine and dung excreted during grazing, and (iii) indirect emissions from nitrogen that is lost through leaching and run-off, and from volatilised and re-deposited N. All N_2O emissions were calculated using emission factors from the IPCC, 2006 guidelines. The emission factor for NO_x was derived from van Ittersum and Rabbinge (1997) and was set at 0.3% of the N input.

N leaching was calculated by multiplying soil N surplus by a region-specific leaching fraction, based on soil texture, land use, precipitation surplus, soil organic carbon content, temperature and rooting depth. Surface run-off fractions were calculated on the basis of slope, land use, precipitation surplus, soil texture and soil depth (Velthof et al., 2009).

The effect of reduced ammonia emissions from agriculture on N deposition was assessed using the GAINS model. The GAINS model describes the interrelations between these multiple effects and pollutants (sulphur dioxide (SO_2), nitrogen oxide (NO_x), particulate matter (PM), volatile organic compounds (NMVOC), NH_3, CO_2, CH_4, N_2O, and F-gases) that contribute to these effects on a European scale (Amann et al., 2011). The activity data for the selected scenario were provided by national experts; thus improving the quality of the national input, while other parameters, such as emission factors and abatement technology implementation rates, were taken from the European scenario. Input data for the activity change in the proposed scenarios were obtained from the MITERRA-Europe model, as described above. The level of oxidised N deposition and averaged area critical load exceedances were based on outcomes of the GAINS model.

2.7. Greenhouse gas emissions

Data on methane (CH_4) emissions used in the MITERRA-Europe model were derived from European regional livestock numbers and IPCC (2006) emission factors. Changes in land use and land management will influence soil organic carbon (SOC) stocks. Following the IPCC (IPCC, 2006) approach, the amount of SOC in mineral soils was calculated by multiplying a default reference value by relative stock change factors for land use, soil management and carbon input. The reference soil carbon stock is a function of soil type and climate region for the upper 30 cm of soil. IPCC assumes a period of 20 years for soil carbon stocks to reach a new equilibrium. Relative stock change factors were assigned for each crop activity (Nemecek et al., 2005). Changes in soil carbon stocks caused by changes in cropping shares were calculated and divided by 20 years to obtain annual CO_2 emissions. All greenhouse gas emissions are expressed in CO_2 equivalents, based on estimates of the potential 100-year global warming values relative to carbon dioxide (CO_2: 1, CH_4: 25 and N_2O: 298) (IPCC, 2006).

3. Results

3.1. Dietary changes and effects on human health

We calculated that in diets with a lower consumption of meat, dairy and eggs, the average consumption of cereals increases by 10–49% (Table 2, S2). The protein intake in the alternative diet is up to about 10% lower than under the reference scenario (Fig. 1a, S2a). Nevertheless, the mean protein intake is still at least 50% higher than the dietary requirements set out by the World Health Organization (WHO) (WHO, 2007). Additional pulses to provide a sufficient supply of proteins were needed under only one alternative diet in one country (Hungary). Under the alternative diets, the intake of saturated fats is reduced by up to 40% (Fig. 1b, S2b). This proportion is close to the recommended maximum dietary intake (RMDI) proposed by the World Health Organization (WHO, 2003, 2008a, 2011), corresponding to an RMDI for saturated fats of 25.5 g per day, in Europe (WHO, 2003). These dietary changes reduce average red meat consumption from the current 89 g per person per day to 46 g (Fig. S3) under a 50% reduction in all meats and dairy foods. This brings diets in line with intake levels advised by the World Cancer Research Fund (a maximum of about 70 g per person, per day) This maximum is equivalent to a population average of 43 g of red meat per person, per day (WCRF and AICR, 2007).

Significant health benefits are expected to result from a lower intake of saturated fats and red meat, as diets rich in saturated fats are associated with an increased risk of cardiovascular diseases (CVD) and stroke. In the World Health Organization European region, currently, around 25% of total mortality can be attributed to CVD and 15% to stroke, in total about 3.8 million deaths, annually (WHO, 2008b). In terms of disease burden, these attributable fractions are around a respective 11% and 6.5% of total annual loss of disability-adjusted life years (DALYs, an aggregate of years of life lost and years spent in reduced health) (WHO, 2008b). There are also indications that the intake of red meat is associated with an increased risk of colorectal cancer (CRC) (Norat et al., 2002; Chan et al., 2011, Pan et al., 2012). Mortality and the disease burden of CRC in the World Health Organization European region are substantially lower than the CVD burden (250,000 annual deaths; 2.5% of total mortality; 1.4% of total annual DALYs). The reduction in livestock production and subsequent reduction in emissions may also have indirect health benefits, related to a lower use of antibiotics (Marshall and Levy, 2011) and improved water quality (nitrates) (Powlson et al., 2008) and air quality (related to the role of NH_x in particulate matter formation) (Moldanová et al., 2011).

3.2. Effects on feed demand and land use

The reduction in livestock production will lead to a reduced demand for feed. The total demand for feed will be reduced from the baseline use of 520 to 285 million tonnes, under a 50% reduction in all meat and dairy production (Table S3). The need for forage grown on arable land will be reduced by 90% – which constitutes the greatest reduction. This is a result of the assumptions that favour forage from grassland over forage from arable land. The 50% meat and dairy reduction diet gives a 75% reduction in soymeal use, a 46% reduction in energy-rich feed imports and a 52% reduction in feed cereal use. Under the diets in which only pig and poultry production is reduced, the use of grass, fodder maize and other fodder grown on arable land is similar to that under the baseline scenario. The reduction in cereal use is larger under alternative diets with a reduction in pig and poultry consumption than those with a reduced level of beef and dairy consumption.

Table 2
Average per-capita consumption of selected[a] food commodity groups under the reference diet and the three alternative diets (g person^{-1} day^{-1}).

	Reference	50% beef and dairy	50% pig and poultry	50% all meat and dairy
Cereals	256	326	311	382
Pulses	4	4	4	4
Dairy (expressed as milk)	554	277	554	277
Beef	23	12	23	12
Poultry	32	32	16	16
Pig meat	62	62	31	31
Sheep and goat meat	3	3	3	3
Eggs	28	28	14	14

[a] The use of sugar, potatoes, fruit, vegetables and fish is assumed to remain constant and, therefore, is not presented here.

Fig. 1. Effects of dietary changes on the average daily per-capita intake of proteins and saturated fats. (a) Population average daily protein intake in the EU27, in g day^{-1}, for the various food commodity groups, under the reference (2007) scenario and in case of the six alternative diets in which meat and dairy consumption is reduced step by step. (b) Idem, for saturated fats.

As the demand for animal feed declines, land currently used in feed production will become available for alternative purposes. In the *high prices* land-use scenario, with a 50% reduction in all meat and dairy production, 9.2 million hectares of mainly intensively managed permanent grassland and 14.5 million hectares of arable land are no longer required for feeding European livestock (Table 3, S4, Fig. S4). This land, instead, will be used for additional cereal production, leading to an increase in EU cereal acreage from 60 to 84 million hectares and in the net export of cereals from 3 to 174 million tonnes (Fig. S5). In the *greening* land-use scenario, around 14.5 million hectares are used in the cultivation of perennial energy crops.

The demand for food cereals will increase when the consumption of meat and dairy is reduced. Feed demand, however, would decrease by more (Fig. 2). In combination with the increased availability of land, domestic cereal production would become much larger than domestic demand, leading to an increase in cereal exports. As a consequence of the dietary changes, the average amount of cropland used within the EU for domestic food production would be reduced from 0.23 to 0.17 hectares per EU citizen.

3.3. *Effects on reactive nitrogen emissions*

A reduction in livestock production would lead to a significant decrease in the reactive nitrogen input and losses across Europe (Fig. 3, Table S5). In the *greening* scenario, under a 50% reduction in all meat and dairy consumption, fertiliser input is reduced from 11.3 to 8.0 million tonnes N yr^{-1}, while emissions of nitrates to groundwater and surface water and ammonia (NH_3) to air both are reduced by 40%, compared with the reference situation. The level of nitrogen use efficiency in the EU food system as a whole would improve, from 22% in the reference situation to 41% under the *greening* scenario and to 47% under the *high prices* scenario. The nitrogen use efficiency here is defined as the N output in food crops and livestock products as a percentage of total N input (Oenema et al., 2009).

Results indicate that at the current level of livestock production, changes in the emission of reactive nitrogen from European agriculture on an EU scale closely relate to relative changes in the magnitude of livestock production. Reducing N emissions through dietary change would lead to a cascade of positive effects (Galloway et al., 2008). Reductions in nitrate leaching and ammonia emissions and deposition would be the highest in regions with intensive livestock production. Under the 50% reduction diet, average NH_3 emissions and NH_x deposition in the EU would be reduced by about 40%, resulting in a reduction in the exceedance of critical load thresholds for adverse reactive nitrogen effects on ecosystems (Fig. 4). Reduced nitrogen emissions will lead to an improvement in water quality and to lower risks of eutrophication. The total N load to rivers and seas for the EU27 in 2005 was estimated at 4.6 million tonnes, 55% of which

Table 3
Agricultural land use in the EU under the different alternative diets and land-use scenarios (in million ha).

	Land-use types for which the area remains constant under both scenarios			*Greening* scenario			*High prices* scenario	
	Semi-natural grassland	Other arable crops	Fodder on arable land	Managed grassland	Cereals	Energy crops	Managed grassland	Cereals
Reference	21.3	43.7	18.9	44.2	59.9	0.0	44.2	59.9
50% beef and dairy	21.3	43.7	4.3	44.2	59.9	14.5	35.0	83.6
50% pig and poultry	21.3	43.7	18.9	44.2	59.9	0.0	44.2	59.9
50% all meat and dairy	21.3	43.7	4.3	44.2	59.9	14.5	35.0	83.6

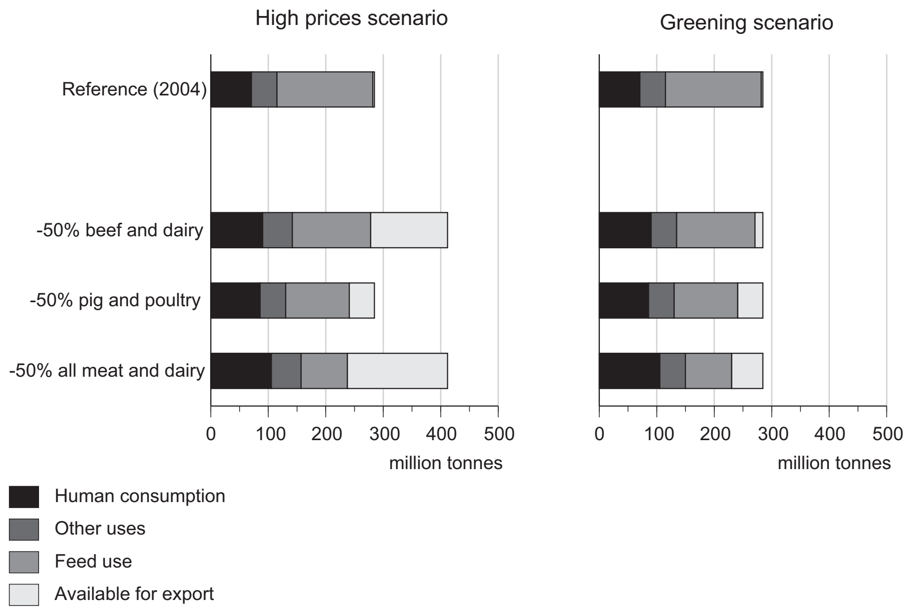

Fig. 2. Cereal demand in the EU as affected by the alternative diets under two land-use scenarios.

from agricultural sources (Grizzetti et al., 2012). Due to human activities, nitrate concentrations in major European rivers have increased by as much as a factor of 10, during the 20th century. Although improvements have been made in recent decades, the eutrophication threshold value for nitrate in fresh water and marine systems is commonly exceeded. Similarly, the World Health Organization nitrate standard for drinking water (50 mg/L) is commonly exceeded in shallow phreatic groundwater (van Grinsven et al., 2012).

3.4. Effects on greenhouse gas emissions

Net greenhouse gas emissions directly related to EU agricultural production (excluding pre-farm and post-farm emissions) will decrease by 42%, from 464 to 268 million tonnes CO_2 eq yr^{-1} under a 50% reduction in all meat and dairy consumption, in combination with the *greening* scenario (Fig. 5, S6). Under the *high prices* scenario, net greenhouse gas emissions will decrease by 19%, to 374 million tonnes CO_2 eq yr^{-1}. Reductions in CH_4 emissions are similar under the two scenarios, as these are directly coupled to the number of ruminants, which form the largest component in the greenhouse gas emission reduction (108 million tonnes CO_2 eq yr^{-1}). N_2O emissions will be reduced to a lesser extent because they are mainly linked to turnover processes of reactive nitrogen in soils that are associated with both livestock and arable farming. Under the *high prices* scenario, tillable grassland in the EU is converted into arable land, leading to additional CO_2 emissions from decreasing soil carbon stocks. These emissions would contribute 59 million tonnes CO_2 yr^{-1}, when averaged over a period of 20 years. Under the *greening* scenario, soil carbon sequestration occurs as the perennial biomass crops increase levels of carbon in the plant–soil system that are equivalent to 36 million tonnes CO_2 yr^{-1}, again averaged over 20 years. Reductions in emissions outside the EU, related to the lower demand for soybean and the higher export of cereals, were not included in our calculations but would provide a substantial additional benefit (Stehfest et al., 2013). The annual amounts of biomass for energy produced under the *greening* scenario represents 2.3 EJ or 54.1 million tonnes oil equivalent, equal to roughly 3% of EU's current primary energy intake (Eurostat, 2011).

4. Discussion and conclusion

Our study explored the consequences for human health and the environment of replacing 25–50% of current meat, eggs and dairy consumption in the EU with plant-based foods, and assuming that consumption and production of livestock products in Europe remain tightly linked. Reducing livestock production by 50% will lead to large structural changes within the EU agricultural sector, resulting in a reduction in the emission of greenhouse gases (25–40%) and reactive nitrogen (around 40%). Due to reduced feed demand, the use of imported soybean meal would drop by 75% and the EU would become a large net exporter of basic food commodities. Given increasing global food demand, the beneficial environmental effects of dietary changes within the EU, therefore, would extend beyond its territory. The results reflect the large share of livestock production in the total environmental impact of EU agriculture, as was already revealed for greenhouse gas (Lesschen et al., 2011; Weiss and Leip, 2012; Leip et al., 2013).

This study was based on a number of important assumptions. The first assumption is on the lower meat, eggs and dairy intake being compensated by a higher cereal intake while maintaining total dietary energy intake. As far as health impacts are concerned, this is a relatively conservative approach. First of all, the current average per-capita energy intake is higher than needed. Full replacement of the calorific contents of livestock products, therefore, will not be necessary. Second, additional health benefits could be expected if this energy replacement were to be partly in the form of fruits and vegetables, since in most European countries the average intake of these is currently below the recommended level (Elmadfa, 2009). As far as environmental impacts are concerned, substituting wheat with other carbohydrate-rich commodities (e.g. potatoes) would yield similar effects, while the use of fruit and vegetables would lead to smaller environmental benefits. This is because, in general, the environmental effects (such as those of land use and greenhouse gas emissions per calorie) of fruits and vegetables are larger than those of cereals, but lower than those of dairy and meat (Garnett, 2013; Nemecek and Erzinger, 2005; Nemecek et al., 2005). We did not investigate the effects of the dietary changes on the intake of micro-nutrients. As the current intake of, for example, calcium and iron is already low

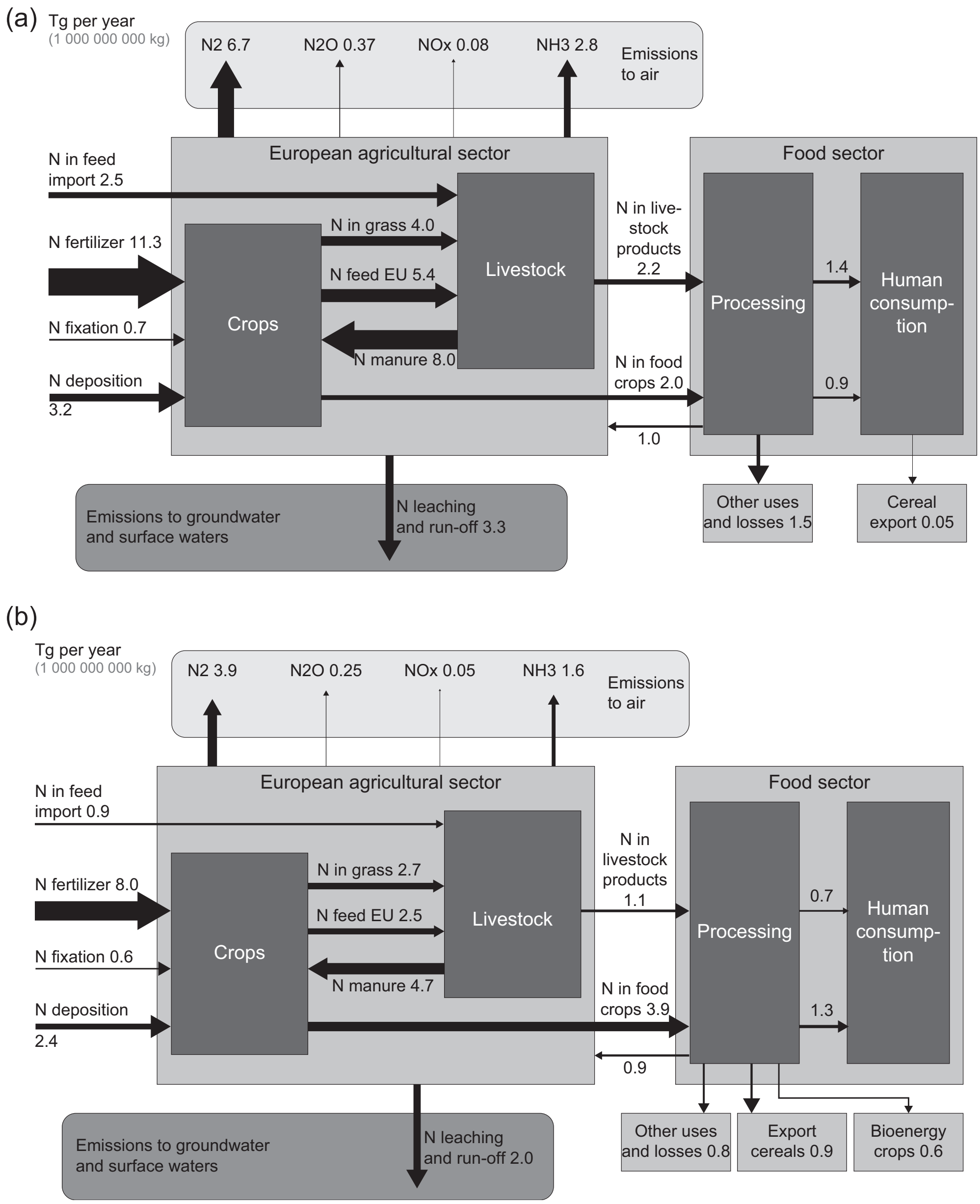

Fig. 3. Nitrogen flows (in $Tg\,yr^{-1}$) in the EU agricultural and food systems, under the reference scenario for 2004 (a) and in the case of the alternative diet with a 50% reduction in the consumption of meat, dairy and eggs, under the *Greening land-use* scenario (b).

in most EU countries (Elmadfa, 2009), this is certainly an aspect that requires further attention. In all diets, the average protein intake in the EU remains higher than required. Even with a 50% reduction in all animal products, the mean EU intake of proteins would still be more than 50% higher than would be required.

The second important assumption is on the reduction in meat, eggs and dairy consumption being followed by a parallel reduction in EU livestock production, meaning that the current tight link between production and consumption in Europe will be maintained. Instead of reducing production, EU farmers and the food industry could try to compensate for reduced domestic markets by increasing exports to other countries. If this happened, the environmental benefits of the consumption change would largely shift from within to outside the EU. As current production costs of many livestock products (except potentially for dairy products) are higher in the EU than in some other countries, such as in Brazil, Australia, the United States and Thailand, it is unlikely that the EU will become a significant net exporter of livestock products, as also indicated by the assessment of similar scenarios by using economic models (Stehfest et al., 2013).

No explicit sensitivity analyses were performed, although the combination of dietary and land-use scenarios could be regarded as a sensitivity analysis. These alternatives show clear, plausible and largely linear outcomes for environmental effects. Previous research has shown that the uncertainty in absolute emission estimates as calculated by using the MITERRA-Europe model is relatively small on EU scale, due to cross-correlations and spatial aggregation (Kros et al., 2012). Uncertainty on the relative changes in emissions between the various alternative diets and scenarios will be even lower. The most sensitive parameter for the reactive nitrogen and greenhouse gas emissions will be the assumed alternative land use.

As stated in the methodology section, only biophysical models were used. Would the use of economic models have yielded different outcomes? And would it be possible to assess the economic effects on the agricultural sector and other economic

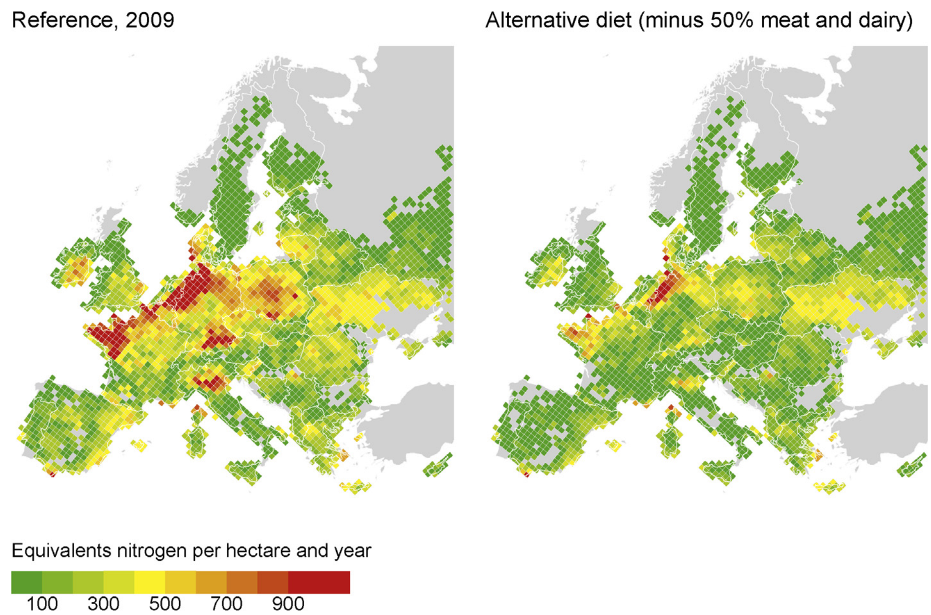

Fig. 4. Annual exceedance of the critical load for N deposition in N ha^{-1} for natural ecosystems, under the reference scenario and the 50% less meat and dairy alternative diet under the *high prices* land-use scenario.

sectors of these dietary changes? Other studies (for example Stehfest et al., 2013; Lock et al., 2010) have assessed the environmental and economic impact of reduced meat and dairy consumption using economic models. It is clear from these studies that the use of economic models is not straightforward and is not as transparent as our approach, for two reasons. First, there is the effect of the choice of model to consider (Stehfest et al., 2013). Computable general equilibrium (CGE) models include all sectors, but usually in less detail, whereas partial equilibrium models (PE) only represent one sector (the agricultural sector) with everything having to be solved within this sector. PE models come up with different answers than CGE models, as within CGE models, labour and other production factors can move from one sector to another. Second, in order to force the models to simulate a reduced consumption of meat and dairy, consumption functions need to be altered. In the approach taken by Lock et al. (2010), who assessed the effects for two countries, assumptions regarding the effect on trade had to be made. Stehfest et al. (2013) also showed that results largely would depend on how trade and trade policies are modelled.

The effects on the livestock sector will most likely be severe, especially if consumer preferences change rapidly. This is demonstrated by a study of the UK food system, using scenarios similar to ours. Audsley et al. (2010) showed that the reduction in the UK farm gate value of livestock from dietary change is not compensated by an increase in the value of crops for direct human consumption. Their study highlighted strong regional effects with gains in areas with high quality arable land and losses of income on less suitable land, particularly in Scotland and Wales. However, if the attitude towards food were to change within society and

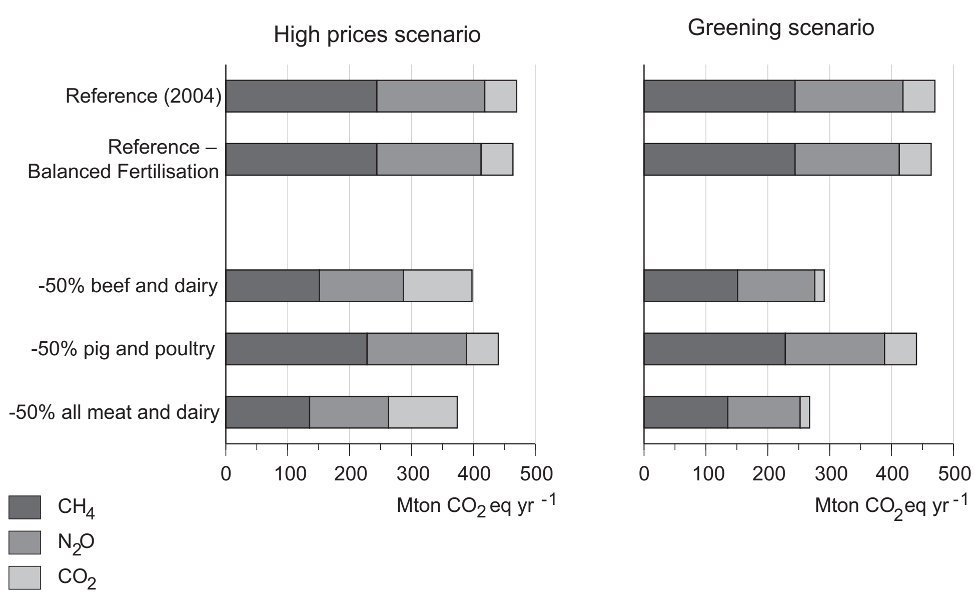

Fig. 5. Greenhouse gas emissions (in Mton CO_2 eq yr^{-1}) from EU agriculture under the reference situation and the three alternative diets for the *high prices* scenario and the *greening* scenario. Balanced fertilisation is fertilisation according to crop requirements.

people would opt for products with a higher added value, such as meat and dairy produced in systems with a higher level of animal welfare, the economic effects on the livestock sector would be less severe. The farm-level economic impact of a change along these lines would crucially depend on the type of new output found for the land released from livestock production.

Our study shows that a change towards diets with a lower consumption of livestock products has clear environmental and health benefits. But this still leaves the question of whether such a change in consumption behaviour would be realistic. Consumer preferences may change due to environmental or health concerns, or simply because eating meat and dairy would become less 'normal' or fashionable for various reasons, a process that is already happening (Dagevos and Voordouw, 2013). A dietary shift could also be actively 'nudged' by governments, food manufacturers, retailers, restaurants and foodservice businesses (such as catering firms) when acting together to stimulate change. In addition, governments could also initiate changes through public procurement policies. Another policy approach could be to assess all policies in every policy field to determine which ones are promoting livestock production (including unintentional promotion) and subsequently to change those policies. A precondition for such an approach would be a sense urgency among decision makers in wanting to reap the combined health and environmental benefits.

A more direct policy intervention could be that of making meat and dairy products more expensive, either by direct taxation (e.g. see Deckers, 2010a,b; Vinnari and Tapio, 2012), or by taxing the environmental effects (e.g. greenhouse gas emissions or nutrient use) caused by their production (e.g. see Wirsenius et al., 2011). Direct taxation could be motivated by either environmental or ethical (animal welfare) concerns. As meat and dairy have larger environmental footprints, the price of animal products would increase more strongly than that of plant-based products. Higher meat and dairy prices would very likely lead to lower consumption.

Meat and dairy prices may also increase within the EU as global demand increases further (FAO, 2006). These higher prices may lead to a lower consumption of meat and dairy within the EU. The same high prices, however, are also likely to work as a stimulus for expanding EU meat and dairy production, in turn resulting in higher export levels of meat and dairy products.

This study is one of the first to examine, in detail, the relationships between diet-led changes in food production and continental-scale effects on land use, the N cycle, greenhouse gas emissions and the associated implications for human health. It demonstrates how dietary changes could produce a cascade of effects, through reduced production of livestock and manure, lower feed demand, resulting in lower N and greenhouse gas emissions, and freeing up agricultural land for other purposes. In Europe, the evidence of diet being an important factor in relation to environmental policy has already impacted the policy community. The Roadmap to a Resource-Efficient Europe (COM, 2011) highlights the food sector as a priority area for developing incentives for a healthier and more sustainable production and consumption of food. Moving in this direction means paying attention to stimulating the changes required and checking for any unintended nutritional consequences. The biggest challenge for agricultural policy in Europe is that of how to achieve such a fundamental change in European agriculture and address the implications for farm incomes, farmed landscapes and planning, at a wide range of scales.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.gloenvcha.2014.02.004.

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Exhibit 6

Land, irrigation water, greenhouse gas, and reactive nitrogen burdens of meat, eggs, and dairy production in the United States

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Livestock production impacts air and water quality, ocean health, and greenhouse gas (GHG) emissions on regional to global scales and it is the largest use of land globally. Quantifying the environmental impacts of the various livestock categories, mostly arising from feed production, is thus a grand challenge of sustainability science. Here, we quantify land, irrigation water, and reactive nitrogen (Nr) impacts due to feed production, and recast published full life cycle GHG emission estimates, for each of the major animal-based categories in the US diet. Our calculations reveal that the environmental costs per consumed calorie of dairy, poultry, pork, and eggs are mutually comparable (to within a factor of 2), but strikingly lower than the impacts of beef. Beef production requires 28, 11, 5, and 6 times more land, irrigation water, GHG, and Nr, respectively, than the average of the other livestock categories. Preliminary analysis of three staple plant foods shows two- to sixfold lower land, GHG, and Nr requirements than those of the nonbeef animal-derived calories, whereas irrigation requirements are comparable. Our analysis is based on the best data currently available, but follow-up studies are necessary to improve parameter estimates and fill remaining knowledge gaps. Data imperfections notwithstanding, the key conclusion—that beef production demands about 1 order of magnitude more resources than alternative livestock categories—is robust under existing uncertainties. The study thus elucidates the multiple environmental benefits of potential, easy-to-implement dietary changes, and highlights the uniquely high resource demands of beef.

food impact | foodprint | geophysics of agriculture | multimetric analysis

Appreciation of the environmental costs of food production has grown steadily in recent years (e.g., refs. 1–3), often emphasizing the disproportionate role of livestock (4–12). Although potentially societally important, to date the impacts of this research on environmental policies (7, 13, 14) and individual dietary choices have been modest. Although pioneering early environmental burden estimates have tended to address wide food classes (notably the animal-based portion of the diet; e.g., refs. 9 and 15), most policy objectives and individual dietary choices are item specific.

For example, a person may consider beef and chicken mutually interchangeable on dietary or culinary grounds. However, even if an individual estimate of the environmental cost of one item exists, it is often not accompanied by a directly comparable study of the considered alternative. Even in the unlikely event that both estimates are available, they are unlikely to consider the costs in terms of more than one metric, and often rely on disparate methodologies. Therefore, environmentally motivated dietary choices and farm policies stand to benefit from more finely resolved environutritional information. Although early work yielded a short list of item-specific environmental cost estimates (16), those estimates were often based on meager data, and addressed a single environmental metric (typically energy), thus requiring expansion, updating, and further analysis to enhance statistical robustness (8).

Current work in the rapidly burgeoning field of diet and agricultural sustainability falls mostly into two complementary approaches. The first is bottom–up, applying rigorous life cycle assessment (LCA) methods to food production chains (17–22). Whereas early LCAs focused primarily on greenhouse gas (GHG) emissions (23–26), or in some cases GHGs and energy use (5, 27), more recent LCAs often simultaneously address several additional key metrics (17, 19–21, 28, 29), notably land, water, and reactive nitrogen (Nr, nitrogen fertilizer) use. Some studies also include emissions of such undesirable gases (in addition to GHGs) as smog precursors or malodors (30, 31), or adverse contributions to stream turbidity or erosional topsoil loss (e.g., refs. 32–34). This bottom–up approach is extremely important, and is poised to eventually merge with the top–down national efforts described in the next paragraph. This merger is not imminent, however, because the bottom–up approach considers one or at most a handful of farms at a time. Because of wide differences due to geography (35), year-to-year fluctuations (36), and agrotechnological practice (17, 37), numerous LCAs are required before robust national statistics emerge. Eventually, when a large and diverse LCA sample is at hand, the picture at the national level will emerge. Currently, however, the results from an LCA conducted in Iowa, for example, are unlikely to represent Vermont or Colorado. Given the current volume and

Significance

Livestock-based food production is an important and pervasive way humans impact the environment. It causes about one-fifth of global greenhouse gas emissions, and is the key land user and source of water pollution by nutrient overabundance. It also competes with biodiversity, and promotes species extinctions. Empowering consumers to make choices that mitigate some of these impacts through devising and disseminating numerically sound information is thus a key socioenvironmental priority. Unfortunately, currently available knowledge is incomplete and hampered by reliance on divergent methodologies that afford no general comparison of relative impacts of animal-based products. To overcome these hurdles, we introduce a methodology that facilitates such a comparison. We show that minimizing beef consumption mitigates the environmental costs of diet most effectively.

Author contributions: G.E., A.S., and R.M. designed research; G.E., A.S., and R.M. performed research; G.E., A.S., T.M., and R.M. analyzed data; and G.E., A.S., and R.M. wrote the paper.

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scope of LCA research, and the complexity and variability of the problem, LCAs are still too few and too local to adequately sample the multifaceted, diverse US food system, and thus to collectively become nationally scalable.

The second agricultural sustainability research thrust, into which this study broadly falls, is a top–down analysis of national (10, 16, 38) or global (8, 39–41) production statistics. The top–down approach we follow here is conceptually straightforward, as described schematically in Fig. 1. The environmental needs (land, irrigation water, etc.) of feed production are collected and distributed among the feed-consuming animal categories. This is termed the partitioning step, and is based on information about the number of animals raised or slaughtered mass in each category, as well as the characteristic feed ration in each category. The burdens attributed to each category are divided by the caloric or protein mass output of that animal category, yielding the final result, the environmental burden per consumed unit (e.g., agricultural land needed per ingested kilocalorie of poultry). This method is mainly appealing because it (*i*) circumvents the variability issues raised above by using national or global aggregations; and (*ii*) it is based on relatively solid data. For the United States in particular, US Department of Agriculture (USDA) data tend to be temporally consistent, nearly all-inclusive (e.g., records of the main crops are based on close to 100% of the production), and are reported after some (albeit modest) quality control. The key challenge with this approach is obtaining defensible numerical values and uncertainty ranges for the tens if not hundreds of parameters needed in the calculations, many of which are poorly constrained by available data. Such parameters include, for example, the average feed required per animal per day or per kilogram of weight gain, or the relative fraction of pasture in beef and dairy diets. The values vary as a function of, at least, season, geographical location, and agrotechnology used. One research effort, focused on a single location, is unlikely to yield definitive results. Significant progress in both approaches is primarily realized through the tenacious and painstaking amassing of many independent analyses over time; analyses from which robust, meaningful statistics can be derived. Because of the challenges associated with each of the research thrusts discussed above, quantitatively robust, multimetric estimates that are comparable across different categories and represent the average national environmental burdens have yet to be devised. Although estimates of total national energy use and GHG emissions by agriculture do exist (e.g., refs. 4, 5, 42, and 43), they require further statistical evaluation. The costs in terms of land, irrigation water, and Nr are even less certain.

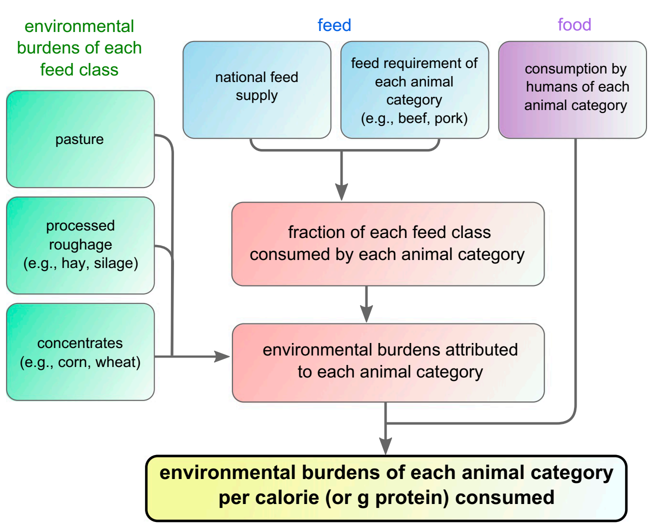

Fig. 1. A simplified schematic representation of the information flow in calculating environmental burdens per consumed calorie or gram of protein. Feed supply and requirements (blue boxes at top) previously yielded (38) the fraction of each feed class consumed by each animal category; e.g., pork requires 23 ± 9% of concentrated feed. Combined with the environmental burdens (green boxes at left; land, irrigation water, and nitrogen fertilizer for each of the three feed classes), these fractions yield the burdens attributed to each animal category. Finally, dividing those overall environmental burdens attributed to each of the five livestock categories by the number of calories (or grams of protein) nationally consumed by humans in the United States, we reach the final result of this paper (yellow box at bottom). Most input data (left and top boxes) is known with relative accuracy based on USDA data, whereas environmental burdens of pasture and average feed requirements are less certain.

Applying a top–down, uniform methodology throughout, here we present estimates of land, irrigation water, GHG, and Nr requirements of each of the five main animal-based categories in the US diet—dairy, beef, poultry, pork, and eggs—jointly providing 96% of the US animal-based calories. We do not analyze fish for two reasons. First, during the period 2000–2013, fish contributed ≈14 kcal per person per day, ≈0.5% of the total and 2% of the animal-based energy (750 kcal per person per day) in the mean American diet (44). In addition, data addressing feed use by fisheries and aquaculture are very limited and incomplete (relative to the five categories considered). We do not claim to cover all important environmental impacts of livestock production. Rather, we focus on key metrics that can be reliably defined and quantified at the national level with currently available data.

Results

We base our calculations on annual 2000–2010 data for land, irrigation water, and fertilizer from the USDA, the Department of the Interior, and the Department of Energy (see *SI Text* and ref. 13 for details). We consider three feed classes: concentrates, which include crops (corn, soybean, wheat, and other minor crops) along with byproducts, processed roughage (mainly hay and silage), and pasture. Data used include land area required for feed production (9); Nr application rates for crops, hay, and pasture; crop-specific irrigation amounts; and category-specific animal GHG emissions (17, 19–23, 28, 45, 46). For GHG emissions we also use LCA data to cover not only feed production but also manure management and enteric fermentation.

We use these data to calculate the amount of resources (e.g., total land or irrigated water) required for the production of all feed consumed by each edible livestock. We then partition the resources needed for the production of these three feed classes among the five categories of edible livestock. These two steps (38) rely on numerical values of several parameters that current data constrain imperfectly. Key among those are the feed demands of individual animals—e.g., 1.8 kg dry matter (DM) feed per 1 kg of slaughtered broiler—for which we could not find a nationwide reputed long-term dataset. Although some of the poorly known parameters impact the overall results minimally, a few of those impact the results significantly. As such, these steps add uncertainty to our results for which our presented uncertainty estimates may account only partially. The partition of feed is performed according to the fraction of the national livestock feed consumption characterizing each category, using recently derived partition coefficients (see Table S1 and ref. 38). Finally, we divide the resource use of each category by the US national animal caloric consumption, obtaining a category-specific burden per unit of consumed energy. For clearer presentation, we report burdens per megacalorie, where a megacalorie is 10^3 kilocalories (also colloquially termed "10^3 calories" in popular US nutritional parlance), equivalent to roughly half of the recommended daily energy consumption for adults. That is, we focus on the environmental performance per unit of energy of each food category. This is by no means a unique or universally

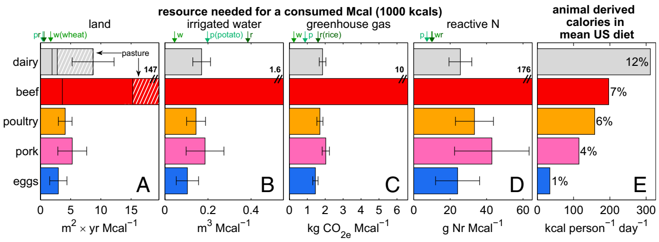

Fig. 2. (*A–D*) Environmental performance of the key livestock categories in the US diet, jointly accounting for >96% of animal-based calories. We report performance in resources required for producing a consumed Mcal (1 Mcal = 10^3 kcal, roughly half a person's mean daily caloric needs). For comparison, resource demands of staple plants potatoes (denoted p), rice (r), and wheat (w) are denoted by arrows above *A–D*. *E* displays actual US consumption of animal-based calories. Values to the right of the bars denote categories' percentages in the mean US diet. The demands of beef are larger than the figure scale and are thus written explicitly next to the red bars representing beef. Error (uncertainty) bars indicate SD. In *A*, for beef and dairy, demand for pastureland is marked with white hatching, and a vertical line separates demand for cropland (to the left), and processed roughage land (to the right).

superior choice. Other metrics, such as environmental costs per gram of protein (16), may be useful in other contexts or favored by some readers. We thus repeat our calculations using the protein metric, as shown in *SI Text*, section 6 and Fig. S1, conflating nutritional and environmental considerations (e.g., refs. 13 and 47).

We correct for feed consumption by other animals (goats, sheep, and horses) as well as export–import imbalances of individual animal categories. As pasture data coverage is poor, we derive the nitrogen fertilizer used for pasture as the residual between the overall agricultural use totals and the sums of crops and processed roughage totals, all well constrained by data. GHG emissions associated with the production of the various animal categories are derived from previous studies, considering CO_2, CH_4, and N_2O (17, 19–21, 28, 45, 46) from manure management, enteric fermentation, direct energy consumption, and fertilizer production inputs. An extended technical discussion of the methodology including data uncertainty and limitations is given in *SI Text*. Note however that using full life cycle GHG estimates (as we do here) renders the GHG approach distinct from those for the other metrics, which address only the feed production phase in total production.

The animal-based portion of the US diet uses ≈0.6 million km^2 for crops and processed roughage, equivalent to ≈40% of all US cropland or ≈2,000 m^2 per person. The total requirements, including pasture land, amount to ≈3.7 million km^2, equivalent to ≈40% of the total land area of the United States or ≈12,000 m^2 per person. Feed production requires ≈45 billion m^3 of irrigation water, equal to ≈27% of the total national irrigation use (48), or ≈150 m^3 per person per year, which is comparable to overall household consumption. It also uses ≈6 million metric tons of Nr fertilizer annually, about half of the national total. Finally, GHG emissions total 0.3×10^{12} kg CO_{2e} which is ≈5% of total US emissions (49), or 1.1 t per person per year, equivalent to about 20% of the transportation sector emissions.

We find that the five animal categories are markedly dichotomous in terms of the resources needed per consumed calories as shown in Fig. 2 *A–D*. Beef is consistently the least resource-efficient of the five animal categories in all four considered metrics. The resource requirements of the remaining four livestock categories are mutually similar. Producing 1 megacalorie of beef requires ≈28, 11, 5, and 6 times the average land, irrigation water, GHG, and Nr of the other animal categories. Fig. 2 thus achieves the main objective of this paper, enabling direct comparison of animal based food categories by their resource use. Its clearest message is that beef is by far the least environmentally efficient animal category in all four considered metrics, and that the other livestock categories are comparable (with the finer distinctions Fig. 2 presents).

A possible objection to the above conclusion is that beef production partly relies on pastureland in the arid west, land that is largely unfit for any other cultivation form. Whereas most western pastureland is indeed unfit for any other form of food production, the objection ignores other societal benefits those arid lands may provide, notably ecosystem services and biodiversity. It further ignores the ≈0.16 million km^2 of high-quality cropland used for grazing and the ≈0.46 million km^2 of grazing land east of longitude 100°W that enjoy ample precipitation (50) and that can thus be diverted to food production. Even when focusing only on agricultural land, beef still towers over the other categories. This can be seen by excluding pasture resources and summing only crops and processed roughage (mostly hay and silage, whose production claims prime agricultural land that can be hypothetically diverted to other crops). After this exclusion, 1 Mcal of beef still requires ≈15 m^2 land (Fig. 2*A*), about twofold higher than the second least-efficient category.

As a yardstick, in Fig. 2 we compare animal categories to three plant staples for which we were able to gather data on all four metrics analyzed. Results for potatoes, wheat, and rice (*SI Text*, section 9) are shown by three downward pointing arrows at the top of Fig. 2 *A–D* accompanied by their initial letters (e.g., "r" for rice). Compared with the average resource intensities of these plant items per megacalorie, beef requires 160, 8, 11, and 19 times as much land, irrigation water, GHG, and Nr, respectively, whereas the four nonbeef animal categories require on average 6, 0.5, 2, and 3 times as much, respectively (Fig. S2). Although potentially counterintuitive, the irrigation water requirements reflect the fact that the bulk of land supplying livestock feed is rainfed, i.e., not irrigated. For example, for the two key caloric contributors to the diet of US livestock, corn and soy,

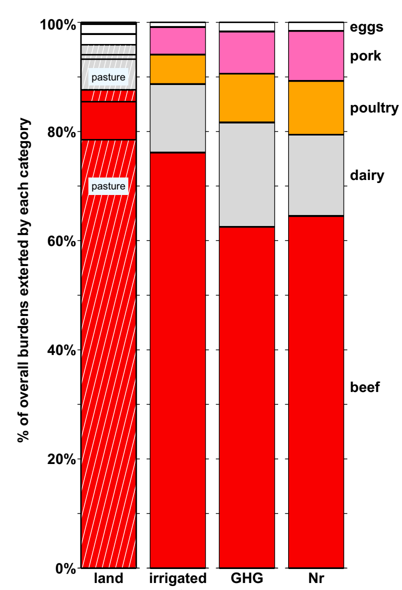

Fig. 3. Percentage of the overall national environmental burdens exerted by the individual animal categories. The results are obtained by multiplying the values of Fig. 2*E*, recast as annual overall national caloric consumption, by the resource per megacalorie of Fig. 2 *A–D*. Beef requires ≈88% of all US land allocated to producing animal-based calories, partitioned (from the bottom up) among pasture (≈79%), processed roughage (≈7%), and concentrated feed (≈2%). The land demands of dairy are displayed in the same format.

only 14% and 8% of the respective allocated lands are irrigated (≈44,000 km^2 and 25,000 km^2 of ≈300,000 km^2 each).

Our conclusions from the comparison among the five considered livestock categories are also valid, albeit slightly numerically modified, when analyzed per unit of protein consumed rather than on a caloric basis as shown in Fig. S1 and *SI Text*, section 6. For the analyzed plant items, whose protein content is lower, the differences are smaller by comparison with the livestock categories, as Fig. S1 shows. A detailed comparison of plant items calls for a dedicated future study. Such a study should also analyze high-protein plants such as soy and beans. We currently do not correct for differing protein digestibility whose relatively small quantitative effect (51) does not qualitatively change our results. We also do not account for differences in essential amino acid content. We note that the practical implications of protein sources in diverse diets are still vigorously debated (52) among nutritionists, and that the combined amino acid mass in current wheat, corn, rice, and soybean production exceeds the USDA recommended intake of these nutrients for the global human population.

Fig. 3 shows the partitioning of the total environmental burdens in the four metrics associated with feed production for the five livestock categories. We obtain these totals by multiplying the per calorie burdens depicted in Fig. 2 *A–D* by the caloric use shown in Fig. 2*E*. Fig. 3 thus identifies categories that dominate overall animal-based burdens, taking note of both resource efficiency and actual consumption patterns. Breaking down the total annual national burdens in each metric, Fig. 3 shows the dominance of beef over the environmental requirements of all other animal categories combined.

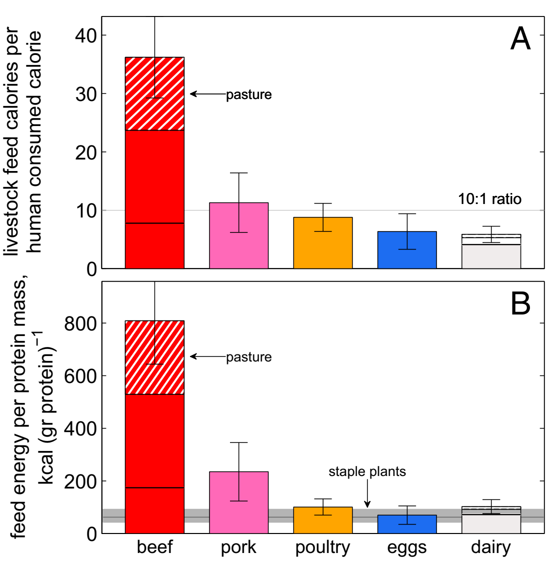

Fig. 4. Feed-to-food and feed-to-protein conversion factors of different livestock categories. The bar height of each category in *A* shows the total livestock feed calories used divided by the human-consumed calories they yield. For example, the value of ≈9 for poultry indicates that, on average, 9 feed calories fed to poultry yield 1 calorie consumed by humans. Note that this factor includes the approximately twofold loss reported by the USDA in the post-farm gate supply chain from primary production through retail to the consumer. The often-quoted 10:1 conversion factor per trophic level arising from studies in ecology is marked as a gray line. *B* depicts the conversion factors from livestock feed to human-consumed protein mass. For beef and dairy, the contribution of concentrates, processed roughage, and pasture is presented from the bottom to the top, respectively. The gray area marks the upper and lower bounds of the three staple plants. Error (uncertainty) bars indicate SD. See *SI Text* for calculation details.

The broad resource demand ranges of Fig. 2 *A–D* partly stem from differences in the basic biology-governed capacity of different farm animals to convert feed energy into calories consumed by humans. Fig. 4*A* quantifies these conversion factors from feed to consumed food for current US agricultural practices and exhibits a wide range, with beef three to six times less efficient than the other (largely mutually comparable) livestock categories. Modern, mostly intensive, US beef production is thus an energy conversion pathway about fourfold less efficient than other livestock. This value is in line with earlier analyses (53) and updates those analyses to reflect current data and practices. Comparing Figs. 2 and 4 suggests that biology does not explain all of the unusually high resource requirements of beef depicted in Fig. 2. Such results and methodology can also be used to quantify the tradeoffs associated with beef production relying primarily on grazing versus on processed roughage and concentrates; whereas grass-fed beef requires more pasture land, its irrigation water and Nr fertilizer needs are lower. In Fig. 4*B* we further show the conversion factor from feed calories to protein mass for each of the animal categories.

Discussion

How does the relative resource consumption calculated in this study compare with the caloric composition of the current mean US diet? In stark contrast with Fig. 2 *A–D*, Fig. 2*E* shows this composition and demonstrates the suboptimality of current US consumption patterns of animal-based foods with respect to the four environmental metrics considered. Beef, the least efficient against all four metrics, is the second most popular animal category in the mean US diet, accounting for 7% of all consumed calories. Interestingly, dairy, by far the most popular category, is not more efficient than pork, poultry, or eggs.

Because our results reflect current US farm policies and agrotechnology, the picture can change markedly in response to changes in agricultural technology and practice, national policies, and personal choice. By highlighting the categories that can most effectively reduce environmental resource burdens, our results can help illuminate directions corrective legislative measures should ideally take. Although our analysis is based on US data, and thus directly reflects current US practices, globalization-driven rapid diffusion of US customs, including dietary customs, into such large and burgeoning economies as those of China or India, lends a global significance to our analysis.

Corrective legislative measures are particularly important because, in addition to ethnic and cultural preferences, current consumption patterns of several food types partly track government policies (such as price floors, direct subsidies, or countercyclical measures). For example, at least historically, the caloric dominance of dairy in the US diet is tied to governmental promotion of dairy through marketing and monetary means (54), and meat ubiquity partly reflects governmental support for grain production, a dominant subsidy recipient in the agricultural sector. Our results thus offer policymakers a method for calculating some of the environmental consequences of food policies. Our results can also guide personal dietary choices that can collectively leverage market forces for environmental betterment. Given the broad, categorical disparities apparent in our results, it is clear that policy decisions designed to reduce animal-based food consumption stand to significantly reduce the environmental costs of food production (55) while sustaining a burgeoning populace.

Materials and Methods

Analysis Boundaries. For land, water, and Nr, we confine our analysis to resources used for feed production. First, on-farm use of these resources has been shown to be negligible by comparison. In addition, data addressing on-farm requirements are more geographically and temporally disparate, not always directly mutually comparable, and thus difficult to scale up into the national level our analysis requires.

We focus on irrigation water (i.e., blue water), neglecting direct precipitation on plants (i.e., green water) as the latter is not directly accessible for alternative human uses. Disregarding green water follows recent studies (10, 56, 57) that favor this approach and point out the large differences between results of studies that focus on irrigation water and those based on combining all water resources.

Beside feed-related costs, livestock production also involves non-CO_2 GHG emissions due to manure management and enteric emissions. These GHG burdens are included in the published LCAs we use in this study (refs. 17, 19–21, 23, 28, 29, and 58 and *SI Text*, section 7).

In analyzing the eutrophication potential of Nr, we address fertilizer use only, excluding manure and emissions of volatile nitrogenous compounds, which are considered in the GHG metric. The decision to focus the biogeochemistry portion of the work on nitrogen has several distinct motivations. First, N is by far the most widely applied nutrient, with application rates by nutrient mass approximately threefold higher than those of the other two agriculturally widely used nutrients, phosphate and potash. Second, because the geographical focus is North America, which has been glaciated recently, its soils and the fresh water systems that drain them are rarely P limited (59). Consequently, N dominates eutrophication and hypoxia in the estuaries and coastal ecosystems surrounding North America (60). Third, our focus on feed production implicitly focuses on the Midwest. This emphasizes the Gulf of Mexico Dead Zone, where N limitation dominates dissolved oxygen levels (61).

Correction for Export–Import. In evaluating national feed use, we take note of domestic consumption only, excluding and correcting for domestically produced exported feed. We similarly correct for net export–import of animal-based food items. To do so, we multiply the overall national resource use by a factor that reflects the export–import imbalance as a fraction of the total consumed calories of each animal category. For example, if 14% of the total pork produced is exported whereas imported pork is 5%, then we multiply each resource used domestically for pork production by 0.91. More details are given in *SI Text*.

Plant Staple Item Choice. We selected for analysis items for which we were able to gather information covering all four metrics, and that are a calorically significant part of the US diet. We note that low-caloric-content plant items, such as lettuce, have relatively high-resource burdens per calorie. As a result, these items do not lend themselves naturally to evaluation by either the per calorie or per gram protein metrics, and probably require a more nuanced, more revealing metric.

Feed Requirements and Fraction of Total Feed Supply of the Animal Categories. Our calculation of the total annual DM intake of each animal category begins with USDA data on livestock headcounts, slaughter weights, and feed requirements per head or slaughtered kilogram (ref. 38 and references therein). (See Dataset S1 for the raw data used and detailed analysis thereof.) We combine the intake requirements with USDA estimates of overall US feed production and availability by feed class (*SI Text*, section 2.1) (38), distinguishing and treating individually concentrated feed ("concentrates," meaning grains and byproducts), and roughage, subdivided into pasture and processed roughage (the latter combining hay, silage, haylage, and greenchop). Most used data are temporal averages over the years 2000–2010 of USDA reports. All data sources are referenced individually in *SI Text*, section 2.1, including USDA grain, oil, and wheat yearbooks; the 2011 Agriculture Statistics Yearbook; and, for pasture, an earlier study by Eshel et al. (38). The soy calculations are an exception to this pattern. They comprise soy feed and residual use plus 60% of crushed (i.e., the caloric and economic fraction of crushed soybean that goes into soybean meal feed). These data jointly yield our feed requirement estimates for each livestock category–feed class combination. The calculations presented take note of several issues. First, feed used by sheep and goats, whose meat jointly constitutes <1% of the American human diet's calories (44), and the more substantial amount of feed consumed by horses, is estimated. These feed values are subtracted from the national available feed totals, to arrive at the feed consumed by the five major edible livestock categories. A second issue is that pasture feed contributions are unknown, and are thus inferred by subtracting the known overall concentrates and processed roughage availability from the total livestock feed requirements. The concentrated feed requirements of poultry, pork, and eggs, which only consume concentrated feed, follow directly from their total feed requirements. From the fractions the three feed classes constitute in dairy rations reported in the cited literature, dairy's total requirements by feed class are obtained (38). Next, beef concentrated feed use is calculated as the total national supply of concentrates minus the combined use by poultry, pork, eggs, and dairy. Following a similar procedure, the processed roughage requirement of beef is inferred as the total available minus the fraction consumed by dairy. Finally, pasture needs of beef are inferred by subtracting from the known total beef feed needs the calculated contributions to these needs made by concentrates and processed roughage. More information is given in *SI Text* and in ref. 38.

We note that the USDA maintains records related to consumption of the main feed sources by the five livestock categories as part of the data yielding Animal Unit indices (62). In principle, this data can facilitate the sought partitioning. However, the underlying conversion factors used to translate headcounts into Animal Units have not changed since the late 1960s, when the USDA first introduced the indices. Because they are based on outdated farm practices markedly different from those used today, using them for environmental cost partitioning is questionable (63).

Byproducts in Beef Feed. One can suggest that beef should be credited in the environmental impact calculus for its ability to use as feed byproducts that would otherwise constitute waste in need of environmentally acceptable disposal. We do not follow this approach here for two reasons. First, such credits do not currently exist, and devising them in an environmentally and arithmetically sound manner is a major undertaking in its own right that we deem outside the current scope. On a more practical level, in addition, our preliminary analysis has established that the total mass of all byproducts (excluding soy meal) is less than 10% of the feed requirements of beef, and thus of small quantitative effect.

Aggregating and Allocating Environmental Burdens. We calculate and aggregate resources (land, irrigation water, and Nr) associated with individual feed types (various crops and hay types; *SI Text*, sections 2.2–2.4) into the three feed classes (concentrates, processed roughage, and pasture) by combining data on feed use, crop yields, irrigation, and nitrogen fertilizer application rates for each crop type and for pasture lands (*SI Text*, section 3). We then partition the overall resource use of each feed class among the five animal categories using the partition coefficients previously calculated (Table S1 and ref. 38) to determine the resources attributable to each animal category (*SI Text*, section 4).

Finally, we divide the total resource use of each animal category (mass GHG emitted and Nr applied, volume of water used for irrigation, and allocated land area for feed) by the contribution of that category to the total US caloric intake, obtaining the resource requirements per human-destined megacalorie. Replacing human destined calories with human-destined protein mass, we use a similar methodology to calculate resource requirements per unit of human-consumed protein (Fig. S1 and *SI Text*, section 6).

Derivation of Uncertainty Estimates. The uncertainty ranges for the raw data are based on variability among independent data sources or interannual variability. In the few cases where neither is available, we use as default an uncertainty of 10% of the parameter value.

We calculate uncertainty estimates using two distinct approaches. Dataset S1 contains traditional formal error propagation. We went to some length to properly handle cases with nonzero cross-covariance. A typical but by no means unique example of this involves feed requirements of, say, beef and the total feed requirement of all animal categories (which includes beef). In addition, we use Monte Carlo bootstrapping Matlab code (Mathworks) to perform 10,000 repeats, in each choosing at random subsets of the raw data, obtaining the end results, and deriving uncertainty ranges in the reported calculations from the distribution of end results thus obtained. Both methods yield similar but not identical uncertainty estimates. We believe the discrepancies, ≈10% on average, stem from imperfect account of all cross-correlations by the formal error propagation. We present the uncertainty estimates (SDs) based on the formal (parametric) error propagation, as we favor the method most easily available for future researchers.

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SUSTAINABILITY SCIENCE

Exhibit 7

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Review Article

Holistic Management: Misinformation on the Science of Grazed Ecosystems

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Over 3 billion hectares of lands worldwide are grazed by livestock, with a majority suffering degradation in ecological condition. Losses in plant productivity, biodiversity of plant and animal communities, and carbon storage are occurring as a result of livestock grazing. Holistic management (HM) has been proposed as a means of restoring degraded deserts and grasslands and reversing climate change. The fundamental approach of this system is based on frequently rotating livestock herds to mimic native ungulates reacting to predators in order to break up biological soil crusts and trample plants and soils to promote restoration. This review could find no peer-reviewed studies that show that this management approach is superior to conventional grazing systems in outcomes. Any claims of success due to HM are likely due to the management aspects of goal setting, monitoring, and adapting to meet goals, not the ecological principles embodied in HM. Ecologically, the application of HM principles of trampling and intensive foraging are as detrimental to plants, soils, water storage, and plant productivity as are conventional grazing systems. Contrary to claims made that HM will reverse climate change, the scientific evidence is that global greenhouse gas emissions are vastly larger than the capacity of worldwide grasslands and deserts to store the carbon emitted each year.

1. Introduction

Lands grazed by livestock include 3.4 billion ha worldwide with 73% estimated to be suffering soil degradation [1]. The solution presented during Allan Savory's February 2013 TED Talk was to use holistic management (HM) to reverse desertification and climate change [2]. He reported that we are creating "too much bare ground" (1:30 in video) in the arid areas of the world and, as a consequence, rainfall runs off or evaporates, soils are damaged, and carbon is released back to the atmosphere. Grasslands, even in high rainfall areas, may contain large areas of bare ground with a crust of algae, leading to increased runoff and evaporation. Desertification is caused by livestock, "overgrazing the plants, leaving the soil bare, and giving off methane" (4:20 in video).

HM is also called holistic resource management, time controlled grazing, Savory grazing method, or short-duration grazing. It is designed to mimic the behavior of grazing animals that are regulated by their predators to gather in large groups. As Savory puts it [2], "What we had failed to understand was that these seasonal humidity environments of the world, the soil and the vegetation developed with very large numbers of grazing animals, and that these grazing animals developed with ferocious pack-hunting predators. Now, the main defense against pack-hunting predators is to get into herds, and the larger the herd, the safer the individuals. Now, large herds dung and urinate all over their own food, and they have to keep moving, and it was that movement that prevented the overgrazing of plants, while the periodic trampling ensured good cover of the soil, as we see where a herd has passed." (9:28 in video). In view of the large amount of attention received from the TED talk it is important to examine the validity of Savory's claims.

Savory's writings lack specifics that could be used for implementation of HM or for scientific testing. Details regarding setting of stocking rates, allowable use by livestock, amount of rest needed for recovery, or ecological criteria to be met for biodiversity, sustainability, wildlife, and watershed protection are absent [3–7]. These publications by Savory and his colleagues show that HM is based on the following assumptions: (1) plant communities and soils of the arid, semiarid, and grassland systems of the world evolved in the presence of large herds of animals regulated by their predators; (2) grasses in these areas will become decadent and die out if not grazed by these large herds or their modern day equivalent, livestock; (3) rest from grazing by these large herds of livestock will result in grassland deterioration; (4) large herds are needed to break up decadent plant material and soil crusts and trample dung, urine, seeds, and plant material into the soil, promoting plant growth; and (5) high intensity grazing of these lands by livestock will reverse desertification and climate change by increasing production and cover of the soil, thereby storing more carbon.

We address these five assumptions of HM with a focus on western North American arid and semiarid ecosystems, principally in the desert, steppe, grassland, and open conifer woodland biomes as described by [8]. We use the broad term, grassland, to be inclusive of these types.

2. Are Western North American Ecosystems Adapted to Herds of Large Hooved Animals?

Not all of today's grasslands, arid, and semiarid systems evolved with herds of large, hooved animals. The Great Plains of North America and subtropical grasslands in Africa that receive moisture during the long, warm, and moist growing season historically supported millions of herbivores [9–11]. Lands west of the Continental Divide of the USA, including the Great Basin, Sonoran, Mojave, and Colorado Plateau deserts, along with the Palouse Prairie grasslands of eastern Washington, western Montana, and northern Idaho, did not evolve with significant grazing pressure from bison (*Bison bison*) [9, 12, 13]. Though bison were abundant east of the Rockies on the Great Plains, they only occurred in limited numbers across western Wyoming, northeastern Utah, and southeastern Idaho [12, 14]. These low numbers and patchy occurrence would not have played the same ecological role as in the plains. Historically, pronghorn antelope (*Antilocapra americana*) were more widespread than bison west of the Rockies, but these animals are smaller and lighter than bison and are not ecologically comparable [9]. Evidence for this general lack of large herds of grazing animals west of the Rockies also includes the lack of native dung beetles in the region. Whereas 34 native species of dung beetle (g. *Onthophagus*) are found east of the Rockies on the plains where bison were numerous, none are found west of the Rockies [15].

The supposition that current western North American plant communities are adapted to livestock grazing because the region supported a diverse herbivore fauna during the Pleistocene epoch ignores that the plant communities have changed in the intervening time [16]. There was rapid evolutionary change following the Pleistocene glaciations in North America with "the establishment of open xeric grasslands in the west central part of the USA . . . less than 10,000 years ago" [17]. Many of the grasses of the Pleistocene have disappeared from the plains and western USA and the fauna of the Pleistocene was altered by the arrival of bison from Eurasia. These were destructive to long-leaved bunchgrasses found west of the Rockies, while the rhizomatous grasses found east of the Rockies in the prairies were more resistant to their grazing pressure. These rhizomatous grasses are the types found in the prairies of the central and western USA in conjunction with fossil remains of bison. In summary, the western USA of the Pleistocene is not the western USA of today. The climate was much wetter and cooler and the vegetation more mesic in the Pleistocene than today [8, 18]. The drier periods following the Pleistocene as temperatures warmed have altered soil conditions and fire cycles and contributed to the changing flora [19, 20].

Grasslands cover large areas that could support forests but are maintained by grasses outcompeting woody species for belowground resources and providing fuel for fires that limit encroachment of woody species [21]. Climate change and increasing CO_2 concentrations have been implicated in the post industrial expansion of woody species and invasive species into grasslands; however, studies from paired locations in grasslands have shown that under similar climatic and CO_2 environments, herbivory by domestic livestock has caused the shifts in woody species and increased invasive species [20, 22, 23]. Elevated CO_2 and climate warming appear to contribute to, but do not explain, the shrub encroachment in these semiarid areas which is due to intensive grazing by domestic livestock [24].

Conclusion. Western US ecosystems outside the prairies in which bison occurred are not adapted to the impact of large herds of livestock. Recent changes to these grassland ecosystems result from herbivory by domestic livestock which has altered fire cycles and promoted invasive species at the expense of native vegetation.

3. Do Grasses Senesce and Die If Not Grazed by Livestock?

A major premise of HM is that grass species depend on large grazing ungulates in some way, and thus grasses become moribund and die if not grazed, leading to deterioration or eventual loss of the entire grass community [6]. The dead or dormant residual leaves and stalks that remain attached to ungrazed grasses at the end of each growing season can be deceptive. The plants are still alive and healthy, with living buds at the plant base. Bunchgrass canopies collect snow and funnel rainwater to the plant base and soil and increase infiltration [25]. The plants and dead leaves in contact with the soil reduce overland flow and erosion [26]. Plant canopies moderate temperature and protect the growing points from temperature extremes [27]. The standing dead litter provides cover and food for wildlife species including large and small mammals, ground-living birds, and insects. The loss of these leaves and stems through heavy grazing by livestock which occurs under HM destroys these natural attributes.

Grasses with attached dead leaves are more productive than grasses from which the dead leaves have been removed. Loss of these dead tissues to grazers increases thermal damage to the growing shoots and reduces the vigor of the entire plant [28]. Dead leaves and flowering stalks on ungrazed grasses inhibit livestock grazing, allowing those grasses to grow larger than their neighbors [29]. Grazing and trampling by domestic livestock damage plants in natural plant communities [30–32], reduce forage production as stocking rates increase [33], and can lead to simplification of plant communities, establishment of woody vegetation in grasslands, and regression to earlier successional stages [20] or conversion to invasive dominated communities [23] and altered fire cycles [20]. In contrast to the assertion that grasses will die if not grazed by livestock, bunchgrasses in arid environments are more likely to die if they are heavily grazed by domestic animals [34, 35].

Conclusion. Grasses, particularly bunchgrasses, have structure that protects growing points from damage, harvests water, and protects the soil at the plant base. Removal of the standing plant material exposes the growing points, leading to loss or replacement by grazing tolerant species, including invasives.

4. Does Rest Cause Grassland Deterioration?

Another principle of HM is that grasslands and their soils deteriorate from overrest, a term that implies insufficient grazing by livestock. However, grasslands that have never been grazed by livestock have been found to support high cover of grasses and forbs. Relict sites throughout the western USA, such as on mesa tops, steep gorges, cliff sides, and even highway rights of way, which are inaccessible to livestock or most ungulates, can retain thriving bunchgrass communities [36–38]. For example, herbaceous growth was vigorous on never-grazed Jordan Valley kipukas in southeast Oregon [37] and on a once-grazed butte called The Island in south central Oregon [36]. Published comparisons of grazed and ungrazed lands in the western USA have found that rested sites have larger and more dense grasses, fewer weedy forbs and shrubs, higher biodiversity, higher productivity, less bare ground, and better water infiltration than nearby grazed sites. These reports include 139 sites in south Dakota [39], as well as sites that had been rested for 18 years in Montana [40], 30 years in Nevada [41], 20–40 years in British Columbia [42], 45 years in Idaho [43], and 50 years in the Sonoran Desert of Arizona [44]. None of the above studies demonstrated that long periods of rest damaged native grasslands. A list and description of such sites can be found in [45].

The HM misinterpretation of the natural history of grazed and ungrazed grasslands is apparent in Savory's description of the Appleton-Whittell Research Ranch in southeastern Arizona [6]. This ranch has been protected from livestock grazing since 1968 with the grasses on the ranch described by Savory as becoming "moribund" (page 211), with "bare spots opening up" (page 211). In contrast to those claims, plant species richness on the ranch increased from 22 species in 1969 to 49 species in 1984, while plant cover increased from 29% in 1968 to 85% in 1984 [46]. Total grass cover on the ranch was significantly higher on ungrazed sites when compared to grazed sites ($P < 0.01$) [47]. These well designed studies produced quantitative data showing that the HM view of the ranch is not the case.

Conclusion. Contrary to the assumption that grasses will senesce and die if not grazed by livestock, studies of numerous relict sites, long-term rested sites, and paired grazed and ungrazed sites have demonstrated that native plant communities, particularly bunchgrasses, are sustained by rest from livestock grazing.

5. Is Hoof Action Necessary for Grassland Health?

A key premise of HM is that livestock can be made to emulate native ungulate responses to predators by moving them frequently in large numbers and tight groups. This promotes very close cropping which is said to benefit grasses and other forage, as well as hoof action that breaks up soil crusts, increases infiltration, plants seeds, and incorporates plant material, manure, and urine into the soil [6]. Other than bison in the plains states, the evidence indicates a low frequency of large hooved mammals in the western USA during pre-Columbian times [48], so the opportunity for hoof action to sustain grasslands and deserts appears limited at best. In contrast to HM claims, elk (*Cervus canadensis*), mule deer (*Odocoileus hemionus*), and other ungulates may avoid areas where predators have an advantage in capturing them [49]. Avoidance is not the same as a panicked flight or tight groupings of animals promoting hoof action. Rather, the major response is greater vigilance and sometimes avoidance of risky areas. While the presence of wolves (*Canis lupus*) affects elk behavior by reducing browsing on willows and aspen [50], snow depth and other ecological needs appear to outweigh the effect of wolves leading to grazing and browsing in areas of higher risk [51, 52]. We found no documentation of native animal responses to predators generating hoof action or herd effect in tight groupings in the western USA.

Soils in arid and semiarid grasslands often have significant areas covered by biological crusts [53–55]. These are made up of bacteria, cyanobacteria, algae, mosses, and lichens and are essential to the health of these grasslands. Biological crusts stabilize soils, increase soil organic matter and nutrient content, absorb dew during dry periods, and fix nitrogen [53, 56–60]. Crusts enhance soil stability and reduce water runoff by producing more microcatchments on soil surfaces. They increase water absorbing organic matter, improve nutrient flow, germination and establishment for some plants, while dark crusts may stimulate plant growth by producing warmer soil temperatures and water uptake in cold deserts [61]. Some crusts are hydrophobic, shedding water [60]. Biological soil crusts are fragile, highly susceptible to trampling [61–63], and are slow to recover from trampling impacts [64]. Loss of these crusts results in increased erosion and reduced soil fertility. The loss of crusts in the bunchgrass communities of the western USA may be largely responsible for the widespread establishment of cheatgrass and other exotic annuals [23, 58, 65]. The rapid spread of introduced weeds throughout the arid western USA is estimated at over 2000 hectares per day [66], largely due to livestock disturbance.

The HM assumption that increasing hoof action will increase infiltration has been disproven. Livestock grazing can compact soil, reduce infiltration, and increase runoff, erosion, and sediment yield [67–71]. Major increases in erosion and runoff occur under normal stocking when comparing grazed to ungrazed sites [68, 71–74]. Extensive literature reviews report the negative impacts of livestock grazing on soil stability and erosion [75–77]. For example, a study of wet and dry meadows in Oregon found the infiltration rate in ungrazed dry meadows was 13 times greater and 2.3 times greater in ungrazed wet meadows, compared to similar grazed meadows [78].

Hoof action is not needed to increase soil fertility and decomposition of litter. It is well-established that soil protozoa, arthropods, earthworms, microscopic bacteria, and fungi decompose plant and animal residues in all environments [79, 80]. Even the driest environments contain 100 million to one billion decomposing bacteria and tens to hundreds of meters of fungal hyphae per gram of soil [81]. Brady and Weil [80] discuss the importance of mammals in the decay process, mentioning burrowing mammals, but not large grazers such as cattle and bison. Removal of plant biomass and lowered production resulting from livestock grazing can reduce fertility and organic content of the soil [70, 82–84].

Conclusion. We found no evidence that hoof action as described by Savory occurs in the arid and semiarid grasslands of the western USA which lacked large herds of ungulates such as bison that occurred in the prairies of the USA or the savannahs of Africa. No benefits of hoof action were found. To the contrary, hoof action by livestock has been documented to destroy biological crusts, a key component in soil protection and nutrient cycling, thereby increasing erosion rates and reducing fertility, while, increasing soil compaction and reducing water infiltration.

6. Can Grazing Livestock Increase Carbon Storage and Reverse Climate Change?

Among the most recent HM claims is that livestock grazing will lead to sequestration of large amounts of carbon, thus potentially reversing climate change [2]. However, any increased carbon storage through livestock grazing must be weighed against the contribution of livestock metabolism to greenhouse gas emissions due to rumen bacteria methane emissions, manure, and fossil fuel use across the production chain [85, 86]. Nitrous oxide, 300 times more potent than methane in trapping greenhouse gases [87], is also produced and released with livestock production. The livestock industry's contribution to greenhouse gases also includes CO_2 released by conversion of forests to grasslands for the purpose of grazing [86].

Worldwide, livestock production accounts for about 37 percent of global anthropogenic methane emissions and 65 percent of anthropogenic nitrous oxide emissions with as much as 18% of current global greenhouse gas emissions (CO_2 equivalent) generated from the livestock industry [85]. It is estimated that livestock production, byproducts, and other externalities account for 29.5 billion metric tons of CO_2 per year or 51 percent of annual worldwide greenhouse gas emissions from agriculture [88]. Lower amounts of greenhouse gas emissions due to livestock may be estimated by using narrower definitions of livestock-related emissions that include feed based emissions only and exclude externalities [89].

Some suggest that grass-fed beef is a superior alternative to beef produced in confined animal feeding operations [90]. However, grass provides less caloric energy per pound of feed than grain and, as a consequence, a grass-fed cow's rumen bacteria must work longer breaking down and digesting grass in order to extract the same energy content found in grain, while the bacteria in its rumen are emitting methane [89]. Comparisons of pasture-finished and feedlot-finished beef in the USA found that pasture-finished beef produced 30% more greenhouse gas emissions on a live weight basis [91].

It is estimated that three times as much carbon resides in soil organic matter as in the atmosphere [92], while grasslands and shrublands have been estimated to store 30 percent of the world's soil carbon with additional amounts stored in the associated vegetation [93]. Long term intensive agriculture can significantly deplete soil organic carbon [94] and past livestock grazing in the United States has led to such losses [95, 96]. Livestock grazing was also found to significantly reduce carbon storage on Australian grazed lands while destocking currently grazed shrublands resulted in net carbon storage [97]. Livestock-grazed sites in Canyonlands National Park, Utah, had 20% less plant cover and 100% less soil carbon and nitrogen than areas grazed only by native herbivores [98]. Declines in soil carbon and nitrogen were found in grazed areas compared to ungrazed areas in sage steppe habitats in northeastern Utah [84]. As grazing intensity increased, mycorrhizal fungi at the litter/soil interface were destroyed by trampling, while ground cover, plant litter, and soil organic carbon and nitrogen decreased [84]. A review by Beschta et al. [20] determined that livestock grazing and trampling in the western USA led to a reduction in the ability of vegetation and soils to sequester carbon and also led to losses in stored carbon.

Conclusion. Livestock are a major source of greenhouse gas emissions. Livestock removal of plant biomass and altering of soil properties by trampling and erosion causes loss of carbon storage and nutrients as evidenced by studies in grazed and ungrazed areas.

7. What Is the Evidence That Holistic Management Does Not Produce the Claimed Effects?

HM is a management system that includes setting goals, monitoring, and adapting in order to continually move towards the goals established by the producer [6]. This more goal-oriented and adaptive management aspect of the HM system, its promise of environmental benefits, and increased production make it attractive to many ranchers [99]. However, researchers who have studied HM in South Africa and Zimbabwe, where Savory originated his theories, have rejected many of HM's underlying assumptions and found that HM approaches result in reduced water infiltration into the soil, increased erosion, reduced forage production, reduced soil organic matter and nitrogen, reduced mineral cycling, and increased soil bulk density [82, 100, 101].

In a recent evaluation of HM by Briske et al. [102], three of its principle claims were addressed: (1) all nonforested lands are degraded; (2) these lands can store all fossil fuel carbon in the atmosphere; and (3) intensive grazing is necessary to prevent the degradation. The authors pointed out that there are well managed lands that are not degraded; deserts are a consequence of climate and soils as well as improper management; and degradation is largely a function of growing populations of humans and livestock, land fragmentation, and other societal issues. As to the claim that these nonforested lands could store all the carbon emissions that humans produce, the researchers show that the potential carbon sequestration of these lands is only about one to two billion metric tons per year (mtpy), a small fraction of global carbon emissions of 50 billion mtpy. They further point out that these lands would have to produce much larger vegetation biomass than they are capable of producing in order to sequester human-caused carbon emissions and that much of the carbon is released back to the atmosphere through respiration as CO_2. They note that grass cover increases dramatically with rest and intensive grazing delays this recovery; many desert grassland soils are sandy, so hoof action does not increase infiltration; and biological crusts stabilize these soils and protect them from wind erosion and carbon loss.

A review of short-duration grazing studies in the western USA by Holechek et al. [83] included locations in the more arid western states as well as prairie types. The researchers found that this grazing system, which is equated with HM, resulted in decreased infiltration, increased erosion, and reduced soil organic matter and nitrogen. Forage production and range condition were similar under short-duration and continuous grazing with the same stocking rates. Under short-duration grazing, standing crop of forage declined as stocking rates increased, while bare ground and vegetation composition were a function of stocking rate as opposed to grazing system. Grazing distribution was not improved over continuous grazing and the claims for hoof action and improved range condition under increased stocking rates and densities were not realized [83]. Another review of grazing systems by Briske et al. [103], including HM, versus continuous grazing concluded that plant and animal production were equal or greater in continuous grazing than in rotational grazing systems.

Even though the ecosystems of the Great Plains states evolved with the pressure of bison, Holechek et al. [83] and Briske et al. [103] found that HM did not differ from traditional, season-long grazing for most dependent variables compared. Studies commonly held up as supporting HM [104–108] used HM paddocks that were grazed with light to moderate grazing, not the heavy grazing that Savory recommends. Further, long-term range studies have shown that it is reductions in stocking rate that lead to increased forage production and improvements in range condition, not grazing system [33, 109, 110]. While HM advocates allowing recovery to take place following grazing, recovery can take many years to decades even under total rest from livestock, but it does occur [43, 111]. Native, western USA bunchgrass species such as bluebunch wheatgrass (*Pseudoroegneria spicata*) and Idaho fescue (*Festuca idahoensis*) are sensitive to defoliation and can require long periods (years) of rest following each period of grazing in order to restore their vigor and productivity [34, 35].

Conclusion. Studies in Africa and the western USA, including the prairies which evolved in the presence of bison, show that HM, like conventional grazing systems, does not compensate for overstocking of livestock. As in conventional grazing systems, livestock managed under HM reduce water infiltration into the soil, increase soil erosion, reduce forage production, reduce range condition, reduce soil organic matter and nutrients, and increase soil bulk density. Application of HM cannot sequester much, let alone all the greenhouse gas emissions from human activities because the sequestration capacity of grazed lands is much less than annual greenhouse gas emissions.

8. What about Riparian Areas and Biodiversity?

In the western USA, riparian areas are rare and valuable ecological systems supporting a disproportionate number of species and providing many ecosystem services [112]. How does HM, with its emphasis on high stocking rates and trampling, affect these systems? Soil compaction from livestock is a common and widespread problem in grazed riparian areas, reducing infiltration rates and water storage and increasing surface runoff and soil erosion during storm events [78, 112]. Soil compaction from livestock increases with increased numbers, as in an HM application [70]. Livestock grazing in riparian areas reduces willow and herbaceous production and canopy cover of shrubs and grasses compared to ungrazed controls [113]. The most effective way to restore damaged riparian areas is to remove livestock [110, 112].

We found very little information about total number of plant, animal, or invertebrate species present when HM is compared to other grazing methods or nongrazed areas, and, further, what proportion of total plant species or total cover of plant species was native or nonnative. Moreover, we did not see other biodiversity considerations addressed in any of the published studies investigating HM. Rotational grazing systems do not improve range condition and plant production over conventional grazing systems [83, 103], while stocking rate is considered the most important variable affecting vegetation production and range condition [33]. Range condition is determined based on the current plant community composition and production as compared to the potential natural community [114]. The relative composition of Increasers, those plants with tolerance for grazing, Decreasers, those plants with low tolerance for grazing, and Invasives, those plants occupying a site that are grazing tolerant and nonnative, forms the basis of the determination of condition. Higher range condition ratings reflect greater similarity to the native plant community for a site [115]. This basic concept reflects the biodiversity of the native plant community, which necessarily declines as range condition declines. Application of HM with its large herd size and density of use, like other grazing systems with high stocking rates, must necessarily decrease native plant diversity and productivity. This affects the animal communities accordingly as habitat structure and production are altered.

A review, by Fleischner [76], of the effects of livestock grazing on plant and animal communities in the western USA found that livestock grazing reduced species richness and abundance of plants, small mammals, birds, reptiles, insects, and fish compared to conditions following removal of livestock. A quantitative review by Jones [77] of published studies of ecosystem attributes in North American arid ecosystems affected by livestock grazing, compared to ungrazed conditions, found decreases in rodent species richness and diversity and vegetation diversity in the grazed areas. Livestock grazing-induced simplified plant communities in western USA arid and semiarid lands have negative effects on pollinators, birds, small mammals, amphibians, wild ungulates, and other native wildlife [20]. Riparian songbird abundance increases as riparian systems recover after livestock exclusion [116, 117], while overall biodiversity increases under long term rest from livestock grazing [46, 47, 118]. Invasives such as cheatgrass (*Bromus tectorum*) are favored and increase in abundance in the presence of livestock grazing [23, 65] and are inversely related to abundance of native perennial grasses [43].

Conclusion. HM does not address riparian areas and biodiversity with its focus on livestock production, although operators could choose these as goals. We have seen no studies of HM impacts on riparian areas and biodiversity, although livestock grazing impacts on riparian areas and biodiversity have been well documented. Livestock degrade riparian areas by removal of streamside vegetation, reduction of cover and food for fish and wildlife, and soil compaction, erosion, and sedimentation. These impacts lead to loss of native fish and wildlife populations. Studies in areas from which livestock have been removed demonstrate increases in diversity and abundance of birds, mammals, insects, and fish.

9. Is Scientific Evidence Important?

Effectiveness studies of HM have been undertaken by ranchers and farmers who were selected because of their commitment to HM [119]. In other words, such studies were neither experimental nor were the participants randomly selected. Livestock producers who may have had negative experiences with HM were not included in the studies. Nearly all of the support and confirmation for HM come from articles developed at the Savory Institute or testimonials by practitioners. Most of the published literature that attempts to rigorously test HM in any scientific fashion does not support its principal assumptions.

Holechek et al. [83] stated that "No grazing approach, including that of Savory, will overcome the adverse effects of drought and/or chronic heavy stocking on forage production." These researchers were also critical of government agencies for adopting these unproven theories rather than basing management on "scientifically proven range management practices and principles" [83] (page 25). Briske et al. [103] stated,

> the rangeland profession has become mired in confusion, misinterpretation, and uncertainty with respect to the evaluation of grazing systems and the development of grazing recommendations and policy decisions. We contend that this has occurred because recommendations have traditionally been based on perception, personal experience, and anecdotal interpretations of management practices, rather than evidence-based assessments of ecosystem responses. [103] (page 11).

Briske et al. [102] state, "Mr. Savory's attempts to divide science and management perspectives and his aggressive promotion of a narrowly focused and widely challenged grazing method only serve to weaken global efforts to promote rangeland restoration and C sequestration." [102] (page 74).

Conclusion. Studies supporting HM have generally come from the Savory Institute or anecdotal accounts of HM practitioners. Leading range scientists have refuted the system and indicated that its adoption by land management agencies is based on these anecdotes and unproven principles rather than scientific evidence. When addressing the application of HM or any other grazing systems, practitioners, including agencies managing public lands, private livestock operations, and scientists, should (1) consider inclusion of watershed-scale ungrazed reference areas of suitable size to encompass the plant and soil communities found in the grazed area, (2) define ecological (plant, soil, and animal community) and production (livestock) criteria on which to base quantitative comparisons, (3) use sufficient replication in studies, (4) and include adequate quality control of methods. Economic analysis of grazing systems should compare all expenditures with income, including externalized costs such as soil loss, water pollution, reduction of water infiltration, and carbon emissions and capture.

10. Management Implications

This review shows that the underlying assumptions of HM regarding the evolutionary adaptation of western North

American landscapes to large herds of hooved animals only applies to prairie grasslands and that most arid and semiarid areas of western North America are not adapted to their impacts. The premise that rest results in degradation of grassland ecosystems by allowing biological crusts to persist and grasses to senesce and die has been disproven by a large body of research. Reliance on hoof action to promote recovery by trampling seeds and organic matter into the soil and breaking up soil crusts needs to be considered in the context of increased soil compaction, lower infiltration rates, and the destruction of biological crusts that normally provide long-term stability to soil surfaces, enhance water retention, and promote nutrient cycling. The use of HM in an attempt to capture atmospheric greenhouse gases and incorporate them into soils and plant communities, thereby reducing climate change effects, is demonstrably impossible because the nonforested grazed lands of the world do not have the capacity to sequester this amount of emissions. Even in the prairie regions of the United States, which are evolutionarily adapted to large herbivores such as bison, research indicates that not only does HM not produce results superior to conventional season-long grazing, but also that stocking rate, rest, and livestock exclusion represent the best mechanisms for restoring grassland productivity, ecological condition, and sustainability. Various studies indicate livestock grazing reduces biodiversity of native species and degrades riparian areas, with nearly all studies finding livestock exclusion to be the most effective, reliable means to restore degraded riparian areas. Claims of the benefits of HM or other grazing systems should be validated by quantitative, scientifically valid studies.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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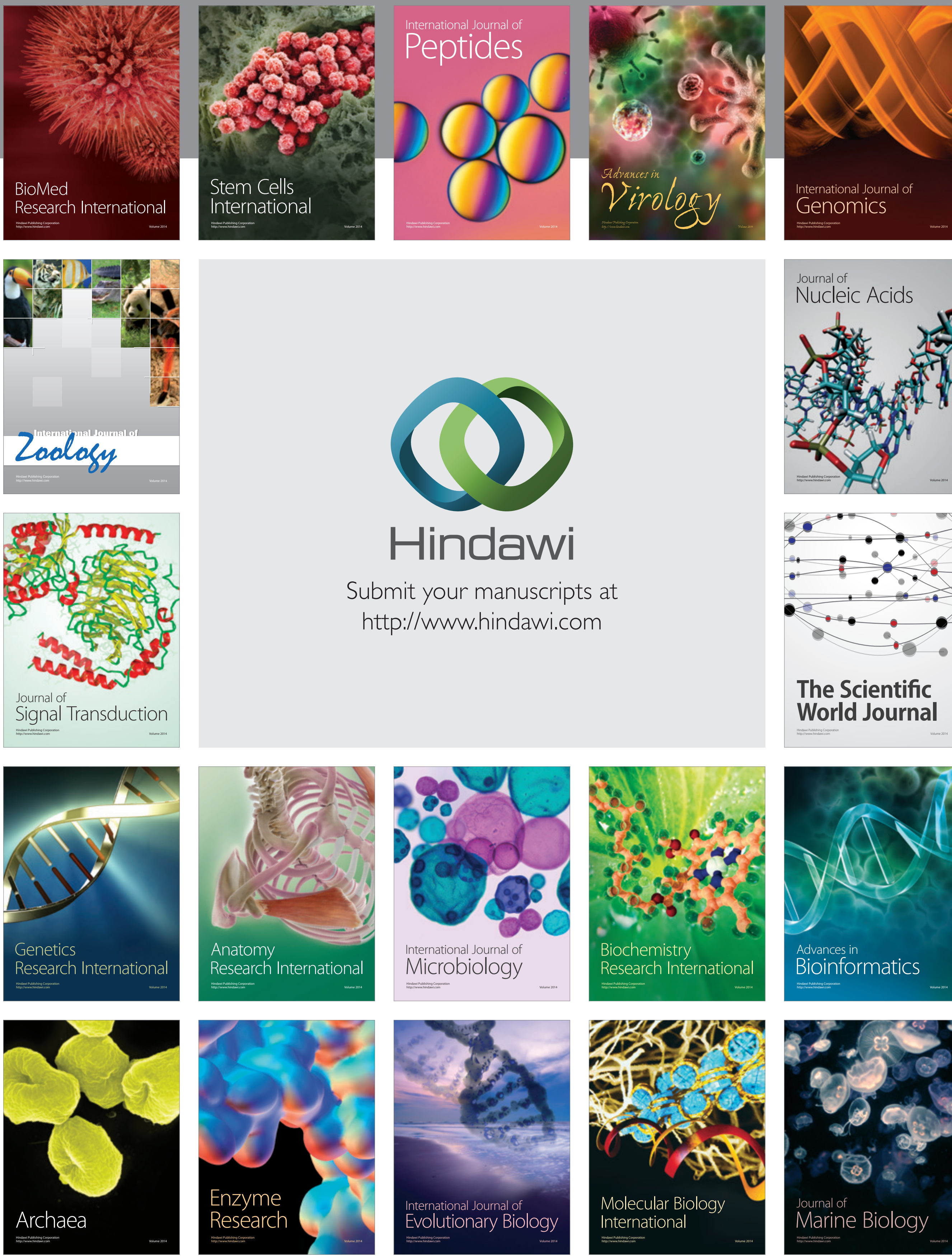

Exhibit 8

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Current situation and future trends for beef production in the United States of America — A review

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Abstract: USA beef production is characterized by a diversity of climates, environmental conditions, animal phenotypes, management systems, and a multiplicity of nutritional inputs. The USA beef herd consists of more than 80 breeds of cattle and crosses thereof, and the industry is divided into distinct, but ofttimes overlapping sectors, including seedstock production, cow-calf production, stocker/backgrounding, and feedlot. Exception for male dairy calves, production is predominantly pastoral-based, with young stock spending relatively brief portions of their life in feedlots. The beef industry is very technology driven, utilizing reproductive management strategies, genetic improvement technologies, exogenous growth promoting compounds, vaccines, antibiotics, and feed processing strategies, focusing on improvements in efficiency and cost of production. Young steers and heifers are grain-based diets fed for an average of 5 months, mostly in feedlots of 1,000 head capacity or more, and typically are slaughtered at 15 to 28 months of age to produce tender, well-marbled beef. Per capita beef consumption is nearly 26 kg annually, over half of which is consumed in the form of ground products. Beef exports, which are increasingly important, consist primarily of high value cuts and variety meats, depending on destination. In recent years, adverse climatic conditions (i.e., draught), a shrinking agricultural workforce, emergence of food-borne pathogens, concerns over development of antimicrobial resistance, animal welfare/well-being, environmental impact, consumer perceptions of healthfulness of beef, consumer perceptions of food animal production practices, and alternative uses of traditional feed grains have become increasingly important with respect to their impact on both beef production and demand for beef products. Similarly, changing consumer demographics and globalization of beef markets have dictated changes in the types of products demanded by consumers of USA beef, both domestically and abroad. The industry is highly adaptive, however, and responds quickly to evolving economic signals.

Keywords: Beef; Production Systems; Growth Promotion; Carcass Quality

INTRODUCTION

Beef production systems in the United States are characterized by a wide range of climates, environmental conditions, animal phenotypes, management practices, and a multiplicity of nutritional inputs. In contrast to international perceptions, USA production systems are, with the notable exception of male dairy calves, predominantly pastoral-based, with young stock typically spending relatively brief portions of their life in confinement facilities for finishing on high-concentrate diets. Beef production at the cow-calf level is widely distributed, and exists in all 50 states, spanning the range from tropical savannah to Arctic tundra, temperate plains, and mountain pastures. Vast differences in geographies and climatic conditions necessitate the use of a broad spectrum of animal phenotypes that are suited to these environments, encompassing both Bos taurus and Bos indicus breeds and crosses thereof. The feedlot phase of production, which normally is between 100 and 300 days duration, is heavily concentrated within the interior of the continental USA, and relies heavily on cereal grains and grain byproducts produced within this area as predominant feed resources, and feedlot cattle most commonly are marketed at ages ranging from 15 to 28 months. Production of beef in the U.S. historically has been very technology driven, utilizing reproductive management strategies, genetic improvement technologies, exogenous growth promoting compounds, vaccines, antibiotics, and feed processing strategies, all of which focused on improving efficiency and(or) decreasing cost of beef production. In more recent years, adverse climatic conditions (i.e., draught), a shrinking agricultural workforce, control of food-borne pathogens, concerns over development of antimicrobial resistance, animal welfare, animal well-being, environmental impact of confinement feeding operations, consumer perceptions of healthfulness of beef, consumer perceptions of food animal production practices, and alternative uses for traditional feed grains have become increasingly important with respect to their impact on both beef production and demand for beef products. Similarly, changing consumer demographics and globalization of beef markets have dictated changes in the types of products demanded from producers of U.S. beef. Beef production systems are thus increasingly dynamic in their nature, and poised to exploit new market opportunities by altering production practices to meet changing consumer demands.

GEOGRAPHICAL DISTRIBUTION OF U.S. COW-CALF OPERATIONS AND FEEDLOTS

As of January 31, 2018, total USA inventory of beef cows was estimated at 31.7 million head, with cow-calf operations in all 50 states [1]. The beef cow inventory fluctuates considerably from year to year, as shown in Figure 1, and can be influenced heavily by market conditions and environmental factors, such as persistent draught conditions. In the USA, about 320 million hectares are used for livestock grazing [2], which is equivalent to 41% of the total land area of the continental USA. Approximately 55% of all beef cows are maintained in the Central region of the continental USA [3], which is characterized by vast native grasslands and expansive production of row crops such as corn, soybeans, wheat, grain sorghum, and other crops. Roughly 20% of the national herd is in the Western region, commonly utilizing expansive land areas that are federally owned and leased to beef producers by government agencies. The Southeastern region, often typified by smaller production units that rely heavily on improved pastures, also is home to approximately 20% of the national herd. The remaining 5% are interspersed throughout the Northeast, Alaska, and Hawaii. Each of these regions makes use of very different systems of beef production, owing to a divergent range of climates and feed resources in each area. For example, western herds frequently employ federal lands for grazing in the spring and summer, and cattle then are removed from federal lands and overwintered on privately-owned pastures and/or fed harvested forages until the beginning of the next grazing cycle. By contrast, operations in the Central region frequently make use of a mixture of native grass pastures, crop residues, harvested forages, and protein concentrates to sustain their cow herds.

Feedlots, unlike cow-calf operations, are far more concentrated geographically, with over 72% of feedlot production occurring in the 5-state area [4] of Nebraska (19.8%), Texas (18.9%), Kansas (17.5%), Iowa (9.0%), and Colorado (7.1%). Concentration of feedlots in this area is largely driven by access to cereal grains and grain byproducts that predominate

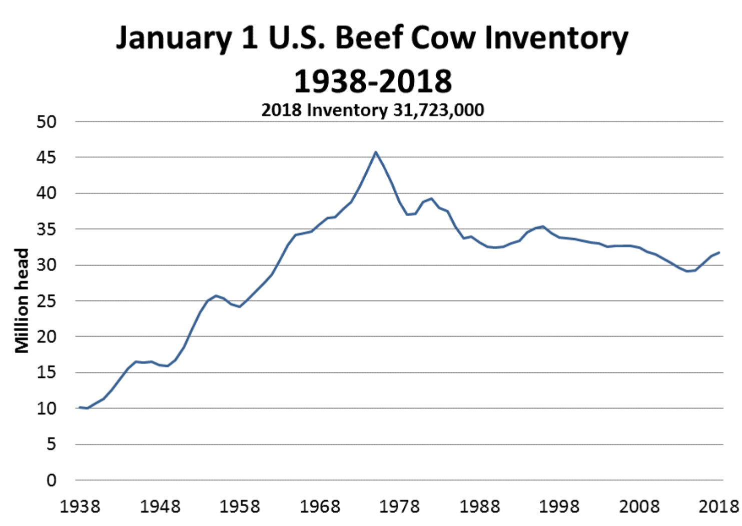

Figure 1. US beef cow inventory on January 1, from 1938 to 2018. Source: United States Department of Agriculture [1].

the diets of finishing cattle. Other important regions for cattle feeding have developed throughout the country in response to availability of low-cost feedstuffs, particularly byproduct feeds. For example, the Washington-Idaho region is a major site for production and processing of potatoes, fruits, and vegetables as foods for humans. Cattle feeding operations have developed in response to availability of large quantities of processed food residues in this region, and represent an important means for disposal of these byproducts, thereby creating additional value to the food chain.

CATTLE BREEDS USED FOR BEEF PRODUCTION IN THE UNITED STATES OF AMERICA

The USA beef herd is very heterogeneous in nature, consisting of more than 80 breeds and crosses thereof, and reflecting the diversity of environments in which they are produced. According to the most recent report on breed registrations by the National Pedigreed Livestock Council [5], member breed associations with the greatest number of registrations were Angus, Hereford, Simmental, Red Angus, Charolais, Gelbvieh, Brangus, Limousin, Beefmaster, Shorthorn, and Brahman. While this list gives some sense of the diversity of cattle types in the U.S., most cattle fed for slaughter actually are crossbreds, with 60% or more having some degree of Angus influence. Dairy breeds, most notably Holsteins, also make up a substantial portion of USA feedlot cattle, with as many as 3 to 4 million dairy calves being fed in USA feedlots each year.

USA SYSTEM FOR BEEF PRODUCTION

The USA system of beef production is highly segmented, often resulting in several changes of ownership between the time animals are weaned and slaughtered. Seedstock operations primarily produce bulls that are used to service cows in commercial cow-calf operations. The primary product of cow-calf operations is weaned calves, which are sold to stocker operators, backgrounding lots, or feedlots. Figure 2 illustrates the possible paths that animals may take through the beef production chain before being slaughtered. Calves from cow-calf operations generally follow one of two paths. They can be

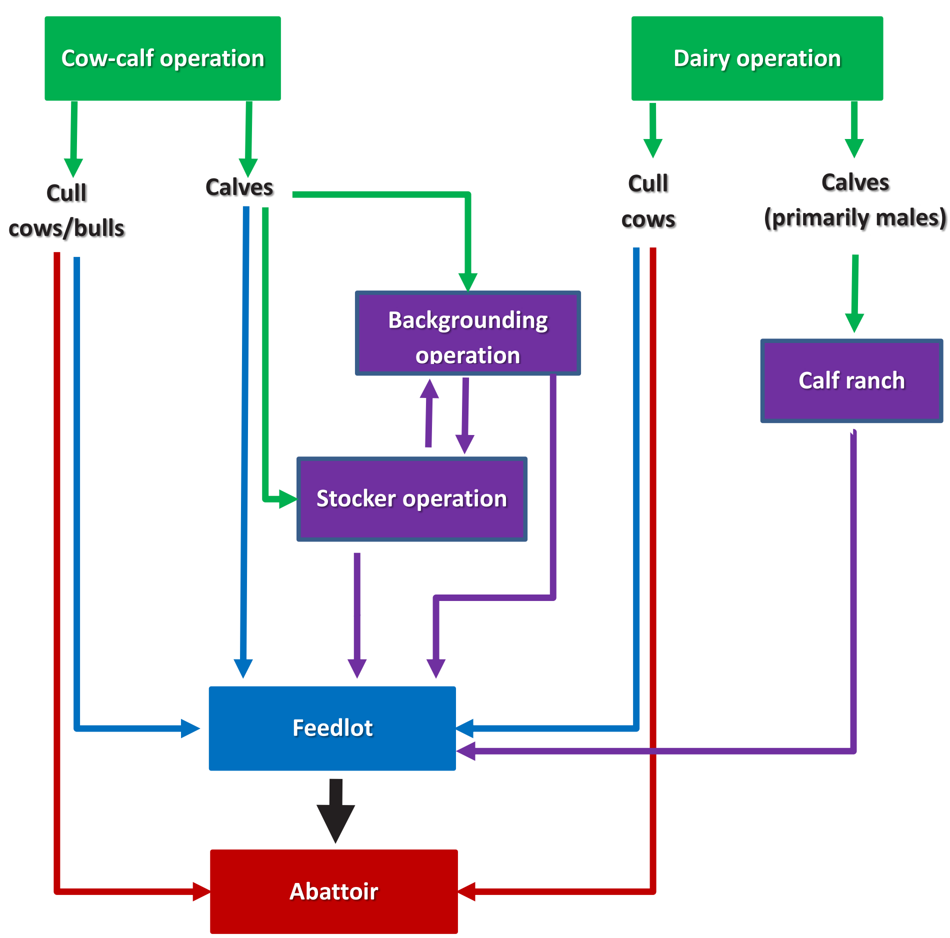

Figure 2. Schematic for flow of cattle through the U.S. beef production chain, illustrating direct entry from cow-calf and dairy operations into feedlots (blue lines) and abattoirs (red lines), or following a growing phase (purple lines) carried out in specialized facilities (calf ranches, backgrounding operations, or stocker operations).

transferred directly to feedlots at or around the time of weaning, in which case they are referred to as "calf-feds" that remain in the feedlot for 240 days or more before being harvested. Calf-fed may make up 40% or more of the fed cattle population in the USA. The largest share of the calf population, usually 60% or more, is first placed into a backgrounding or stocker operation, or a combination thereof, to be grown for a period of time before fattened on high-concentrate diets. These animals are grown mostly using forage-based diets and then transferred to feedlots when they are a year or more of age, and thus are referred to as "yearlings". Stocker (grazing) and backgrounding (drylot) systems rely heavily on forages as the predominant component of the diet, supplementing protein, energy, vitamins, and minerals as needed to optimize cattle performance. A relatively small proportion of backgrounded cattle are grown at modest rates of gain using limit-feeding programs in which they are fed high-concentrate diets, similar to a high-energy finishing diet, but in restricted amounts to prevent premature fattening.

Male calves from dairies also constitute an important component of the beef cattle market. These calves are gathered from dairies at an early age (normally about three days) and transferred to specialized rearing operations known as calf ranches. Calves typically are confined to individual stalls to prevent intermingling, as they are highly susceptible to disease at this stage of their lives. Calves are fed a combination of milk replacers, grain, and small amounts of forage until weaning at 40 to 80 days of age, and then transferred to group housing within the same operation. These animals commonly are sold to feedlots when they reach a weight of approximately 150 to 200 kg.

Cull beef and dairy animals also contribute to the beef supply, and most commonly are shipped from seedstock, cow-calf, or dairy operations directly to abattoirs for harvest. A relatively small and variable proportion is sent to feedlots to be fed high-energy diets for 50 to 100 days before being slaughtered. The number of cull animals that are fattened in feedlots before being slaughtered varies substantially from year to year, and is largely a function of the relationships between feed costs, beef supply, and beef demand.

Male cattle in the USA are nearly always fed as steers, and abattoirs apply heavy discounts to intact males or males that display advanced secondary sex characteristics. Castration effectively decreases the occurrence of undesirable social behaviors and meat quality characteristics, such as dark, firm, and dry beef. Muscle from steers also contains less connective tissue than that from bulls, and steers deposit more intramuscular fat (marbling) than bulls. Castration can occur at various times between birth and after entry into feedlots, with the vast majority being castrated before or near the age of weaning. A relatively small proportion is castrated after entry into feedlots, though this practice is heavily discouraged and significant discounts are applied to intact feeder cattle due to high morbidity rates in animals that are castrated at an advanced age. In terms of methodology, bull calves are most frequently castrated surgically or by banding.

Heifers fed in feedlots constitute approximately 28% to 30% of beef supply in the USA [4]. Compared to steers, however, most feedlot heifers are fed intact, and while some are ovariectomized, it is far more common to feed melengestrol acetate (a synthetic form of progesterone) to inhibit estrus behavior.

Market conditions at the time of weaning can greatly impact the age at which cattle are placed into feedlots. Size of the national herd is cyclical in nature, owing to fluctuations in weather (such as extended draught periods), and fluctuating prices. When overall size of the national beef herd is relatively low, fewer animals are available, creating competition between stocker and backgrounding operations and feedlots for supply of cattle. Relationships between prices of grain and forages also can influence age of entry into feedlots. When costs for pasture and harvested forages are low in comparison to grains, producers have incentive to grow cattle before placing them into feedlots. By contrast, when grain prices are low relative to prices for forages, a greater proportion of eligible animals may enter the feedlot directly.

Weather also plays a very significant role in the age at which cattle are placed into feedlots. Environmental temperatures and precipitation patterns obviously impact both quantity and quality of forages produced, so it stands to reason that adverse climatic conditions can influence duration of the grazing season, and as a result the proportion of cattle that are marketed as calves versus as yearlings. For example, several million cattle normally are grazed on small grain pastures in Texas, Oklahoma, and Kansas in the fall and winter each year. In the absence of adequate rainfall, poor forage yield may dictate premature termination of the grazing season, in which case cattle are transferred to feedlots to be fed. The same is true for native grass pastures that are grazed in the spring, summer, and fall. Drought conditions can force producers to market cattle early, as they frequently have limited feed reserves. Regardless of cause, the system of merchandising cattle is very dynamic, responding quickly to market conditions.

Prices paid for slaughter cattle in the U.S. are influenced by age, quality grade, yield grade, and weight. The USA quality grading system takes into account age, as determined by bone ossification patterns, color of lean tissue, and the amount of intramuscular fat (marbling). Increased intramuscular fat deposition increases grade, and premiums are paid for cattle that have high intramuscular fat content. Yield grade is a measure of fatness that accounts for increases in fat within the subcutaneous, intermuscular, and peritoneal regions of the carcass. Animals that deposit excesses of fat in these areas generally have poor red meat yield, and prices are discounted accordingly. Weight of carcasses also is an important determinant of value, as carcasses that are less than 250 kg or more than 430 kg are subject to substantial discounts. Given the high correlation between intramuscular fat and other fat depots, securing high market value requires that cattle be fed long enough to attain sufficient (but not excessive) body fat, produce carcasses ranging in weight from 250 to 430 kg, and do so at fewer than 30 months of age. Consequently, there are limitations with respect to the ability to shift cattle into different production scenarios. For example, cattle that are heavily influenced by British-breed ancestry often are smaller framed, and therefore benefit from extended growing programs that allow for skeletal growth and muscle deposition before fattening, thereby ensuring that they achieve desired market weights at appropriate fatness. Initiating the feedlot phase too early in the life of the animals can predispose them to premature fattening, low carcass weights, or both. This is particularly true for heifers, which comprise a substantial portion of the fed cattle population in the USA. Alternatively, large-framed phenotypes that are typical of breeds from continental Europe can produce carcasses with excessive weights if grown for extended periods of time before finishing in feedlots. These animals are well-suited to the calf-fed feedlot system in which they are placed into feedlots directly after weaning.

The segmented nature of the beef industry in the USA is an important distinction from the vertical integration commonly associated with other meat animal production systems such as pork and poultry. While there is a relative absence of vertical integration in the beef supply chain, there are increasingly attempts for producers representing the various production segments to align vertically with other segments via supply agreements. The value of, or necessity for, vertical alignment is particularly evident with branded beef programs. For example, marketing of some branded beef products is based on the premise of no antibiotic or steroidal hormone use throughout the lifetime of the animal, requiring that purveyors have control over production methods employed through each phase of production in order to ensure compliance. This frequently is accomplished using supply agreements that reward producers with premiums for producing animals that meet specifications of the branded beef program.

USE OF GROWTH PROMOTING TECHNOLOGIES IN U.S. BEEF PRODUCTION SYSTEMS

Beef producers in the USA historically have been very technology driven. Examples of this include strategic supplementation of forage-based diets to fulfill animal requirements for protein, energy, vitamins, or minerals. Several key classes of growth promotants also are used widely, either as feed additives or as hormone-impregnated implants that are inserted beneath the skin of the ears.

Steroidal-based growth implants have been used in the USA for decades, thus making it possible to regain some of the growth-promoting effects of endogenous hormones that are lost as a result of castration. Implants employ estrogenic (estradiol or zeranol) and androgenic (testosterone or trenbolone acetate) components, or combinations thereof. Steroidal implants stimulate feed intake and protein deposition, and have dramatic impact on cattle performance and efficiency of feed utilization. Their use is very widespread, encompassing both growing and finishing phases of production. They are most heavily used in confinement operations, including backgrounding operations and feedlots. Notable exceptions are branded beef programs that disqualify their use, such as natural, organic, or non-hormone treated cattle programs aimed at specific value-added markets.

Similarly, antibiotics have been widely used in USA cattle production systems. Ionophore antibiotics, the most common of which are monensin and lasalocid, are used widely for beef production in the USA, both for control of coccidiosis and for improving feed efficiency. Feed additive forms of tetracyclines and macrolide antibiotics have been used extensively in the United States. Starting in January, 2017, the USA Food and Drug Administration imposed new regulations that prohibit sub-therapeutic feeding of medically-important antibiotics [6], which includes oxtetracyline, chlortetracycline, and the macrolide antibiotic, tylosin. These drugs now are restricted for use only in the treatment or prevention of disease, and must be prescribed by a veterinarian. Changes in the regulatory status of these compounds has spawned an unprecedented interest in alternative production methods and research aimed at reducing or eliminating antibiotics from food animal production systems, particularly for compounds that are deemed medically important for human health. Essential oils, minerals, prebiotics, and probiotics are among the many product categories that are now being evaluated as alternatives to traditional antibiotics for promotion of growth and efficiency.

Beta adrenergic receptor agonists are used extensively in diets of feedlot cattle to stimulate muscle accretion. Beta agonists are non-steroidal, and they stimulate muscle accretion by increasing protein synthesis and decreasing protein catabolism. The beta adrenergic agonist, ractopamine hydrochloride, was approved for use in cattle starting in 2003. Zilpaterol was approved for use in the USA in 2008, and though more potent than ractopamine, zilpaterol it is now seldom used due to restrictions imposed by major abattoir companies. Ractopamine is administered to cattle during the final 28 to 42 days before slaughter, and though the exact number of cattle fed ractopamine is not known, it is used by the vast majority of USA feedlots. A recent survey of feedlot nutritionists [7] revealed that approximately 85% of feedlots represented in the survey use beta agonists.

Synthetic progestin (melengestrol acetate) is fed to synchronize estrus in breeding herds, particularly where artificial insemination is used. It is estimated that fewer than 10% of beef females are bred by artificial insemination, so the greatest use of synthetic progestin is in feedlots, where they are included in the diet to suppress estrus in heifers that are fed in confinement for slaughter. Feeding progestin aids in minimizing physical injuries attributable to sexual behaviors in which animals mount one another, and also improves efficiency of feed utilization. Melengestrol acetate is not approved for use in male bovines.

THE FEEDLOT SECTOR

The most recent census of agriculture [3] reported an estimated 26,586 feedlots in the USA. Of these, approximately 61% have fewer than 100 cattle. Approximately 77% of cattle were produced in feedlots with capacity greater than 1,000 animals. These feedlots exist throughout the USA, but by far the heaviest concentration of cattle finishing occurs in the Great Plains region, which is mostly characterized by a semi-arid, temperate climate that is well-suited to cattle production. Approximately two thirds of USA feedlot cattle production is concentrated within the states of Nebraska, Kansas, and Texas. Logically, large abattoirs also are concentrated within this region. Crop production in this geography is heavily dependent on groundwater from the underlying Ogallala aquifer, which is used extensively for irrigation of corn, wheat, sorghum, and other crops.

FEEDLOT FINISHING DIETS

Energy content of finishing diets, expressed as net energy for gain (NE_g), typically ranges from 1.50 to 1.54 Mcal/kg. Consequently, diets of feedlot cattle consist primarily of cereal grains and cereal grain byproducts. Corn is by far the predominant cereal grain. Wheat, which mostly is regarded as a human food crop, frequently is used to displace a portion of corn in feedlot diets. Its use typically is restricted to certain times of the year when wheat prices are low in comparison to corn, such as immediately following wheat harvest. Wheat and barley are, however, the predominant grains used by feedlots in the Pacific Northwest. Sorghum is an important cereal crop produced in the semi-arid states of Kansas and Texas, and to a lesser extent Oklahoma, Colorado, South Dakota, and Nebraska. Though regarded as being nutritionally inferior to corn, it too is incorporated into feedlot diets when economic conditions favor its use.

Feedlots are opportunistic users of a broad range of byproduct energy feeds. Cereal grain byproducts have become increasingly important as staples of feedlot cattle diets, particularly in the interior of the continental USA where corn and sorghum production prevail. The most important of these is distiller's grain, which is a byproduct of fuel ethanol production from cereal grains. Distiller's grains can be fed either as wet or dried co-products, the form of which is dictated by proximity of feedlots to ethanol production facilities. Growth of the fuel ethanol industry between 2000 and 2007 represented an unprecedented period of change for the USA beef industry, during which traditional feedstuffs (i.e. grains) reached historically high prices while distiller's grains increased dramatically in abundance. This was cause for major shifts in composition of feedlot diets. Wet corn gluten feed (approximately 60% dry matter), which is derived as a byproduct from the production of corn sweeteners and starches, also is widely used in the feedlot sector. Distiller's grains, gluten feed, and other byproducts most commonly comprise between 10% and 40% of the diet dry matter for feedlot cattle. Large differentials in pricing between grain and grain byproducts occasionally dictate much greater rates of inclusion, with concentrations of byproducts reaching 70% or more of diet dry matter in some circumstances. Other byproducts are used as well, including cull potatoes or potato processing wastes (predominantly in the Pacific Northwest), fruit and vegetable byproducts, byproducts from sugar refining, and co-products derived from milling of wheat and processing of soybeans. Many of these byproduct feeds also contain intermediate to high concentrations of protein, thus making it possible to displace all or a portion of the oilseed meals (soybean, cottonseed, sunflower, canola, and others) traditionally used to satisfy protein requirements of cattle. Consequently, dietary protein often is fed in excess, which has potentially important environmental implications. Byproduct feeds typically contain more phosphorus than the cereal grains that they replace, further contributing to environmental challenges associated with confined animal feeding operations.

Forages normally constitute a relatively small fraction of feedlot diets, and are used primarily to promote digestive health. Alfalfa hay and corn silage are the most commonly used roughages. Increased reliance on byproduct feeds in recent years has made it economically feasible to use low protein roughages in feedlot diets, including corn stalks, wheat straw, and other low-value crop residues. Forage content of finishing diets typically is in the range of 6% to 12% [7].

PRODUCTION AND DISPOSITION OF BEEF

The objective of USA feedlots is to produce beef from young cattle (<30 months of age) with ample tenderness and with relatively high intramuscular fat content. The USA system of beef quality grading rewards feedlots for production of highly marbled beef, but also discourages over-fattening of cattle through classification of carcasses into one of five yield grade categories. Animals that yield carcasses in higher yield grade categories (4 or 5) generally incur heavy market penalties. Size of carcasses also is important, and abattoir companies generally apply heavy price discounts for undersized (<250 kg) or oversized (>430 kg) carcasses.

The beef slaughter industry in the USA is heavily concentrated, with only 4 firms accounting for more than 80% of the beef slaughter capacity. Most of the beef they process is distributed in boxed form, a significant portion of which is exported to other countries. Domestic beef production in 2017 was 11.98 million metric tonnes, approximately 10.6% (1.26 million tonnes) of which was exported [8], either as variety meets or as high-quality beef products. The largest volume export markets for USA beef in 2017 were Japan (24.3%); Mexico (18.8%); South Korea (14.6%); Hong Kong (10.4%), Canada (9.2%); and Taiwan (3.5%). Exports were roughly offset by imports (1.36 million tonnes), with Canada (24.7%), Australia (23.2%); Mexico (19.2%), and New Zealand (18.6%) making up the vast majority of imported beef (and veal) products.

Per capita beef consumption of beef in the USA in 2017 was 25.8 kg [9], and consumption is expected to be slightly higher or stable through 2027 [10]. It is estimated that 57% of the beef consumed is in the form of ground products [11]. Imported products, particularly from Australia, are important in fulfilling the increasing demand for ground beef products.

FUTURE TRENDS IN THE BEEF INDUSTRY

Domestic demand for beef products is expected to remain stable. Consequently, export markets are increasingly recognized as being an important target for increasing demand for USA beef products. OECD/FAO estimates of 1.5% annual increases in demand for meat products through 2026 [10] are cause for optimism among producers. Though it is projected that most of this demand will be fulfilled by increases in production of poultry products, it is likely that all meat sectors will benefit to some degree.

There is a growing trend within the USA for large purveyors of meat products to exert influence on livestock producers, encouraging them to implement production practices that are perceived as being in line with consumer interests. Among the major players are abattoir companies, wholesalers, grocery chains, the hotel and restaurant industries, and others. Topics such as sustainability, animal welfare/wellbeing, environmental compatibility, traceability, antimicrobial resistance, use of exogenous growth promotants, natural or organic production systems, and other areas are becoming increasingly common, and have emerged as central elements in marketing campaigns adopted by many major food companies. This evolution in thinking challenges conventional food animal production systems, and is forcing rapid change in production practices. As a consequence, the focal points of many research programs across the USA have shifted to encompass these topics.

USA beef producers have a long history of adapting quickly to changing market signals in an effort to capture added value. Branded beef programs, which constitute a form of vertical integration or alignment, are relatively commonplace. Perhaps the best known of these is the Certified Angus Beef program, which since its inception in 1978 has arguably transformed the USA beef industry as a result of substantial premiums paid to cattle producers for producing beef that fulfills certain quality standards. In excess of 60% of cattle fed in the USA now have some proportion of Angus ancestry, which is testimony to the success of the program that is now recognized globally as being consistent with quality. Numerous other programs have been spawned in the last 40 years, with the US Department of Agriculture (USDA) Agricultural Marketing Service now listing 90 different federal certification programs for beef, 80 of which were conceived in the year 2000 or later. Scores of other non-certified branding programs have appeared at the consumer level as well, touting features such as omega-3 enrichment of beef; antibiotic free; hormone-free; organic feeding programs; grass-fed programs, and others that are distinguished by the region of production, specific producers, or other features. All are aimed at enhancing value by advertising appealing attributes for which consumers are willing to pay price premiums. As branding programs become more prevalent, vertical alignment between various sectors of the beef industry also is increasingly common. A form of symbiosis can develop in which large production units or consortia of producers align themselves with retail outlets, hotels, or large restaurant companies to ensure ongoing demand or to capture market premiums for their products. In turn, the food companies benefit through supply agreements that guarantee availability or pricing of products that are produced to meet certain standards that can encompass beef quality, meat composition (as in the case of omega-3 enrichment), environmental compatibility, sustainability, or production practices that exclude antibiotics and(or) growth promotants, and numerous other marketable concepts.

Traceability programs have been a topic of much discussion for the past two decades. This discussion intensified immediately following events in December of 2003 surrounding importation of a cull dairy cow from Canada that was discovered to have been infected with bovine spongiform encephalopathy. Several key export markets subsequently were closed to USA beef, which had devastating financial consequences for beef producers and abattoir companies in the USA. Producer organizations are, for the most part, however, opposed to development of a federally-mandated traceability system, opting instead for a voluntary system of animal identification and traceability that is market-driven.

In January of 2017 the USA Food and Drug administration fully enacted revised regulations aimed at decreasing use of medically-important antibiotics in food animal production systems [6]. Central to the new regulations is the necessity for veterinary oversight of antibiotic use. Drugs that previously were available "over the counter" now can be used only with the written prescription of a licensed veterinarian. Since the regulations took effect, pharmaceutical companies that produce affected drug compounds have cited sharp declines in demand for their products, meat purveyors and retailers have publicly announced timelines for procurement of products produced without antibiotics, and major beef producers have announced strategies that will be (or have been) implemented to decrease antibiotic use. The "anti" antibiotic movement is thus well underway, and it has given birth to an era of research pertaining to identification of antibiotic alternatives for use in livestock. Much of our own research at Kansas State University is devoted to the task of finding alternative strategies for mitigation of digestive disorders or infectious diseases, but without use of antibiotics. Whether as a result of market pressures or regulatory changes, it seems inevitable that beef production systems of the future are apt to employ production practices that preclude use of antibiotics.

Probiotics are becoming increasingly prevalent in the beef production chain, but especially feedlot systems. It has been estimated that approximately 60% of feedlot cattle receive some form of probiotic [7]. Often these consist of *Lactobacillus* species, fed alone or in combination with *Propionibacterium*. Normalization of gastrointestinal tract function and competitive inhibition of food-borne pathogens, such as *E. coli* O157:H7 [12], are the most commonly cited reasons for their use. More recently, *Megasphaera elsdenii*, a lactate-utilizing bacteria, has been introduced into the market. Reported benefits include avoidance of ruminal acidosis and the ability to transition more quickly to high-concentrate diets [13], as well as improved cattle performance and decreased incidence of disease in young cattle after arrival in feedlots [14]. Anecdotal evidence from commercial abattoirs has suggested it may also decrease fecal shedding of food-borne pathogens, but this effect has yet to be validated in a controlled research experiment.

Plants extracts as feed additives constitutes another active area of inquiry, with the notion that these compounds may be useful as substitutes for conventional antimicrobial drugs as a result of their antimicrobial activities. Several plant extracts have been studied in depth, including beta acids of hops [15], menthol [16], eugenol [17], cinnamaldehyde [18], limonene [19], and others, and their impact on gut microflora is in some cases well documented. These compounds often emulate the actions of traditional antibiotic drugs, owing in part to similarities in chemical structure. Similarly, heavy metals, including the trace minerals copper and zinc, have been exploited for antibiotic-like effects [20], particularly when used in pigs or poultry, but also in cattle. Zinc is the antimicrobial mineral of choice in cattle due to the relative toxicity of copper, and frequently it is fed at supra-nutritional concentrations to suppress bacteria that cause foot-rot (infectious pododermatitis), or to aid in combatting respiratory illness. Numerous studies have revealed that it is possible to co-select for resistance to antimicrobial drugs when bacteria are exposed to plant extracts [21] or high concentrations of heavy metals [22,23], even without exposure to the antimicrobial drugs themselves. Given that the basis for excluding antibiotic drugs from the diets of cattle is to avoid development of antimicrobial resistance in gastrointestinal tract bacteria, it would seem that similar caution is warranted in the application of plant extracts or heavy metals as antimicrobials, in spite of the fact that they are not marketed specifically as antibiotics.

The USDA does not maintain official statistics on volumes of antibiotic-free, non-hormone treated, or organic beef. In 2012 it was estimated that over 4% of retail foods sold in the U.S. were organically produced [24]. Fruits and vegetable led the market in organic sales, while 3% of meat/poultry/fish were estimated to have been produced organically. According to the Organic Trade Association [25], sales of organic meat and poultry surged by 17% in 2016, and total sales were expected to exceed $1 billion dollars for the first time in 2017. Certification of organically produced meats is administered by the USDA, which maintains official standards for organic production practices. Currently, availability of sufficient quantities of certified organic feedstuffs constitutes a major limitation for growth of this segment of the beef industry. Several branding programs certified by the USDA Agricultural Marketing Service specify beef as being "antibiotic free" or "non-hormone treated". Some of these restrict their definition to a specified production phase, while others reflect production practices employed throughout the lifetime of the animal. There is a sense that demand for this market segment is increasing, but official estimates are not available. Programs for production of cattle without use of hormones, referred to as non-hormone treated cattle, are key to penetrating certain markets, both domestically and internationally. Cost of production generally is higher for any of the specialty programs compared to conventional production systems, and producers must therefore be rewarded accordingly with price premiums.

CONCLUSION

USA beef supply is the product of a multi-segmented industry that is consolidating into larger and larger production units, and is increasingly characterized by vertical alignment among industry segments, as well as with food wholesalers and retailers and the hotel and restaurant industries. The industry makes use of a broad spectrum of nutritional inputs and animal phenotypes that span a wide range of geographies and climates. The industry is closely tied to natural grazing resources, as well as cereal grains and cereal grain byproducts.

It is highly adaptive, responding rapidly to market signals that reward innovation and alignment with consumer demands. The industry makes extensive use of a wide range of technologies related to feed processing, identity preservations, and growth promotion. Complexity of beef markets is increasing due to extensive branding efforts and development of niche markets, and demand for production of beef representing grass-fed, non-hormone, non-antibiotic, and organic beef markets is growing steadily. Maintaining and expanding demand for USA beef likely will necessitate ongoing efforts to develop markets for export, both for variety meats and for high-value cuts of beef.

CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Exhibit 9

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Nationwide shift to grass-fed beef requires larger cattle population

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Abstract

In the US, there is growing interest in producing more beef from cattle raised in exclusively pasture-based systems, rather than grain-finishing feedlot systems, due to the perception that it is more environmentally sustainable. Yet existing understanding of the environmental impacts of exclusively pasture-based systems is limited by a lack of clarity about cattle herd dynamics. We model a nationwide transition from grain- to grass-finishing systems using demographics of present-day beef cattle. In order to produce the same quantity of beef as the present-day system, we find that a nationwide shift to exclusively grass-fed beef would require increasing the national cattle herd from 77 to 100 million cattle, an increase of 30%. We also find that the current pastureland grass resource can support only 27% of the current beef supply (27 million cattle), an amount 30% smaller than prior estimates. If grass-fed systems include cropland-raised forage, a definition that conforms to typical grass-fed certifications, these supplemental feeds can support an additional 34 million cattle to produce up to 61% of the current beef supply. Given the potential of forage feed croplands to compete with human food crop production, more work is required to determine optimal agricultural land uses. Future US demand in an entirely grass-and forage-raised beef scenario can only be met domestically if beef consumption is reduced, due to higher prices or other factors. If beef consumption is not reduced and is instead satisfied by greater imports of grass-fed beef, a switch to purely grass-fed systems would likely result in higher environmental costs, including higher overall methane emissions. Thus, only reductions in beef consumption can guarantee reductions in the environmental impact of US food systems.

1. Introduction

Beef cattle represent an important component of the US economy, totaling over $67bn in sales from more than 32 million cattle slaughtered in 2016 [1], with over three million cattle's worth of meat exported each year [2]. However, beef cattle have recently received focus as an inefficient means of procuring protein, resulting in greater feed and water costs and higher greenhouse gas emissions per unit of protein than other forms of meat or plant-based protein [3–6].

While cattle are evolved to eat a diet primarily of grass and other forages not edible to humans, cattle are fattened in the final stages of their lives, or 'finished', on a diet of primarily grain in feedlots. The feedlot system has been the focus of concerns and investigations regarding food safety [7], environmental externalities [8], and animal welfare [9]. Feedlot systems rely on a high throughput of intensively grown crops, require frequent antibiotic and growth hormone usage, are located in regions where cattle are prone to heat exhaustion [9], and do not permit cattle to perform activities that conform with their natural instincts (i.e. grazing on open pasture). Furthermore, high volumes of manure and intensive manure management create odors which may result in human health consequences for agricultural workers and nearby residents [10] and undesirable aesthetic conditions. However, due to grain feed's higher nutrient density relative to grass, it requires significantly less land and generates less methane per unit of meat produced [3, 6]. Large shifts in cattle herd management following macro-level consumer trends must therefore be quantified in light of environmental tradeoffs.

Because beef is the most land-demanding agricultural product in the US and the world, some have explored restricting cattle feed to pasturelands that are non-competitive with human food production [11]. Currently, 'grass-finished' beef accounts for less than 1% of the current US supply [12]. Imports of grass-finished beef to the US from Australia far outweigh the domestic US grass-finished beef supply [13]. Rapid growth in the grass-fed beef market of 20%–35% per year is leading suppliers to consider shifting domestic production to grass-finished beef [12]. Prior studies have considered market and infrastructure barriers to scaling grass-fed beef production [14]. However, biological and physical limits may inhibit the expansion of US grass-finished beef, including additional land for increased pasture and forage feed requirements.

To model future shifts to exclusively grass-fed beef, the size, lifespan, and weight gain of the present US beef cattle herd must be well understood. Multiple resources and studies have published global and national estimates of beef cattle populations [15–17], but national mean growth rates and residence times have not previously been reported. Grass-finished cattle have lower average daily weight gain (ADG) and finished weights than their grain-finished counterparts, because cattle eating grass have less efficient feed conversion ratios (FCR). This information has been widely reflected in localized studies about grass-finishing operations [18], but no study to date has calculated the consequences for scaling grass-finished operations up to the national level. A recent study found that current pastureland can support 35% of our present day beef output [19]. However, their model assumed a single aggregated FCR across all stages of rearing and finishing and did not model changes in ADG or finishing weight. These recent findings must be updated to adequately reflect differing feed requirements primarily in the finishing stage of production.

Here, we provide a top-down method for understanding the demographic changes and resource constraints for a nationwide shift towards entirely grass-fed. Specifically we ask: (1) *How many more exclusively grass-fed cattle would be required to produce the same amount of finished beef that is currently consumed?* (2) *How much exclusively grass-fed beef can the existing pasture resource support?* To answer these questions we use a simple demographic model of US beef cattle. We then use this model to predict population changes necessary for pasture-finishing systems to keep pace with modern beef production rates and improve estimates of the amount of entirely pasture-raised beef that our present-day pastureland resources can support. We end with a discussion of sustainability metrics that warrant further study, as well as shifts in demand that would be required to keep exclusively grass-fed cattle production within biophysical limits.

2. Methods

2.1. Populations and residence time for feedlot cattle

Cattle on feedlots at any given time represent a fraction of the total US cattle population. Cattle are placed on feedlots only after reaching maturity so that their skeletal development and immune systems can support the high rate of fattening they are subjected to on feedlots. Additionally, the low fecundity rate of cows relative to other farmed animals, of roughly one calf per year, means that many additional cows and bulls are needed to produce calves that replace the slaughtered population. The large population of breeding cattle and their calves are herein referred to as the *cow-calf* beef herd. Within this population, we include stocker cattle, which are more mature than calves but have not yet been placed on feedlots. Beef cattle that have matured and been placed onto feedlots are referred to as feedlot cattle. Dairy cattle are almost an entirely different herd in the United States, and we distinguish them separately from the beef cattle that are the subject of our analysis.

We used the 2012 national annual cattle population reported by the EPA in their Annual Emissions Inventory [20], which were derived from point-in-time cattle censuses conducted by USDA. All beef cattle that were not in feedlots were classified as cow-calf herd cattle, and include calves, dry and lactating cows, bulls, heifer replacements for dairy cows, and stocker cattle. Mean slaughter weight of cattle from feedlots were calculated using 2012 survey feedlot placement numbers, 2013 survey slaughter rates, and 2013 mean dressed weight at slaughter from the USDA NASS [21]. The mean weight of steers and heifers slaughtered in federally inspected commercial slaughterhouses was reported in dressed weight (carcass weight minus blood and internal organs). The dressed weight of commercially slaughtered finished heifers and steers was norMalized by the slaughtered number of each of these subpopulations then divided by 0.604, the ratio of live weight to dressed weight for all slaughtered cattle in aggregate, in order to obtain a live weight for feedlot cattle at slaughter.

$$w_{\text{slaughter}} = \frac{w_{\text{dressed}}}{0.604}. \tag{1}$$

This number may be biased slightly low because 9% of cattle slaughtered in these facilities are culled stocker heifers and steers. Nonetheless, the resulting weight, $w_{\text{slaughter}} = 1386$ lbs, is our best estimate for the national average live weight of grain-finished cattle from feedlots.

To obtain the mean residence time of cattle on feedlots, the 2012 national yearly mean feedlot population was divided by the 2012 yearly rate of cattle feedlot placements, which we assume is approximately in steady-state and approximately equivalent to 2013 yearly slaughter rates. We then multiply the yearly mean residence time by 366 days to obtain residence time.

$$\tau_{\text{feedlot}} = \frac{n_{\text{feedlot}}}{r_{\text{placement}}} \times 366 \text{ days} \quad (2)$$

where τ_{feedlot} is mean residence time in days, n_{feedlot} is the number of cattle on feedlots averaged over the full year in 2012, and $r_{\text{placement}}$ is the 2012 yearly rate of placements of cattle on feedlots in units of head per year.

To independently corroborate feedlot residence times, the daily weight gain implied by our mean residence time was calculated and compared to literature estimates. The resulting live slaughter weight of feedlot cattle was subtracted from their mean placement weight derived from 2012 USDA surveys to obtain daily feedlot weight gain representing the national average. Feedlot weight gain was then divided by mean feedlot residence time to obtain mean weight gain per day on feedlots, which was compared with literature values of 2.7 to 3.3 lbs day^{-1} [20].

$$\text{ADG}_{\text{feedlot}} = \frac{w_{\text{slaughter}} - w_{\text{placement}}}{\tau_{\text{feedlot}}} \quad (3)$$

where $\text{ADG}_{\text{feedlot}}$ is the average daily weight gain on feedlots, and w_{placed} is the national average placement weight.

2.2. Hypothetical pasture-finished beef populations.

Cattle finished on pasture reach a smaller maximum weight of approximately 1115 lbs [22]. In order to produce the same annual quantity of beef, the rate of cattle shipped to slaughter, hence the rate of cattle graduating to finishing from their cow-calf herds in a new equilibrium grass-fed system, must increase in proportion to the new lower slaughter weight.

$$r_{\text{placed (grassfed)}} = r_{\text{slaughter (grassfed)}} = \frac{w_{\text{slaughter (feedlot)}}}{w_{\text{slaughter (grassfed)}}}. \quad (4)$$

Cattle finishing on pasture also fatten at a slower rate, meaning that cattle must remain finishing on grass for a longer duration than their feedlot counterparts are finished on grain.

$$\tau_{\text{finishing (grassfed)}} = \frac{w_{\text{slaughter (grassfed)}} - w_{\text{placement}}}{ADG_{\text{grassfed}}} \quad (5)$$

where $\text{ADG}_{\text{grassfed}} = 1.4$ lbs day^{-1} is the average daily weight gain of cattle finishing on grass, $w_{\text{slaughter(grassfed)}} = 1115$ lbs is the mean slaughter weight of grass-finished cattle, and $w_{\text{placed}} = 720$ lbs is the mean placement weight which we assume does not change from the present-day system. The longer residence time means that more cattle must reside within finishing operations, assuming steady-state:

$$n_{\text{finishing(grassfed)}} = \frac{\tau_{\text{finishing (grassfed)}} \cdot r_{\text{placed (grassfed)}}}{366 \text{ days}} \quad (6)$$

where $n_{\text{finishing(grassfed)}}$ is the number of cattle finishing on grass, averaged over the year, required to sustain present-day beef production rates. Lastly, we assume that the number of cow-calf herd cattle must increase proportionally to the new rate of placement on grass-finishing operations.

$$n_{\text{calf-cow(grassfed)}} = \frac{r_{\text{placement(grassfed)}}}{r_{\text{placement (feedlot)}}}. \quad (7)$$

The totals do not reflect resource constraints; they merely reflect the increase in population needed to maintain the same yearly beef output in total carcass weight.

2.3. Comparison to previous studies

The estimated proportion of cattle that could be raised in the United States on pastureland grass resources relative to the present-day population has been previously calculated as 35% [19]. The conversion was calculated as the proportion of the present-day total cattle feed on a dry matter (DM) basis consisting of grass from pastureland. However, because less than 1% of cattle are finished on grass, this conversion rate did not appropriately account for the increased energy density, feed efficiency, and maximum fattening rate for finishing cattle on concentrates relative to grass-finished cattle.

We calculate the proportion of the present-day beef output that an exclusively grass-fed system can support as the following:

$$P = \frac{F_{\text{pasture}}}{\text{FR}*(n_{\text{calf-cow (grassfed)}} + n_{\text{finishing (grassfed)}})} \cdot \frac{2205 \text{ lbs MMT}^{-1}}{366 \text{ days}} \quad (8)$$

where F_{pasture} is the national total pastureland-produced grass: 99 million metric tons (MMT) DM per year based on 2012 estimates [5] and used by Eshel *et al* [19]. The sum of $n_{\text{cow-calf(grassfed)}}$ and $n_{\text{finishing(grassfed)}}$ is the total cattle population required to sustain present-day beef output, while FR is the average daily feed requirement for grass-fed cattle, aggregated for the entire herd, in lbs DM head^{-1} day^{-1}. To calculate FR, we used National Research Council (NRC) nutrition requirements [23]. Fact sheets from the Oklahoma State Extension provide summary tables of NRC-derived feed requirements in lbs DM day^{-1} for typical US cow-calf subpopulations (including weaning calves, lactating and gestating cows, bulls, heifer replacements, and stocker cattle, but not finishing cattle) and rations [24]. We referenced these lookup tables using mean US cattle weights from EPA for each subpopulation to find their respective FR, then calculated the aggregate US cow-calf herd mean FR weighted by EPA subpopulation totals, excluding cattle finishing on grass. For grass-finishing cattle, we assumed similar feed requirements as larger stocker cattle, who are presently fed pasture and roughages, and we assumed a mean weight of 918 lbs, the linear mean of their starting placement weight $w_{\text{placement}} = 720$ lbs and ending slaughter weight $w_{\text{slaughter(grassfed)}} = 1115$ lbs. The resulting aggregated grass-fed cattle FR was 21.8 lbs head^{-1} day^{-1}. The denominator of equation 9 represents the total feed needs for the entire future grass-fed herd.

3. Results and discussion

3.1. Present-day distributions and productivity of beef cattle

A simple box model of national cattle populations is presented in figure 1. The national beef cow-calf herd cattle population is almost five times larger than the population of cattle on feedlots. This imbalance of cattle populations in different stages of rearing before slaughter explains why in the US most cattle can be seen grazing on pastures, but almost all beef in the US comes from confined feedlot operations [12]. This apparent paradox is explained by the facts that (1) many more breeding cattle are needed to replace the feedlot population annually and (2) beef cattle spend only 41% of their 18 month-long lives on feedlots. We calculated a mean residence time of 223 days, or approximately 7.5 months, of cattle on feedlots. Mean placement weight was 720 lbs and mean slaughter weight was 1386 lbs. Over 223 days, this corresponds to 2.98 lbs per day on feedlots, which agrees with the literature reported values of 2.7 to 3.3 lbs per day.

Assuming an approximate steady state, 22 million cattle are slaughtered at 1386 lbs to produce more than 12 billion lbs of beef from feedlot cattle. Additional slaughter from culled dairy cows, beef cows and bulls, replacement steers and heifers, and veal calves, totaling 10 million cattle annually, are not included in this analysis, as their meat either goes towards lower-quality beef products such as ground beef mixtures and pet food or is sold as specialty veal.

3.2. How many more cattle fed exclusively on grass would be required to produce as much beef as is currently consumed?

Replacing the 13 million cattle presently finished in feedlots is not as trivial as raising an equivalent number of cattle on pasture. Cattle on pasture fatten at slower rates than those on feedlots. What follows is an analysis of the necessary increases in residence times and population that are needed in order to produce the same quantity of high-quality beef, approximately 12 billion lbs, currently produced by the feedlot system.

Cattle finishing on pasture fatten at a rate of approximately 1.4 lbs per day and reach a smaller maximum weight of approximately 1115 lbs [22]. Therefore, to gain the necessary slaughter weight, finishing cattle need to spend 281 days, more than 9 months, grazing on pasture (table 1), as well as eating hay and forage supplements outside of their respective regions' growing seasons. To produce the same amount of high-quality beef as the current feedlot system, grass-finishing cattle would need to be slaughtered at a rate of 27 million cattle per year instead of 22 million, with just as many required for placement onto finishing systems (table 2). Due to the slower fattening rate and longer residence time, this would require 21 million cattle instead of 13 million cattle residing in finishing systems on an annually averaged basis, an increase in 67% (figure 2, table 2).

Increases in cattle population, placements, and slaughter rates are demonstrated in figure 2. The increased slaughtering and placement numbers would also require a 24% increase in the size of the national beef cow-calf herd, proportional to the increased annual grass-finishing placement rate, in order to provide additional cattle to stock the grass-finishing stage. Increases in both the cow-calf herd and the grass-finishing population together would result in a total increase to the US cattle population of an additional 23 million cattle, or 30% more than the current US beef cattle population as a whole (table 2).

Supporting a larger grass-fed cattle population would involve environmental tradeoffs. Emissions of methane, a greenhouse gas with a large warming effect relative to carbon dioxide per molecule, come from beef cattle in the forms enteric fermentation and manure emissions. We calculated a 43% increase in methane from enteric fermentation (table 2), assuming that cattle finishing on grass had the same daily methane emissions as present-day stocker cattle, who have nearly identical ADG and are fed primarily on roughage. Modeling the nuanced differences to present-day stocker cattle's diet would be largely hypothetical and subject to large geographic variation. Additionally, manure methane emissions are proportionally small for present-day beef cattle, about 4% relative to enteric fermentation. Future manure methane would thus likely increase proportionally to the cattle population but would be smaller than the increase in enteric fermentation. Taken together, an exclusively grass-fed beef cattle herd would raise the United States' total methane emissions by approximately 8%. Changes in other environmental impacts such as nitrous oxide emissions and water pollution are more challenging to predict, and are discussed further in section 3.4.

The precision of our present-day beef cattle demographic model (figure 1) is made possible by inputs from nationally-representative USDA censuses (equations 1–3). Equivalent sampling does not exist for exclusively grass-fed systems. Because of a high level of heterogeneity in ADG and slaughter weights among individual grass-finished operations, reflecting different climatic conditions, terrain, soil, physical cattle activity, and nuanced management decisions

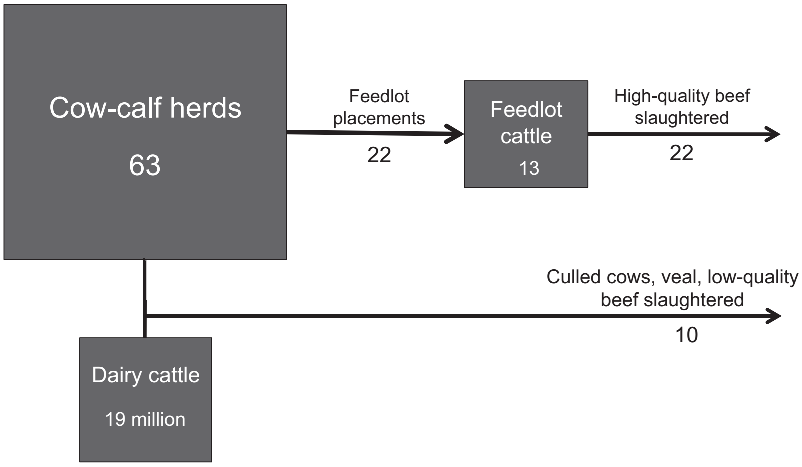

Figure 1. Fluxes and populations of cattle in millions for the current US grain-finishing beef system in 2012.

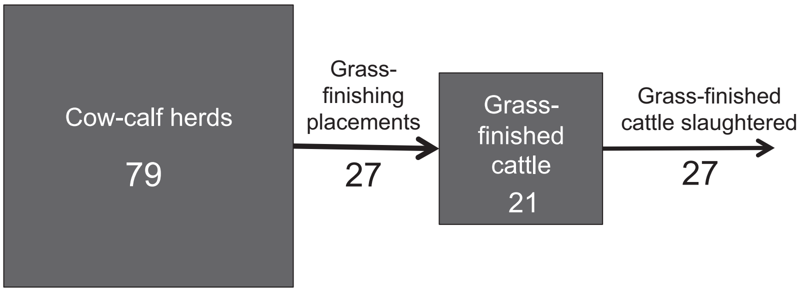

Figure 2. Fluxes and populations of cattle in millions for hypothetical future grass-finishing system. Estimate assumes that the annual slaughtered amount of high-quality beef is held constant from 2012 at approximately 14 billion lbs, that grass-finished cattle are slaughtered at 1115 lbs, and that cattle are fattened on grass at a rate of 1.4 lbs per day. The mean productivity of cow-calf herds remains constant, with total population changing in proportion to the increased placement and slaughter rate.

Table 1. Finishing and slaughter rate parameters for present-day conventional feedlot-finished cattle and future hypothetical grass-finishing cattle. ∗Source: USDA NASS. ∗∗Source: Pelletier *et al* 2010 [22].

	Residence time (τ)	Average daily gain (ADG)	Slaughter rate (r)	Slaughter weight ($w_{\mathrm{slaughter}}$)
	days	lb head^{-1} day^{-1}	head year^{-1}	lbs
Conventional	223	3.0	21 864 000∗	1386
Grass-fed	281	1.4∗∗	27 185 000	1115∗∗

such as cultivated forages and rotational grazing regimens, our estimates for exclusively grass-fed beef cattle production in the US are meant to reflect an approximate and hypothetical scenario. Different estimates can be made by assuming different values for ADG and finished weights (table 1) in equations (4–7). We performed a simple sensitivity analysis and found that increasing $\mathrm{ADG}_{\mathrm{grassfed}}$ and $w_{\mathrm{slaighter(grassfed)}}$ each by 10% led to a decrease in the total grass-fed population of 1.9% and 3.7% respectively. This suggests that future developments in nutritional science, animal genetics, pasture management, and forage quality may enable producers to achieve higher efficiency in pasture-based systems than the estimates in this analysis [25].

3.3. How much exclusively grass-fed beef can the existing pasture resource support?

We estimate that present-day pastureland grass resources can sustain only 27% ($P = 0.27$) of our current beef output. The amount of grass feed needed to sustain present-day beef production in an exclusively grass-fed system is 387 MMT DM year^{-1}, a 37% increase in dry weight relative to present-day national total cattle feed of 283 MMT DM year^{-1} [5], which includes grain. Using the present-day total feed weight of 283 MMT DM year^{-1} reproduces the result of 35% ($P = 0.35$) from Eshel *et al* [19]. Therefore, it is apparent that Eshel *et al* assume a constant feed conversion ratio for beef across all feeds, i.e. that grass and grain are interchangeable for beef cattle growth.

Table 2. Beef cattle population and enteric fermentation methane emissions (in millions of metric tons) of present-day conventional beef systems and future hypothetical exclusively grass-fed beef systems. ∗Source: US EPA.

	Cow-calf	Population finishing	Total	Enteric fermentation methane MMT CH_4
Conventional∗	63 493 000	13 328 000	76 821 000	4.76
Grass-fed	78 946 000	20 876 000	99 822 000	6.79

To the contrary, these two feed stocks have disparate feed efficiencies, produce different metabolic byproducts such as methane and manure, and allow cattle to fatten at different maximum rates [23]. We updated their results by calculating the increase in size of the beef cattle herd and increased feed needs for a larger exclusively grass-fed herd (equation 9), rather than simply dividing the dry weight of grass presently fed to cattle by the dry weight of all feeds presently feed to cattle.

This estimate excludes grain, hay, silage, and other roughage grown on croplands as a potential feed source for exclusively pasture-raised cattle to match the definition of 'sustainable beef' used by Eshel *et al* and others [11, 19]. However, hay and silage from these lands provide a critical source of supplemental feed to pasture-raised cattle during dormant cold or dry seasons and pasture-based certifications schemes by third parties allow for supplemental forage feed during dormant seasons [26]. Adding the 126 MMT DM year^{-1} of roughage feed that are presently grown on croplands to F_{pasture} brings the amount of grass-fed beef that pastures in the US could support to 61% ($P = 0.61$) of our current beef supply.

Additionally, croplands currently utilized for grains fed to farmed animals could be substituted for alfalfa, a high-yielding forage crop. On more than 5 million highly-productive cropland hectares on which 38 MMT DM grain beef cattle is presently grown each year, we calculate that farmers could instead grow 34 MMT DM of alfalfa at present yields on high-productivity cropland (assuming 29% dry matter). Including these 'replaced' forages, the US land base could support up to 71% of the current US beef production exclusively grasses and forages. These forages, however, would necessarily be in competition with human food crops, a scenario that advocates for an exclusively grass-fed cattle future would likely hope to avoid.

Research is still needed to assess yield gaps between present and potential future productivity of US pasturelands and roughage croplands. Statistical and processed-based modeling can assess underperforming areas [27], which could be optimized through better fertilizing, soil conditioning, and rotational management. Currently, less than 2% of all agricultural lands in the US undergo a rotation between cropland and pasture [28], though this type of management is known to increase forage productivity [29]. The required 30% increase in the overall cattle population must be accompanied by large increases in the productivity of existing pastures, on the order of 40%–370%, to avoid clearing additional native vegetation or competition with the human food supply.

3.4. Implications for sustainability and future research directions

In a future shift to grass-fed beef, although more cattle would have to be raised for the same quantity of beef, fewer cattle could be raised overall in the US. A reduction in the US cattle population would reduce the aggregate environmental impact of the US beef sector, yet, the average methane footprint per unit of beef produced would increase by 43% (table 2) because of slower growth rates and higher methane conversion rates. Tradeoffs in other environmental impacts demand further quantitative research. For example nitrous oxide emissions associated with grain feed crops would be reduced, but could be outweighed by increased nitrogen oxidation from manure and leguminous forages. Soil carbon sequestration contributes a potential CO_2 sink, however evidence suggests that this sink is unstable and reversible over decadal timeframes [30]. Additionally, moving cattle from feedlots and onto pasture could create additional manure pollution burdens for watersheds that are near or past safe nutrient loads [31]. Harmful effects of air pollution on humans would likely decrease as pollution sources would be more spatially diffuse. Soil erosion and native vegetation suppression from overgrazing are likely to pose additional challenges. Further modeling of both aggregate and marginal environmental impacts is therefore needed. Social outcomes are as unclear as the balance in tradeoffs of environmental impacts, as human society must pay for externalities of production. Vulnerable communities often bear disproportionate burdens of these externalities [32, 33].

Animal welfare, an additional concern motivating the shift towards exclusively pasture-based production, may be better provided for in a shift to exclusively pasture-based management, but with important caveats. There are presently no legal protections for the welfare of cattle on farms at either the federal and state levels in the United States [34]. Improvements in the physical environment, allowing cattle to better express natural behaviors, may be offset by poorer oversight of larger cattle herds. Grass-finished cattle may be subject to disease, injury, and harsh weather such as heat, storms, and freezing temperatures, which presently affect cow-calf herds. The private sector may fill the gap left by legal protection and enforcement, but welfare certification organizations could also face new challenges in the face of large-scale management shifts and would continue to lack legal oversight.

Shifts to a pasture based system need not abandon supplemental feeding. Not all roughage croplands may be put to productive use for human food (or efficient bioenergy sources). Although this likely does not apply to most of the 126 MMT DM year^{-1} of roughages grown in the US, the proportion of these roughages grown on marginal croplands present logical sources of dormant season silage for supplemental feeding on pasture during periods of lower biomass production (a dry and/or winter season). Thus, the definition of 'sustainable beef' used by Eshel *et al* and others [11, 19] as a pasture-only system should be reconsidered.

While the environmental costs of exclusively grass-fed beef under constant US beef consumption are likely quite high, environmental and social sustainability could be enhanced if domestic consumption of beef decreases. Reductions in total beef production could represent a hardship for US farmers, but grass-fed beef currently sells at a higher price. The increased value associated with perceptions of environmental stewardship and changing consumer preferences regarding taste could potentially compensate the cattle sector for a portion of the shortfall from lower productivity and limits to grass resource availability. Presently, prices for grass-fed beef are 47% greater by weight [35] than conventional beef [36] across all cuts. If demand is not perfectly inelastic (the price does not remain constant despite a change in supply), a reduction in the amount of beef produced in the US is likely increase the price of beef domestically. Additionally, imports of grass fed beef could be reduced, shifting demand for this premium product back to US farmers, thus making exclusively grass-fed cattle management more profitable. This outcome could benefit declining rural economies in the US. More nuanced economic modeling is needed to understand the shifts in demand associated with supply-side changes in management and the market prices that would result from changes in demand. However, this analysis suggests that consumer demand for beef could fall while still maintaining farmer livelihoods. Both higher prices and an overall reduction in demand for beef are necessary steps towards a more environmentally and economically sustainable US agricultural system.

4. Conclusions

Understanding the consequences of moving towards entirely grass-fed cattle requires disaggregating the present day herd between cow-calf herds, wherein high-quality beef cattle are bred and raised on grass and roughages before shipping to feedlots, and feedlot cattle who are rapidly fattened on high-grain diets before slaughter. The nearly five-to-one ratio of cow-calf beef cattle to feedlot cattle accounts for the paradox that cattle grazing on pasture are visibly abundant across the country, but the majority of our beef comes from feedlot-fed cattle.

Future management shifts towards grass-finished beef cattle production would require a large increase in the US cattle population, both in finishing cattle and cow-calf herd populations, to accommodate slower fattening rates and lower slaughter weights. The required 30% increase in the overall cattle population must be accompanied by massive increases in the productivity of existing pastures to avoid native ecosystem encroachment or competition with the human food supply. Changes in cattle population and management would also create an even higher land and methane environmental footprint for beef. Other impacts such as fresh water eutrophication, soil erosion and native vegetation suppression from overgrazing, and nitrous oxide emissions are likely to create additional environmental burdens, but must be more precisely quantified. Given the environmental tradeoffs associated with raising more cattle in exclusively grass-fed systems, only reductions in beef consumption can guarantee reductions in the environmental impact of US food systems. If a reduction in the US beef supply increases prices, then lower consumer demand could be feasibly be met using limited present-day grass resources, while still allowing farmers to profit.

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Exhibit 10

nature climate change

ARTICLES

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Consumers underestimate the emissions associated with food but are aided by labels

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Food production is a major cause of energy use and GHG emissions, and therefore diet change is an important behavioural strategy for reducing associated environmental impacts. However, a severe obstacle to diet change may be consumers' underestimation of the environmental impacts of different types of food. Here we show that energy consumption and GHG emission estimates are significantly underestimated for foods, suggesting a possible blind spot suitable for intervention. In a second study, we find that providing consumers with information regarding the GHG emissions associated with the life cycle of food, presented in terms of a familiar reference unit (light-bulb minutes), shifts their actual purchase choices away from higher-emission options. Thus, although consumers' poor understanding of the food system is a barrier to reducing energy use and GHG emissions, it also represents a promising area for simple interventions such as a well-designed carbon label.

There is a widespread scientific consensus regarding the urgency to reduce GHG emissions[1], and on the need to study alternative interventions to do so. Much research has emphasized technological solutions such as greater energy efficiency and increased use of renewable sources of energy[2]. More recently, it has been recognized that diet change is also a potential solution worth exploring[3–5]. Economic analysis has examined the virtues of market-based mechanisms to influence demand, such as a carbon tax that increases prices in line with social costs[6]. Increasingly, however, social scientists have turned their attention to possible behavioural interventions to influence demand[7]. For example, social psychological research on social norms shows their effectiveness in producing behaviour change in some contexts[8,9]. However, social norms are problematic when the desired behaviour is rare[10]. Another intervention approach is to 'boost' consumer decision-making by providing relevant skills, knowledge and decision tools[11]. The efficacy of such boosts requires first understanding the relevant knowledge gaps.

Attempts to modify behaviour typically presume that consumers recognize the connection between their acts and the consequences for energy consumption and GHG emissions[12,13]. However, there is a growing body of research demonstrating that consumers are often unaware or misinformed. For example, Attari, et al.[14] found that people had a rudimentary understanding of the relative energy use of different electrical household appliances (henceforth, appliances) and activities. On average, people correctly recognized that refrigerators used more electricity than light bulbs, but were insensitive to the true difference between relatively high- and low-emitting appliances.

Research suggests that the food system contributes 19%–29% of global GHG emissions[15], which is similar to emissions from US household electricity use[16]. Many factors combine to produce such considerable emissions. Agriculture is highly industrialized. Refrigeration and transportation tend to depend heavily on fossil fuels. Natural gas is a key input in the manufacture of fertilizer. Cattle raised for beef and dairy products are major sources of methane. Moreover, the process of raising meat is inherently inefficient: fertilizer is used to grow feedstock, but only a small portion of the feed becomes animal protein; the rest becomes manure and methane. Thus, it takes 38 kg of plant-based protein inputs to produce 1 kg of edible beef[17]. Finally, in many parts of the world, burning forests to create grazing and agricultural land also emits GHG emissions. A significant reduction in GHG emissions from food could be achieved by changing consumers' diet; in particular, by moving toward more vegetarian or vegan meals[18,19]. Even changing the type of meat consumed could have a large beneficial environmental impact[20].

Existing research, which typically asks consumers via survey to indicate knowledge or agreement with facts about the environmental impact of food, suggests that consumer awareness of the environmental impact of meat production is low[21–24]. Importantly, however, those who believe that reducing meat consumption effectively reduces GHG emissions are much more likely to intend to reduce eating meat[22,25].

Understanding consumers' perceptions of energy consumption and GHG emissions of individual food items in a way similar to Attari et al.[14] is important because it can inform the design of information interventions to help consumers understand the true impact of their behaviours. Experimental studies investigating simple interventions to increase pro-environmental food consumption behaviour have yielded only modest results[26]. Therefore, additional research that identifies effective 'boosts' is needed.

One of the most straightforward ways to attempt to influence food choice is through labels[27]. For example, a carbon label communicates information about the total amount of GHG emissions from within a defined supply chain (for example, from cradle to grave). Carbon labels provide information to consumers that can be factored into purchase choices and also exert pressure on manufacturers and retailers to provide consumers with lower-emission options[28].

The research associated with environmental labels on foods is mixed. Some research suggests that consumers desire carbon labels[29,30]. However, other research suggests that consumers barely use environmental labels when making food choices[31]. Still other research indicates that environmental labels can move consumption

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towards foods with lower GHG emissions under certain conditions[26]. Several countries, including the UK, USA and Australia, have developed carbon labels that have been adopted for some products[32]. Labels vary from simply stating the manufacturer's commitment to reduce GHG emissions to stating a numerical estimate of the carbon dioxide equivalent emitted to providing a green–yellow–red traffic light system indicating levels of GHG emissions[33]. However, many consumers find it difficult to understand existing carbon labels[29,30]. This confusion is problematic because labels are effective in changing consumers' purchase decisions only when they provide information that is easy to understand. Confusion may be responsible for the lack of effectiveness.

In Study 1 (modelled after ref. [14], see also ref. [34]), we elicited people's perceptions of the energy consumption (Study 1A) and GHG emissions (Study 1B) embedded in food production and transportation. We examined both energy consumed and GHG emissions because they are not perfectly correlated and different audiences may have interests in just one of these areas. To serve as a reference, we also measured the same perceptions for common appliances, thus extending the work of Attari et al.[14] to include additional items and GHG emissions. We found systematic underestimation for both food and appliances with food impacts being underestimated significantly more than those of appliances. In Study 2, we found that the provision of food GHG emissions information in terms of a familiar metric influenced food choice behaviour, such that consumers' choices shifted toward foods with lower GHG emissions when such information was made explicit.

Perceived versus actual energy use and GHG emissions

Participants estimated the energy consumption (Study 1A, $n=518$) or GHG emissions (Study 1B, $n=514$) from producing and transporting a serving of 19 foods and from the 1 h use of 18 appliances (8 of which were the same as those in ref. [14]; see Methods and Supplementary Note 1). The items were selected to span a wide range of energy consumption. The correlation between the actual values of energy use and GHG emissions was 0.96 for foods ($P<0.0001$) and 1.00 for appliances. Note that in the food domain, GHG emissions result not only from energy use in food production but also from other sources (for example, methane release). In both studies, participants were provided with reference information for a 100-W incandescent bulb used for 1 h (that is, it consumed '100 units' of energy or it emitted '100 units' of GHG emissions). Two additional studies that included a food reference unit—a medium-sized tomato—yielded parallel results (see Supplementary Note 2).

Figures 1 and 2 show participants' estimated energy use and GHG emissions plotted against actual values after transforming both variables with base-10 logarithms to reduce positive skew. Actual values were calculated from literature-based best estimates obtained by averaging the values reported in multiple sources (see Supplementary Note 3 and Supplementary Tables 2–4). For each dataset, we ran two mixed-effects models using the maximum-likelihood method (see Table 1). We used the mixed-effects model because it enabled the modeling of correlated data—inherent to the nature of our design—without the violation of important regression assumptions[35]. The first model in each study regressed estimated values on actual values to obtain an intercept, slope and main effect for domain. Participant 'ID' was entered as a random effect. We entered 'domain' (coded $0=$appliances, $1=$foods), the log of the actual value (mean centred; 'actual') and the quadratic 'actual^2' as independent variables. We entered the log of the estimated value (centred relative to the mean of actual) as the dependent variable. As in Attari et al.[14], the intercept and slope of actual was modelled as a random effect and thus free to vary. The second model in each study added interaction terms between domain and actual, and between domain and actual^2. We report results from additional models that include a range of covariates and that assume minimum plausible actual values in Supplementary Note 4. These confirm the results presented in Table 1 and described below.

For perfectly accurate estimates, the lines of best fit plotted in Figs. 1 and 2 would lay along the identity line with an intercept of 0 and a slope of 1. However, the results in Table 1 show that, for both studies, the average intercept (which gives the average elevation of estimate at the mean of actual when $\text{domain}=0$) was significantly negative. This indicates that participants underestimated energy consumed and GHG emissions for appliances. In both studies, there was a significant main effect of domain. As expected, this negative coefficient indicates that estimates were significantly lower for foods than for appliances. In both studies, there was also a significant effect of actual, indicating that people gave higher estimates for items with higher actual values. As expected, however, these slopes were significantly less than 1 (the 95% confidence intervals ranged between 0.14 and 0.24), showing that people were insufficiently sensitive to the magnitude of difference between items. Finally, in both studies there was also a significant effect of actual^2, reflecting that moderate-energy-consuming/GHG-emitting items were estimated relatively more inaccurately than low- or high-energy consuming/GHG-emitting items, thus producing a quadratic 'U' shape.

We also tested for interactions between domain and actual and between domain and actual^2, which were both significant. In both studies, the positive relation between actual and estimated values was stronger for appliances than for foods, and the U quadratic shape was more pronounced for foods than for appliances. Put simply, consumers were relatively insensitive to the difference in energy consumed and GHG emissions of most foods (for example, fruits, vegetables, nuts, milk and cheese), but were relatively more sensitive to the difference in energy consumed and GHG emissions between red meat (for example, beef) and non-meat items (for example, potatoes). Nevertheless, they underestimated red meat by the widest margin.

The effectiveness of a carbon label

Study 1 suggests that consumers significantly underestimate the energy consumption and GHG emissions associated with food production and transportation, and to a greater degree than for appliances. The substantial underestimation of the environmental impact of the food's life cycle is likely to be reflected in consumers' food choices. Namely, consumers may be unwilling to move away from high-GHG-emitting foods such as beef because of a lack of understanding of beef's environmental consequences. In Study 2, we tested whether correcting these misperceptions with a carbon label may be a viable strategy to influence behaviour.

Lessons from nutrition and fuel economy labelling suggest that an effective carbon label should be simple to understand and include reference values that permit comparisons and put information in context[36,37]. One effective approach used with fuel economy labels has been to translate obscure attributes into more comprehensible attributes[38,39]. We therefore designed a label that provides salient, concrete GHG information and that facilitates the understanding of information by expressing GHG emissions in terms of a familiar unit (equivalent light-bulb minutes), and facilitating evaluation by using a simple green-to-red scale relative to products in the same category[40].

Participants ($n=120$) were presented with a menu on a computer screen of six cans of soups—three beef and three vegetable—and were asked to buy three cans of soup using some of the money they received for showing up to participate (see Methods and Supplementary Note 5). For those in the control group, each soup was described in terms of name, image, serving size, price, calories and information about the macronutrients. The label group was additionally presented with GHG emission information in

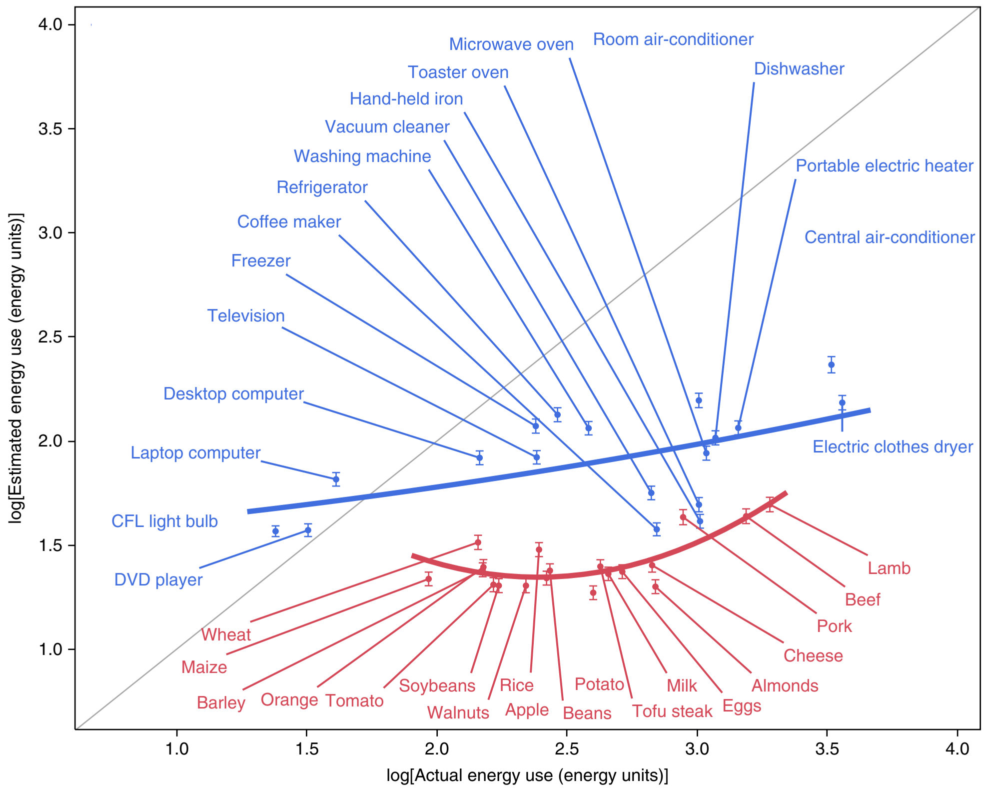

Fig. 1 | Mean estimates of energy used relative to actual energy used. The red fitted line depicts the relationship between the actual energy consumed throughout the life cycle of 19 foods (x axis) and the estimates provided by Study 1A participants (y axis). The blue fitted line depicts the relationship between the actual energy used of 18 electrical appliances (x axis) and the estimates provided by Study 1A participants (y axis). Accurate estimates would produce a set of points that fall along the grey 45° line. As shown, participants ($n = 518$) underestimated the energy consumption of all foods and almost all appliances (with the exception of compact fluorescent lamp (CFL) light bulbs, laptop computers and DVD players). The underestimation was greater for foods than for appliances. Note that all estimates are expressed in terms of energy units and participants were told that a 100 W incandescent light bulb turned on for 1 h uses 100 energy units. All data are logged. The error bars represent the standard error of the mean.

terms of lb CO_2e, 'light-bulb minutes' and a coloured rating scale ranging from 'Lower Carbon Footprint' (in a green zone) to 'Higher Carbon Footprint' (in a red zone) based on the range of actual values observed for soups (see Fig. 3 for an example). The main dependent variable was the number of beef soups purchased.

The carbon label had the predicted effect: those in the label group ($M = 0.98$, s.d. = 1.04) purchased fewer cans of beef soup than those in the control group ($M = 1.51$, s.d. = 1.06), $t(118) = -2.74$, $P = .007$, $d = 0.50$ (all significance tests are two-tailed; see Supplementary Note 6 for regressions including a range of covariates).

To examine the impact of the label on participants' knowledge, we calculated the ratio between estimated beef soup GHG units to estimated vegetable soup GHG units. We removed from the analysis two outliers who were more than six standard deviations from the mean ratio ($M = 3.67$, s.d. = 7.07, before exclusion). The true ratio was approximately 10 (see Supplementary Note 7). A two-sided t-test revealed that those in the label group ($M = 3.45$, s.d. = 2.65) estimated a higher ratio of emissions from beef over vegetables than those in the control group ($M = 2.16$, s.d. = 1.23), $t(116) = 3.38$, $P = .001$, $d = 0.62$.

To examine whether the label affected soup purchases because of a change in knowledge, we conducted a mediation analysis using Hayes' PROCESS tool for SPSS[41]. In the mediation analysis (Model 4, 5,000 bootstrap samples), the independent variable was 'label' (0 = absent, 1 = present), the mediating variable was the estimated beef-to-vegetables ratio and the dependent variable was the number of beef soups purchased. As shown in Fig. 3, the analysis revealed the expected significant indirect effect of label on the number of beef soups purchased via the estimated beef-to-vegetables ratio, $B = -0.11$ (95% confidence interval = −0.25, −0.01).

These results suggest that provision of food GHG emissions information in an understandable way increases consumers' tendency to choose relatively low-emission options compared to when no GHG emission information is provided. On average, this information improved understanding of relative GHG emissions between alternatives, which in turn shifted choice towards lower-GHG-emitting options.

Discussion

People tend to underestimate the energy consumed by and GHG emissions from the production, storage and transport of a range of foods. This blind spot regarding food production as a source of energy consumption and GHG emissions may have consequences for related daily decisions.

In general, people tended to appropriately rank items by energy used and GHG emissions. For example, higher GHG emissions were estimated for producing a serving of beef than producing an apple. However, the actual difference in magnitude between high- and low-emission items was not reflected in people's estimates. For example, items associated with high emissions, such as beef, were underestimated much more than items associated with low emissions, such as apples. The worrying implication of this finding is that the typical consumer is unaware of the benefits that can be obtained by shifting away from high-energy and high-GHG-emission options. For example, according to one estimate for the average weekly diet of an Australian family, replacing ruminant meat (for

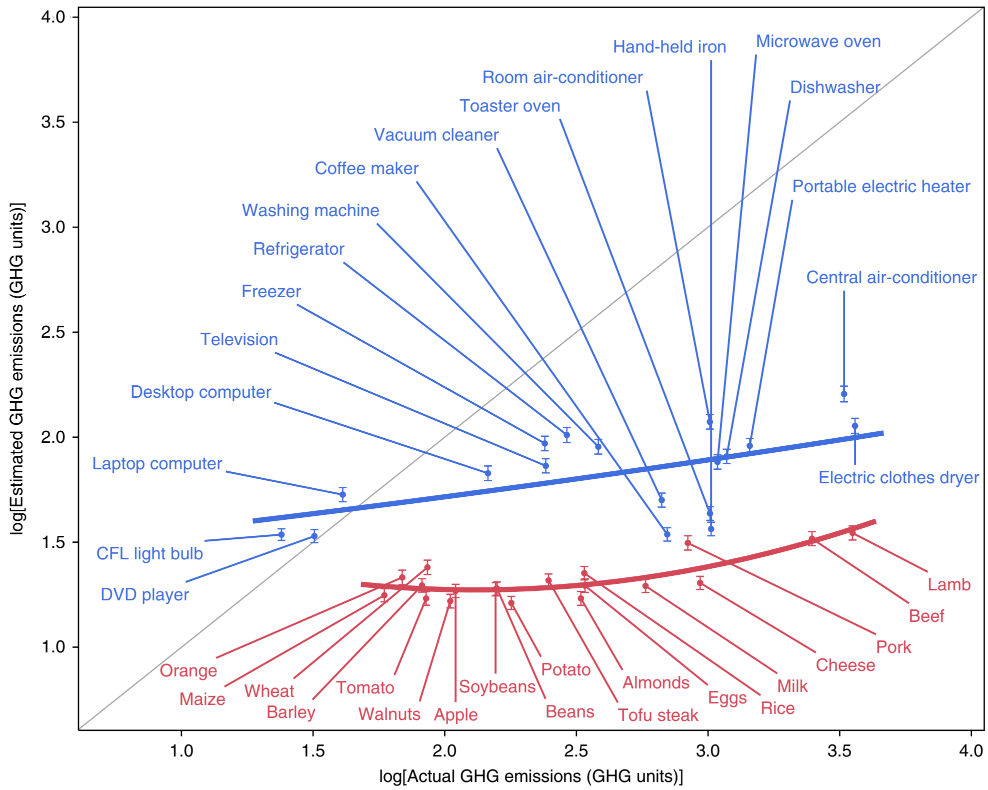

Fig. 2 | Mean estimates of GHG emitted relative to actual GHG emitted. The red fitted line depicts the relationship between the actual GHG emitted throughout the life cycle of 19 foods (*x* axis) and the estimates provided by Study 1B participants (*y* axis). The blue fitted line depicts the relationship between the actual GHG emitted of 18 electrical appliances (*x* axis) and the estimates provided by Study 1B participants (*y* axis). Accurate estimates would produce a set of points that fall along the grey 45° line. As shown, participants ($n = 514$) underestimated the GHG emitted of all foods and almost all appliances (with the exception of CFL light bulbs, laptop computers and DVD players). The underestimation was greater for foods than for appliances. Note that all estimates are expressed in terms of GHG units and participants were told that a 100-W incandescent light bulb turned on for 1 h emits 100 GHG units. All data are logged. The error bars represent the standard error of the mean.

Table 1 | Results of multilevel regressions for predicting consumers' perceptions of energy consumption (Study 1A) and GHG emissions (Study 1B)

	Study 1A		**Study 1B**	
	Model 1	**Model 2**	**Model 3**	**Model 4**
Intercept	−0.709***	−0.693***	−0.723***	−0.713***
Domain (domain)	−0.464***	−0.530***	−0.466***	−0.509***
Log of actual value (actual)	0.217***	0.210***	0.161***	0.176***
Quadratic term (actual^2)	0.065***	0.025*	0.039***	0.010
domain × actual		−0.033*		−0.062***
domain × actual^2		0.421***		0.132***

The independent variable domain refers to whether participants were estimating foods (coded '1') or appliances (coded '0'). The independent variable actual, which was logged and mean-centred, refers to the actual energy consumed or GHG emissions for each item. The dependent variable—estimated, which was also logged and centred relative to the mean of actual—refers to the participant's estimated energy consumed or GHG emissions for each item. Coefficients are unstandardized. ***$P < 0.001$, *$P < 0.05$.

example, beef) with non-ruminant meat (for example, duck), and selecting alternative fish species, produces an estimated 30% reduction in food-related emissions[3].

A key question that emerges from our observations is: why do consumers underestimate energy consumed and GHG emissions? Previous research in cognitive psychology shows that people often overestimate their understanding of common everyday objects and activities, such as how a zipper operates[42–44]. Rozenblit and Keil[43] argue that the folk theories people hold are fragmentary and incomplete but largely unchallenged—people rarely need to explain the operation of complex everyday objects and therefore are unaware of the gaps in their understanding. We believe that food is a similarly familiar but complex phenomenon. Just as with zippers, consumers encounter food every day; however, the complex production and distribution process is hidden. For example, many consumers may be unaware that cattle release methane, a GHG that is 28–36 times more potent than CO_2[45]. Therefore, we suggest that one of the main reasons for misperception is that consumers fail to consider important factors underlying energy consumption and GHG emissions, and this failure is accentuated for food items. Unlike appliances, which have energy labels, are plugged into an electrical outlet, emit heat, have clear indications of drawing power, and their usage affects a monthly electricity bill, the consumption of energy in the production and transportation of food is largely invisible[46]. Moreover, unlike energy, which is closely associated with the burning of fossil fuel and release of carbon dioxide, the GHG emissions embodied in food result from different processes of the life cycle, such as the large amounts of nitrous oxide emissions from fertilizer[47]. This may explain why we found greater underestimation for food than for appliances. Recent support for this general explanation comes from Attari et al.[48], who asked people to draw diagrams illustrating how water reaches the tap in an average home in the United States. The results revealed major gaps in understanding.

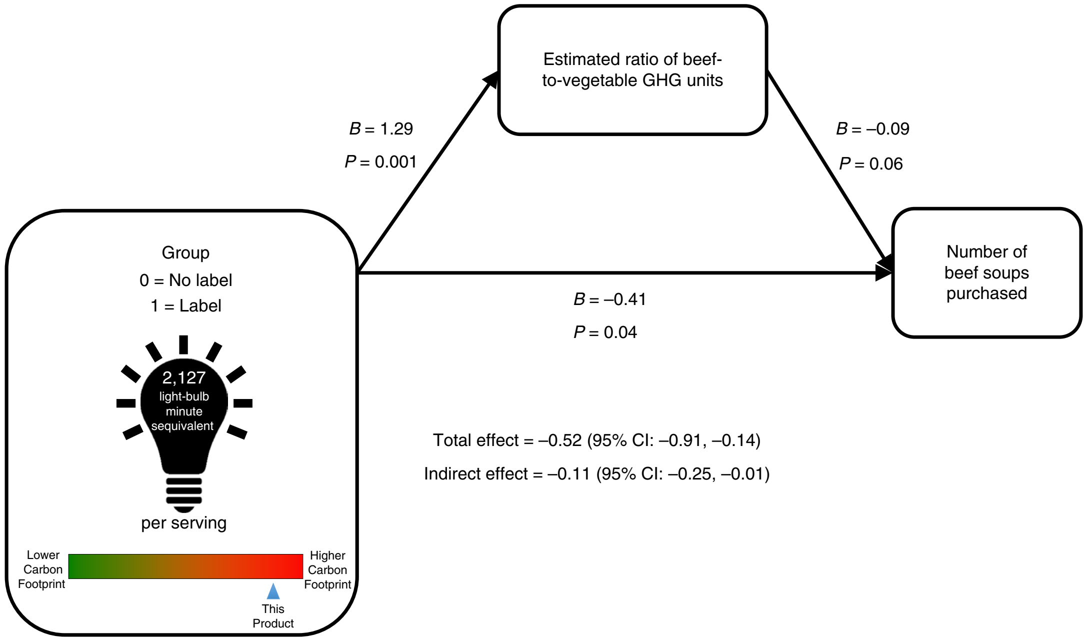

Fig. 3 | Results of a mediation analysis in Study 2. Participants were either presented with information about the GHG emissions embodied in the soup options or were not. For the former group, information was presented in terms of equivalent light-bulb minutes as well as a green-to-red scale indicating the GHG emissions of the current product relative to others in the same category. An example is provided for Vegetable Beef Soup in the study. The mediation analysis revealed an indirect effect of GHG emissions information on the number of beef soups purchased via the estimated ratio of beef-to-vegetable GHG units. CI, confidence interval.

A second key question that emerges from our observations is how to help consumers improve their general ability to make more accurate estimates. In Study 2, we found that provision of GHG emission information in a relatable format led consumers to more frequently purchase relatively low-emission foods. It may be that a carbon label serves as a decision signpost: reminding consumers of their values and then directing them to options most consistent with those values[39]. We also acknowledge that knowledge alone is often insufficient to change behaviour[49]. In the real marketplace, factors such as perceived behavioural costs[50], norms[51] and identity[52] also influence behaviour. Moreover, the extent to which knowledge influences behaviour in this context is influenced by factors such as political affiliation and level of trust in scientists[53]. Therefore, our promising observations warrant replication outside a laboratory setting.

A limitation of our research is the data we used as best estimates of the 'true' values of energy use and GHG emissions associated with food and appliances[3]. Different environmental life-cycle analyses produce different results depending on geographic, temporal or system boundaries, and other assumptions, and hence the true value is not a point estimate but a range. Fortunately, there does seem to be convergence in the general ranking of energy use and GHG emissions associated with broad food categories[3,54], and our conclusions are unlikely to change due to this factor alone. Furthermore, a sensitivity analysis indicated that participants' estimates were lower than even the minimum value reported across different sources. The difficulty in quantifying with precision the environmental impacts of foods and the variability of these impacts across supply chains suggests that a label reporting a range of GHG emissions representing both variability and uncertainty of these estimates may be a more suitable approach than a food label with a specific carbon score. This range could be implemented as a band that covered the space between the lower and upper bound (for example, 10th and 90th percentiles) of the distribution of possible GHG emissions for a given food. A traffic light code could still compare the extremes of this range with the least and most environmentally friendly foods. Uncertainty bounds are usually reported as part of life-cycle assessment studies, but more research should be conducted on how to best communicate this to consumers.

Online content

Any methods, additional references, Nature Research reporting summaries, source data, statements of data availability and associated accession codes are available at https://doi.org/10.1038/s41558-018-0354-z.

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Author contributions

A.R.C., R.P.L., S.H. and D.P.-E. designed the research. A.R.C. and S.H. performed the research. A.R.C. and S.H. analysed the data. A.R.C., R.P.L. and D.P.-E. wrote the paper.

Competing interests

The authors declare no competing interests.

Additional information

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Methods

For all studies, the sample size was selected on the basis of similar past research. The actual energy and GHG emissions from the foods and appliances we used are presented in Supplementary Note 3 and Supplementary Tables 2–4. The research was approved by the Duke University IRB board and the RMIT University Ethics Committee. Informed consent was obtained from all participants.

Study 1A. *Participants.* The 518 participants who completed the study were recruited from the Qualtrics online panel and were paid for completion. The survey was available only to people in the United States. Quota sampling ensured that the sample reflected the American adult population in terms of age, gender and race. The participants ranged in age from 18 to 84 years with a mean of 43.6 (s.d. = 14.6). Among the survey respondents, 52% were female and 59% were employed full time or part time. Racially, 63% were non-Hispanic White, 16% Hispanic, 12% African American, 5% Asian, and 4% as other. Politically, 37% identified as Democrats, 31% as Independent, 28% as Republican, and 4% as other.

Materials and procedure. Participants were first asked to indicate the percentage of household GHG emissions produced from operations, transportation and food production (see Supplementary Note 1 for the full methods). Next, participants were asked to estimate how many units of energy are consumed in the production and transport of a serving size of 19 foods and the powering for 1 h of 18 appliances. The reference was that using a 100-watt incandescent light bulb for 1 h consumes 100 units of energy. Half of the participants judged the food domain items first and the others judged the appliance domain items first. Within each domain, the order of the items was randomized for each participant. Each domain of items also included an attention check item that read `Enter the number 100 in this box'. The participants who failed this attention check question were immediately filtered out of the survey. On the next page, participants answered two further attention check questions related to the task. On the next page, participants were asked to complete the revised New Ecological Paradigm revised (NEPr) scale, a 15-item questionnaire for assessing pro-environmental worldview[55]. Scores on the NEPr scale range from 15 to 75 with higher scores indicating a more pro-environmental worldview. Finally, participants answered a set of basic demographic questions. We also excluded one participant who completed the study in less than a third of the median soft-launch survey complete time.

Study 1B. *Participants.* The 514 participants who completed the study were recruited from the Qualtrics online panel and were paid for completion. The survey was available only to people in the United States. Quota sampling ensured that the sample reflected the American adult population in terms of age, gender and race. The participants ranged in age from 18 to 83 years with a mean of 43.5 (s.d. = 14.4). Among the survey respondents, 52% were female and 53% were employed full time or part time. Racially, 64% were non-Hispanic White, 15% Hispanic, 12% African American, 5% Asian, and 4% as other. Politically, 40% identified as Democrats, 31% as Independent, 23% as Republican, and 6% as other.

Materials and procedure. The materials and procedure were identical to Study 1A except that the reference was that using a 100-watt incandescent light bulb for 1 h released 100 units of GHG emissions (see Supplementary Note 1 for the full methods).

Study 2. *Participants.* The 120 participants who completed the study were recruited from the Duke University Behavioral Research community participant pool and were paid for completion. The convenience sample ranged in age from 18 to 74 years with a mean of 27.4 (s.d. = 9.5). Among the survey respondents, 62% were female and 61% were employed full time or part time. Racially, 33% were Caucasian/White, 8% Hispanic/Latino, 17% African American, 40% Asian/Pacific Islander, and 2% as other. Politically, 54% identified as Democrats, 28% as Independents, 4% as Republican and 14% as other.

Materials and procedure. The study was carried out in a computer laboratory together with two other, unrelated studies. The data were collected over multiple sessions in a single day. Each session comprised up to 16 participants. Research assistants, blind to the hypotheses, managed the data collection. Before beginning the bundle of studies, participants answered a series of demographic questions. When the current study began, participants were informed that they would earn US$6 for completing the study but that US$3 of the payment was to be spent purchasing goods that they would actually get at the end of the study. Next, participants were presented on screen with six cans of soup—three beef soups and three vegetarian soups—and asked to buy three of the soups (see Supplementary Note 5 for the full methods). Each type of soup could be purchased only once. The arrangement of the soups was the same for all participants. The information available for each soup was: name, image, price, serving size, calories, fats per serving, carbohydrates per serving and proteins per serving. Depending on the group allocation, participants were also presented with GHG emissions per serving (in terms of grams of carbon dioxide equivalent and light-bulb minutes equivalent), as well as a GHG emissions rating per serving. The rating displayed an arrow 'This Product' on a continuum ranging from Lower Carbon Footprint, coloured green, to Higher Carbon Footprint, coloured red. On the next page, participants were asked, as in Study 1B, to estimate how many units of GHG emissions were released in the production and transport of a serving size of beef soup and vegetable soup. Next, participants answered three attention check questions followed by a question measuring the participant's familiarity with the soups presented in the study. Next, participants completed the NEPr[55]. Next, participants completed a modified version of the Food Choice Questionnaire, which measures 36 factors that drive food choices such as health and convenience[56,57]. Finally, participants answered additional demographic questions including type of diet.

Data availability

The data that support the plots within this paper and other findings are available at https://osf.io/smj67.

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Exhibit 11


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R0510

Exhibit 12

April 27, 2023

FSIS Docket Clerk
Department of Agriculture
Food Safety and Inspection Service
Room 2534 South Building
1400 Independence Avenue, S.W.
Washington, DC 20250-3700

Re: Petition to Prohibit "Low-Carbon Beef" Claim and Require Third-Party Verification for Similar Claims and a Numerical Carbon Disclosure.

The Environmental Working Group respectfully submits this petition to the U.S. Department of Agriculture (USDA) to:

- Prohibit the "Low-Carbon Beef" Claim recently approved by USDA.
- Require third-party verification for similar carbon claims.
- Require a numerical on-pack carbon disclosure when such claims are made.

Thank you for your consideration of this petition. Replies and other communication can be directed to sfaber@ewg.org.

Sincerely,

Scott Faber[1] and Kalena Wojtala[2]
Environmental Working Group
1250 I Street N.W., Suite 1000
Washington, D.C. 20005

[1] Scott Faber is Senior Vice President for Government Affairs for the Environmental Working Group
[2] Kalena Wojtala is a J.D. candidate at Vermont Law School and intern for the Environmental Working Group

Summary

Consumers are increasingly seeking to use their buying power to reduce greenhouse gas emissions. Misleading climate claims, including the "Low-Carbon Beef" claim recently approved by the USDA, undermine these efforts by confusing consumers. Many of these claims are not verified by independent, qualified third parties, and experts agree that USDA lacks reliable measurement, monitoring, reporting, and verification protocols.

To address misleading climate claims, we urge USDA to reject misleading claims, such as the agency's Low-Carbon Beef claim, and to modernize USDA's verification system for climate claims to require independent third-party verification of claims. We further urge USDA to require a numerical carbon disclosure whenever such claims are made.

Allowing misleading climate claims, including USDA's Low-Carbon Beef claim, or allowing climate claims without sufficient verification and an accompanying numerical carbon disclosure, violates federal laws which prohibit false and misleading claims.

About the Petitioner

The **Environmental Working Group** (EWG) is a public interest, nonprofit, nonpartisan organization, with offices in Washington, D.C., San Francisco and Sacramento, California, and Minneapolis, Minnesota. EWG aims to empower people to live healthier lives in a healthier environment, and for over two decades, it has worked to protect human health and the environment through breakthrough research and education, encouraging consumer choice and civic action.

Full Statement of the Action Requested

Pursuant to 5 U.S.C. 553 (e), 7 CFR § 1.28, and 9 C.F.R. § 392.5, the Petitioner requests that FSIS take the following actions:

1) Prohibit "Low-Carbon Beef" claims, which are false and misleading;
2) Require independent third-party verification of any climate claims; and
3) Require a numerical carbon disclosure whenever such claims are made.

Basis for the Action Requested

A. Low-Carbon Beef Claims Are Inherently Misleading

There is no such thing as "Low-Carbon Beef." In fact, no food choice results in more greenhouse gas emissions than choosing beef.[3] However, many consumers viewing the Low-Carbon Beef label approved by USDA are likely to assume that beef bearing such a label will help reduce greenhouse gas emissions.

Even the beef which meets the "Low-Carbon" beef standard approved by USDA still results in more greenhouse gas emissions than any other food choice, including any other meat or poultry choice. Making matters worse, beef meeting USDA's "Low-Carbon" beef standard would still result in more emissions than much of the beef produced elsewhere in the U.S. or Canada.[4] By any measure, choosing beef is a bad choice for the climate. Per gram of protein, beef production results in approximately nine times more greenhouse gas emissions than poultry, six-and-a-half times more than pork, and 25 times more than soybeans.[5]

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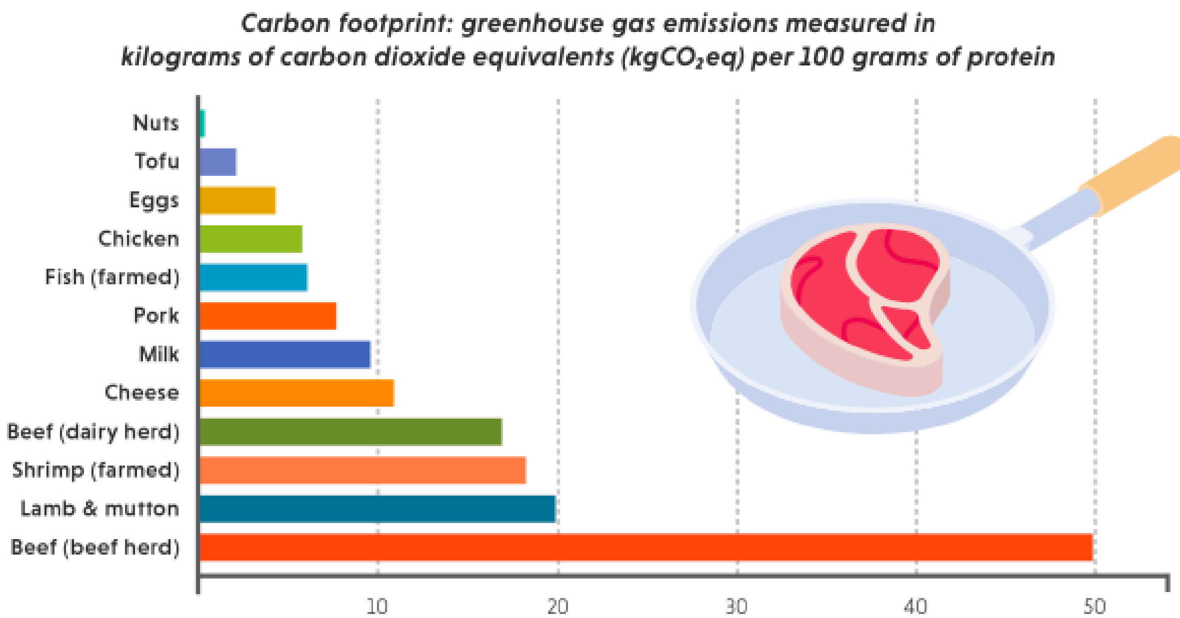
[3] Xiaoming Xu et al., *Global Greenhouse Gas Emissions From Animal-Based Foods are Twice Those of Plant-Based Foods*, Nature Food 724 (2021), https://www.nature.com/articles/s43016-021-00358-x.

[4] To meet USDA's "Low Carbon" Beef standard, beef production must reduce emissions by 10% of 26.3 kilograms of carbon dioxide equivalents per kilogram of carcass weight. Matt Reynolds, *Is There Really Such a Thing as Low-Carbon Beef?*, Wired (Jan. 17, 2022), https://www.wired.com/story/low-carbon-beef/. However, a recent study of beef production in the U.S. found beef production resulted, on average, 21.3 kilograms of carbon dioxide equivalents per kilogram of carcass weight. *Id.* (citing C. Alan Rotz, *Environmental Footprints of Beef Cattle Production in the United States*, 169 Agricultural Systems 1 (2019), https://www.sciencedirect.com/science/article/pii/S0308521X18305675). In Canada, the average is approximately 19 kilograms of carbon dioxide equivalents per kilogram of carcass weight. *Id.* (quoting Karen Beauchemin, an expert on cattle nutrition at Canada's Department of Agriculture and Agri-Food).

[5] *Id.* (citing J. Poore & T. Nemecek, *Reducing Food's Environmental Impacts Through Producers and Consumers*, 360 Science J. 987 (2018), https://www.science.org/doi/abs/10.1126/science.aaq0216), https://www.wired.com/story/low-carbon-beef/.



Source: EWG analysis of GHG data based on global averages of all production types.[6]

B. Many Carbon Claims are Inherently Misleading

Consumers are deeply confused by similar carbon claims, including but not limited to Net-Zero, Carbon Neutral, Carbon Negative, Climate Neutral, Net-Zero Carbon, Climate Positive, Climate Neutral, and Carbon Positive. Many of these claims are already appearing on products subject to USDA regulation, such as:

[6] Environmental Working Group, *EWG's Quick Tips For Reducing Your Diet's Climate Footprint*, (2022), https://www.ewg.org/sites/default/files/2022-04/EWG_TipSheet_Meat-Climate_C02.pdf.

Silver Fern Farms Net Carbon Zero Angus Beef.[7]

Maple Leaf Carbon Neutral Label on Products.[8]

[7] Silver Fern Farms, https://silverfernfarms.com/us/en/our-range/net-carbon-zero-beef-range (last visited Apr. 23, 2023).
[8] Maple Leaf Foods, https://www.mapleleaffoods.com/sustainability-report/better-food/ (last visited Apr. 23, 2023).

Conagra Evol Brand Carbon Neutral Label.[9]

Purely Organic Carbon Neutral Label.[10]

Studies show that consumers are often misled by these claims. Most consumers believe these claims reflect reductions in actual greenhouse gas emissions in-house, not offsets of these

[9] Conagra Brands, https://www.conagrabrands.com/news-evolr-becomes-first-frozen-brand-to-offer-carbonfreer-certified-carbon-neutral-meals-prn-122805 (last visited Apr. 23, 2023).

[10] Purely Organic, https://www.noblefoods.co.uk/purely-organic-certified-carbon-neutral/ (last visited Apr. 23, 2023).

emissions through changes in farming practices by others.[11] When consumers are told that claims could be made by reliance on offsets in lieu of actual emissions reductions, most consumers report feeling misled.[12] Experts have found the lack of a standard definition for terms like "net zero" and "carbon neutral" contributes to consumer confusion. In the absence of a standard definition, consumers report wanting more information on offsets, including verification measures.[13]

C. Carbon Claims Should be Subject to Third-Party Verification

All carbon claims, including claims which rely on carbon offsets, should be subject to independent third-party verification.

Experts agree that USDA currently lacks reliable measurement, monitoring, reporting, and verification protocols, or MMRV protocols, for farm stewardship practices. In addition, consumers, NGOs (non-governmental organizations), and academics also do not have access to the data which supports these protocols, sowing doubt with regard to promised environmental benefits.[14] One recent report concluded, "[T]here are major questions regarding the validity of agricultural-based carbon offset emanating from voluntary carbon markets . . . Simply put, the lack of practical and scientifically sound approaches for confirming specified practices generates claimed benefits, and the lack of access to confirmatory data poses major systemic impediments to rewarding farmers and ranchers for deploying climate-smart practices."[15]

Companies making carbon claims often rely on models that do not provide a "sound basis for quantifying or monetizing increases in carbon sequestration in soils or decreases in methane and nitrous oxide emissions."[16] In particular, measuring and monitoring soil carbon presents unique challenges, as different regions have widely different soil types, and carbon concentration can vary significantly within a particular field. What's more, soil carbon can take many years to

[11] The Advertising Standards Authority (ASA) found through a survey that in making [carbon neutral and net zero] claims, businesses were not believed to be taking an offsetting-first approach – instead, they were believed to have been reducing their absolute emissions in-house. Sarah George, *Consumers Confused Over Net-Zero Claims in Ads, ASA Warns*, Edie (Oct. 20, 2022), https://www.edie.net/consumers-confused-over-net-zero-claims-in-ads-asa-warns/ (citing Advert. Standards Auth., *Environmental Claims in Advertising: Qualitative Research Report*, Jigsaw Research (Oct. 2022)).

[12] *Id.* When the ASA explained that brands could technically claim carbon neutrality by offsetting alone, a majority said that they would feel misled.

[13] *Id.* The ASA found that members of the public would like more information on offsetting and emissions reductions, with accompanying time frames, from the brands that they shop with.

[14] Kim Novick, et al., *The Science Needed for Robust, Scalable, and Credible Nature-Based Climate Solutions in the United States*, (Ind. Univ. O'Neill School of Public and Environmental Affairs, 2022), https://scholarworks.iu.edu/dspace/handle/2022/28264.

[15] David J. Hayes et al., *Data Progress Need for Climate-Smart Agriculture*, Stanford Law School, Law and Policy Lab, (Apr. 2023) [Hereinafter "Stanford Report"].

[16] *Id.*

accumulate.[17] These limitations "have eliminated or severely limited the availability of reliable baseline data against which changes in soil concentrations due to good soil management practices can be measured and monitored. Unmoored from baseline conditions, subsequent soil carbon sampling activities using traditional methods arguably offer only random data points that cannot support meaningful conclusions about sequestered carbon quantities or trends."[18] The American Society of Agronomy, in recent comments to the USDA, concluded that "the scientific community currently lacks consensus" on the best approaches to measure soil carbon sequestration, citing the need for better data.[19]

As a result, experts recently called on USDA's Natural Resources Conservation Service to rescind the agency's soil carbon protocols.[20] Similar concerns have been raised regarding USDA protocols to assess reductions in nitrous oxide[21] and methane emissions.[22] More data is needed from a more representative set of samples to quantify the benefits of climate-smart practices, whether implemented alone or in combination with other practices.[23] In particular, nitrous oxide emissions vary significantly, and efforts to increase soil carbon can result in increases in nitrous oxide emissions.[24]

A growing body of evidence has demonstrated that land- and forest-based carbon offsets have produced few emissions reductions and inconsistent forest protection.[25] While methane and

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[17] Emily Oldfield, et al., *Agricultural Soil Carbon Credits: Making Sense of Protocols for Carbon Sequestration and Net Greenhouse Gas Removals* (2021), https://www.edf.org/sites/default/files/content/agricultural-soil-carbon-credits-protocol-synthesis.pdf.

[18] Stanford Report, *supra* note 15, at 13.

[19] American Society of Agronomy et al., *Comment Letter on Request for Public Input About Implementation of the Inflation Reduction Act Funding*, (2022).

[20] Environmental Defense Fund, et al., *Joint Comment in Response to Request for Public Input About Implementation of the Inflation Reduction Act Funding*, (Dec. 21, 2022).

[21] Stanford Report, *supra* note 15, at 9.

[22] *Id.*

[23] Novick, *supra* note 14 at 9.

[24] *Id.*

[25] *E.g.*, Shane Coffield and James Randerson, *Satellites Detect No Real Climate Benefit from 10 Years of Forest Carbon Offsets in California*, The Conversation (Dec. 01, 2022), https://theconversation.com/satellites-detect-no-real-climate-benefit-from-10-years-of-forest-carbon-offsets-in-california-193943.
See also Kate Dooley et al., *Carbon Removals from Nature Restoration are no Substitute for Steep Emission Reductions*, 5 One Earth, 812 (2022), https://www.cell.com/one-earth/fulltext/S2590-3322(22)00323-2?_returnURL=https%3A%2F%2Flinkinghub.elsevier.com%2Fretrieve%2Fpii%2FS2590332222003232%3Fshowall%3Dtrue. Thales A. P. West et al., *Overstated Carbon Emission Reductions from Voluntarily REDD+ Projects in the Brazilian Amazon*, 117 Proceedings of the Nat'l Academy of Sciences, 24188 (2020), https://www.pnas.org/doi/full/10.1073/pnas.2004334117. Thiago Chagas et al., *A Close Look at the Quality of REDD+ Carbon Credits*, Climate Focus, (Mar. 20, 2020), https://climatefocus.com/publications/close-look-quality-redd-carbon-credits/. Grayson Badgley et al., *Systematic Over-Crediting of Forest Offsets*, (Carbon)Plan, (Apr. 29, 2021), https://carbonplan.org/research/forest-offsets-explainer. Lisa Song and Paula Moura, *An Even More Inconvenient Truth: Why Carbon Credits For Forest Preservation May be Worse Than Nothing*, ProPublica, (May 22, 2019), https://features.propublica.org/brazil-carbon-offsets/inconvenient-truth-carbon-credits-dont-work-deforestation-redd-acre-cambodia/. Dr. Martin Cames et al., *How Additional is the Clean Development Mechanism: Analysis of the Application of Current Tools and Proposed Alternatives*, Öko-Institut e.V., 11 (Mar. 2016),

nitrous oxide emissions produce most of the emissions from agriculture, few of the offsets issued between 1996 and 2021 reduced emissions of these powerful greenhouse gasses.[26] As a result, many offsets used to support carbon claims fail to produce promised benefits. A recent analysis of more than 215,000 offsets over the past decade found that global brands routinely relied on suspect offsets.[27] As a result, many products that carry claims like "climate neutral" or "climate positive" likely result in increases, not decreases, in greenhouse gas emissions.[28]

Consumers are willing to choose or even pay more for products that reduce greenhouse gas emissions. For example, one study of tomatoes and apples found that consumers were willing to pay a premium for products that reduced their carbon footprint.[29] Many younger consumers report changing buying behavior to reflect concern about the environment.[30] Other studies found similar results.[31]

Consumers expect that these carbon claims have been verified by an independent third party. However, USDA relies on affidavits by farmers and food companies that are not subject to verification by USDA or a qualified third-party.[32] In other words, USDA currently relies upon

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https://climate.ec.europa.eu/system/files/2017-04/clean_dev_mechanism_en.pdf. Raphael Calel et al., *Do Carbon Offsets Offset Carbon?*, Grantham Rsch. Inst. on Climate Change & the Env't, Ctr. for Climate Change Econ. & Policy, (Nov. 2021), https://www.lse.ac.uk/granthaminstitute/wp-content/uploads/2021/11/working-paper-371-Calel-et-al..pdf. Derik Broekhoff, *Expert Report on CO2 Compensation*, Stockholm Env't Inst., (July 2022), https://www.clientearth.org/media/exyfip2p/productie-4-broekhoff-expert-report-v2-2-final.pdf.

[26] Ruth DeFries et al., *Land Management Can Contribute to Net Zero,* 376 Sci. 1163, 1164 (2022).

[27] Akshat Rathi et al., *Junk Carbon Offsets Are What Make These Big Companies 'Carbon Neutral'*, Bloomberg (Nov. 21, 2022), https://www.bloomberg.com/graphics/2022-carbon-offsets-renewable-energy/#xj4y7vzkg.

[28] *See* Joe Sandler Clarke and Luke Barratt, *Top Airlines' Promises to Offset Flights Rely on 'Phantom Credits'*, Unearthed Greenpeace UK (Apr. 2021), https://unearthed.greenpeace.org/2021/05/04/carbon-offsetting-british-airways-easyjet-verra/.

[29] A significant proportion of consumers are willing to pay a premium for reducing their carbon footprint by choice or requested a discounted price for products with a higher carbon footprint. Christina Lampert, *Will Carbon-Labeled Products Sell More? Here's What We Know*, Sustainable Brands (Feb. 2022), (citing *Id.* (citing Onozaka et al., *Defining Sustainable Food Market Segments: Do Motivations and Values Cary by Shopping Locale?*, 93 Am. J. Agric. Econ. 583-589 (2011)).)

[30] 64% of Gen X consumers will spend more on a product if it comes from a sustainable brand, and it jumps to 75% among millennials. GreenPrint, *Business of Sustainability Index*, (Mar. 2021), https://greenprint.eco/wp-content/uploads/2021/03/GreenPrint-Business-of-Sustainability-Index_3.2021.pdf).

[31] Most consumers are willing to pay more for food products that exhibit a lower carbon footprint. Maurizio Canavari et al., *Consumer Stated Preferences for Dairy Products with Carbon Footprint Labels in Italy*, 8 Agric. & Food Econ. (2020), https://doi.org/10.1186/s40100-019-0149-1).
See also Mengmeng Xu et al., *Towards Low-Carbon Economy by Carbon Label?: Survey Evidence From First-Tier Cities in China*, 97 Env't Impact Assessment Rev. 106902 (Nov. 2022), https://doi.org/10.1016/j.eiar.2022.106902. Julia A. Wolfson et al., *Effect of Climate Change Impact Menu Labels on Fast Food Ordering Choices Among US Adults: A Randomized Clinical Trial*, 5 JAMA Netw. Open. 2248320 (2022), doi:10.1001/jamanetworkopen.2022.48320.

[32] Under FSIS Guidelines, the only documentation needed to support such climate-smart claims are written descriptions from the farmers explaining how their process supports their claim. Food Safety and Inspection Service, *Animal Raising Claims Labeling Guidelines Update*, (Sep. 2021), PowerPoint. https://www.fsis.usda.gov/sites/default/files/media_file/2021-09/Animal-Raising-Claims-labeling-and-Non-GMO-slides-2021-09-01.pdf.

the honor system. Fortunately, third-party verification is familiar to USDA. For example, qualified third parties must certify that organic food meets USDA standards. Experts have identified measurement and monitoring protocols that feature sampling and analytical tools designed to measure changes in carbon, methane, or nitrous oxide levels.[33]

USDA recognizes that better measurement, monitoring, and verification tools are badly needed before offsets should be permitted to support carbon claims. Indeed, one purpose of the USDA's Partnership for Climate Smart Commodities is to "quantify, monitor, report and verify climate results." [34] In particular, USDA finds[35] the following barriers to the use of carbon claims:

- The lack of standard definitions of climate-smart commodities;
- The lack of clear standards for the measurement of climate benefits;
- The potential for double counting of benefits.

USDA further recognizes that the effects of climate-smart practices vary depending upon the location, landscape position, methods of installation, and type of activity.[36] To address these uncertainties, USDA is currently creating a "learning network" to incorporate the lessons learned from individual projects. One of the purposes of the program is to "learn from different approaches in deploying climate-smart practices [and in] innovation in greenhouse gas quantification, monitoring, and verification."[37] Congress also provided $300 million in the Inflation Reduction Act (IRA) to "quantify" and "monitor and track" emissions by collecting "field-based data" to measure the benefits of climate-smart practices funded by the IRA.[38]

D. Any Carbon Claim Should be Accompanied by a Numerical Disclosure

To avoid consumer confusion and address uncertainties in measurement, any carbon claims should be accompanied by an on-pack numerical carbon disclosure.

Many products already feature an on-pack numerical disclosure, including:

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[33] Stanford Report, *supra* note 15, at 6.
[34] USDA, *Partnership for Climate Smart Commodities*, https://www.usda.gov/climate-solutions/climate-smart-commodities (last visited on Apr. 4, 2023).
[35] USDA, *Programmatic Environmental Assessment for Climate-Smart Commodities*, (Aug. 26, 2022), https://www.usda.gov/sites/default/files/documents/partnerships-climate-smart-commodities-pea.pdf (last visited on Apr. 4, 2023).
[36] *Id.* at 34.
[37] USDA, *Partnerships for Climate-Smart Commodities FAQs*, (Jan. 2023) https://www.usda.gov/climate-solutions/climate-smart-commodities/faqs.
[38] Inflation Reduction Act of 2022 § 21001(a)(1)(B)(iii), 136 Stat. 1818.

Quorn Carbon Footprint Label.[39]

Oatly Carbon Footprint Label.[40]

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[39] Quorn, https://www.quorn.co.uk/company/press.quorn-unveils-carbon-footprint-labelling-of-its-products-and-calls-on-other (last visited Apr. 24, 2023).
[40] CarbonCloud, https://carboncloud.com/2021/10/07/oatly/ (last visited Apr. 24, 2023).

Ty Ling Carbon Label.[41]

On-pack numerical disclosures are based upon complex Life Cycle Assessments (LCAs), [42] which should also be carefully reviewed and approved by both USDA and the Environmental Protection Agency (EPA). Different types of LCAs include ISO Compliant,[43] PEF Compliant,[44] and Screening LCAs.[45]

E. Legal Basis for Requested Action

U.S. citizens have the right to petition the government to add, amend, or repeal rules under the First Amendment of the U.S. Constitution and the Administrative Procedures Act (5 U.S.C. 553(e)), and may petition to amend USDA rules under 7 CFR 1.28 and 9 CFR 392.5.
Under this authority, the petitioner requests that the Secretary of Agriculture prohibit "Low-Carbon Beef" claims, require third-party verification of carbon claims, and require a numerical carbon disclosure when such claims are made.

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[41] Ty Ling, https://tyling.com.carbon-label-packaging/ (last visited Apr. 24, 2023).
[42] Eco Matters, *What is an LCA Process?*, https://www.ecomatters.nl/services/lca-epd/life-cycle-assessment/ (last visited Apr. 23, 2023).
[43] An ISO-Compliant LCA follows all the steps recommended by ISO standards 14040 and 14044 and is grounded in a detailed LCA report. Quantis, *Guidelines for Credible, Science-driven Environmental Footprint Claims*, (2022), https://25337892.fs1.hubspotusercontent-eu1.net/hubfs/25337892/environmental-footprint-claims-guidance-reportquantis2022.pdf?utm_medium=email&_hsmi=67241665&_hsenc=p2ANqtz-8U_FMpXwFw1h5obPtsd1XkXN8BpS1e3BKqGZOUCGqPOQ0EXGXMQVZ2W-KMhlk31b8kMRnbnUOpNMz8RZ-BXbCxFOxe8g&utm_content=67241665&utm_source=hs_automation
[44] *Id.*
[45] *Id.*

Prohibiting a "Low-Carbon Beef" claim, requiring third-party verification and a numerical carbon disclosure are permitted under the *Central Hudson* test. Under the *Central Hudson* test, a four-part test is used to determine to what extent commercial speech is protected by the First Amendment.[46] First, the court must determine whether the speech in question is protected commercial speech. Protected commercial speech must "concern lawful activity and not be misleading."[47] Second, USDA must show it has a substantial interest in controlling the speech. Protecting consumers from fraud, deception, and coercion are substantial state interests.[48] Third, USDA must show that the regulation directly advances the government's stated substantial interest.[49] Finally, the scope of the regulation must be necessary to serve the government's interest, that is, the government must ensure that the law does not "burden substantially more speech than necessary."[50] The government need not use the *least* restrictive means.[51] The government must show a "fit between the legislature's ends and the means chosen to accomplish those ends, a fit that is not necessarily perfect, but reasonable."[52]

Requiring a mandatory numerical carbon disclosure when carbon claims are made is permitted under the *Zauderer* test. Under *Zauderer v. Office of Disciplinary Counsel of Supreme Court of Ohio*, commercial speech that is not *false* or *deceptive* and does not concern unlawful activities may be restricted only in the service of a substantial governmental interest, and only through means that directly advance that interest.[53] Where an action compels disclosure of "purely factual and uncontroversial information," the law need only be "reasonably related to the [government's] interest in preventing deception of consumers to pass under the First Amendment."[54] Regulators and courts can require businesses to disclose undisputedly factual and ideologically neutral information about their products, such as a numerical carbon label.

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[46] The four-part test under *Central Hudson* is (1) whether the speech is protected at all, (2) whether the government has a substantial interest in controlling the speech, (3) whether the regulation advances the substantial government interest, and (4) whether the government's regulation is necessary to serve that substantial interest.

[47] Mackenzie Battle & Cydnee Bence, *How Does the First Amendment Apply to Food and Supplement Labels*, Ctr. for Agric. & Food Sys., (citing *Central Hudson*, 447 U.S. at 564.), https://labelsunwrapped.org/wp-content/uploads/2021/06/First-Amendment-Food-Labeling-Issue-r5.pdf.

[48] *Id.* (citing *Edenfield v. Fane* at 768; *Rubin v. Coors Brewing Co*., 514 U.S. 476, 484 (1995).

[49] *Id.* (citing *Central Hudson*, 447 U.S. at 565).

[50] *Id.* (citing *Board of Trustees of State University of New York v. Fox*, 492 U.S. 469, 478 (1989)).

[51] *Id.*(citing *Board of Trustees of State University of New York v. Fox*, 492 U.S. 469, 479(1989)).

[52] *Id.* (citing *Board of Trustees of State University of New York v. Fox*, 492 U.S. 469, 478 (1989). At 480 (quoting *Posadas de Puerto Rico Assoc. v. Tourism Co. of Puerto Rico*, 478 U.S. 328, 341 (1986), overruled by *44 Liquormart, Inc. v. Rhode Island*, 517 U.S. 484 (1996)) (internal quotations omitted)).

[53] *Zauderer v. Office of Disc. Counsel*, 471 U.S. 626, 637-638.

[54] *Id.* at 651.

Under *American Meat Institute v. USDA,*[55] the D.C. Circuit held that *Zauderer* applies to "factual and uncontroversial" disclosure mandated by the government for *any purpose*.[56] By promoting "the robust and free flow of accurate information," factual disclosure mandates further the interests protected by the commercial speech doctrine.[57] In particular, the court found that a compelled disclosure must be "purely factual and uncontroversial." Like the facts disclosed in the *American Meat Institute* case, which conveyed facts that are "directly informative of intrinsic characteristics of the product," the disclosure we propose is not one-sided,[58] nor does a numerical carbon disclosure convey messages that are biased against or are expressly contrary to a corporation's views.[59]

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55 *Am. Meat. Inst. v. U.S. Dep't of Agric.*, 760 F.3d 18 (D.C. Cir. 2014) (en banc).
56 *Id.* at 22.
57 *Id.* (quoting *AMI*, 760 F.3d at 29 (quoting *Nat'l e;ec. Mfrs. Ass'n v. Sorrel*, 272 F.3d 104, 114 (2d Cir. 2001)).
58 *AMI*, 760 F.3d at 24-25 (citing *Nat'l Ass'n of Mfrs. v. NLRB*, 717 F.3d at 958, describing one party's argument that disclosures were "one-sided … favoring unionization").
59 *AMI*, 760 F.3d at 25 ("*Zauderer* does not leave the state "free to require corporations to carry the messages of third parties, where the messages themselves are biased against or are biased against or are expressly contrary to the corporation's views." (citing *Pacific Gas & Electric Co. v. Public Utilities Commission*, 475 U.S. 1, 15-16 n.12, 106 S. Ct. 903,89 L. Ed. 2d 1(1986)).