How does COVID-19 affect the life cycle environmental impacts of U.S. household energy and food consumption?

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Supplementary Materials

Contents

Section 1 Household expenditure

Table S1 Household consumption items matched with sectors in the USEEIO v2.0[1]

Sector number in USEEIO	Sector name in USEEIO	Household consumption items
111200/US	Fresh vegetables, melons, and potatoes	Fresh vegetables
111300/US	Fresh fruits and tree nuts	Fresh fruits
112300/US	Poultry farms	Eggs
311225/US	Refined vegetable, olive, and seed oils	Fats and oils
311230/US	Breakfast cereals	Cereals and cereal products
311300/US	Sugar, candy, and chocolate	Sugar and other sweets
311410/US	Frozen food	Miscellaneous foods
3118A0/US	Cookies, crackers, pastas, and tortillas	
311910/US	Snack foods	
311940/US	Seasonings and dressings	
311990/US	All other foods	Food prepared by consumer unit on out-of-town trips
311920/US	Coffee and tea	Nonalcoholic beverages
311930/US	Flavored drink concentrates	
312110/US	Soft drinks, bottled water, and ice	
311420/US	Fruit and vegetable preservation	Processed fruit and vegetables
311513/US	Cheese	Other dairy products
311520/US	Ice cream and frozen desserts	
312120/US	Breweries and beer	Alcoholic beverages
312130/US	Wineries and wine	
312140/US	Distilleries and spirits	
722110/US	Full-service restaurants	Full service restaurants
722211/US	Limited-service restaurants	Limited service restaurants
722A00/US	All other food and drinking places	All other food and drinking places for food away from home
221100/US	Electricity	Electricity
221200/US	Natural gas	Natural gas
324110/US	Gasoline, fuels, and by-products of petroleum refining	Fuel oi, propane and kerosene. Gasoline used for transportation
481000/US	Air transport	Public and other transportation
483000/US	Water transport (boats, ships, ferries)	
485000/US	Passenger ground transport	

Table S2 U.S. household food expenditure (millions of dollars)[2]

	Food at home	Food away from home*	Alcohol at home	Alcohol away from home
2019	790,086.25	759,774.88	105,378.75	98,446.93
2020	856,949.44	632,252.63	115,976.80	66,938.96

*Food away from home expenditure only includes household purchasers, excluding government and business purchasers.

Table S3 Breakdown of food away from home[2]

	Full service restaurants	Limited service restaurants	Other eating and drinking places	Total
2019	33.1%	38.7%	28.2%	100%
2020	27.7%	44.4%	27.9%	100%

Table S4 U.S. household expenditure breakdown of food at home (2018-2019), derived from[2]

Food at home	100%
Cereals and bakery products	
Cereals and cereal products	3.97%
Bakery products	8.70%
Meats, poultry, fish, and eggs	
Beef	5.75%
Pork	4.02%
Other meats	2.83%
Poultry	4.06%
Fish and seafood	3.29%
Eggs	1.34%
Dairy products	
Fresh milk and cream	3.14%
Other dairy products	6.79%
Fruits and vegetables	
Fresh fruits	7.03%*
Fresh vegetables	6.35%
Processed fruits	2.48%
Processed vegetables	3.18%
Other food at home	
Sugar and other sweets	3.47%
Fats and oils	2.55%
Miscellaneous foods	19.94%
Nonalcoholic beverages	9.79%
Food prepared by consumer unit on out-of-town trips	1.30%

*As the data do not include tree nuts that are included in the sector 111300 in Table S1. The final demand of fresh fruits and tree nuts was adjusted based on the value of production reported by the USDA[3] and documented in Table S5.

Consumer Price Index (CPI) was used to transfer all expenditure in 2020 and 2019 to the 2012 year. CPI measures the average changes of consumer prices over time for different goods[4], and it has been widely used in EEIO to convert prices to the same year. CPI can be used to covert prices using the equation below[5]:

$$Price_{2012} = \frac{CPI_{2012}}{CPI_{recent}} \times Price_{recent} \quad (1)$$

Table S5 The U.S. Household expenditure before and in pandemic in 2012 producer price (Million $)

	Sector Name	2020	2019
111200/US	Fresh vegetables, melons, and potatoes	27225	25750
111300/US	Fresh fruits and tree nuts	16344	16893
112300/US	Poultry farms	9039	8688
221100/US	Electricity	173626	136754
221200/US	Natural gas	46106	48340
311225/US	Refined vegetable, olive, and seed oils	19877	18572
311230/US	Breakfast cereals	19909	18692
311300/US	Sugar, candy, and chocolate	20146	19194
311410/US	Frozen food	20941	19980
311420/US	Fruit and vegetable preservation	30492	29088
311513/US	Cheese	22352	21103
31151A/US	Fluid milk and butter	17194	16726
311520/US	Ice cream and frozen desserts	20698	19541
311615/US	Packaged poultry	25680	25002
31161A/US	Packaged meat (except poultry)	76913	76078
311700/US	Seafood	19129	18210
311810/US	Bread and other baked goods	38709	36538
3118A0/US	Cookies, crackers, pastas, and tortillas	20482	19542
311910/US	Snack foods	20863	19906
311920/US	Coffee and tea	20741	19805
311930/US	Flavored drink concentrates	20931	19986
311940/US	Seasonings and dressings	20644	19697
311990/US	All other foods	26715	25457
312110/US	Soft drinks, bottled water, and ice	15976	15255
312120/US	Breweries and beer	29234	33206
312130/US	Wineries and wine	27300	31009
312140/US	Distilleries and spirits	35997	40888
324110/US	Gasoline, fuels, and by-products of petroleum refining	321672	504119
481000/US	Air transport	84938	110625
482000/US	Rail transport	84938	110625
483000/US	Water transport (boats, ships, ferries)	84938	110625
485000/US	Passenger ground transport	84938	110625
722110/US	Full-service restaurants	142609	210338
722211/US	Limited-service restaurants	225943	243208
722A00/US	All other food and drinking places	143996	180011

Table S6 U.S. residential energy consumption[6]

	Natural Gas (trillion Btu)	Electricity (trillion Btu)	Fuel Oil (trillion Btu)	Propane (trillion Btu)	Kerosene (trillion Btu)
2019 (before the pandemic)	5204.854	4914.266	470.583	563.405	10.754
2020 (during the pandemic)	4818.444	4988.199	404.652	516.997	12.356

Table S7 Prices of energy delivered to the U.S. household ($ in the year listed)[6, 7]

	Natural gas ($/thousand cubic feet)	Electricity (cents/kWh)	Fuel oil ($/gallon)	Propane ($/gallon)	Kerosene ($/gallon)
2019 (before pandemic)	10.51	10.54	3.09	2.18	2.02
2020 (during the pandemic)	10.84	13.20	2.55	1.91	1.31

Table S8 U.S. personal spending on transportation (in chained 2012 dollar)[8]

	Gasoline and Other Energy Goods (billion $)	Transportation Services (billion $)
2019	445	$443
2020	389	$340

The path exchange method was used to incorporate more recent energy and GHG emission data of the electricity generation sector. The total energy use of the U.S. electric power sector was 37003 Trillion Btu in 2019 and 35744 Trillion Btu in 2020[6], which were divided by the electricity sales[9] (raw data in Table S18 that were converted to 2012) to derive the energy use factors for the same year. The energy use factors were timed with the total requirement of electricity that was estimated using the Leontief matrix and the final demands of the U.S. household energy and food consumption. The estimated energy use was used to replace the total energy use estimated by the USEEIO for the electricity sector. The same approach was used to estimate the renewable and non-renewable energy use and GHG emissions using the data collected from the U.S. EIA[6, 10].

Section 2. GHG Emissions of Fuel Combustion

As the system boundary of EIO-LCA is cradle to gate, the GHG emissions of fuel combustion in the use phase are not included. Excluding the emissions of fuel combustion underestimates the impacts of household energy consumption. In this study, the GHG emissions of fuel combustion were estimated and added to the GHG emissions estimated using the USEEIO[1].

For gasoline used in transportation, the CO_2 emission factor of gasoline was 8.89 kg/Gallon based on the data from the U.S EIA[11]. The gasoline price data were collected from the U.S. EIA[12] and then converted to 2012 dollar using the CPI[4] to be consistent with the expenditure data. The converted prices were 3.6128 $/gallon in 2019 and 3.6075 $/gallon in 2020, expressed in 2012$. The price data were used to estimate the volume of gasoline consumption before and in the pandemic. For other fuels used by U.S. households, the emission factors from U.S. EPA were used and documented in Table S9.

Table S9 Emission factors of fuels[13]

	kg CO_2 per mmBtu	g CH_4 per mmBtu	g N_2O per mmBtu
Natural Gas	53.06	1	0.1
Fuel Oil	73.96	3	0.6
Propane	62.87	3	0.6
Kerosene	75.2	3	0.6

Section 3 Additional Results

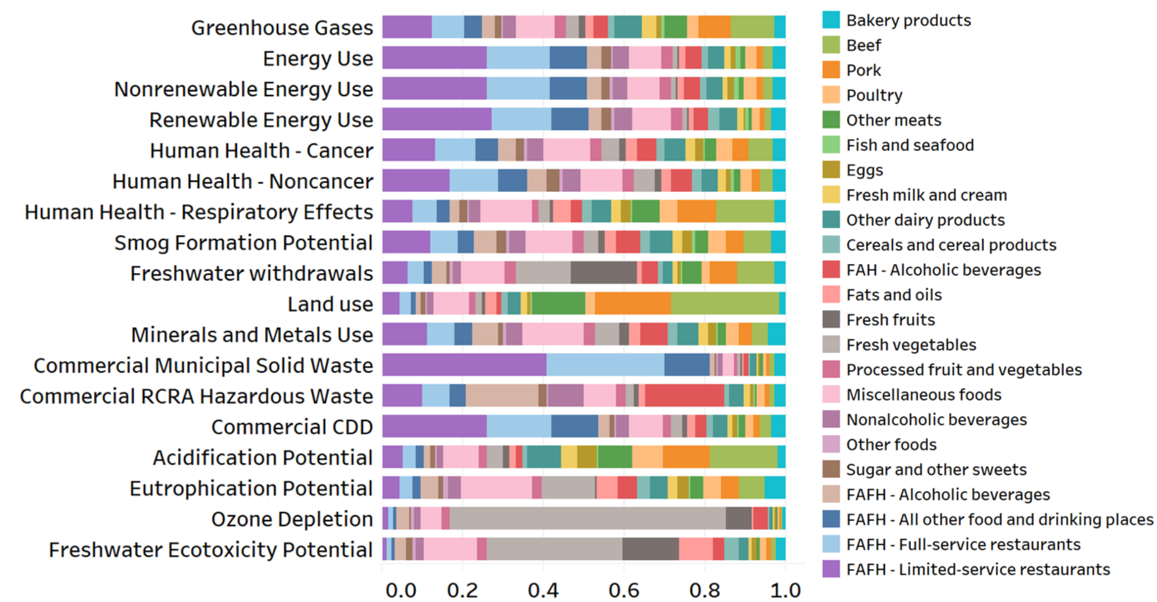

Figure S1 life-cycle environmental impact breakdown by household food consumption types before the pandemic

Table S10 Environmental impacts associated with transportation (before the pandemic)

Impact categories	Gasoline, other fuels, and motor oil	Transportation services	Total
Acidification Potential	23%	77%	100.0%
Commercial Construction and Demolition Debris	47%	53%	100.0%
Commercial Municipal Solid Waste	22%	78%	100.0%
Commercial RCRA Hazardous Waste	80%	20%	100.0%
Energy Use	86%	14%	100.0%
Eutrophication Potential	45%	55%	100.0%
Freshwater Ecotoxicity Potential	50%	50%	100.0%
Freshwater withdrawals	62%	38%	100.0%
Greenhouse Gases	82%	18%	100.0%
Human Health - Cancer	45%	55%	100.0%
Human Health - Noncancer	40%	60%	100.0%
Human Health - Respiratory Effects	44%	56%	100.0%
Land use	45%	55%	100.0%

Minerals and Metals Use	48%	52%	100.0%
Nonrenewable Energy Use	86%	14%	100.0%
Ozone Depletion	56%	44%	100.0%
Renewable Energy Use	48%	52%	100.0%
Smog Formation Potential	26%	74%	100.0%

Table S11 Environmental impacts associated with transportation (during the pandemic)

Impact categories	Gasoline, other fuels, and motor oil	Transportation services	
Acidification Potential	20%	80%	100.0%
Commercial Construction and Demolition Debris	42%	58%	100.0%
Commercial Municipal Solid Waste	18%	82%	100.0%
Commercial RCRA Hazardous Waste	77%	23%	100.0%
Energy Use	83%	17%	100.0%
Eutrophication Potential	40%	60%	100.0%
Freshwater Ecotoxicity Potential	45%	55%	100.0%
Freshwater withdrawals	57%	43%	100.0%
Greenhouse Gases	83%	17%	100.0%
Human Health - Cancer	40%	60%	100.0%
Human Health - Noncancer	36%	64%	100.0%
Human Health - Respiratory Effects	39%	61%	100.0%
Land use	40%	60%	100.0%
Minerals and Metals Use	43%	57%	100.0%
Nonrenewable Energy Use	84%	16%	100.0%
Ozone Depletion	51%	49%	100.0%
Renewable Energy Use	43%	57%	100.0%
Smog Formation Potential	22%	78%	100.0%

Table S12 Changes of environmental impacts associated with transportation (Change% = (During the pandemic – before the pandemic)/before the pandemic)

Impact categories	Gasoline, other fuels, and motor oil	Transportation services	Total
Acidification Potential	-8.6%	-17.9%	-26.5%
Commercial Construction and Demolition Debris	-17.5%	-12.4%	-29.9%
Commercial Municipal Solid Waste	-8.1%	-18.2%	-26.3%
Commercial RCRA Hazardous Waste	-30.0%	-4.6%	-34.6%
Energy Use	-32.2%	-3.3%	-35.5%
Eutrophication Potential	-16.7%	-12.9%	-29.6%
Freshwater Ecotoxicity Potential	-18.8%	-11.6%	-30.4%
Freshwater withdrawals	-23.4%	-8.7%	-32.1%
Greenhouse Gases	-14.0%	-4.3%	-18.3%
Human Health - Cancer	-16.9%	-12.7%	-29.7%

Human Health - Noncancer	-15.1%	-13.8%	-29.0%
Human Health - Respiratory Effects	-16.4%	-13.1%	-29.5%
Land use	-17.0%	-12.7%	-29.7%
Minerals and Metals Use	-18.1%	-12.0%	-30.1%
Nonrenewable Energy Use	-32.4%	-3.2%	-35.6%
Ozone Depletion	-21.1%	-10.1%	-31.3%
Renewable Energy Use	-15.3%	-10.2%	-25.4%
Smog Formation Potential	-9.7%	-17.2%	-26.9%

Table S13 Environmental impacts associated with household direct energy consumption (before the pandemic)

Impact categories	Electricity	Natural gas	Fuel oil, propane, and kerosene	Total
Acidification Potential	90.6%	6.8%	2.7%	100.0%
Commercial Construction and Demolition Debris	71.3%	21.8%	6.9%	100.0%
Commercial Municipal Solid Waste	67.1%	26.8%	6.1%	100.0%
Commercial RCRA Hazardous Waste	39.1%	8.8%	52.1%	100.0%
Energy Use	88.7%	5.9%	5.4%	100.0%
Eutrophication Potential	88.1%	9.6%	2.3%	100.0%
Freshwater Ecotoxicity Potential	86.3%	8.5%	5.2%	100.0%
Freshwater withdrawals	95.5%	4.1%	0.4%	100.0%
Greenhouse Gases	62.8%	29.3%	7.9%	100.0%
Human Health - Cancer	72.4%	16.2%	11.5%	100.0%
Human Health - Noncancer	88.3%	7.9%	3.7%	100.0%
Human Health - Respiratory Effects	88.8%	6.6%	4.6%	100.0%
Land use	59.8%	20.4%	19.8%	100.0%
Minerals and Metals Use	78.2%	14.6%	7.3%	100.0%
Nonrenewable Energy Use	87.6%	6.2%	6.2%	100.0%
Ozone Depletion	74.1%	12.8%	13.2%	100.0%
Renewable Energy Use	96.5%	3.3%	0.3%	100.0%
Smog Formation Potential	82.4%	10.7%	7.0%	100.0%

Table S14 Environmental impacts associated with household direct energy consumption (during the pandemic)

Impact categories	Electricity	Natural gas	Fuel oil, propane, and kerosene	Total
Acidification Potential	92.9%	5.2%	1.9%	100.0%
Commercial Construction and Demolition Debris	77.2%	17.7%	5.1%	100.0%
Commercial Municipal Solid Waste	73.4%	22.0%	4.6%	100.0%
Commercial RCRA Hazardous Waste	48.1%	8.1%	43.7%	100.0%

Energy Use	91.6%	4.6%	3.8%	100.0%
Eutrophication Potential	91.0%	7.4%	1.6%	100.0%
Freshwater Ecotoxicity Potential	89.6%	6.7%	3.7%	100.0%
Freshwater withdrawals	96.6%	3.1%	0.2%	100.0%
Greenhouse Gases	68.3%	25.2%	6.5%	100.0%
Human Health - Cancer	78.4%	13.2%	8.5%	100.0%
Human Health - Noncancer	91.2%	6.1%	2.6%	100.0%
Human Health - Respiratory Effects	91.7%	5.1%	3.2%	100.0%
Land use	67.5%	17.3%	15.2%	100.0%
Minerals and Metals Use	83.1%	11.6%	5.3%	100.0%
Nonrenewable Energy Use	90.5%	5.0%	4.5%	100.0%
Ozone Depletion	79.9%	10.3%	9.7%	100.0%
Renewable Energy Use	97.5%	2.3%	0.2%	100.0%
Smog Formation Potential	86.6%	8.4%	5.0%	100.0%

Table S15 Changes of environmental impacts associated with household direct energy consumption (Change% = (During the pandemic – before the pandemic)/before the pandemic)

Impact categories	Electricity	Natural gas	Fuel oil, propane, and kerosene	Total
Acidification Potential	24.4%	-0.3%	-0.4%	23.7%
Commercial Construction and Demolition Debris	19.2%	-1.0%	-0.9%	17.3%
Commercial Municipal Solid Waste	18.1%	-1.2%	-0.8%	16.0%
Commercial RCRA Hazardous Waste	10.5%	-0.4%	-6.9%	3.2%
Energy Use	22.7%	-0.3%	-0.7%	21.7%
Eutrophication Potential	23.8%	-0.4%	-0.3%	23.0%
Freshwater Ecotoxicity Potential	23.3%	-0.4%	-0.7%	22.2%
Freshwater withdrawals	25.8%	-0.2%	0.0%	25.5%
Greenhouse Gases	10.8%	-2.1%	-0.9%	7.8%
Human Health - Cancer	19.5%	-0.7%	-1.5%	17.2%
Human Health - Noncancer	23.8%	-0.4%	-0.5%	23.0%
Human Health - Respiratory Effects	24.0%	-0.3%	-0.6%	23.0%
Land use	16.1%	-0.9%	-2.6%	12.5%
Minerals and Metals Use	21.1%	-0.7%	-1.0%	19.4%
Nonrenewable Energy Use	20.2%	-0.3%	-0.8%	19.1%
Ozone Depletion	20.0%	-0.6%	-1.8%	17.6%
Renewable Energy Use	38.3%	-0.1%	0.0%	38.1%
Smog Formation Potential	22.2%	-0.5%	-0.9%	20.8%

Table S16 Flow contribution breakdown for ozone depletion potential

	During the pandemic (2020)	Before the pandemic (2019)
Methyl bromide/emission/air/troposphere/rural/ground-level/kg	77.02%	74.37%
Methyl bromide/emission/air/kg	7.73%	8.22%
Carbon tetrachloride/emission/air/kg	5.93%	6.75%
CFC-113/emission/air/kg	3.46%	3.92%
CFC-114/emission/air/kg	1.99%	2.26%
Halon 1301/emission/air/kg	1.15%	1.40%
HCFC-22/emission/air/kg	1.05%	1.22%
Chloromethane/emission/air/kg	0.41%	0.43%
CFC-11/emission/air/kg	0.38%	0.44%
1,1,1-Trichloroethane/emission/air/kg	0.32%	0.34%
CFC-12/emission/air/kg	0.18%	0.20%
Halon 1211/emission/air/kg	0.15%	0.18%
CFC-115/emission/air/kg	0.08%	0.10%
HCFC-142b/emission/air/kg	0.07%	0.08%
HCFC-123/emission/air/kg	0.03%	0.04%
CFC-13/emission/air/kg	0.03%	0.03%
HCFC-124/emission/air/kg	0.01%	0.02%
HCFC-133a/emission/air/kg	0.01%	0.01%
Other emissions	0.0004%	0.0005%
Total	100%	100%

Table S17 Flow contribution breakdown for freshwater ecotoxicity potential

	During the pandemic (2020)	Before the pandemic (2019)
.lambda.-Cyhalothrin/emission/water/fresh water body/kg	24.16%	23.90%
Cyfluthrin/emission/water/fresh water body/kg	19.80%	19.58%
Fenpropathrin/emission/water/fresh water body/kg	11.37%	11.83%
Chlorothalonil/emission/water/fresh water body/kg	10.51%	10.28%
Chlorpyrifos/emission/water/fresh water body/kg	5.37%	5.43%
Chlorothalonil/emission/air/troposphere/rural/ground-level/kg	2.38%	2.32%
Diflubenzuron/emission/water/fresh water body/kg	2.13%	2.24%
Cyfluthrin/emission/air/troposphere/rural/ground-level/kg	1.87%	1.85%
Bifenthrin/emission/water/fresh water body/kg	1.86%	1.85%
Chlorothalonil/emission/ground/human-dominated/agricultural/rural/kg	1.64%	1.60%
Esfenvalerate/emission/water/fresh water body/kg	1.13%	1.15%
Atrazine/emission/water/fresh water body/kg	1.12%	1.11%
S-Metolachlor/emission/water/fresh water body/kg	0.96%	0.98%
Propanil/emission/air/troposphere/rural/ground-level/kg	0.85%	0.87%
Propanil/emission/ground/human-dominated/agricultural/rural/kg	0.76%	0.78%
Beta Cypermethrin/emission/water/fresh water body/kg	0.60%	0.62%
Acetochlor/emission/water/fresh water body/kg	0.60%	0.61%

Phosmet/emission/water/fresh water body/kg	0.59%	0.59%
.lambda.-Cyhalothrin/emission/air/troposphere/rural/ground-level/kg	0.59%	0.58%
Pendimethalin/emission/water/fresh water body/kg	0.56%	0.57%
Tefluthrin/emission/water/fresh water body/kg	0.56%	0.57%
Other emissions	10.6%	10.7%
Total	100%	100%

Section 4 Benchmark Estimations

A test was performed to compare the results from the USEEIO with a few benchmarks estimated using real-world data. Most data reported by the U.S. government agencies, such as U.S. EIA or the U.S. Department of Agriculture (USDA), are at the national level that covers all activities happened in the U.S. As this study only focuses on the activities related to the life cycle of U.S. household energy and food consumption (instead of everything consumed in the U.S.), it is necessary to disaggregate these national-level data and exclude activities that may not be associated with the supply chains of energy and food consumed by the U.S. households. The following paragraphs document the detailed estimations of each benchmark.

Electricity Benchmark Estimation

The total domestic requirement of electricity (in million $ in 2012 price) was benchmarked against the total sales of electricity to ultimate consumers in the U.S. in 2019 and 2020. The total electricity sales data were obtained from the U.S. EIA[9]. The sales data include all sectors in the U.S. economy, namely residential, commercial, industrial, and transportation sectors. The data of 2019 and 2020 in million dollars are shown in Table S18.

Table S18 Electricity sales to ultimate customers in the U.S. in 2019 and 2020 (in million dollars)[9]

Year	Residential	Commercial	Industrial	Transportation	All Sectors
2019	187,436	145,280	68,285	737	401,738
2020	192,663	136,372	63,956	648	393,639

The residential and transportation can be considered as fully related to the life cycle of U.S. households. The industrial sector is complicated as some activities are related (e.g., fertilizer production, gasoline production), but not all industrial sectors are related. Therefore, the U.S. Manufacturing Energy Consumption Survey (MECS)[14] data were used to identify and estimate these industrial sectors that are mostly related to the upstream production of food and energy consumed by U.S. households. Specifically, Table S19 shows the sectors identified for their direct relevance to U.S. household food and energy consumption. Other sectors such as petrochemicals also include products that are used in the upstream supply chain of food and energy products consumed by U.S. households. However, it is challenging to disaggregate these sectors further. Similarly, some commercial use of electricity (e.g., cooking services) are related. However, EIA only reports total commercial electricity uses without further details on the use breakdown[6]. Thus, only the energy consumption of sectors listed in Table S19 was included to estimate the percentage of total electricity consumption related to the life cycle of U.S. household food and energy consumption (see Equation 2). Furthermore, some products made in the U.S. are exported and thus not consumed by U.S. households. The energy consumption of making these products should be excluded in the benchmark estimation. The shares of export in the total production of relevant industrial sectors were collected and documented in Table S20.

$$Pin = \sum_{1}^{n} E_n \times (1 - E_p) \Big/ To \quad (2)$$

Pin is the total percentage of electricity consumption related to the life cycle of U.S. household food and energy consumption in the total U.S. electricity consumed by the industrial sectors. n include industrial sectors identified in Table S19 and E_n is the electricity consumption of each industrial sector identified (data available in MECS[14]). E_p is the percentage of exports in the total production of each industrial sector as documented in Table S20. To is the total electricity consumption of the U.S. industrial sector. Pin was estimated as 16.3% using the latest MECS data in 2018[14].

The total electricity benchmark was then estimated as the summation of electricity consumed by residential, transportation, and 16.3% of industrial use listed in Table S18, which was then converted to 2012 price using the CPI index[4]. The USEEIO[1] shows that the purchaser to producer price ratio for the electricity sector was 1 in the past (latest in the 2018 year), which was used to convert the benchmark sales to 2012 producer price as listed in Table 1 in the paper.

Table S19 Industry sectors in 2018 MECS identified by this study for their direct relevance to the U.S. household energy and food consumption

NAICS Code	
311	Food
3121	Beverages
324110	Petroleum Refineries
325311	Nitrogenous Fertilizers
325312	Phosphatic Fertilizers

Table S20 Export share of production by industrial sectors in 2018*

Sector	Share of export
Food	24.9%[15]
Beverages	24.9%[15]
Petroleum Refineries	16.5%[16]
Nitrogenous Fertilizers	19.9%[17]
Phosphatic Fertilizers	19.9%[17]

*The latest year of data from the USDA is 2018. Using the data in 2018 is also consistent with the MECS data that reports the latest U.S. industrial energy consumption by sectors in 2018.

Total Energy Benchmark Estimation

The total energy consumption benchmarks were estimated using the similar approaches discussed above. The primary energy consumption of main sectors in the U.S. was collected from the U.S. EIA Monthly Energy Review, and the raw data were documented in Table S21[6]. The commercial sector was not included given the difficulties in further disaggregating and identifying activities the most relevant to the life cycle of U.S. household food and energy consumption.

Table S21 Primary energy consumption by main sectors in the U.S. in 2019 and 2020 (Trillion Btu)[6]

Year	Residential	Industrial	Transportation	Electric Power
2019	7088.212	22939.804	28596.828	37003.283
2020	6616.842	22024.882	24372.597	35744.049

As discussed previously, not all industrial activities are related to the life cycle of U.S. household food and energy consumption. Therefore, a similar approach (Equation 2) was used to estimate the percentage of industrial energy use that is the most relevant to U.S. household food and energy consumption. Using the latest MECS data[14], it was estimated that 22% of all industrial energy consumption in the U.S. was the most related. Using the EIA data, it was estimated that 70.6% of transportation energy is related, excluding energy used for military, commercial freight, and pipeline transport[18]. For the electric power sector, the share of each sector was documented in Table S24, estimated based on the data in Table S23. The percentage of electricity uses that are the most relevant to the life cycle of household energy and food consumption were estimated by the summation of the shares of residential, transportation, and 16.3% of the industrial sector (estimated in the previous section for industrial electricity use) in Table S24 for year 2020 and 2019, respectively. The resulting percentages of relevant electricity usage are 44% for 2020 and 42% for 2019. Then the benchmark of total energy consumption was estimated as the summation of energy consumed by the residential sector, transportation sector multiplied by 70.6%, industrial energy consumption multiplied by 22%, and electric power energy use multiplied by 44% for 2020 and 42% for 2019. The same approach was applied to renewable energy consumption, and the data of different sectors were collected from the U.S. EIA (Trillion Btu) and documented in Table S22[6]. The non-renewable energy consumption benchmarks were estimated as the differences between total energy consumption and renewable energy consumption.

Table S22 Renewable energy consumption of main sectors in the U.S. (Trillion Btu)[6]

Year	Residential	Industrial	Transportation	Electric Power
2019	835.442	2423.142	1496.593	6401.59
2020	787.671	2298.456	1361.771	6952.028

Table S23 Electricity consumption by sectors in the U.S. (million kWh)[6]

Year	Residential	Commercial	Industrial	Transportation	Total
2019	1440288.909	1360876.555	1002352.849	7632.15	3811150.463
2020	1461957.642	1275718.315	919533.398	6531.987	3663741.342

Table S24 Electricity consumption shares by sectors in the U.S. (calculated based on the data in Table S23)

Year	Residential	Commercial	Industrial	Transportation	Total
2019	37.8%	35.7%	26.3%	0.2%	100%
2020	39.9%	34.8%	25.1%	0.2%	100%

Fertilizer Benchmark Estimation

The benchmark of fertilizer usage (Fb in million dollars) was estimated using Equation (3).

$$Fb = Fs \times (1 - Di) \times PC \times (1 - Fe) \quad (3)$$

Fs is the farm expenditure on fertilizers in the U.S., which were $22,300 million in 2019 and $24,400 million in 2020, according to the USDA data[19]. Di is the ratio of fertilizers that are met by import (as the total requirement estimated by USEEIO is only for domestic production, therefore the fertilizers imported should be excluded). The IBISWorld industrial database reports that 34.3% and 29.9% of domestic fertilizer demands were imported in 2019 and 2020, respectively[17]. PC is the ratio of producer price to purchaser price, which was 0.56 in the year 2018[1] and assumed to be the same for the year 2019 and 2020 due to the lack of data. Not all crops grown in the U.S. are consumed by U.S. households. Therefore, the fertilizer used to produce food exported to other countries should be excluded. Fe is the average export value share of the total production of crops and food in the U.S., which was estimated as 39.7% in the year 2019 based on the data collected from USDA for crops, food grains, feed grains, oilseeds, vegetables and melons, fruits and tree nuts[15]. The estimated Fb for the year 2020 and 2019 were converted to the same 2012 year using the Producer Price Index (PPI) published by the U.S. Bureau of Labor Statistics[20]. As the export data of food and crops in the U.S. are not available for 2020, this estimation has uncertainties, which may explain the differences between the estimated benchmarks and the results of this study in Table 1.

Packaged Meat Benchmark Estimation

The benchmark of packaged meat (PMb in million dollar) was estimated using the Equation (4).

$$PMb = \sum_{1}^{n} D_n \times P_n \tag{4}$$

D_n is the total consumption (in other words, disappearance) of meat *n* (including beef and pork, two main meat types consumed in the U.S.). Poultry was not included in this industrial category. The total disappearance of beef in the U.S. was reported as 27,275 and 27,561 million pounds in 2019 and 2020, respectively[21]. The total disappearance of pork in the U.S. was reported as 22,189 and 22,121 million pounds in 2019 and 2020, respectively[21]. P_n is the retail price of the meat *n*. For beef, the average retail price of all fresh beef in 2019 was 582 cents/pound, this price increased to 639 cents/pound in 2020[21]. For pork, the retail price in 2019 was 384 cents/pound, and the price increased to 403 cents/pound in 2020[21]. The estimated benchmark for packaged meat was then converted to 2012 producer price using CPI index for beef and pork[4] and producer to purchaser price ratio estimated based on the retail values and wholesale value reported by the USDA[21].

Fresh Fruits and Tree nuts Benchmark Estimation

USDA reported the value of production of total fruits (including citrus and noncitrus fruits) and tree nuts as $29,027 million in 2019 and $28,119 million in 2020[3]. These two values were converted to 2012 values using the PPI index[20].

References

1. U.S. Environmental Protection Agency (EPA). USEEIOv2.0. https://doi.org/10.23719/1521337 (accessed 07/10/2021).
2. U.S. Department of Agriculture (USDA). Food Expenditure Series. https://www.ers.usda.gov/data-products/food-expenditure-series/ (accessed 07/12/2021).
3. US Department of Agriculture (USDA). Fruit and Tree Nuts Yearbook Tables. https://www.ers.usda.gov/data-products/fruit-and-tree-nuts-data/fruit-and-tree-nuts-yearbook-tables/ (accessed 11/23/2021).
4. U.S Bureau of Labor Statistics. Consumer Price Index. https://www.bls.gov/cpi/data.htm (accessed 07/05/2021).

5. Matthews, H.; Hendrickson, C.; Matthews, D. *Life Cycle Assessment: Quantitative Approaches for Decisions that Matter*. 2014.
6. U.S. Energy Information Administration (EIA). Monthly Energy Review. https://www.eia.gov/totalenergy/data/monthly/index.php (accessed 06/25/2021).
7. U.S. Energy Information Administration (EIA). State Electricity Profiles. https://www.eia.gov/electricity/state/archive/2019/ (accessed 07/02/2021).
8. U.S. Department of Transportation. Monthly Transportation Statistics. https://data.bts.gov/stories/s/m9eb-yevh (accessed 07/10/2021).
9. U.S. Energy Information Administration (EIA). Electric Power Monthly: Table 5.2. Revenue from Sales of Electricity to Ultimate Customers. https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_02 (accessed 11/22/2021).
10. U.S. Energy Information Administration (EIA). U.S. Electric Power Industry Estimated Emissions by State. https://www.eia.gov/electricity/data/state/ (accessed 11/23/2021).
11. U.S. Energy Information Administration (EIA). Carbon Dioxide Emissions Coefficients. https://www.eia.gov/environment/emissions/co2_vol_mass.php (accessed 07/01/2021).
12. U.S. Energy Information Administration (EIA). Gasoline and Diesel Fuel Update. https://www.eia.gov/petroleum/gasdiesel/ (accessed 07/05/2021).
13. U.S. Environmental Protection Agency (EPA). Emission Factors for Greenhouse Gas Inventories. https://www.epa.gov/sites/production/files/2018-03/documents/emission-factors_mar_2018_0.pdf (accessed 07/02/2020).
14. U.S. Energy Information Administration (EIA). 2018 MECS Survey Data. https://www.eia.gov/consumption/manufacturing/data/2018/#r1 (accessed 11/20/2021).
15. U.S. Department of Agriculture (USDA). U.S. Agricultural Trade Data. https://www.ers.usda.gov/topics/international-markets-us-trade/u-s-agricultural-trade/data/ (accessed 11/19/2021).
16. IBISWorld. Petroleum Refining in the US. https://my.ibisworld.com/us/en/industry/32411/key-statistics (accessed 11/22/2021).
17. IBISworld. Fertilizer Manufacturing in the US. https://my.ibisworld.com/us/en/industry/32531/key-statistics (accessed 11/22/2021).
18. U.S. Energy Information Administration (EIA). Use of energy explained, Energy use for transportation. https://www.eia.gov/energyexplained/use-of-energy/transportation-in-depth.php (accessed 11/24/2021).
19. U.S. Department of Agriculture (USDA). Chemical, Fertilizer, Labor, and Feed Expense by Year – United States. https://www.nass.usda.gov/Charts_and_Maps/Farm_Production_Expenditures/arms3cht9.php (accessed 11/18/2021).
20. U.S. Bureau of Labor Statistics. Producer Price Indexes. https://www.bls.gov/ppi/ (accessed 11/20/2021).
21. U.S. Department of Agriculture (USDA). Livestock and Meat Domestic Data. https://www.ers.usda.gov/data-products/livestock-and-meat-domestic-data/ (accessed 11/23/2021).