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Supplementary Information for:

Modeling American Household Fluid Milk Consumption and their Resulting Greenhouse Gas Emissions

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S.1. Explanation of how GHG Emissions were Calculated

Simulations were run for 10,000 days for 50 different seed values. To save time on manual labor, a parameter sweep was performed. This means that each combination of the parameters specified, shown in Figure 1, was performed in one "run". This means that any combination of parameters can be modeled without having to run each parameter individually. Once parameters were determined, simulations were run remotely via a secure shell at MSU's high performance computing center. Raw data is available upon request. Analysis was done in R, thus most files are in .Rdata file. These can be converted into other file types if needed. Below are some of the summary data tables that were produced during analysis. Calculations done for the GHG emissions, shown in Figure 3, were done by taking data on climate change impacts of fluid milk delivery systems from Burek et al [1]. To determine the climate change impacts from packaging, container usage had to be first aggregated by type. Containers purchased from the top-up shop were totaled separately than containers bought from regular grocery store shopping trips (Table S1, S2, and S3). Packages that were thrown away with milk in them were summed separately from containers that were thrown away empty. Once the total amount of containers used in a year's time was determined, population estimates from the U.S. Census Bureau were retrieved via the tidyverse [2] application program interface. These population estimates, shown in Table S5, were multiplied by the GHG emissions for consumption, spoilage, and container waste from Table S1, S2, and S3.

Table S1. Summary statistics for 50 one-person households modeled using different scenarios. Each column represents the emissions generated from containers used in a years' time. Column names with "TP" represent containers that were purchased from the top-up shop, while column names with "wasted" represent containers that were thrown away with milk still inside them. The last three columns represent the emissions from containers that were consumed in full. Three scenarios were tested for one-person households: purchase of a half-gallon container, two-quart containers, and a 1-quart container on weekly grocery shopping trips. Each scenario listed above assumed that consumers purchased 1-quart containers during top-up shopping trips for more milk.

	Cont1QTP1PHG	Cont1QTP1P2Q	Cont1QTP1P1Q	wastedcontHG1P	wastedcont2Q1P	wastedcont1Q1P	contHG1P	cont2Q1P	cont1Q1P
max	5368351.899	4529546.915	38081746.28	141941243.7	281167431	61903807.84	195051262.7	487513456.8	242750162.4
range	5368351.899	4529546.915	37746224.29	14962467.29	36571897.3	20634602.61	5661474.108	15434011.71	7045961.868
sum	93107353.25	61736046.84	823538733.5	6765596356	1.3126E+10	2589726508	9613183036	23966336009	11964211012
median	1761490.467	1006565.981	15182370.21	135673183.1	262210438	51586506.53	192355322.7	478622124	239394942.5
mean	1862147.065	1234720.937	16470774.67	135311927.1	262515763	51794530.17	192263660.7	479326720.2	239284220.2
SE.mean	220707.1942	153288.587	1758961.248	512918.6358	1351340.2	674660.107	183593.9659	536150.0139	228650.35
CI.mean.0.95	443527.7121	308044.9486	3534764.966	1030748.589	2715619.8	1355780.245	368945.8876	1077433.791	459490.0813
var	2.43558E+12	1.17487E+12	1.54697E+14	1.31543E+13	9.1306E+13	2.27583E+13	1.68534E+12	1.43728E+13	2.61405E+12
std.dev	1560635.537	1083913.993	12437734.26	3626882.456	9555418.18	4770567.367	1298205.383	3791153.106	1616802.13

Table S2. Summary statistics for 50 two-person households modeled using different scenarios. Each column represents the emissions generated from containers used in a years' time. Column names with "TP" represent containers that were purchased from the top-up shop, while column names with "wasted" represent containers that were thrown away with milk still inside them. The last two columns represent the emissions from containers that were consumed in full. Two scenarios were tested for two-person households: purchase of 2 half gallon containers and 1-gallon container on weekly grocery shopping trips. Each scenario listed above assumed that consumers purchased half gallon containers during top-up shopping trips for more milk.

	contHGTP1G	contHGTP2HG	wastedcontG	wastedcontHG	contG	contHG
min	0	0	10075656.36	18631755.43	26684299.73	71098173.61
max	1764848.281	1512727.098	13104067.25	23321209.43	27769956.46	73568961.21
range	1764848.281	1512727.098	3028410.89	4689454.004	1085656.734	2470787.594
sum	34691874.78	31212602.46	587054594.1	1030797457	1358613693	3604475705
median	705939.3125	516848.4252	11761281.29	20535270.36	27160464.97	72056234.11
mean	693837.4957	624252.0492	11741091.88	20615949.14	27172273.86	72089514.11
SE.mean	80244.24292	65609.10998	90258.53813	167585.808	30633.96505	72874.12179
CI.mean.0.95	161256.8435	131846.4427	181381.3232	336776.2899	61561.25759	146446.0306
var	3.21957E+11	2.15228E+11	4.0733E+11	1.40425E+12	46921990744	2.65532E+11
std.dev	567412.4832	463926.4657	638224.2437	1185010.613	216614.8442	515297.8569

Table S3. Summary statistics for 50 four-person households modeled using different scenarios. Each column represents the emissions generated from containers used in a years' time. Column names with "TP" represent containers that were purchased from the top-up shop, while column names with "wasted" represent containers that were thrown away with milk still inside them. The last three columns represent the emissions from containers that were consumed in full. Three scenarios were tested for four-person households: purchase of 3 half gallon containers, 4 half gallon containers, and 2-gallon containers on weekly grocery shopping trips. Each scenario listed above assumed that consumers purchased half gallon containers during top-up shopping trips for more milk.

	contHGTP4P2G	contHGTP4P3HG	contHGTP4P4HG	wastedcont2G4P	wastedcont3HG4P	wastedcont4HG4P	cont2G4P	cont3HG4P	cont4HG4P
min	2859064.506	19267608.63	2921218.082	32257536.55	11001182.99	67933858.81	131471764.7	261977323.8	347314183.9
max	8266425.637	27658341.42	8079964.909	42916140.33	20759294.46	87823003.2	136167184.9	270181595.8	362231042.2
range	5407361.131	8390732.79	5158746.826	10658603.78	9758111.467	19889144.39	4695420.167	8204272.061	14916858.29
sum	268316988.5	1162334029	256259194.8	1889249259	767410205.6	3912754084	6693227540	13303600069	17717747052
median	5407361.131	23090053.57	5096593.25	37680746.84	15165472.6	78655350.71	133819474.8	265986229.4	354772613.1
mean	5366339.771	23246680.58	5125183.895	37784985.17	15348204.11	78255081.68	133864550.8	266072001.4	354354941
SE.mean	159206.7742	257116.4545	160396.733	318563.5374	258290.719	744942.6455	145710.7085	256158.9242	455354.2467
CI.mean.0.95	319937.9909	516694.8601	322329.3027	640177.3962	519054.6329	1497018.293	292816.6317	514770.6309	915068.6184
var	1.26734E+12	3.30544E+12	1.28636E+12	5.07414E+12	3.3357E+12	2.7747E+13	1.06158E+12	3.28087E+12	1.03674E+13
std.dev	1125761.896	1818087.885	1134176.176	2252584.375	1826391.189	5267539.962	1030330.301	1811317.124	3219840.757

Table S4. Aggregated data on 1, 2, and 4-person households. The "amt" indicates the GHG emissions of containers, consumption and spoilage. The standard deviation is represented for the mean by "sd". The household type is represented by "hh". The "type" column specifies whether the amt is for a container, consumption and spoilage. Similar to the tables listed above, container impacts were separated by whether they were consumed fully and bought from top-up shop. The last column, "pkg", specifies whether the scenario was "Assumed", "Suggested", or "Optimal". The "Optimal" is the scenario which reduces the total amount of milk purchased.

amt	sd	hh	type	pkg
1862147.06	1560635.54	1 NFM	Containers from top-up shop	Assumed
1234720.94	1083913.99	1 NFM	Containers from top-up shop	Suggested
16470774.7	12437734.3	1 NFM	Containers from top-up shop	Optimal
135311927	3626882.46	1 NFM	Containers w/ Milk	Assumed
262515763	9555418.18	1 NFM	Containers w/ Milk	Suggested
51794530.2	4770567.37	1 NFM	Containers w/ Milk	Optimal
192263661	1298205.38	1 NFM	Containers Used	Assumed
479326720	3791153.11	1 NFM	Containers Used	Suggested
239284220	1616802.13	1 NFM	Containers Used	Optimal
5366339.77	1125761.9	4 FM	Containers from top-up shop	Assumed
23246680.6	1818087.89	4 FM	Containers from top-up shop	Suggested
5125183.9	1134176.18	4 FM	Containers from top-up shop	Optimal
37784985.2	2252584.38	4 FM	Containers w/ Milk	Assumed
15348204.1	1826391.19	4 FM	Containers w/ Milk	Suggested
78255081.7	5267539.96	4 FM	Containers w/ Milk	Optimal
133864551	1030330.3	4 FM	Containers Used	Assumed
266072001	1811317.12	4 FM	Containers Used	Suggested
354354941	3219840.76	4 FM	Containers Used	Optimal
693837.496	567412.483	2 NFM	Containers from top-up shop	Assumed
624252.049	463926.466	2 NFM	Containers from top-up shop	Suggested
11741091.9	638224.244	2 NFM	Containers w/ Milk	Assumed
20615949.1	1185010.61	2 NFM	Containers w/ Milk	Optimal
27172273.9	216614.844	2 NFM	Containers Used	Assumed
72089514.1	515297.857	2 NFM	Containers Used	Suggested
4008924144	8187.36203	1 NFM	Consumed	Suggested
1853316616	8474.62665	2 NFM	Consumed	Suggested
9070298112	17872.9835	4 FM	Consumed	Suggested
3947302911	7908.41673	1 NFM	Consumed	Assumed
1815981226	10863.8295	2 NFM	Consumed	Assumed
9162208914	18523.1568	4 FM	Consumed	Assumed

3644811496	#N/A	1 NFM	Consumed	Optimal
9182037098	#N/A	4 FM	Consumed	Optimal
2263378151	10616.3668	1 NFM	Spoiled	Suggested
386422235	6786.13948	2 NFM	Spoiled	Suggested
338065038	7447.60099	4 FM	Spoiled	Suggested
2507079256	8361.84407	1 NFM	Spoiled	Assumed
540415263	7044.4723	2 NFM	Spoiled	Assumed
1828257415	20449.8724	4 FM	Spoiled	Assumed
586143741	#N/A	1 NFM	Spoiled	Optimal
1755382811	#N/A	4 FM	Spoiled	Optimal

Table S5. Census Bureau data for 4-person family households, and 1 and 2 person non-family households. Data was retrieved using an API key. The "variable" column refers to the Census variable assigned to each household type, while the "estimate" is the number of households of those type. Lastly, the "moe" represents the margin of error, as listed by the U.S. Census Bureau.

Variable Name	NAME	variable	estimate	moe
Four Family Household	United States	B11016_005	15029459	113507
One-person non-family household	United States	B11016_010	32595486	46684
Two-person non-family household	United States	B11016_011	609658	22939

Table S6. Climate change (kg CO2-eq) impacts of gallon, half-gallon, and quart HDPE containers. Data was obtained from Burek et al [1]. The last column represents the emissions from consumption, which were determined by subtracting total cradle to grave impacts from container and end of life (EOL) impacts. *Climate change impacts for quart containers were not analyzed in the study, therefore, the impact for quart containers was calculated by using data for gallon and half-gallon containers.

Container Type		Raw milk transport	Container	Processing plant	Distribution center	Retail Center	Consumption	EOL	Total Cradle to Grave	Total Emissions from Consumption
Gallon	Climate change (kg CO2-eq)	2.85E+01	6.94E+01	8.58E+01	2.05E+01	1.29E+02	2.40E+02	1.37E+01	2.00E+03	1.92E+03
Half-Gallon		2.85E+01	9.04E+01	8.16E+01	2.27E+01	1.31E+02	2.40E+02	1.96E+01	2.03E+03	1.92E+03
Quart*		2.85E+01	1.11E+02	7.74E+01	2.49E+01	1.33E+02	2.40E+02	2.55E+01	2.06E+03	1.92E+03

1. Burek, J.; Kim, D.; Nutter, D.; Selke, S.; Auras, R.; Cashman, S.; Sauer, B.; Thoma, G. Environmental Sustainability of Fluid Milk Delivery Systems in the United States. *J. Ind. Ecol.* **2017**, *22*, 180–195.

2. Wickhan, H. tidyverse: Easily Install and Load the “Tidyverse”. R package version 1.2.1 2017.