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Life Cycle Analysis: Comparison of Hand-Washing and Dishwasher Machines

Abstract

Washing dishes by hand or using the dishwasher is a choice that modern households often make. Hand-washing involves more of an individual's time while the dishwasher may take more total time to clean the dishes. Hand-washing may or may not produce a cleaner dish. Dishwashers use electricity to run the machine and the machine itself must be produced. Both hand-washing and dishwashing use hot water. To answer the question, which method of cleaning is better for the environment, our study evaluated the water efficiency, energy use, and carbon emissions for each cleaning mode. We also looked at national and the Los Angeles Department of Water and Power (LADWP) data to account for regional variation.

On average, we found that hand-washing and dishwashers are similar along the dimensions of energy use and greenhouse gas (GHG) emissions but differ in terms of water intensity. The difference between our total base energy use for hand-washing and dishwashing was only 9,000 joules with dishwashers using slightly more energy. As for GHGs, hand-washing generates slightly more emissions than a dishwasher. From our sensitivity analysis, we found the energy to generate electricity and the electricity to run the dishwasher have the largest impact on total energy use. Despite the similar energy use, hand-washing on average is more water intensive per dish and per load. Transporting and treating water has the greatest impact on total GHG emissions for hand-washing. These numbers were reinforced by analysis of LADWP data.

Overall, total energy, water, and GHG emissions depend on how an individual washes their dishes regardless of their choice to hand-wash or use a dishwasher. For example, if an individual fills the sink basin to hand-wash a full load of dishes, the total GHG emissions are lower than using a dishwashing machine. If an individual pre-washes dishes before loading the dishwasher or if the dishwasher is not washing a full load of dishes, then the dishwasher will be more energy intensive and emit more GHG emissions per dish. Since individual behavior has the largest impact on total energy use and GHG emissions, public education can help make dish washing a more ecological process.

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Goal and Scope

The goal of this analysis is to determine whether or not a dishwashing machine is more energy efficient and more water efficient than hand-washing dishes. Additionally, the analysis aims to see which process of cleaning dishes has a larger environmental impact, as measured by carbon dioxide (CO_2). Every time a household faces the choice of hand-washing or using a dishwasher, the household impacts the environment. While the economic cost of investing in a dishwasher is well documented, the environmental cost is not clear.

The processes that can contribute to the environmental impact of hand-washing include the water supply (transportation & treatment) and the gas used to heat the water. The processes that can contribute to the environmental impact of dishwashers include the water supply (transportation & treatment), the gas to heat the water, electricity to run the dishwasher (electricity generation), and the manufacturing of the dishwasher. Since these inputs are regionally sensitive, we will look at the national average impact using the EIOLCA, and we will look at a local impact based on the Los Angeles Department of Water and Power (LADWP). The scope of this analysis does not include the inputs of soap and sponges. We estimate the environmental impact per dish from the sponge to be minimal as a sponge may be used for a long period of time. There was also limited information on sponge's environmental effects. Additionally, both dishwashing machines and hand washing require the use of soaps. Environmental impacts resulting from soap use depends then not on which method of washing is used but rather on the type of soap an individual buys. Finally, we did not evaluate the environmental implications of sinks because it was assumed all households will have a kitchen sink whereas that is not the case with a dishwasher.

Literature Review

Since the modern dishwasher entered the US consumer market in the 1950s,[i] it has been marveled as a time-saving addition to any household. Rather than washing your dishes by hand, the dishwasher offers the same service – all you need to do is load and unload the dishes. However, many have debated the dishwasher's efficiency. Does it really save you time? Does it use less water and energy? What are the environmental impacts? While looking through literature, it seems that using a dishwasher is the better choice. Modern dishwashers are highly water and energy efficient making it difficult for hand-washing to compete. In fact, between 1990 and 2005, dishwashers reduced energy use by 34% and reduced water use by 30%.[ii] Furthermore, studies show on average that a dishwasher produces a cleaner dish and saves time.[iii]

Hand washing, on the other hand, does not require machinery and only uses energy to heat water. In Los Angeles, many homes use a gas heated water tank which may have a lower carbon footprint than electricity grids. Some homeowners also invest in tank-less water heaters or solar water heaters which can further decrease the carbon footprint of heated water. Advocates for hand-washing dishes also mention space, mindfulness, and cleanliness as key reasons for choosing to hand-wash.[iv]

Today, 60-65% of American homes have a dishwasher.[v] As more households continue to invest in dishwashers for the first time, or upgrade to newer energy efficient dishwashers, it is important to understand the total environmental impact of using a dishwasher or washing a dish by hand. At the University of Bond in Germany, a study recorded the hand washing methods of residents from seven European countries. This study was then replicated in other European countries. Our study uses data from the German study, the UK study, and our own independent research. Overall, there is a large variation in how individuals wash dishes with no correlation to age, gender, or country of origin.[vi] Each participant washed 12 plate settings or 144 dishes (including pots, pans and cutlery). The water use, energy use, time and cleanliness were then compared to the machine dishwasher averages. While on average, machine dishwashers were shown as more efficient, an efficient hand-washer could beat the machine and a diligent hand-washer could produce a cleaner dish.[vii]

Energy efficiency and water efficiency in dishwasher machines also have high levels of variation. The older your dishwasher, the more energy and water inefficient the dishwasher is. Dishwashers on the market today also vary in their efficiency levels and each dishwasher has multiple settings that also alter the dishwashing efficiency. To understand this variance, we looked at a "Summer Study on Energy Efficiency in Buildings" by the American Council for an Energy Efficient Economy. The authors compared estimated energy use per cycle of 453 dishwashers available in 2008 based on the Department of Energy (DOE) test procedure which combines machine energy use, water heating energy use, and drying energy use. The majority of dishwasher models clustered around the energy star minimum requirement (with the average efficiency being slightly more efficient than the Energy Star minimum).[viii] The authors then compared the energy use of three specific modern dishwasher models: a Kenmore 665-1658220, Energy Star Kitchen Aid KUDS011 JBTI, and the most efficient dishwasher on the market in 2008, the Bosch SHX98M09. Using the data for these three models, we analyzed the energy efficiency dishwashers use in various settings and inputs. These tests found that on average, the dishwashers could be used more efficiently than the tested settings under DOE guidelines. Thus, dishwashers when used on the most efficient settings use even less energy than reported within user manuals.[ix]

However, most consumers do not follow factory recommendations when operating their machine dishwasher. According to a Virginia Tech survey, 93% of respondents pre-rinsed some dishes before loading the dishwasher.[x] Pre-rinsing can significantly add to the water and energy consumption within a household. Manufacturers recommend scrapping food off dishes before loading the dishwasher, not pre-rinsing.[xi] Furthermore, new and top-of-the-line machine dishwashers have multiple levels that allow for more intensive washing of highly soiled dishes and some even have sensors to adjust energy and water use in comparison to the dishes cleanliness.[xii] Despite these consumer options, many people continue pre-rinsing out of habit or cleanliness concerns.[xiii]

Most studies still recommend machine dishwashers because dishwashers are consistently shown to, on average, use less energy and water during the use-phase of the dishwasher. However, hand washing requires no machine production. To understand the full lifetime environmental impact of dishwashing, it is important to look into the materials used to create dishwashers as well as the production process. According to Appliance Magazine, the use-phase of dishwasher machines accounted for 90% of its primary energy consumption.[xiv] The production of the dishwasher accounted for 4,300 MJ of primary energy consumption compared to 80,900 MJ of primary energy use during its use phase (assuming a lifetime of 15 years with 300 cycles per year).[xv] The paper also asserted that the use-phase dominated with 95% of the total environmental burden. Unfortunately, this paper did not release its primary data collection, only aggregate numbers. The environmental impact of the dishwasher thus varies on the energy sources for both the production and use phase. Since dishwashers are a global commodity, the 4,300MJ of primary energy consumed in production may be from coal or other fuels with great Global Warming Potential (GWP). At the same time, the sourcing for materials such as plastic, metals (steel), and even cotton may have unaccounted environmental impacts. For example, the authors specifically site the cotton as an input with high environmental consequences due to water consumption for irrigation of cotton.[xvi]

Another concern for dishwashers is its end of life. Once the appliance becomes waste, the dishwasher can be “separated into different material flows for reuse, recycling energy recovery or disposal.”[xvii] However, our study did not find data for the energy use and environmental impact of this end of life treatment. According to the Appliance Magazine LCA, the primary energy use for dishwashers’ end of life treatment was less than 1% of its lifetime primary energy consumption.[xviii] Thus, little attention was given to the topic. However, given the potential environmental impacts from recycling electronic waste, we feel this is a subject that deserves further study.

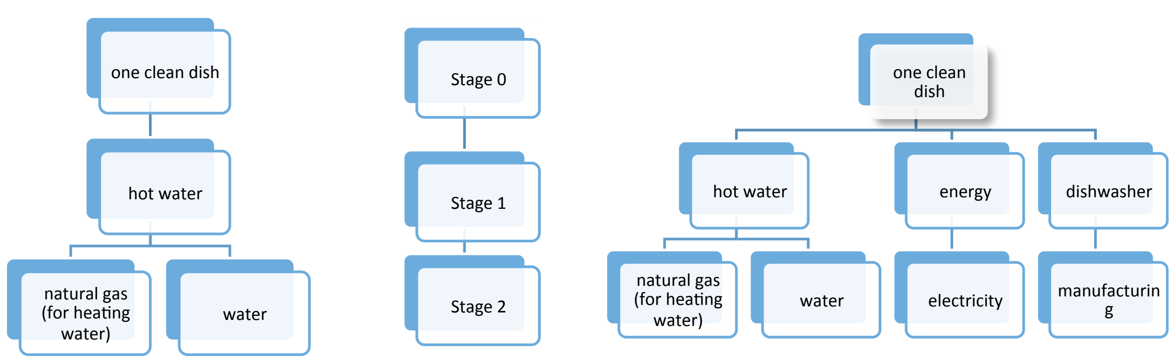
Functional Unit of Analysis, Impact Categories, and System Boundary

We will use *one dirty dinner-sized plate as our functional unit of analysis* for our study. We will make appropriate conversions based on a full load of dishes an average dishwasher. From the study in Bonn University in Germany, we estimate that one full load is 12 place settings. Each place setting has 12 pieces of dishes including bowls, plates, cutlery, pots and pans. Thus a full load is 144 dishes.[xix]

The *impact categories* that we examine are CO_2 emissions, total water use, and total energy use.

Our *system boundary* includes 2 stages of washing. We will exclude soap, sponges, and the sink as inputs.

Hand Washing *Dishwasher*



Methodology

Our project used primary and secondary research to assess the energy, water, and greenhouse gas emissions associated with washing dishes. We estimated water use when dishes are hand-washed by reviewing other studies and comparing those results to our project's mini-experiment. The experiment had four trials in which three dishes were washed. To account for variation in food's adhesiveness, the experiment used four different meals and dishes were washed immediately after the meal in two trials and washed hours later in the other two trials. Water use was measured by collecting the water with a bucket, while natural gas to heat the water was measured using the equation:

Joules = mass * water specific heat * Celsius temperature change

The results were averaged per dish. Our project also used dishwasher and manual hand-washing studies as discussed in the literature review. This hybrid approach of combining primary and secondary resources created a more thorough picture than either method alone could provide.

Lifecycle Inventory Analysis (National Average)

Manual Hand-Washing

For our base hand-washing scenario, we assumed washing was done with running water. This assumption was used because a study of manual dish-washing behavior in seven European countries found there was no "typical" water-use behavior.[xx] There were not statistically significant correlations between demographic dimensions like age, location, or gender and whether a person filled a sink or left the water running. Since the project researchers washed their dishes with running water, we decided to err on the side of washing dishes with running water. Our base also assumed most households "cold" water is 15˚C and was heated to 35˚C. Thirty-five degrees was selected because the Australian government advised using temperatures significantly below 50˚C to avoid scalding.[xxi]

We estimated how much households spend for the water and natural gas to wash a dish by averaging residential rates from across the country for water and natural gas supply. We then plugged those figures into the EIOLCA tool to determine the energy associated with the water use and the greenhouse emissions generated with when transporting and heating the water. More information on the calculations is in the appendix.

Hand Washing Inputs (National)				
		Units	Base Value	GHG Potential (tons)
Phase 1	Water	Water Used (L)	1.18	Included in phase 2
Phase 2	Heated Water (35C)	Natural Gas (J) to Heat Water	99161	.00000207
	Water Supply	Energy (J) to distribute water	8520	0.00000814
			Total GHG (tons)	0.0000102
			Total Energy	107,681.00

Dishwasher:

We made assumptions on the model, dishwasher size, water temperature, and production in order to generate the base numbers below. Firstly, our base dishwasher was a 2008 dishwasher that barely met the U.S. Department of Energy's (DOE) dishwasher efficiency performance standard. The DOE periodically sets energy standards which appliances must perform as well as, or better, than.[xxii] We used an inefficient dishwasher as a base because many households will have older dishwashers since the appliances have a lifespan of approximately 15 years.[xxiii] Dishwashers have become more energy efficient over time,[1] so an inefficient dishwasher will more accurately reflect the energy use of older dishwashers than a more efficient dishwasher.

Secondly, we assumed the dishwashers could hold 12 place settings and were fully loaded when run. A place setting includes dinner plates, serving plates, glass tumblers, bowls, and silverware. The third assumption was that the water heater was set to 50˚C. If water heaters were set to a lower temperature, the dishwasher would require more electricity to heat the water and run through the wash cycle.[xxiv] The assumptions were reflective of most households since it is standard to set water heaters to 50 ˚C[xxv] and for dishwashers to hold 12 place settings.[xxvi] Finally, we determined energy and greenhouse gas emissions associated with dishwasher production using the EIOLCA tool -- Other Major Household Appliance Manufacturing category. Dishwasher prices range from $200 to $2,000,[xxvii] and we used a lower end price of $500 to reflect the likely price of the model analyzed in the base scenario. Energy and emissions were divided by 15 (average lifespan of a dishwasher) and 300 (average loads per year). The inputs below are per load. To get the per plate inputs, we divided the results by 144, the total number of pieces of serving ware, per load. The assumption was that some dishes, like cups, may require more energy to clean than plates while pieces, like a spoon, may require less.

Dishwasher Inputs					
Phase 1			Base Liters Used	Temperature	
	Water Use	Liters Used	18.9	50	
			Base Energy Use (J)		
	Energy Use	Energy to Run Dishwasher	2,772,000		
Phase 2			Base Energy Use (J)	GHG Potential (tons)	
	Heated Water (Natural Gas)	Energy to Heat Water	2,767,716.0	0.0000582	
	Water Supply	Energy to Distribute the Water	1,340,000.0	0.000128	

[1] Hoak, D., Parker, D., Hermelink, A., "How Energy Efficient are Modern Dishwashers", Proceedings of ACEEE 2008 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, Washington, DC, August 2008.

	Energy Supply	Energy to Generate Electricity	9,890,000.0	0.000832	
	Dishwasher Manufacturing	Energy to Manufacture Dishwasher (Per Load)	110.4	7.26667E-05	
				Per Load	Per Dish
			Total GHG (tons)	0.001090867	7.57546E-06
			Total Energy (J)	16,769,826.40	116457.1278

Baseline Inventory Analysis Results

As shown in the table below, dishwashers use approximately 9,000 joules more energy than hand-washing. This is the result of more inputs like electricity to run the dishwasher and energy to generate the electricity.

Total Energy Use					
Phase 1		Water (L)	Energy (J)		
	HW	1.18			
	DW	0.13125	19,250		
Phase 2		J To Heat Water	J to Supply Water	J to Generate Electricity	J to Manufacture Dishwasher
	HW	99,161.00	8,520	n/a	
	DW	19,220.25	9,305.56	68,680.56	110.40
			Grand Total (J)	HW=	107,681.00
				DW=	116,566.76

As shown below, dishwashers generate fewer greenhouse gas emissions than hand-washing. The primary difference is that hand-washing uses more water which creates greenhouse gas emissions from the water distribution and the energy to heat the water.

Greenhouse Gas Emissions (Kg)					
Phase 1		Water (L)			
	HW	1.18			
	DW	0.13125			
Phase 2		To Heat Water	Water Supply	Electricity Supply	Dishwasher Production
	HW	0.00205	0.00814000	n/a	
	DW	0.000404167	0.000888889	0.00577778	0.00050463
			Grand Total (Kg)	HW	0.0102
				DW	0.0076

Our base comparison of hand-washing a dish with running water versus an 2008 energy inefficient dishwasher in normal wash and full load found that dishwashers use slightly more energy (~9,000 joules = ~0.0025 kWH), use less water per dish, and generate ~.0026 kilograms fewer greenhouse gas emissions than hand-washing.

Lifecycle Inventory Analysis (Local LADWP Data)

We selected data from the Los Angeles Department of Water and Power (LADWP) for this portion of our analysis, which serves as a case study of regional variance over water and energy use. LADWP not only serves as a highly relevant example as a local and large utility company, but may also provide interesting insight into the energy associated with moving water long distances as LADWP does.

In order to perform our local LCA inventory, we knew we needed data on the following: proportion of energy consumed by residential customers (as we are looking at home's water use), the amount of energy used to supply the water, and the GHG emissions associated with energy supplied by LADWP. We found all of this data available in the LADWP's most recent 2010 "Urban Water Management Plan," which is updated every five years. The following annual data for 2009 was extracted from this report:

LADWP Data Used for Local LCA Inventory (2009)	
Total Volume Delivered (AF)	562,480
Total Energy Intensity (kWh/AF)	1,934
Total Carbon Footprint (tons CO2)	433,698
Total Energy (kWh)	1,087,836,320
Total Residential Energy (kWh)	445,577,757

Table extracted from "Urban Water Management Plan" LADWP, 2010.[xxviii]

We used this data to calculate the following numbers and make the following conversions to use in our LCA inventory analysis for local numbers:

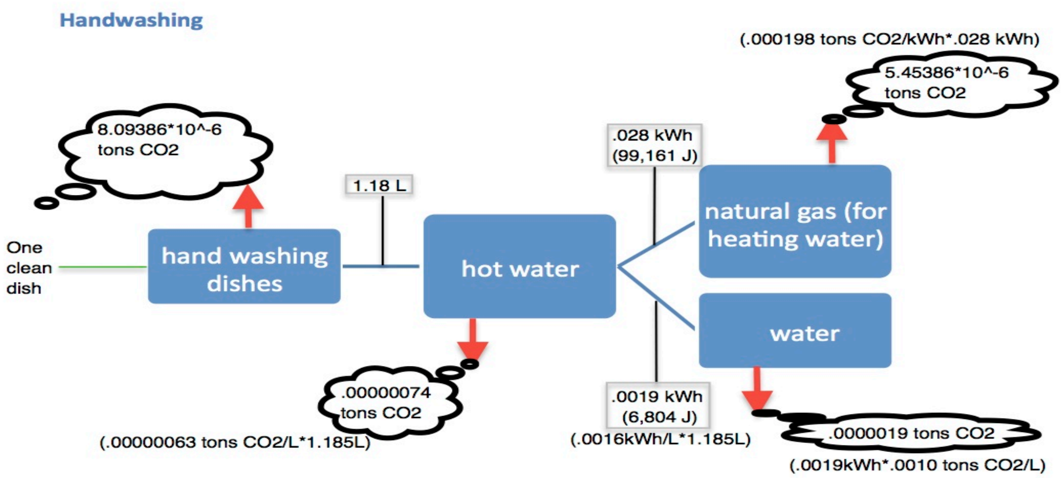
LADWP Energy and GHG Emissions Intensity Ratios for kWh and Liters of Water Used	
Energy use associated with transport of water (total kWh/AF, converted to L)	.0016 kWh/L
GHG emissions associated with transport of water (total GHG emissions/AF, converted to L)	.00000063 tons CO2/L
GHG emissions associated with energy use (total GHG emissions/residential kWh)	.0010 tons CO2/kWh

Lastly, in order to calculate the energy and GHG emissions associated with heating water in a water tank to wash dishes by hand, we used the same base numbers as the national numbers for kWh used to heat water to 90 degrees Fahrenheit using natural gas. We used the same numbers for both dishwashing and hand washing as in the national scenario. In order to calculate the GHG emissions associated with using natural gas to heat water, we converted data from the US Environmental Protection Agency (EPA) to learn that natural gas emits approximately .000198 tons of CO2 per kWh.[xxix]

LCA Inventory for Hand Washing – One Clean Dish

For hand-washing, we used the same base numbers as in the national inventory (.028 kWH of natural gas used to heat 1.185L of water to 35 degrees Celsius; 1.185L of water consumed by washing dishes by hand). We also used LADWP GHG ratios and energy intensity ratios for both liters of water transported and kWhs consumed to determine the total energy use and GHG's emitted for this process. The total energy used by this system is 106,001 J per dish, and the total tons of CO2 per dish are .0000081. Our results are shown in the following diagram:

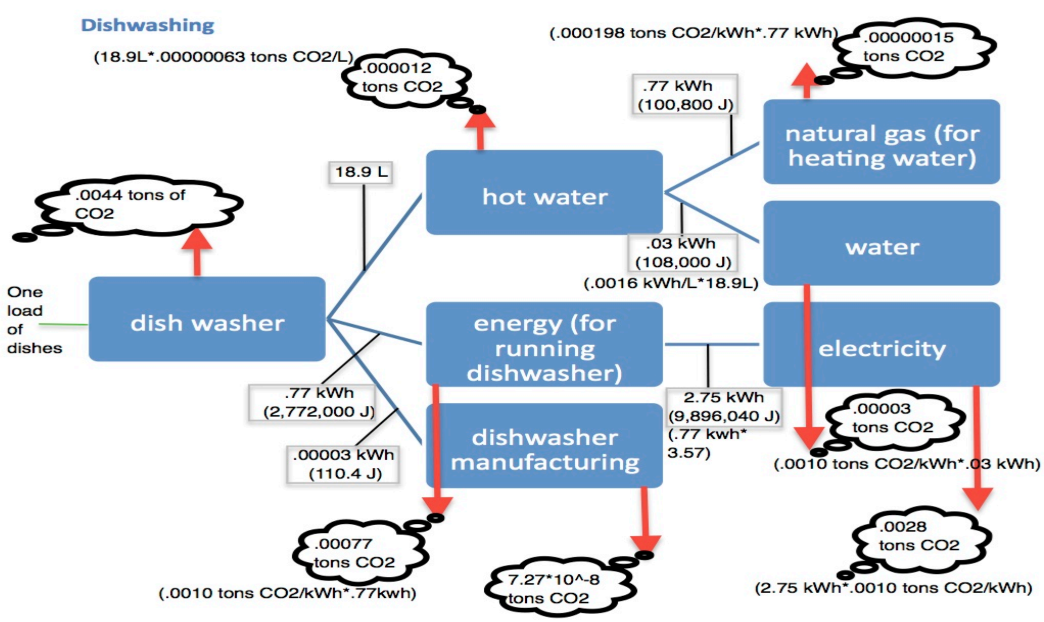
LADWP Hand-washing Inventory Analysis



LCA Inventory for a Dishwasher – One Clean Load of Dishes

For the dishwasher, we used most of the same base numbers as in the national LCA inventory (.77 kWH of natural gas used to heat 18.9L of water to 35 degrees Celsius; 18.9L of water consumed by a dishwasher). Again, we used the LADWP GHG ratios and energy intensity ratios for both liters of water transported and kWhs consumed to determine the total energy consumed and GHG's emitted by a dishwasher to clean one load of dishes. To find the electricity to create the energy to run the machine, we used the same energy ratio (3.57) as found through the EIOLCA. The total energy used by this system is 106,001 J per load of dishes, and the total CO_2 are .004 tons per load of dishes. Our results are shown in the following diagram:

LADWP Dishwasher Inventory Analysis



Life-Cycle Impact Analysis

Over the course of one year, a family doing 300 loads of 12 settings would use 1,292 kWH if washing by hand and 1,397 kWH using a dishwasher. That family would save approximately $12 a year with those energy savings.[2] Overall, the dishwasher's energy use is only marginally higher than washing by hand, and dishwashing behavior does not have a big impact on a family's energy use or expenses.

Total Energy (J)	Per Dish (dinner dish)	Per Load (12 settings)	Per Year (300 Loads per Year)
HW	107,681.00	15,506,064.00	4,651,819,200.00 J = 1,292.2 kWH
DW	116,457.13	16,769,826.40	5,030,947,920.00 J = 1397.5 kWH

Manual dish washing generates 113 kg more greenhouse gas emissions than a dishwasher over the course of a year. This is roughly the emissions released from using 13 gallons of gasoline when driving.[3xxx]

Total GHG Emissions (kg)	Per Dish (dinner dish)	Per Load (12 settings)	Per Year (300 Loads per Year)
HW	0.0102	1.47	440.21
DW	0.0076	1.09	327.26

Sensitivity Analysis

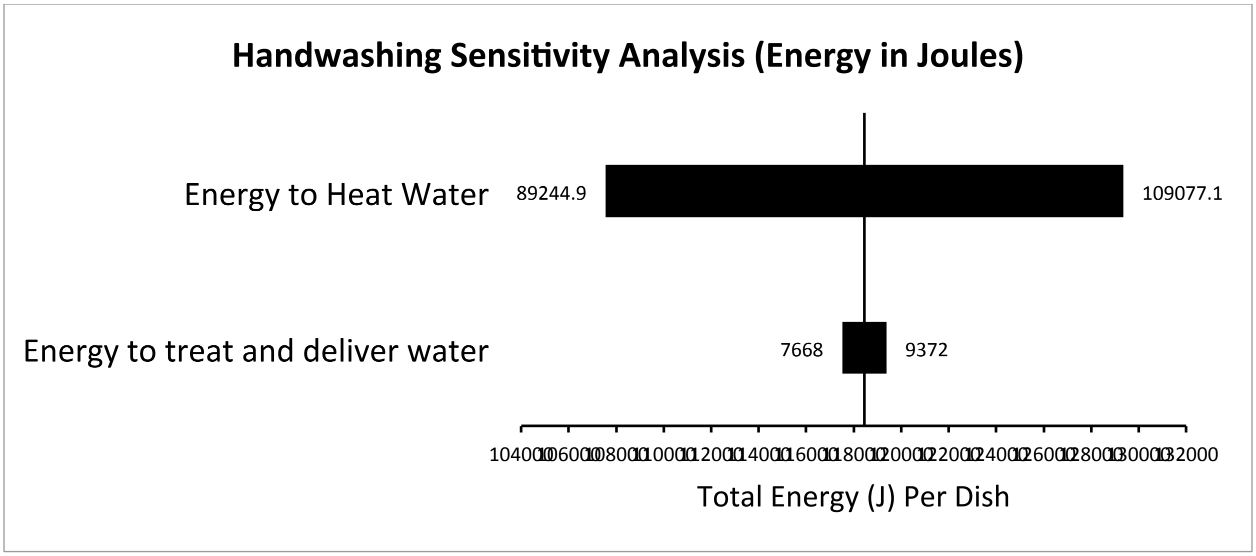
We conducted sensitivity analyses using the SensIt excel formulas to determine which inputs have the biggest impact on hand washing and dishwashing energy use and greenhouse gas emissions. We used the base figures described above and varied the figures by 10% in either direction for the minimum and maximum values.

Manual Hand-washing

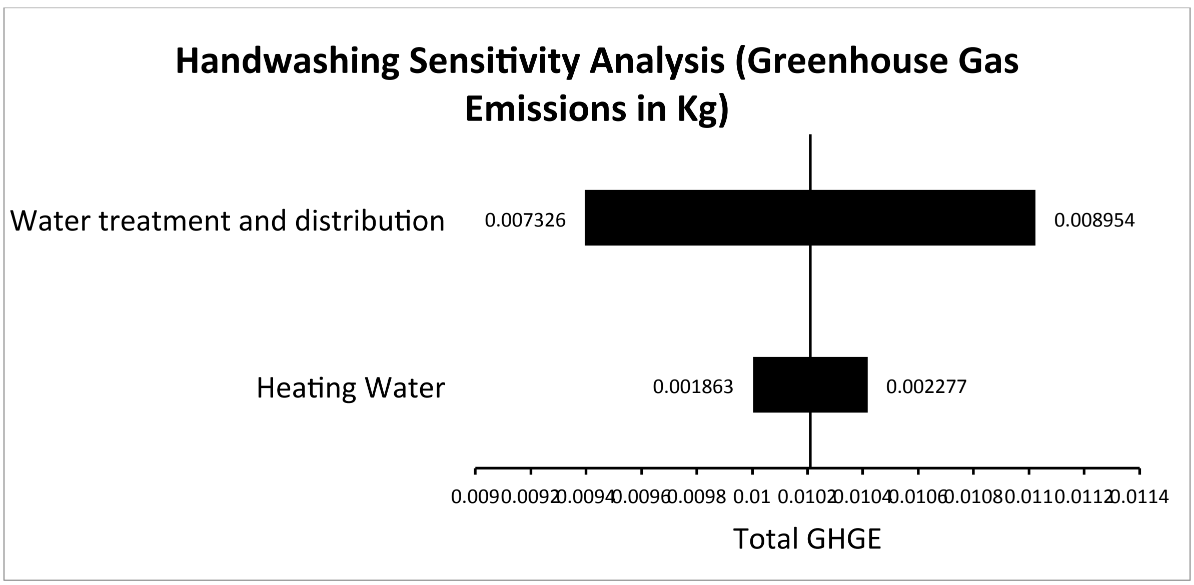
With hand-washing, the total energy use is most sensitive to the input of energy to heat the water. The water source also contributes to total energy use but to a much smaller degree than the energy to heat the water.

[2] ~12= 105 kWH* $.115/kWH

[3] According to the EPA, a gallon of gasoline contains 8.887 kg of carbon dioxide equivalent emissions. 113 kg/ 9 kg/ gallon of gasoline = 12.5 gallons.



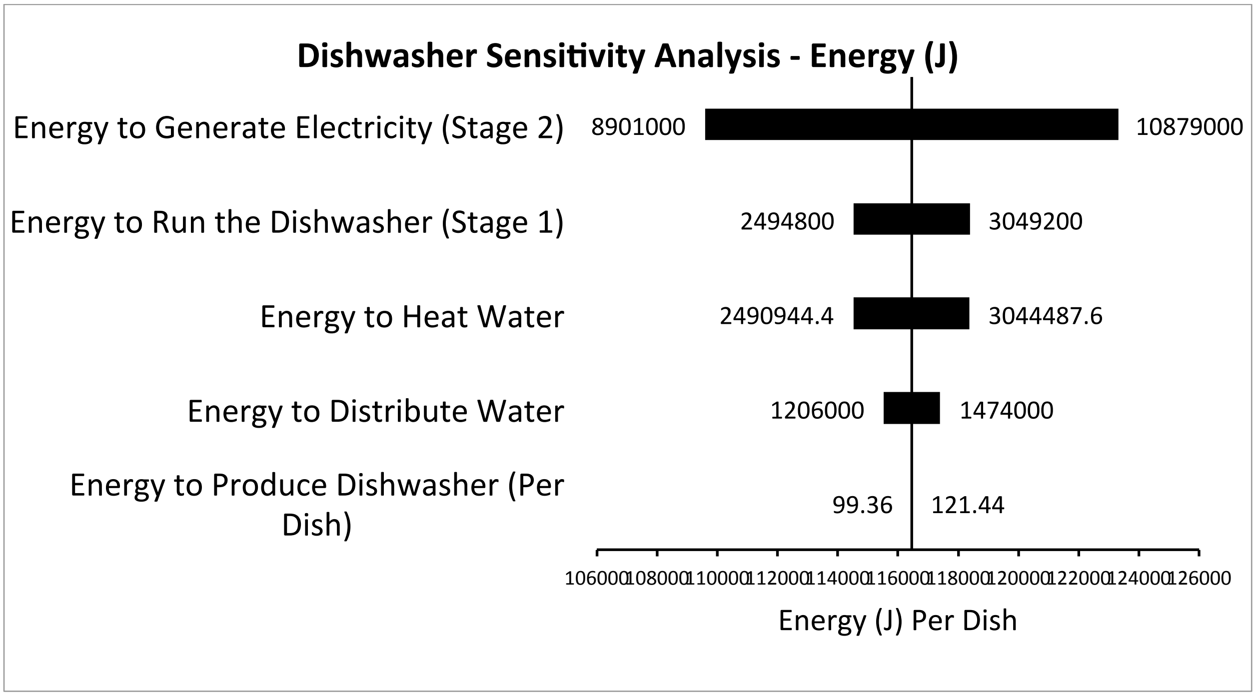
Hand-washing greenhouse gas emissions are most sensitive to emissions from the water distribution and treatment.

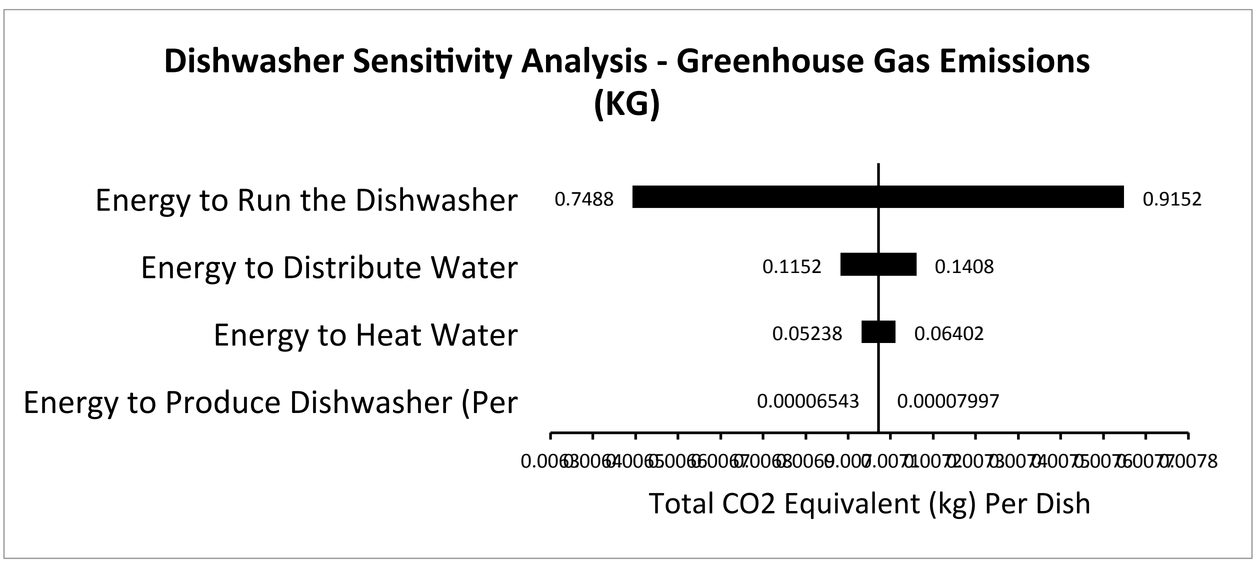


Dishwasher

Our dishwasher sensitivity analysis looked at all inputs to a dish cleaned by a dishwasher. Total dishwasher energy use and greenhouse gas emissions are most sensitive to the inputs of energy to generate electricity and electricity to run the dishwasher. The energy to run the dishwasher is influenced by the dishwasher setting and water temperature. Water probably has a smaller overall influence on energy use and greenhouse gas emissions because dishwashers are less water-intensive than hand-washing.

As dishwashers become more energy efficient, electricity to run the dishwasher may influence total energy use less over time. Additionally, whether energy comes from dirtier sources or from more efficient production will have a big impact on dishwashers total energy use and greenhouse gas emissions.





Varying Hand-washing and Dishwasher Inputs

A follow-up consideration was whether varying hand-washing techniques or dishwasher models and settings would change the story. Our base numbers found the two approaches roughly equivalent on energy use and found hand-washing generated more greenhouse gas emissions.

Varying Hand-washing Inputs

One study found water use per dish as low as 0.3 liters when the dish was washed in a filled sink, rather than with running water. With such a practice, manual dish-washing emits fewer greenhouse gas emissions at temperature range of cold (15˚C) to hot (35 ˚C). With running water, manual hand-washing is more greenhouse gas intensive than a dishwasher however. Even when the running water is unheated at 15˚C, it emits 0.008 kg of emissions which is higher than a dishwasher's 0.0076 kg. *This means the hand-washing in only cleaner than a full dishwasher when the dish is washed with other dishes in a filled sink basin.* See appendix for more details on calculations and figures.

Varying Dishwasher Inputs

By varying the dishwasher setting and model year, the dishwasher can use less energy or generate more greenhouse gas emissions than our base manual hand-washing example. The dishwasher used less energy than hand-washing with a light wash setting, rather than normal wash setting. Conversely, the dishwasher emitted more greenhouse gas emissions than hand-washing with a heavy wash setting in a 2008 model and with a normal wash in a 1993 dishwasher. Most households will have a newer dishwasher than a 1993 model, given that their average lifespan is 15 years.[xxxi] *With a light wash setting, a fully-loaded dishwasher without prewashing is "greener" than hand-washing along energy and greenhouse gas emission dimensions. A dishwasher is dirtier than hand-washing with the heavy wash setting or use of a dishwasher from 1993.*

Future studies should consider examining prewashing behavior, dishwasher loads, and a broader range of dishwasher model years. A future study could examine how many dishes people prewash and whether households run partially filled dishwashers. Data on these inputs may mean dishwashers use even more energy and emit more greenhouse gas emissions than manual hand-washing.

Limitations

We chose ultimately to focus on the water and energy usage associated with hand washing and dishwashers. This meant that we made choices to omit several inputs from our analysis, and make specific choices about how we would examine energy and water data.

Inputs

Initially, we considered examining three additional inputs for our study: dish soap and sponges (hand washing) and dish detergent (dish washers). Our initial research failed to identify any publicly available life cycle assessment studies for these inputs. In the absence of soap life cycle LCA studies, we performed research into the toxicity of both hand washing dish soap and dishwasher detergent to learn what key ingredients in the products had the most substantial environmental impacts. However, when we discovered that toxicity varied across products, and that individual products were applied differently, we found the varying qualities made dish soaps and detergents too complicated to include given the scope of and timeframe available for our study. Furthermore, we learned that phosphates are typically the most toxic component of soaps. In the past years, many states have passed laws limiting the phosphates soaps can contain. This variation in states' phosphate regulations further complicated using soaps as an input. We also found no data on the environmental impacts of sponges that we could practically include in our study.

Water and Energy Use

Our study did not account for many key factors like green measures, regional variation, and pre-washing behaviors. Overall, none of the data accounted for "green measures" such as water recycling or energy conservation strategies. We secondly believe another limitation is using national data on water and energy use from EIOLCA because this data makes fairly large generalizations that do not account for regional variations and the conditions that create these regional variations (water transport, regional availability of resources, etc.). Thirdly, pre-washing was unaccounted for because we could not find comprehensive data on key factors like what typically prewashing behaviors involve and how much water on average is used with prewashing. This is an important limiting factor because pre-washing may play a significant role in the environmental impact of dishwashers due to additional water use during the pre-wash phase. Lastly, we found it challenging to obtain strong data on how much energy is consumed in the production of dishwashers. We did find an industry LCA for dishwasher manufacturing, but it only provided us with aggregate numbers and lacked the information details necessary for a more thorough analysis. Details, such as how production energy consumption varies across brands and models, the portfolio for energy consumed in production, and the breakdown of energy consumed across production phases are necessary for conducting an adequate analysis of the environmental impacts of dishwasher production. We recommend future studies examine these limitations.

Conclusion

Our LCA inventory analysis revealed that the two methods, washing dishes by hand and by dishwashing machine, are surprisingly similar. Our inventories of hand washing that compared national energy and water use numbers with local numbers from LADWP data revealed that hand washing energy use and GHG emissions are almost identical using this method. GHG emissions were the same at .0081 kg CO_2, and the national average for energy used by hand washing was only slightly higher than the LADWP average by 1,680 J. For the dishwasher, we found that national averages used slightly more energy (a difference of 8,514 J) and emitted slightly more GHG emissions (a difference of .0066 kg CO_2) than running a dishwasher using LADWP energy and water. Our conclusion is that even though there are slight differences between national and LADWP numbers, dishes washed with LADWP water and energy (both by hand and in a machine) are basically on par with the national average.

Through our sensitivity analysis we learned that the energy to heat the water is the most important factor that causes variation in both energy consumed and GHG's emitted by washing dishes by hand. Our analysis also revealed that when water use and temperatures are varied, the amount of water used and not the temperature determined whether or not hand washing had fewer GHG emissions than washing dishes in a machine. The only scenario in which hand washing was comparable to a dishwasher was when a person washing dishes by hand filled the sink's basin rather than allowing the water to run continuously while washing the dishes.

As far as the dishwasher is concerned, we learned that energy used to run the dishwasher and energy used to heat water for the dishwasher are the most important variables. This implies that the setting that is used and the water temperature have the greatest impact on energy use for a dishwasher. Energy to run the dishwasher, i.e. the setting used, and the energy to heat the water are again the most important variables for GHG emissions as well. We varied dishwasher settings and models (models ranging from old to new i.e. less energy efficient to more energy efficient) to see whether or not the dishwasher could use less energy than hand-washing with the running water method, or to see whether or not a dishwasher could generate more emissions than hand washing. Our results revealed that using a light wash setting, as opposed to a normal setting, in a 2008 energy efficient model generated higher energy efficiency. The same model or an even older dishwasher becomes more inefficient and emits more GHG's due to higher water and energy use rates required to run the dishwasher.

Implications

Ultimately, the most significant finding of our study revealed that the comparison between dishwashers and hand washing entirely depends on the model and setting of the dishwasher, and the methods that are used in hand-washing. While dishwashers generally generate fewer GHG emissions and use less water than hand-washing, they use more energy than hand washing. We expect future trends to have a positive impact on both methods. Previous trends demonstrate that dishwashers are consistently becoming more energy efficient and many utilities are cleaning up their acts by transitioning their energy portfolios away from fossil fuels. We expect that increasing clean energy sources, better overall water and energy conservation strategies, and improved dishwasher models will make both methods friendlier for the environment. We believe that our study and findings help contribute to an improved understanding of how to lessen dish cleaning's impact on the environment by encouraging hand washers to use the basin method, rather than allowing their water to continuously run. We also found it significant that prewashing dishes before placing them in the dishwasher, while not contributing to the dish's cleanliness, substantially contributes to energy use and GHG emissions. We hope that hand washers and machine users will take these findings into consideration for the future!

Appendix:

Base Inputs

Hand-washing Inputs and Data			
Source	**Avg Per Dish (L)**	**Min Per Dish (L)**	**Max Per dish (L)**
EU Dishwashing LCA	0.715	1.181	0.319
UK Handwashing Study	0.342	1.429	0.097
Our Study Experiment	1.185	1.460	0.950

Water Usage & Heat Energy	Quantity (g)	Specific Heat Capacity	Heated to 50C (J)	Heated to 35C (J)	Heat to 20 (J)
Base	1185	4.184	173531.4	99160.8	24790.2
High Water Use	1460	4.184	213802.4	122172.8	30543.2
Low Water Use	319.4	4.184	46779.4	26731.11111	6682.777778
Average	988.1	4.184	144704.4	82688.23704	20672.05926

Final Hand-washing Base	
Water Use	1.185 L
Energy Use (Gas)	99160 J
National Ave. Price per Liter	$0.0038549
National Gas Price	$ 9.24

Dishwasher Efficiency							
Source	**Avg (kwh)**	**Min (kwh)**	**Max (kwh)**	**Avg. Water (L)**	**Min Water (L)**	**Max Water (L)**	**Avg Water Temp (in-take)**
Hoak	.77kwh	.38 kwh	2.17 kwh	18.9 L	14.3 L	23 L	50 C
Bonn	1.5 kwh	.88 kwh	1.4 kwh	13.4 L	12.4 L	16.3 L	50 C

Dishwasher Base Numbers	
Water Use	18.9 L
Energy Use	.77kwh
National Gas Price	$9.24
National Ave. Price per Liter	$0.0038549
National Electricity Price	$.1153/kwh

Inputs to hand-washing dishes:

The letters refer to the cells in the table below.

<u>A) Energy to Heat the Water</u>:
Generated using the equation: Joules = mass * water specific heat * Celsius temperature change = 99161 Joules

<u>B) Heating the Water (Greenhouse Gas Emissions):</u>

Then determine amount spent to use 99,161 joules of natural gas energy:
1) Amount Spent (Joule) = ($9.24/1000 metric cubic feet) * (1 metric cubic foot/1.082GJ)*(1 GJ/1 billion joules)* 99,161

2) Plug that number into EIOLCA into "natural gas distribution option" to get greenhouse gas emissions.

<u>C) Water Supply</u>:
1) To determine the amount spent, multiply liters used by national average charge per liter of $0.0038.
2) This number was used with the EIOLCA tool for "water, sewage, and other systems"

Hand Washing Inputs (National)				
		Units	Base Value	GHG Potential (tons)
Phase 1	Water	Water Used (L)	1.185	Included in phase 2
Phase 2	Heated Water (from 15 C to 35 C)	Natural Gas Energy (J) to Heat Water	A) 99161	B) .00000207
	Water Supply	Energy (J) to distribute water	C) 8520	C) 0.00000814
			Total GHG (tons CO2)	0.0000102
			Total Energy	107,681.00

Dishwasher Inputs

<u>A) Running the Dishwasher</u>
Based on information from research and dishwasher manuals.

<u>B) Generating Electricity to Run the Dishwasher:</u>
1) Converted joules to kilowatt hours
2) Used a national average price per kilowatt hour of $0.1153 and multiplied that by kilowatt hours. This figure was used with the EIOLCA option of power generation and supply.

<u>C) Heating the water:</u>
1) Calculate joules to heat 18.9 liters from 15˚C to 50˚ C.
2) Convert the joules into dollars using this equation:
($9.24/ 1000 metric cubic feet) * (1 metric cubic foot/1.082GJ)*(1 GJ/1 billion joules)*(Joules)
3) Use that figure in EIOLCA's natural gas distribution

<u>D) Water Supply:</u>
1) To find the amount spent, multiply liters used by national average charge per liter ($0.0038).
2) This number was used with the EIOLCA tool for "water, sewage, and other systems"

<u>E) Dishwasher Manufacturing:</u>
1) Selected midrange dishwasher price of $500
2) Used this figure with the EIOLCA option "other major household appliance manufacturing"

Dishwasher Inputs					
Phase 1			Base Liters Used	Temperature	
	Water Use	Liters Used	18.9	50	
			Base Energy Use (joules)		
	Energy Use	Energy to Run Dishwasher	A) 2,772,000		
Phase 2			Base Energy Use (J)	GHG Potential (tons)	
	Heated Water (Natural Gas)	Energy to Heat Water	C) 2,767,716.0	C) 0.0000582	
	Water Supply	Energy for Water Distribution	D) 1,340,000.0	D) 0.000128	
	Energy Supply	Energy to Generate Electricity	B) 9,890,000.0	B) 0.000832	
	Dishwasher Manufacturing	Production Energy (Per Load)	E) 110.4	E) 7.26667E-05	
				Per Load	Per Dish
			Total GHG (tons)	0.001090867	7.57546E-06
			Total Energy (J)	16,769,826.40	116457.1278

Varying Hand-washing Inputs:

Using the methods described in the previous appendices, figures for the following scenarios were generated:

Varying Water Temperature:

Hand washing Inputs (National) - Lower Bound- No heat

		Base Energy Use J	GHG Potential kg
15 cel	Heated Water	0	0
1.185	Water Supply	8520	0.00814
	Total	8520	0.00814

Handwashing Inputs (National) - Mid-range

		Base Energy Use J	GHG Potential kg
21 cel	Heated Water	29719.8	0.000616
1.185	Water Supply	8520	0.00814
	Total	38239.8	0.008756

Varying water and temperature:

		Base Energy Use J	GHG Potential kg
30 cel	Heated Water	18828	0.00038
0.3	Water Supply	22	0.00206
	Total	18850	0.00244

	Base Energy Use J	GHG Potential kg

35 cel	Heated Water	25104	0.00052
0.3	Water Supply	22	0.00206
	Total	25126	0.00258

Varying Dishwasher Inputs

Varying Electricity Use:

Lower Bound (DW): Light wash in 2008 inefficient DW or Regular wash in 2008 energy star DW			
		Energy (J)	GHGE (kg)
.35 KWH	Energy Use	1260000	
50 C	Heated Water	2767716	0.0582
18.9 L	Water Supply	1340000	0.128
Step 2 energy	Energy Supply (Energy put into creating that electricity)	4490000	0.378
EIOLCA	Dishwasher Manufacturing	110.4	0.072667
	Total (per load)	9857826.4	0.636867
	Per dish	68457.12778	0.004423

Upper Bound (DW): 1993 DW or 2008 DW with heavy wash			
		Energy (J)	GHGE (kg)
2.6 KWH	Energy Use	9360000	
50 C	Heated Water	2767716	0.0582
18.9 L	Water Supply	1340000	0.128
2.6 KWH	Energy Supply (Energy put into creating that electricity)	33,400,000	2.81
EIOLCA	Dishwasher Manufacturing	110.4	0.072667
	Total (per load)	46867826.4	3.068867
	Per Dish	325471.0167	0.021312

Varying Dishwasher Water Use:

	2008 Light Wash	Energy (Joules)	GHGE (kg)
.77 KWH	Energy Use	2,772,000.0	
50 C	Heated Water	2,767,716.0	0.0582
12.4 L	Water Supply	878,000.0	0.0839
.77 KWH	Energy Supply (Energy put into creating that electricity)	9,890,000.0	0.831
EIOLCA	Dishwasher Manufacturing	110.4	0.072666667
	Total (per load)	16307826.4	1.045766667
	Per Dish	113248.7944	0.007262269

	Extreme Bound: 1993 DW	Energy (Joules)	GHGE (kg)
.77 KWH	Energy Use	2,772,000.0	
50 C	Heated Water	2,767,716.0	0.0582
38 L	Water Supply	2,690,000.0	0.257
.77 KWH	Energy Supply (Energy put into creating that electricity)	9,890.0	0.831
EIOLCA	Dishwasher Manufacturing	110.4	0.072666667
	Total (per load)	8239716.4	1.218866667
	Per Dish	57220.25278	0.008464352

End Notes

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