Life Cycle Assessment of Wine Packaging

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The stated views and conclusions of this report are those of the authors and do not necessarily reflect the views or positions of the Client.

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EXECUTIVE SUMMARY

This report describes the Life Cycle Assessment (LCA)-based comparison of the environmental footprint of three different packaging options for wine -- glass bottles, bag-in-the-box containers, and stainless steel kegs. The environmental metrics we estimated are: cumulative energy demand, Global Warming Potential (GWP) and Acidification Potential. The three materials were compared consistently on the basis of impacts per liter of wine packaged. In LCA parlance, a functional unit of 1 liter was chosen. The goal of this report is to answer two main questions: 1) How do the life cycle impacts of the three different wine packaging options compare in terms of all inputs and outputs? 2) How can wine companies best lower their environmental footprint in regards to packaging?

To find the energy inputs for each form of packaging, we utilized basic information about the standard dimensions of each packaging material along with energy and environmental demands for each material, which we obtained from the literature. The literature we surveyed includes peer-reviewed publications in leading scholarly journals, and where this was lacking, we relied on publicly available reports from governmental agencies and private industry reports. Averaging across these different sources for each material type, we estimate the following. The embodied energy content is 7.89 MJ / L for glass, 6.03 MJ / L for bag-in-the-box, and two different values for keg depending on the number of times it is reused: 0.21 MJ / L for 100 reuses and 0.043 MJ / L for 500 reuses, respectively. Using these estimates we compute the GWP based on the mix of different types and forms of energy used in the life cycle and the emission intensity for each type of energy used. The mean GWP for glass was 0.69 kg C02e/L, 0.172 kg C02e/L for bag-in-box, 0.023 kg C02e/L for a keg reused 100 times, and 0.005 kg C02e/L for a keg reused 500 times. Finally, the mean Acidification Potential values were calculated; glass has an Acidification Potential equal to 2 g SO_2e/L, the Acidification Potential for bag-in-the-box is equal to 1.05 g SO_2e/L, a 100 reuse keg is equal to 0.355 g SO_2e/L, and a 500 reuse keg is equal to 0.071 g SO_2e/L.

In the manufacturing process of glass bottles, the melting and refining stage is the most energy demanding. The energy demand for the melting and refining phase is 46% of the total energy required. The forming stage makes up 33% of total energy demand, followed by post forming (15%), and batch preparation (6%) (Pellegrino, 2002). For stainless steel kegs, the refining of the raw materials is the process that requires the most energy, and subsequently

contributes the most to the product's global warming potential and acidification potential (Johnson, 2007). Finally, for the bag-in-the-box, no information could be found on the energy requirements of each step in the production process; however, our results indicate that the polyethylene bag requires roughly two times more energy than the carton to produce.

Finally, we conducted sensitivity analyses to identify potential options to lower the environmental footprint of each type of packaging material. The sensitivity analysis for glass was based on the effects of changing the type and mix of electricity used making glass. There was an overall trend of lower GWP/emissions when energy consisted less of coal and more renewables, as well as when the glass was produced in a location with cleaner energy mix i.e. California. For bag in the box, two sensitivities were conducted. The first was a sensitivity on the lightweighting of materials. The second sensitivity increased the volume capacity of the box. Both showed reduced environmental impacts. Finally, the sensitivities for keg included the number of reuses (already mentioned above), as well as the energy mix of electricity with varying amounts of energy originating from each type of electricity source. The reuse sensitivity showed that the more the keg was used, the less impact there was. The energy mix sensitivity showed that the more of the electricity mix came from renewables, and the more of the overall energy requirement came from electricity, the less the overall environmental impact.

Overall, the keg has the lowest environmental impact. However, since kegs are mainly for wholesale purposes, they are not a direct substitute for retail packaging, wherein bag-in-the-box has smaller environmental footprint relative to glass. Therefore, we believe research on consumer preference for bag-in-the-box relative to glass bottles is an important area for further research. When switching materials is not an option, lightweighting, altering the energy mix of the location of the package production, purchasing renewable energy credits, are some options available to wine manufacturers.

1. INTRODUCTION

California is the 4th largest wine producer in the world, producing around 680 million gallons of wine per year ("US/California Wine Production"). Wine is packaged in a variety of ways each with different environmental impacts during the production, use, and end-of-life phases. Approximately 230 million tons of solid waste is generated in the US per year - over 4.6 pounds per person per day. Food packaging contributes over 23 percent of the solid waste reaching landfills (EPA, 2013). The environmental burden of this waste is becoming an issue in the eyes of consumers and stakeholders alike, and in response, socially responsible companies are reevaluating their practices to create more sustainable products.

To that end, we have partnered with Fetzer Vineyards to conduct a life cycle assessment (LCA) of three packaging formats: a glass bottle, bag-in-the-box, and wine keg. Fetzer Vineyards is known as one of the most sustainable wine producers in the country. They are the largest winery in California to become a certified B Corporation, and use renewable energy and organic farming practices (Swindell, 2015). However, Fetzer recognizes packaging as an important component of the overall environmental impact of wine production.

A life cycle assessment helps estimate the various environmental burdens arising at each phase of life cycle of a product system and it can be used to compare alternative product systems. This includes information on resource extraction, material processing, manufacturing, transportation, usage, waste disposal, and recycling. The final products will be an inventory analysis, which tracks the energy and material inputs and outputs for each packaging component. This involves looking at a number of individual unit processes in the supply chain. We will also prepare an Impact Assessment, which will interpret the emissions and resource consumption data into terms of environmental burdens.

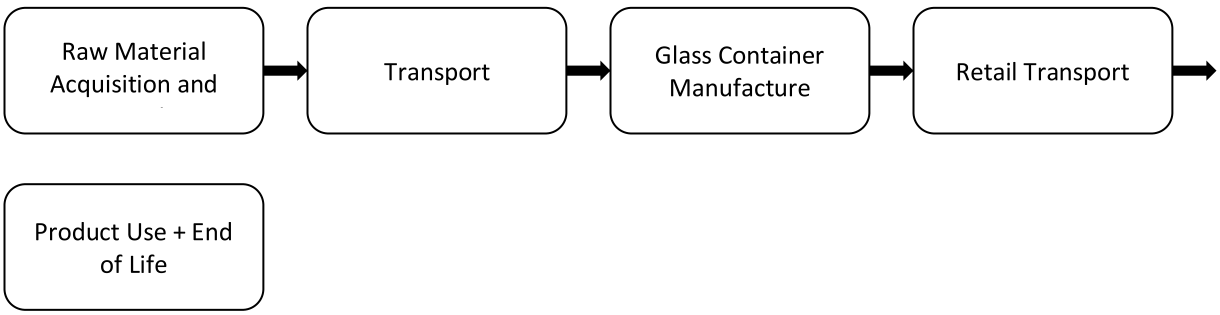
2. GOAL AND SCOPE

The main goal of this LCA is to evaluate the life cycle impacts of a glass bottle, bag-in-the-box, and wine keg and compare them in terms of inputs and outputs. The second part is to propose improvements that would enable wine companies to lower their environmental footprint in regards to packaging.

2.1. System boundary

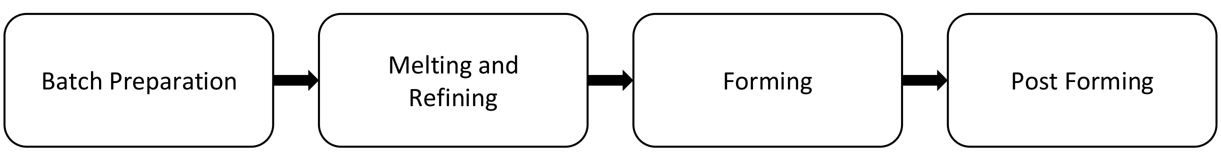
The systems that were investigated were divided into smaller subsystems. The stages/processes for each packaging type are summarized in the figures below.

Glass Bottle

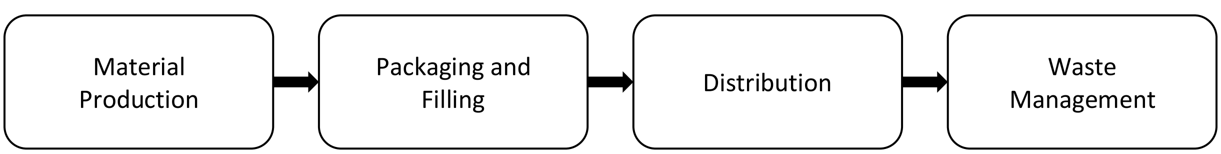


Glass Container Manufacture

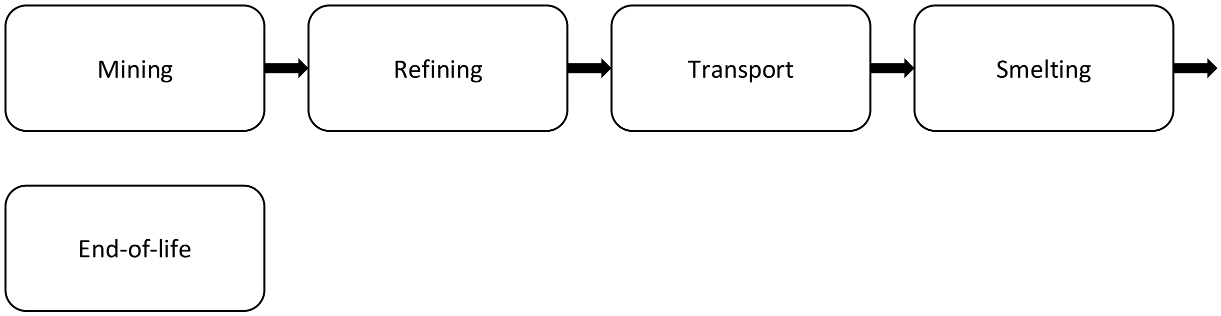
The glass manufacture phase is broken down into 4 stages:



Bag-in-the-box



Keg



2.2. Functional unit

A functional unit allows equivalent comparison between two or more products. The functional unit for this LCA is the amount of environmental burden used per liter of wine packaged.

2.3 Impact Categories

The Environmental indicators that were considered include: total energy consumption, Global Warming Potential (GWP) and Acidification Potential (AP). Total energy consumption is the sum of all types of energy (coal, natural gas, solar, etc.) used in the lifecycle of a material and is given in units Megajoules (MJ). GWP is a relative measure of the level of contribution to global warming, and is expressed as a factor of carbon dioxide, whose GWP is standardized to 1. GWP is compared in kilograms of carbon dioxide equivalents (kg CO_2 eq). Similarly, AP is a measure of the extent to which a substance or process contributes to the acidification of abiotic resources, which may have various effects on the ecosystem. AP is standardized and expressed in kilograms of sulfur dioxide equivalents (kg SO_2 eq).

3. METHODOLOGY

3.1. Stainless Steel Kegs

To begin the stainless steel keg analysis, an extensive literature search was conducted to understand the materials flow and the energy requirements for every stage of the manufacturing process. This search was conducted specifically towards the formation of stainless steel with the assumption being that little to no energy would be used to bend the steel sheet into a keg. Upon conducting this search it became apparent that there is a lack of extensive peer-reviewed information regarding stainless steel formation. Only one study breaking down the steps in the life cycle of stainless steel formation and the energy requirements for each was found. It is titled "The energy benefit of stainless steel recycling" (Johnson, 2007). Two other studies were found that give a more abbreviated life cycle process for stainless steel production and only give the total energy requirement without a breakdown of energy for each step. They are titled "Alternative Routes to Stainless Steel Production" (Norgate, 2004) and "Assessing the Environmental Impact of Metal Production Processes" (Norgate, 2007). For the third of these mentioned studies, two separate stainless steel formation methods were identified with different energy use and global warming potential values listed for each. Neither of the other studies identified which of the two techniques they were analyzing, therefore the different methods mentioned in the third study are treated as two separate data points that both contribute to the average energy value and global warming potential found in this study.

Once the sources for this analysis were identified, the total energy use in megajoules per tonne of stainless steel was taken for each of these reports. These values were then converted to our functional unit of megajoules per liter of wine packaged. This was done under the assumption that one keg packages 19.5 liters of wine using 6.35 kilograms of stainless steel. This calculates down to a conversion factor of 0.3256 kilograms of stainless steel per liter of wine packaged. The megajoule per tonne values were then divided by 1000 to convert to megajoule per kilograms and then multiplied by 0.3256 to get values for megajoules per liter of wine packed.

Once the different total energy requirements in the functional unit were found, the global warming potential in terms of carbon dioxide equivalent as well as acidification potential was calculated. To begin with global warming potential, the second and third studies previously mentioned gave values for overall carbon dioxide equivalent in the study. However the first did not, so it was calculated using the given energy mix of the study. The average energy emission intensity values were used from a report by the World Nuclear Association that analyzed between 5 and 14 sources for each energy source. The different energy sources used were petroleum, nuclear, natural gas, coal, propane, and renewables. To find the energy intensity for renewables, the average value was taken between solar, wind, and hydroelectric. These intensities, which were in values of tonnes of carbon dioxide equivalent per gigawatt hour were converted to kilograms of carbon dioxide equivalent per megajoule and multiplied by the previously calculated energy value to get kilograms of C02e per liter of wine packaged for each energy source. Then these were all added up to get total global warming potential. This was then compared to the global warming potentials given by the other studies.

Similar to global warming potential, acidification potential values were provided by the second two studies but had to be calculated. As there was limited energy information given by the first study the assumption that only the energy used from coal contributed to acidification potential. A value for acidification intensity emission by coal use was taken from a National Energy Technology Laboratory report, and was converted from lbs. of SO_2 per megawatt hour to kilograms of SO_2 per megajoule. It was then multiplied by the previously calculated megajoule per liter of wine from coal to get an acidification potential value for this study. This was then compared to the given acidification values from the other two studies.

3.2. Glass Bottles

This section describes the methodology used to obtain: energy consumption, global warming potential, and acidification potential values for the 750 mL glass bottle. Like kegs, the starting point was a literature search. Five studies were selected for analysis. The first of these is an EPA archive document on glass manufacturing. In this document, the current mix of production from recycled inputs and virgin inputs was assumed to be 23% recycled glass and 77% virgin glass (EPA, 2015). The other studies were adjusted in order to maintain a uniform percentage of recycled content. In terms of energy, the EPA study provided two energy values for the glass manufacturing process, one for recycled manufacture and one for virgin manufacture, as well as a value for transportation energy. Based on the percentages of recycled and virgin glass, total energy was calculated by taking 23% of the energy value provided for recycled glass and taking 77% of the value for virgin glass (EPA, 2015). Energy consumption was then converted from the unit million BTU / short ton into MJ / L using the following conversion factor: 1 kWh = 3412.14 Btu = 3.6 MJ, as well as the empty bottle weight 750 mL = 0.470035 kg. The percentages for recycled and virgin glass were also applied to the two GHG emission numbers. The unit for GHG emissions is kg of CO2 eq / L. Another study, an LCA titled “Carbon Footprint and Energy Consumption of Beverage Packaging” also reported a set of energy and GWP numbers for a landfill end of life scenario (virgin glass) and a recycling end of life scenario for different types of glass beverage containers (Pasqualino, 2011). We chose the data for white and green glass beer bottles because these containers are similar to glass wine bottles. The calculations were carried out in the same way that they were for the EPA document taking 23% of the recycled scenario, 77% of the landfill, and carrying out the necessary unit conversions. The “Life Cycle Assessment of North American Container Glass” gave the energy consumption for general container glass in units of MJ/ kg of glass and GWP in units kg CO_2 eq / kg of glass. To convert both numbers to a per liter basis, again, the weight of the bottle was used (Cattaneo, 2010). The studies “Energy and Environmental Profile of the U.S Glass Industry” and “LCA of Beer Production in Greece” were unique in that they broke down the energy use involved in the glass manufacturing process by the different types of energy i.e. electricity, natural gas, diesel, heating oil etc. used in each step. The individual values were then summed to get the total energy and then the total energy was normalized to 1 liter (Koroneos, 2005). The CO2 emissions for “Energy and Environmental Profile of the U.S Glass Industry” were normalized to 1 liter as well. The sulfur oxide and nitrogen oxide emissions that were given were equated using TRACI, an environmental impact assessment tool and were then summed to obtain acidification potential. For the “LCA of Beer Production in Greece”, GHG emissions were calculated by multiplying the emission intensity factors for electricity (330 g CO2/MJ), diesel (102.01 g CO2/MJ), natural gas (79.71 g CO2/ MJ), heating oil (102.01 g CO2/MJ), lignite or coal (330 g CO2/MJ) and propane (60.6 g CO2/ MJ) by the energy make up (Pellegrino, 2002). Acidification potential was given in units of kg SO2 eq / kg of glass; this was normalized to 1 liter. Finally, we did a sensitivity analysis to understand how our results would differ with different input amounts and to also take into account any uncertainty in our analysis. We ran a sensitivity analysis that looked at how emissions varied when the energy input was manipulated. The model consisted of three different scenarios: energy as 100% electricity from coal, 100% electricity from natural gas, and 100% of electricity produced in the state California.

3.3. Bag-in-the-Box

This section describes the methodology that is used to understand, energy consumption, water consumption, global warming potential, and acidification potential of bag-in-the-box, a kind of material that can function as wine packaging.

Bag-in-the-box is a composite packaging material that contains a bag which is an inner layer of polyethylene and a box which is an outer layer of paperboard carton. Regarding that there is almost no research has been done for bag-in-the-box as a whole, two studies of polyethylene and carton have been done separately and then the results have been aggregated together. To begin with the analysis, five extensive literature searches, including four peer-reviewed research papers and one industrial report, were conducted to understand the different stages of material production. The first of these is an industrial report which offers production inputs and outputs data of bag-in-the-box as a whole and carton itself (Pandelieva, 2014). This industrial report divides the whole production into four phases: packaging, filling, distribution, and waste management. Regarding that transportation should not be considered into final results and highly variable recycling rate in different places, distribution and waste management has been subtracted from the original amount. The second literature is a research paper about carton production (Cote, 2009). The functional unit is transferred from 1 kg of carton to 1 liter pack of wine by a converting factor of 1 kg carton is equal to 25.8 liter pack of wine that is provided in the literature. In this literature, Energy is broken into different types such as diesel, coal, propane, and natural gas. The third life cycle analysis, which is about wine packaging in Nordic Country, provides inventory and impact analysis for both polyethylene and carton (Markwardt el al, 2017). This report gives out clear comparison between common materials and helps to compare the values and get reasonable final results. Another lifecycle analysis, which introduces the production of polyethylene, gives out inventory and impact data for four phases of production including mining, ethanol production, polymerization, and transportation (Liptow el al, 2012). Transportation stage is excluded from the total value and a conversion factor that 35 grams of polyethylene is equal to 1 Liter pack of wine is taking directly from literature text. And the last lifecycle analysis which is about milk packaging production also provides information for energy consumption, water consumption, global warming potential, and acidification potential (Fry el al, 2010). A conversion factor of 1000 uk pints is equal to 568 Liter pack of wine is taken.

After excluding the information that is out of system boundary and normalizing all the values to the study's functional unit which is 1 L pack of wine, the averages of energy consumption, water consumption, global warming potential, and acidification potential are taken to considering but minimizing the effect of extreme values. In general, there are total 4 data points for carton and 3 data points for polyethylene. Considering the energy mixes of carton and polyethylene are largely different and the energy mix information is not available in many literatures, energy mix is not calculated in bag-in-the-box section. All the data for global warming potential and acidification potential are sourced directly from literature without calculation. Total energy consumption is calculated by the energy intensity of 48 MJ/kg of diesel, 39.5 MJ/kg of fuel, 46.4 MJ/kg of gasoline, 30 MJ/kg of coal, 55/5 MJ/kg of natural gas, 46.4 MJ/kg of propane, 41.5 MJ/kg of old tires, and 18 MJ/kg of biomass.

The sensitivity analysis has been done for two cases. The first case that tests the sensitivity to lightweighting of carbon with no change in polyethylene since polyethylene is the main structure to hold the weight of wine. In the second case, different volumes of packaging are assumed to understand the relative inputs or outputs ratio when the packaging becomes larger.

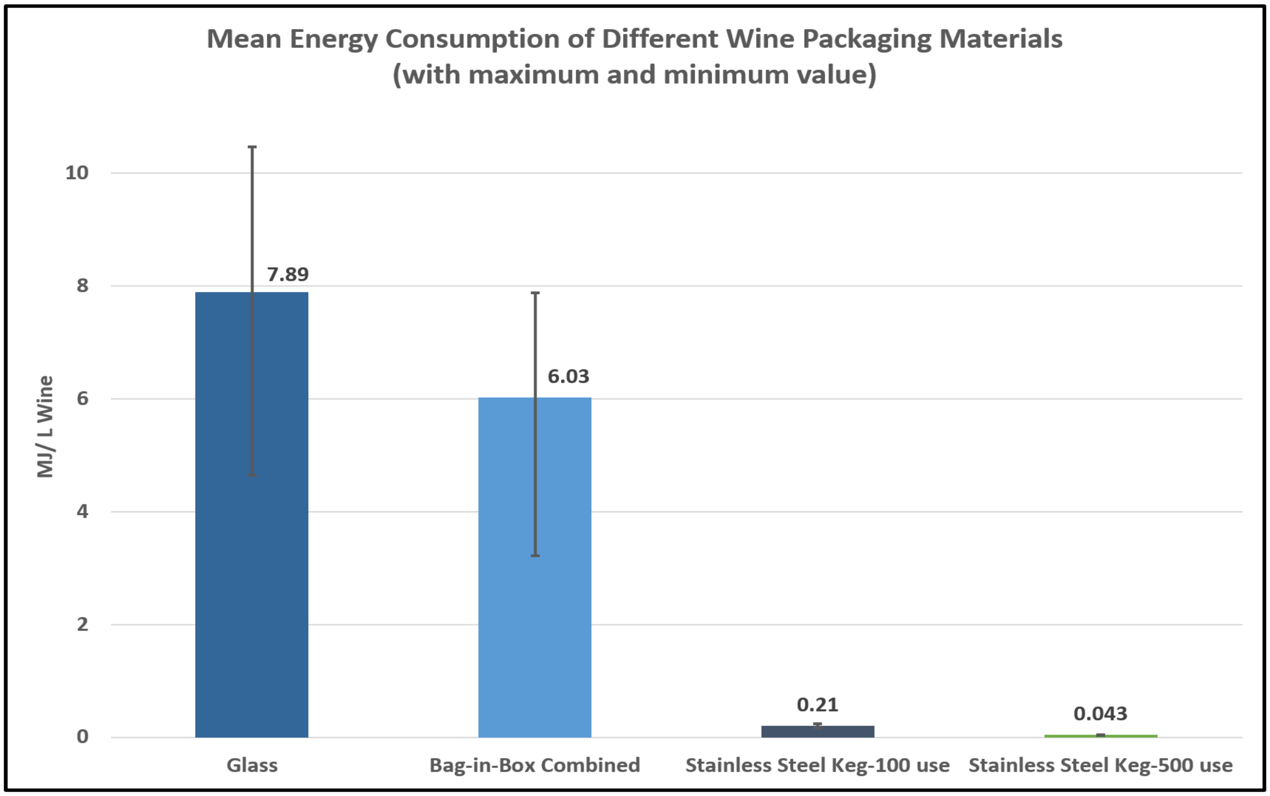
4. RESULTS

4.1 Master Sheet

The master sheet included in this report is a summary table of the environmental impact results from each packaging type. Along the top, the materials of each packaging type are broken down into their main components or their impacts per 100 uses or 500 uses for kegs. The amount of recycled material is also listed for each material, as well as their respective assumed end-of-life scenarios. The environmental impacts that were calculated are listed along the left-hand side, and include total energy requirement, global warming potential, acidification potential, water consumption, and breakdown of energy usage (where applicable). The master sheet provided the raw data that our team used to create the graphs of our results, which will be discussed below.

4.2 Total Energy Consumption

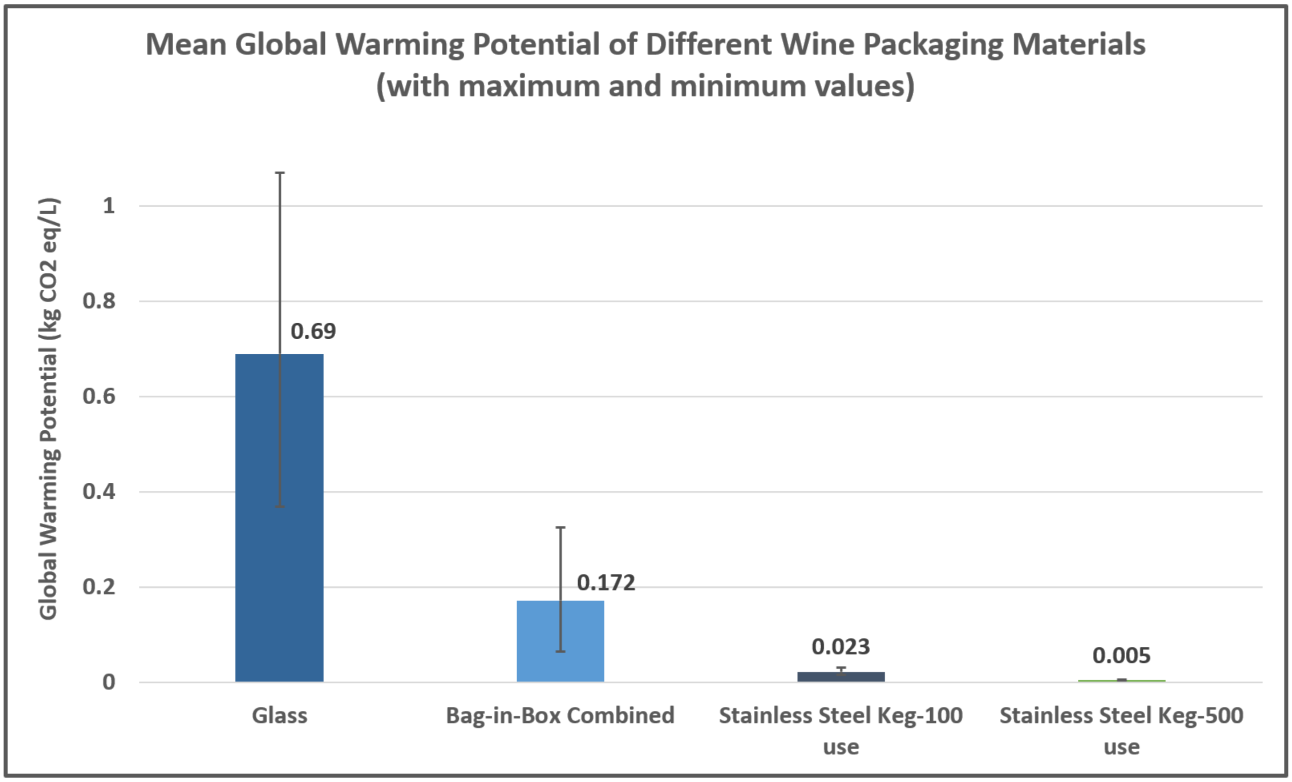
Graph 1 displays the amount of energy consumed during the life cycle of each packaging. For one liter of wine packaged, glass bottles consume 7.89 MJ of energy, which is slightly higher than 6 MJ for bag-in-the-box. The production of a single use keg consumes over 20 MJ of energy; however, kegs are usually reused multiple times during their lifecycle, thus recycling rates should be taken into account. Considering to recycling scenarios, stainless steel kegs consume only 0.21 MJ of energy if they are reused 100 times, and an even lower 0.043 MJ of energy when they are reused 500 times.



(Graph 1: Mean Energy Consumption of Different Wine Packaging Materials with maximum and minimum value)

4.3 Global Warming Potential

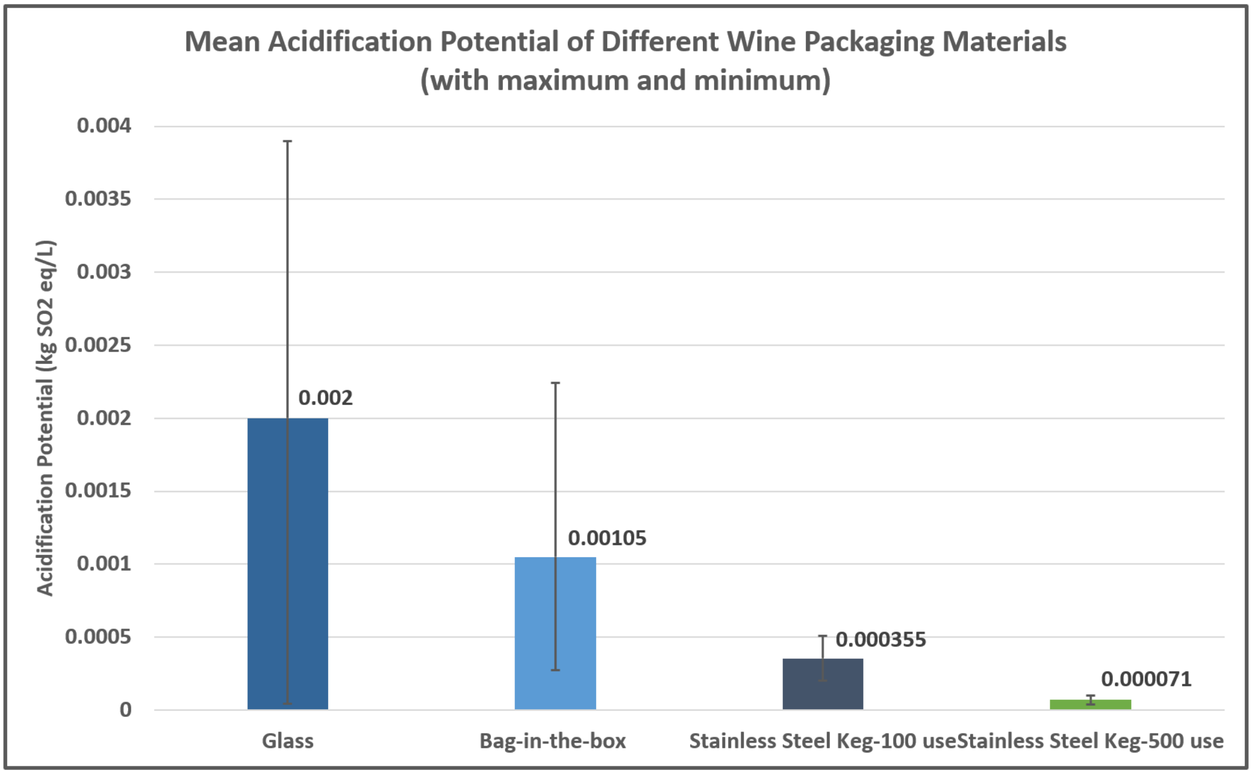
As shown in Graph 2, Glass bottle packaging releases 0.69 kg CO_2 eq for per liter of wine. This is over 4 times more CO_2 emissions than bag-in-the-box, which only releases 0.172 kg CO_2 eq / L wine. So between the two alternative retail packaging, bag-in-the-box is more environmental-friendly in terms of global warming effects. Kegs have the lowest level of impact (0.023 kg CO_2 eq / L with 100 reuses, and 0.005 kg CO_2 eq / L with 500 reuses) due to their high recycling rates.



(Graph 2: Mean Global Warming Potential of Different Wine Packaging Materials with maximum and minimum values)

4.4 Acidification Potential

In terms of Acidification Potential Graph 3, bag-in-the-box releases 0.002 kg SO2 eq to package one liter of wine. This is only half the amount of SO_2 equivalents emitted by glass bottles used for the same packaging purpose (0.00105 kg SO2 eq / L). Again, bag-in-the-box has a lower environmental burden than glass bottles do. It is worth noting here that stainless steel kegs don’t show as much of an advantage when it comes to Acidification Potential (0.000355 kg SO2 eq / L, over ⅓ the AP of bag-in-the-box), even when they are reused over 100 times.



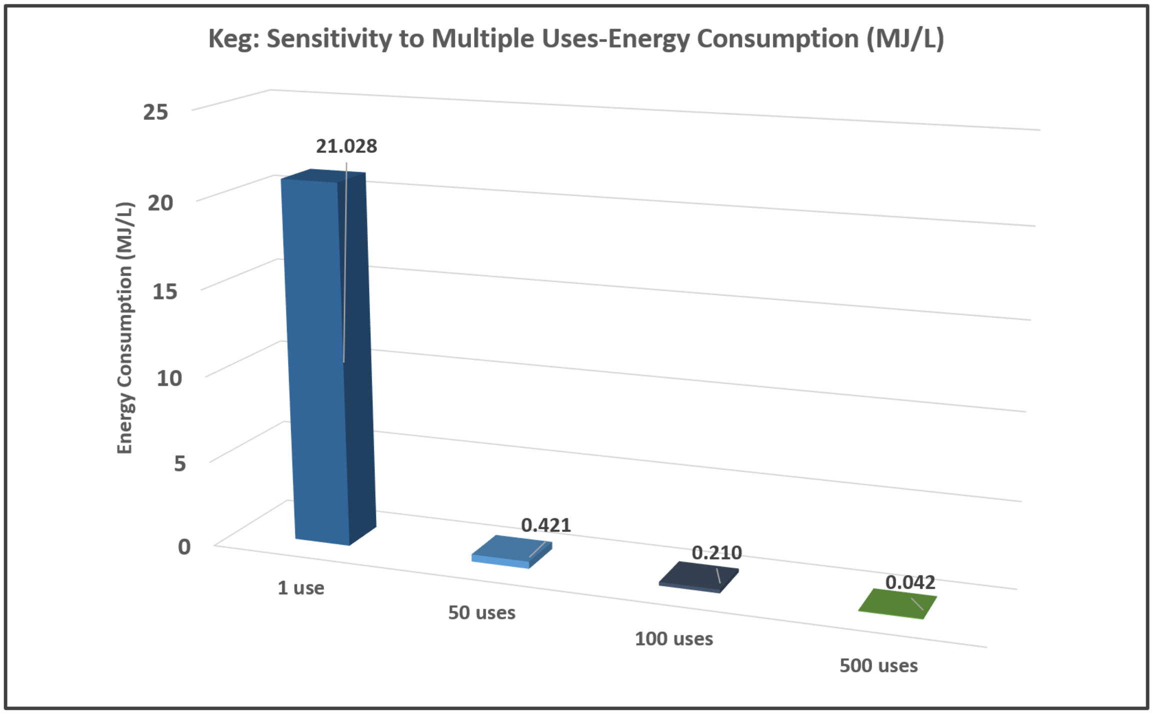
(Graph 3: Mean Acidification Potential of Different Wine Packaging materials with maximum and minimum)

5. SENSITIVITY ANALYSIS

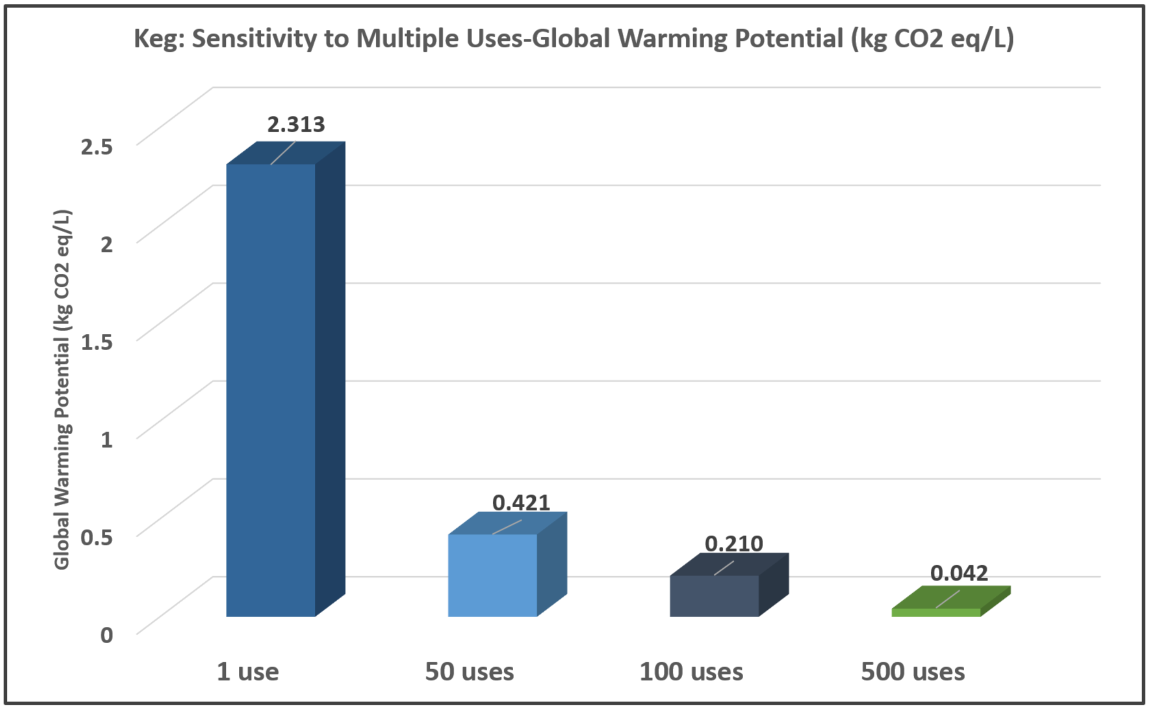
Sensitivity analysis is critical to know how the outcomes of the LCA can vary based on manipulation of the input amounts.

5.1. Reuse

Because the functional unit being used is per liter of wine packaged, the number of re-uses of the keg is a significant factor. Both the client as well as the literature were not able to provide any metric regarding average re-uses of these kegs. Therefore four different values were chosen as a sensitivity analysis for number of reuse: 1, 50, 100, and 500 uses. For each of these numbers, both the average energy use and global warming potential values for one use were divided by the number of uses. Graph 5 and Graph 6 show the resultant values. There is a clear correlation showing that the more reuses the less the impact per liter packaged.



(Graph 5: Keg: Sensitivity to Multiple Uses-Energy Consumption)

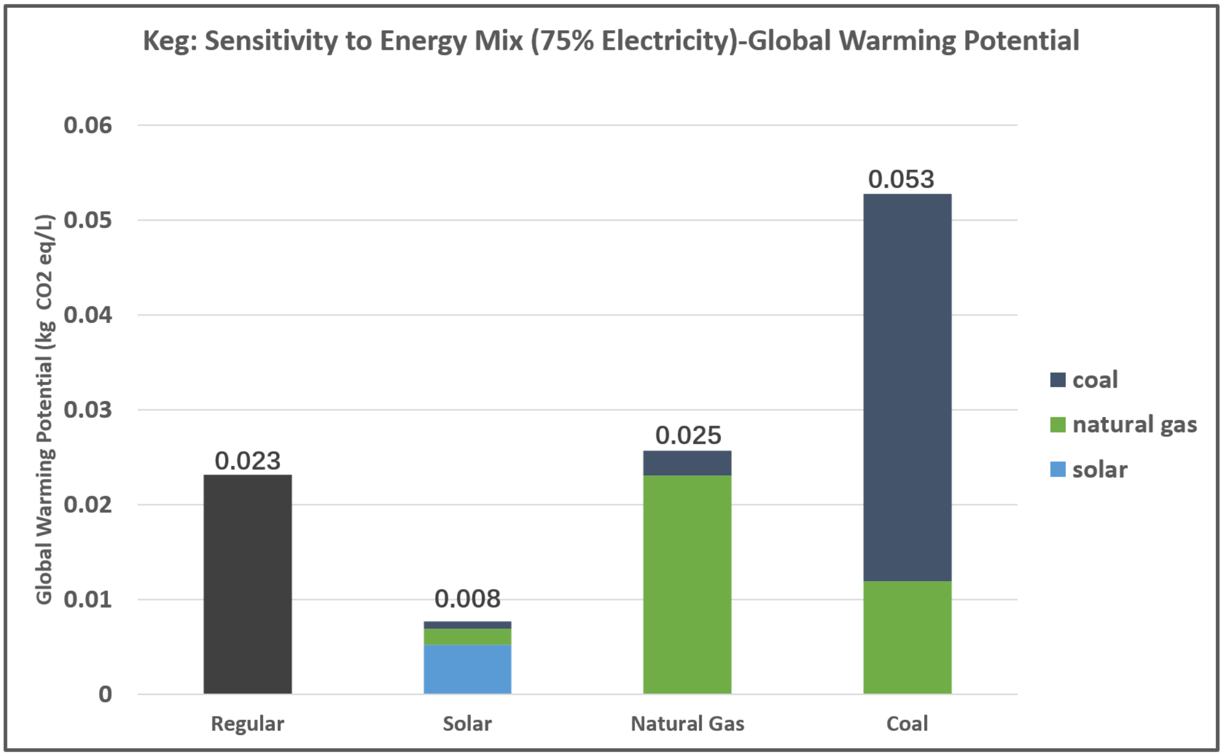


(Graph 6: Keg: Sensitivity to Multiple Uses-Global Warming Potential)

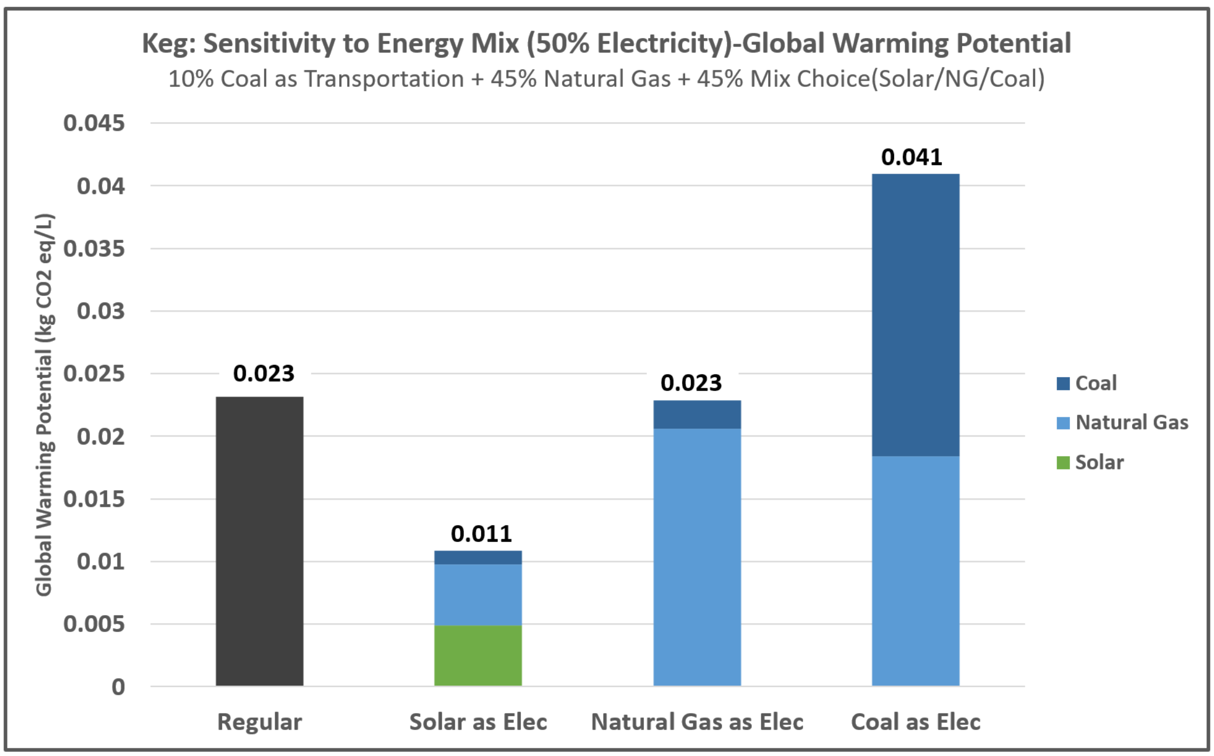
5.2. Energy mix

The kegs studied in this report were manufactured in Germany. As there is uncertainty regarding how well the global warming potential values found in the three literature sources apply to Germany's energy mix, both a sensitivity analysis for different energy mixes as well as a case study for the probable conditions of manufacturing the kegs and transporting them to the US were performed. Beginning with the sensitivity analysis, two scenarios were analyzed using the energy values from each study: having either 75% or 50% of the energy not used in transportation originate from electricity use. The remaining 25% or 50% of energy use was assumed to come from heat originating from natural gas. As it was the average value for the previously mentioned sensitivity, 100 uses was taken as the number of uses for all of the scenarios. Transportation was assumed to be 10% of overall energy use for this sensitivity analysis. Within each of these scenarios three different scenarios were analyzed in which the electricity mix originated from energy from entirely renewables, natural gas, or coal. This was done in an effort to give clear picture over the broad range of the possible electricity mixes and to give a clear picture of how focusing energy consumption towards a specific source would affect overall keg impact.

To begin, 90% of the overall energy value was taken. Then either 75% or 50% of this value was taken and multiplied by the corresponding renewable, gas, or coal used for electricity emission intensity value. The remaining 25% or 50% of energy consumption was taken and multiplied by the natural gas used for heat emission intensity value and added with the previous value. The remaining 10% of overall energy was multiplied by the petroleum energy intensity and added to the previous value to have an overall global warming potential for each of these scenarios. This ultimately provided six different global warming potential values for each study which were then averaged to get a mean value for each scenario, as shown in Graph 7 and Graph 8. There is a clear trend shown that as more of the electricity mix originates from renewables and less from coal, and as more overall energy originates from electricity and less from heat, the overall impact is decreased.



(Graph 7: Keg: Sensitivity to Energy Mix (75% Electricity-Global Warming Potential)

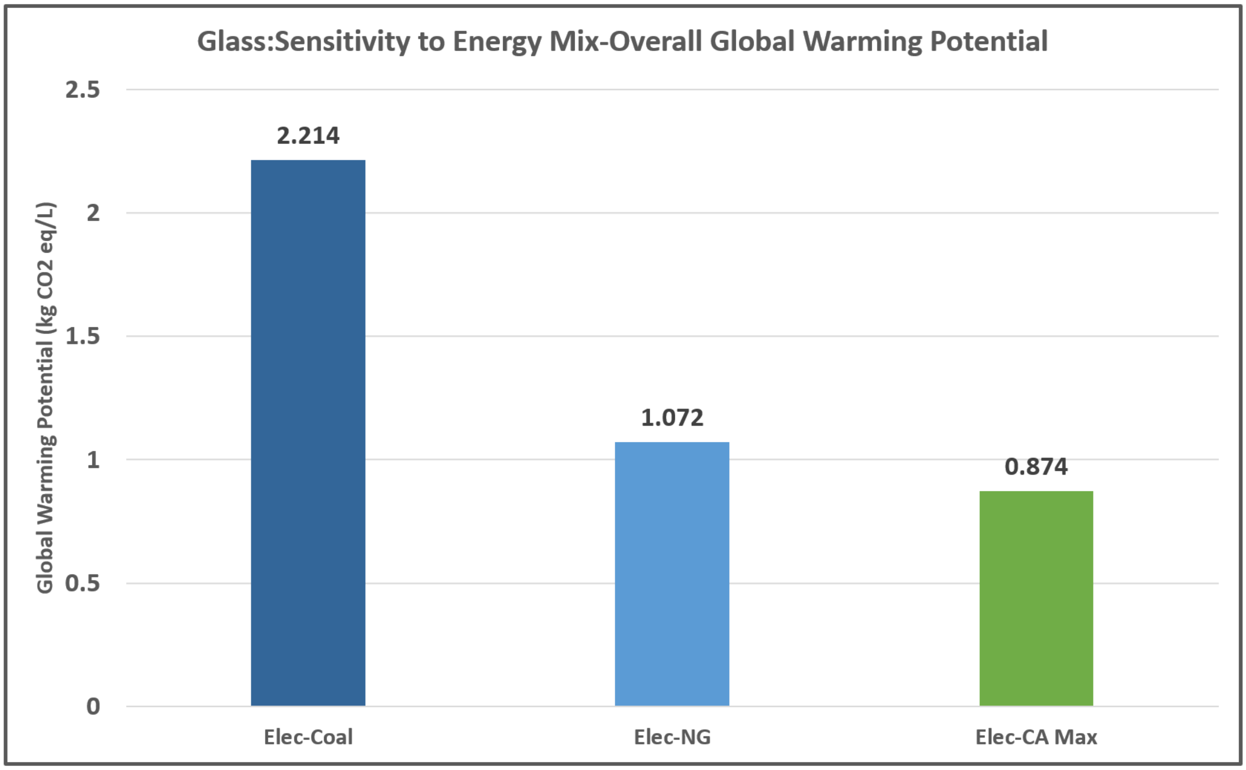


(Graph 8: Keg: Sensitivity to Energy Mix (50% Electricity)—Global Warming Potential)

For the German case study, we used a combined average of the total energy requirement from each study. This total of 64697 MJ/ton was then used to conduct the case study based on the energy mix of Germany. The breakdown is as follows: German electricity is 33.3% Renewables, 13.2% Natural Gas, 14.1% Coal, 22.5% Lignite, and 11.7% Nuclear (Appunn et al, 2018). The case study was then conducted under two models: one in which 75% of the total energy used for production came from electricity, with the other 25% from natural gas, and the other in which the energy split was 50% electricity and 50% natural gas. After converting the energy breakdowns into CO_2 equivalents, the totals were added together and converted to kg of CO_2 equivalents per L, our functional unit.

The transportation energy was then calculated based on the distance from Berlin, Germany to Napa, CA. It was assumed that this distance would be traveled by airplane, as any further vehicle transportation would be of a far lesser impact. Using a distance of 5600 miles, and the knowledge that 1 mile of air travel is equivalent to 24.18 kg CO_2 (Clayton, 2002), we found that an additional 135,408 kg CO_2 would be added to the kg of CO_2 from stainless steel production, greatly increasing the product's Global Warming Potential.

Looking at the glass bottle, the model depicted in Graph 9 consists of three different scenarios: electricity generated from 100% coal, electricity from 100% natural gas, and 100% of electricity produced in the state California. When energy is sourced entirely from coal, the GWP is the highest and equal to 2.214 kg CO2 eq / L. When energy is sourced from 100% natural gas, GWP is at 1.072 kg CO2 eq / L. When all energy is sourced from CA-mix electricity, GWP is at its lowest and equal to 0.874 kg CO2 eq/ L. Therefore, electricity generated in California is the most environmental-friendly energy source in terms of global warming effects.

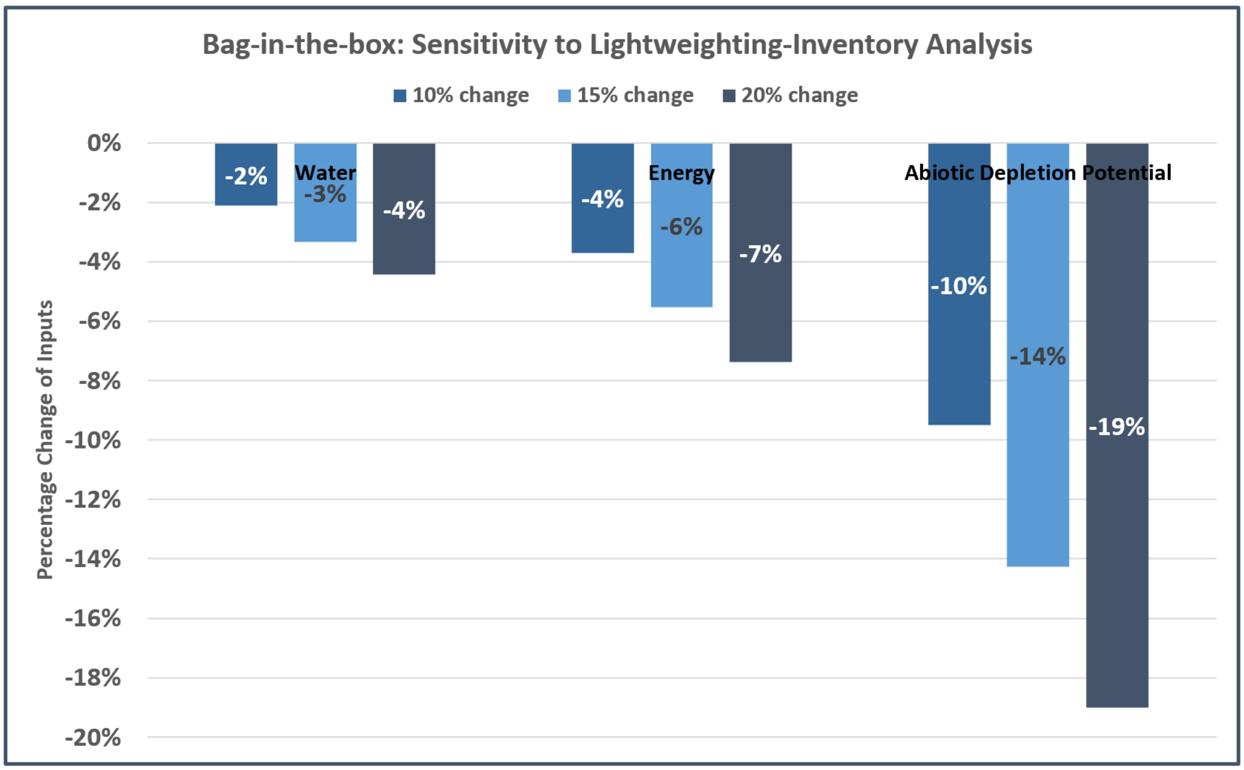


(Graph 9: Glass: Sensitivity to Energy Mix-Overall Global Warming Potential)

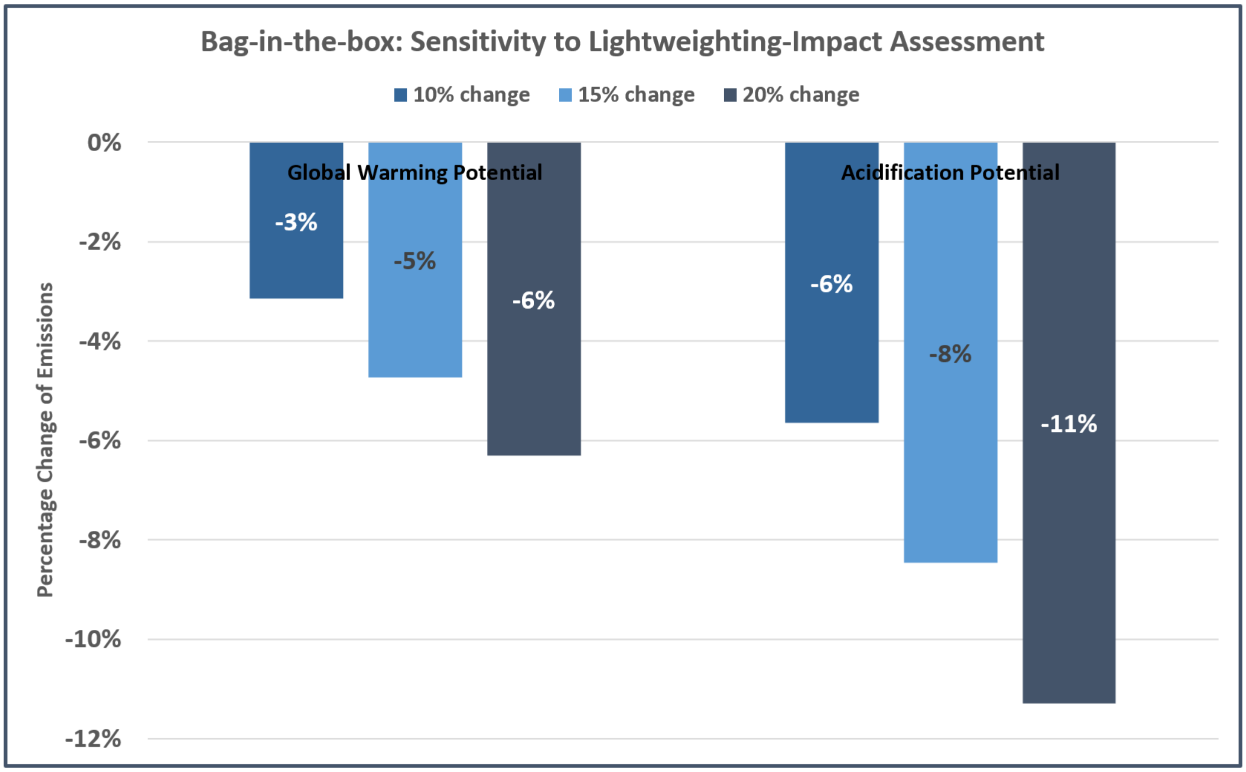
5.3. Lightweighting

Since the bag-in-the-box consists of two different materials (polyethylene and paperboard carton), which do not have the same energy mix, it is difficult to make any assumptions on how the energy mix should be shifted. A more appropriate sensitivity analysis is the consideration of lightweighting.

In a Bag-in-the-box, the plastic bag, made of polyethylene, is the material that holds the liquid. As long as the bag can safely hold the product, there is potential to reduce the thickness of the outer box. This would lessen the amount of paperboard produced and used. Three lightweighting scenarios were considered: a 10%, 15%, and 20% reduction in material used in the production of carton boxes. It is important to note that the assumption here is that the surface area of the box is held constant, so the source of material reduction comes from a reduction in the thickness of the box. This is why we did not exceed a lightweighting percentage of more than 20%. The box needs to be able to hold the weight of the contents inside. Graph 10 shows how inputs (water consumption, energy use, and abiotic resources depletion) are affected by 10%, 15%, and 20% lightweighting. In the case of 15% lightweighting, 3% less water and 6% less energy is consumed. 14% less abiotic resources, such as land and ores, are depleted. Graph 11 demonstrates how end impacts decrease with lightweighting. Reducing the weight of the box by 15% results in a 5% drop in CO_2 emissions and an 8% reduction in SO_2 emissions into the atmosphere. This is not a huge amount on its own, but considering that numerous boxed wine cartons are produced each year, this small saving can have a significant impact. Note that the percent reductions in the 10%, 15%, and 20% models are not linear, because only the "box" portion is lightweighted, while the "bag" portion of the bag-in-the-box remains the same.



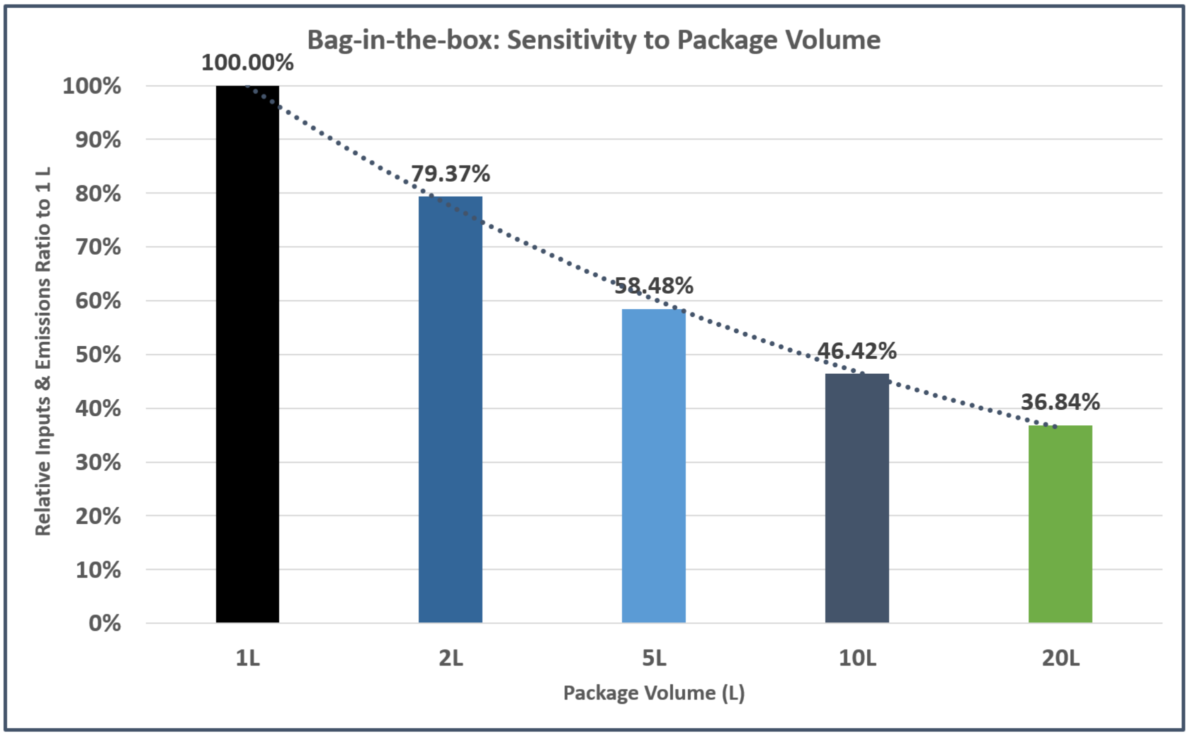
(Graph 10: Bag-in-the-box: Sensitivity to Lightweighting-Inventory Analysis)



(Graph 10: Bag-in-the-box: Sensitivity to lightweighting-Impact Assessment)

5.4. Volume Change

The second sensitivity that was done for bag-in-the-box involved changing the volume of the packaging. The amount of a material is proportional to its thickness and surface area. After analyzing the effects of lightweighting the box (reducing thickness), we attempted to decrease the surface area of packaging material. A way to achieve this is by increasing the volume, which in turn decreases the surface area to volume ratio of a packaging, and ultimately less material is used. As indicated in Graph 12, doubling the volume of the bag-in-the-box from 1L to 2L reduces the surface area per liter of wine packaged, and results in a reduction of over 20% in CO_2 emission levels.



(Graph 12: Bag-in-the-box: Sensitivity to Package Volume)

6. LIMITATIONS

6.1 Generic data set

We relied on publically available data on production of different material types. Therefore, we might be over or under-estimating the impacts for any given material for any given wine manufacturer.

6.2 Scaling

Estimates of the environmental footprint might vary with the scale of production.

6.3 Regional limitations

This lifecycle analysis is mainly based on California region, which has its own production policy and energy supplies. Given many packaging manufacturers are located in

Europe, it is hard to assume the energy consumption in different countries especially when energy mixes in different regions differ largely. The regional specific data will render a limitation for client who wants to apply the results into different regional contexts.

7. CONCLUSION

In selecting the most sustainable wine packaging, it is important to note that the three wine packaging types are not perfect substitutes. Of the three, while wine kegs produce fewer emissions and have a lower energy demand, they are used primarily for sale to commercial establishments. Glass bottles and bag-in-the-box are used for sale for household or small scale consumption. According to our three indicators (Energy demand, Global Warming Potential, and Acidification Potential), bag-in-the-box packaging is more sustainable relative to glass bottle.

One potential option to further reduce environmental impacts is to lightweight the bag-in-the-box. A mere 10% decrease in the thickness of the outer cardboard would result in a percentage reduction in each impact category. Additionally, altering the energy mix used in manufacturing would lessen the impacts of all three wine packaging materials. Simply replacing the electricity generated from coal with electricity produced from natural gas would emit far less emissions. If convincing suppliers to change their practices or material choices is beyond the scope, wine manufacturers might consider the purchase of renewable energy credits as a lower cost option. Renewable energy credits are tradeable, energy commodities; each energy credit represents a megawatt hour of renewable electricity generated and delivered to the power grid.

Though bag-in-the-box wine has a lower environmental footprint than the wine packaged in glass bottles, widespread use of bag-in-the box in the U.S is limited today, while there seems to greater acceptance of the same in European markets. We therefore believe research on better understanding consumer preferences and the means to increasing consumer acceptance of bag-in-the-box in the US could be a fruitful area to focus on.

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