ARIZONA STATE UNIVERSITY

SCHOOL OF SUSTAINABLE ENGINEERING AND THE BUILT ENVIRONMENT

CESEM

Center for Earth Systems Engineering and Management

A Consequential Comparative Life Cycle Assessment of Seitan and Beef

Andrew Berardy

SSEBE-CESEM-2012-CPR-002
Course Project Report Series

May 2012

ASU Ira A. Fulton Schools of Engineering

A Consequential Comparative Life Cycle Assessment of Seitan and Beef

Andrew Berardy, PhD Student, Arizona State University School of Sustainability

LCA for Civil Systems

Outline

I. Executive Summary

II. Background & Literature Review

   a. Sustainable consumption

   b. Dietary life cycle assessment

III. Research Statement

IV. Methodology & Assumptions

   a. Defining the products and setting up the LCA

   b. Data availability

V. Findings & Uncertainty

   a. Inventories and impacts

   b. Uncertainty and data quality

VI. Interpretation & Discussion

   a. Significance of findings in context of economic markets

   b. Relevance to policy makers and consumers

VII. Conclusion

Executive Summary

Meaningful sustainable consumption patterns require informed consumers who understand the actual impact of their actions on a quantitative and tangible basis. Life cycle assessment (LCA) is a tool well suited to achieving this goal, but has only been superficially applied to the analysis of plant-based diets. Such LCA work typically ignores the wide variety of processed plant-based alternatives to animal-based foods. Therefore this analysis looks at a common component of plant-based meat alternatives: a wheat-based protein known as seitan, which is a common substitute for beef.

A comparative consequential analysis shows the overall change in environmental impact when 1000 servings of seitan displace 1000 servings of beef. The functional unit for comparison is one serving of seitan or one serving of beef and the system boundaries include production but not distribution, consumption or disposal. Life cycles are created for seitan and beef in the LCA modeling software SimaPro and an analysis is run using the Eco-indicator 99 methodology. The beef life cycle is created using complete existing LCA data, while the seitan life cycle is created using LCA data for constituent materials and processes.

Findings indicate that beef is much more environmentally impactful than seitan, but the largest difference is found in land use change. Significant data quality and uncertainty issues exist due to the data being incomplete or not representative for US processes and the use of proxy processes to estimate industrial processing. This analysis is still useful as a screening tool to show rough differences in impact.

It is noted that despite seitan having a lower environmental impact than beef, increasing seitan production will probably have the effect of increasing overall environmental impacts, as beef production is not likely to decrease as a result. Massive changes in consumer purchase patterns are required before reductions in impact can be expected. Recommendations for future work include expanding system boundaries and obtaining industry specific data for seitan production.

Background & Literature Review

Discourses of sustainable consumption depend upon understanding the environmental impact of different choices made in daily life, including what to eat. It is insufficient to make environmental claims based on intuition, simplifying assumptions, or unsupported claims of special interest groups. Life cycle assessment can serve as a useful tool to go beyond the superficial nature of certain environmental movements such as the "buy local" movement and provide a quantitative basis by which multiple options can be compared (Weber and Matthews, 2008).

Food consumption is one of the most polluting and energy-intensive everyday activities, emissions from the food sector are significant, and there is substantial room for improvement (Carlsson-Kanyama, et al, 2003). Consumers have a unique opportunity to reduce their impact by making the right food choices due to their high degree of personal choice and the lack of long-term lock-in effects (Weber and Matthews, 2008). However, producers have less flexibility in their decision making process to account for environmental factors (Jungbluth, et al, 2000). For these reasons, dietary choice may be the single most powerful decision available to individuals when attempting to incorporate sustainable decisions into daily life.

Existing life cycle assessments demonstrate that plant-based dietary choices have far lower impacts on the environment than traditional omnivore diets on an attributional basis (Baroni, et al, 2006; Risku-Norja, 2009). The reason for this is that those who consume plant foods eat at a lower trophic level and therefore require less input for the same nutrition. Previous analyses using LCA of dietary choices indicate that it is the absence of meat and dairy that causes this lowered impact. An implicit assumption in these studies is that vegetarians and vegans eat the same products as omnivores, with the exception of meat and dairy, and simply eat more of those products or use very simple alternatives such as tofu to make up for their absence (Baroni, et al, 2006). However, the wide variety of processed alternatives to animal products is not addressed even though for many vegetarians and vegans, as well as environmentally conscious consumers, this constitutes a significant percentage of their diet. People who choose a plant-based diet out of environmental concerns need a rich understanding of the environmental impacts associated with these processed foods.

LCA work already addresses the issue of diet, but in a superficial way that does not reflect a rich understanding of actual dietary patterns and motivations for dietary choice. A US-based study finds that dietary shifts are more effective than reduction of food-miles in reducing environmental impact, showing that a vegetable-based diet is the least intensive choice (Weber and Matthews, 2008). A study in Finland compares the impacts of four diet options, but defines vegan diets on the basis of what is excluded rather than performing a thorough analysis of a realistic diet (Risku-Norja, et al, 2009). An Italian study of dietary impacts defines vegan as a "plant only diet, which excludes any food of animal origin," but does not mention what vegans eat instead of animal-derived foods. It is clear from these papers that LCA work involving diet must make significant simplifying assumptions, but these should be limited, as they distort the reality of impacts. Lack of data availability may be the reason for certain simplifying assumptions. For example, there is no available complete LCA of seitan, so to include it in a dietary LCA, a separate LCA of seitan would first have to be performed.

Therefore, from the perspective of a sustainability oriented consumer, there is a knowledge gap in the lack of consideration for alternatives to animal-based products. If a person wishes to make shifts in their dietary patterns, there is a need not only to compare plant-based and animal-based products, but also a need to clearly rank the plant-based alternatives they are likely to eat instead. In this way, the consumer will know which alternatives are the best in terms of environmental impact, and understand how choosing one product over another influences their overall environmental impact.

Research Statement

A comparative analysis of seitan (wheat-based protein) and beef determines the difference in the environmental impact between these two foods using comparative consequential LCA. This information provides a clear path that enables consumers to reduce their footprint from consumption and help researchers more precisely determine the differences in impacts between omnivorous and plant-based diets. Although such an analysis does not directly address the issue of assessing the environmental impacts of highly processed plant-based products frequently found in vegan diets, knowing the environmental impacts of seitan supports future work because it is a common ingredient in such products.

Methodology & Assumptions

The consequential comparative life cycle assessment presented here examines the energy use, greenhouse gas emissions and land use change associated with a shift in production from beef to seitan in the amount of 1000 servings.

In defining the product, functional unit and reference flows, instructions from the 2004 paper by Weidema, et al, "The Product, Functional Unit and Reference Flows in LCA," are consulted. This process enhances the quality of this LCA. Although these steps are followed in an iterative process as recommended, the results of that process are presented here in a linear order to minimize confusion.

First, products being analyzed must be described. Seitan is a processed wheat-based food product intended for human consumption. Beef is the flesh of a cow intended for human consumption. Both products are known to be high in protein, and are consumed primarily for protein, as well as for their texture and taste. It is assumed that these products are substitutable for each other and equivalent in the eyes of consumers.

Next, the relevant market segment must be defined. In this case, it is assumed to be the same, again implying the substitutability of one product for the other. The primary identifying characteristic of this market segment is that it is composed of people who desire a high protein food with a pleasant texture and taste that can be incorporated into meals. There are no specific geographic or temporal restrictions, other than the assumption that the consumer is a modern United States citizen.

Third, relevant product alternatives must be defined. Seitan in this case is considered a product alternative to beef, and is mainly consumed in vegetarian and vegan meals. Other alternatives to beef that might substitute for seitan include other animal protein sources, such as chicken, pork, or fish, or other plant-based protein sources including tofu, mock meats, and tempeh. The adequacy of any one of these products to substitute for another depends on context, including the preferences of the person making the consumption decision in regards to the taste, health, and environmental aspects of food.

The functional unit must be defined based on its obligatory, positioning, and market-irrelevant properties. Obligatory properties of beef include being safe for human consumption and providing nutritional value, especially protein. Positioning properties of beef include whether it is lean or fatty, its USDA grade, USDA organic certification, and the breed of cow that it comes from. Market-irrelevant properties of beef include the type of packaging it comes in. Obligatory properties of seitan include being safe for human consumption and providing nutritional value, especially protein. Positioning properties of seitan include whether it is higher or lower quality, USDA organic certification, and whether it is a mix to make at home or pre-made. Market-irrelevant properties of seitan include the type of packaging it comes in.

Fifth, the reference flow must be established. For beef, this is based on the number of cows required to provide a serving of beef. For seitan this is based on the number of acres of wheat required to provide a serving of seitan.

Finally, the end of life behavior of the product must be considered. Beef degrades rapidly, and if spoiled is not usable for other purposes. Seitan mix degrades slowly, but after expiration is not usable. Prepared seitan degrades rapidly and if spoiled is not usable for other purposes.

With these characteristics defined, it is now possible to move to system boundary selection. System boundaries for this analysis start at farm production and end just before distribution, making this a farm to gate analysis. Production of capital goods, packaging, distribution, consumption and disposal are not included in this analysis due to lack of data availability. These boundaries are selected based on the understanding that they reflect what the average consumer would likely be most concerned with in the life cycle of the products and the expectation that the majority of environmental impacts would be captured, as these are typically found in the production phase.

Primary indicators that are tracked through the system include greenhouse gas emissions, energy use, and land use change. These indicators are relevant both from a consumer standpoint and from an academic perspective.

Although good data availability is important to create a robust and credible LCA, unfortunately in the case of food, many barriers exist. Confidentiality and trade secrets of the industry prevent open access to much of the data needed to perform a thorough LCA of beef and seitan. Therefore, SimaPro's Food database is used to create life cycle inventories and subsequent analyses for beef and seitan. It should be noted that these are based off of information from multiple countries including Denmark, so the data may not be representative of United States practices.

Finally, the environmental profiles of beef and seitan are certainly not the only motivating factors for people choosing one over the other. Therefore, a discussion of the social and cultural drivers leading people to choose beef or seitan, and more generally, animal-based or plant-based food, is included. These drivers may include taste, perceived nutritional benefit, ethical reasoning, ideas of what is masculine or feminine, and other preferences. Any one of these factors could potentially outweigh environmental considerations in the minds of consumers.

Findings

In the analysis, seitan and beef are considered comparable and substitutable products, allowing their evaluation on an equivalent, per-serving basis. That is, it is assumed that consumers will find the same value and functionality from seitan as they do from beef and vice versa. Nutrition information found on a package of Westsoy brand cubed seitan indicates that one serving, or 85 grams, of seitan provides 21 grams of protein. A nutrition information website indicates that one 85 gram serving of beef minced meat also provides 21 grams of protein (USDA SR-21, n.d.). Beef minced meat, or ground beef, is selected due to its similarities to seitan in terms of cooking uses and consumer preference as well as better data availability. Seitan is marketed as a substitute for beef due to similar taste, texture and versatility in cooking. Based on these findings, it seems fair to assume the average consumer would agree that these two products serve roughly the same purposes so that one serving of one product can substitute for one serving of the other.

Life cycle inventories are created for beef minced meat and seitan using the LCA software SimaPro. Life cycles are constructed from assemblies by using one serving of each product as their basis. In turn, these assemblies are made up of materials and processes from the SimaPro database. Once the life cycles are constructed, SimaPro's analytical tools are utilized to yield the desired environmental impact analysis.

The beef life cycle consists of the beef minced meat assembly, which itself is represented by 57 different materials and processes which are discussed in Appendix A. Detailed assumptions are discussed in Appendix B. This life cycle is fairly simple to establish because SimaPro already has life cycle data from a Danish food LCA (Dall, et al, 2002).

The seitan life cycle is more complicated as no pre-existing data is available. Materials for the seitan assembly include wheat flour, tap water (both for seitan and soy sauce to go in seitan), and soybeans (for soy sauce to go in seitan). Processes for the seitan assembly include the boiling of water on a stove to represent the cooking of seitan (in the production phase). All of these materials are available in SimaPro. The quantity of each ingredient is determined by examining a recipe which makes six servings, so each ingredient listed is divided by six to yield the amount used in one serving to create the assembly for one serving of seitan. Seitan is represented by 27 different materials and processes which are discussed in Appendix A. Detailed assumptions are discussed in Appendix B.

The next step determines the theoretical consequence of 1000 servings of seitan being produced with the result of 1000 servings of beef not being produced. This is done by first analyzing the life cycle "Beef" for 2000 servings compared to 1000 servings using the Eco-indicator 99 methodology. Eco-indicator 99 assigns points to various impact categories to characterize environmental damage captured by the assessment. This analysis shows that the reduction in consumption of beef reduces Eco-indicator points from 132 to 65.9 total, representing a 66.1 point reduction. As illustrated in the graph below, the largest change is in land use, which is reduced from 92.8 to 46.4 points. Details of specific land use change can be found in Appendix C. Respiratory inorganics, acidification and eutrophication, fossil fuels and climate change are other categories that also show significant reductions in impacts.

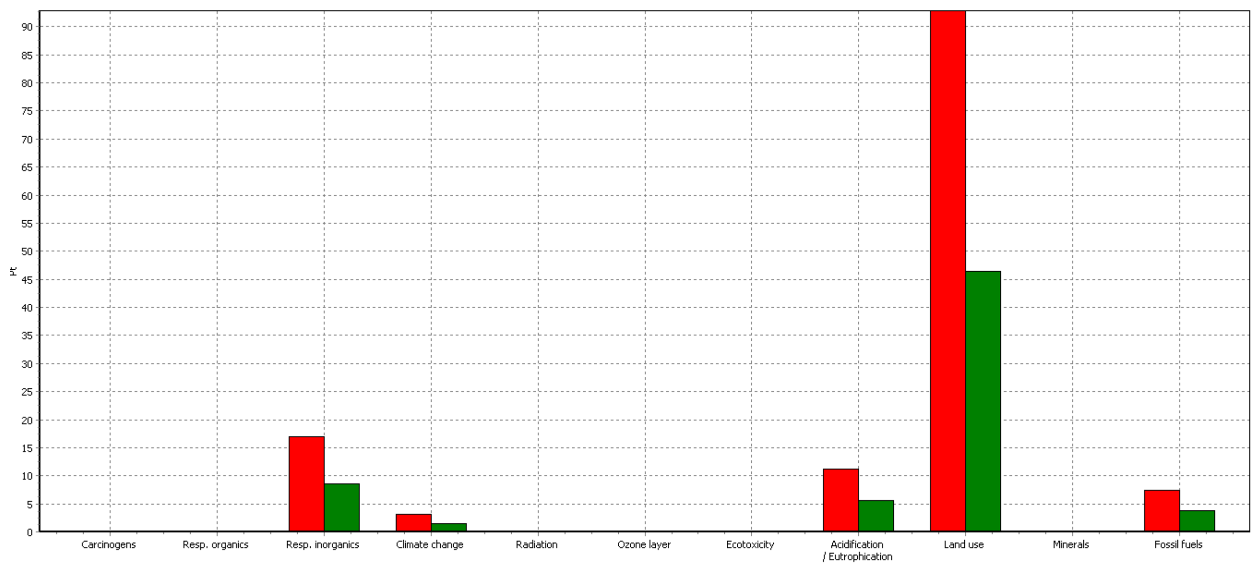


Figure 1 - 2000 vs. 1000 Servings Beef

Next, the life cycle "Seitan" is analyzed with the Eco-indicator 99 methodology for 1000 servings compared to 2000 servings, making the assumption that 1000 consumers ate seitan instead of beef for one serving. This analysis shows that this change increases the Eco-indicator points from 15.9 to 31.7 total, or a 15.8 point increase. Again the largest change is in land use, which increases from 11 to 21.9 points. Details of specific land use change can be found in Appendix C. Respiratory inorganics, acidification and eutrophication, fossil fuels and climate change are other categories which experience significant increases in impacts.

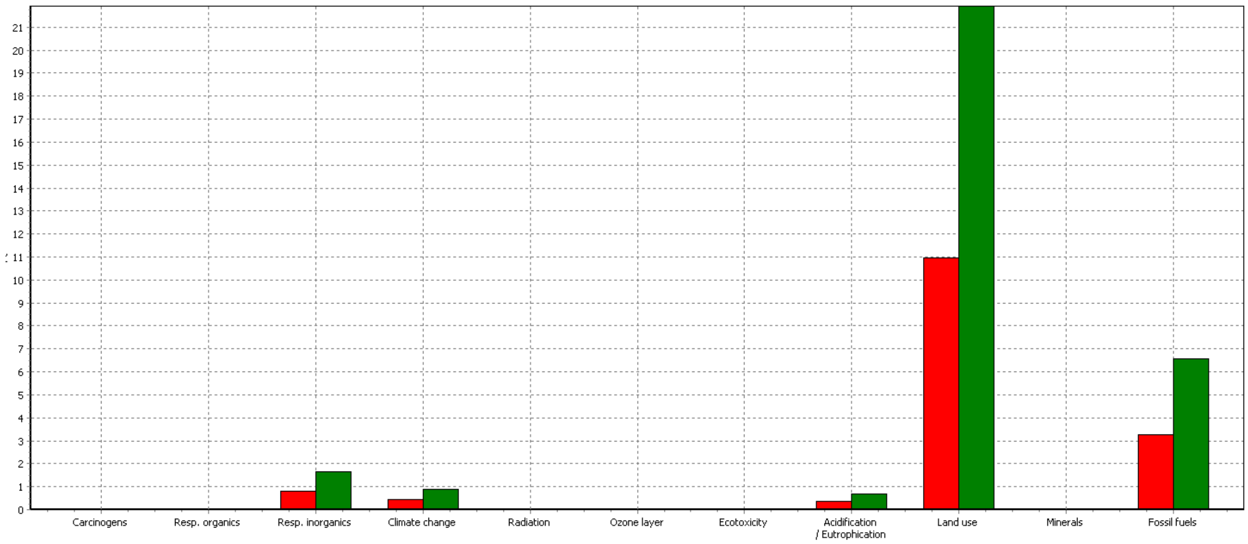


Figure 2 - 1000 vs. 2000 Servings of Seitan

Finally, the cumulative effect of this change is found by taking the absolute value of the reduction in environmental impacts resulting from the reduction of beef consumption and subtracting the absolute value of the increase in environmental impacts resulting from the increase of seitan consumption. This total is 66.1-15.8, or 50.3 points. In land use alone, there is a reduction of 35.5 points. The overall change for "Beef" and "Seitan" before and after the change in number of servings produced can be seen below.

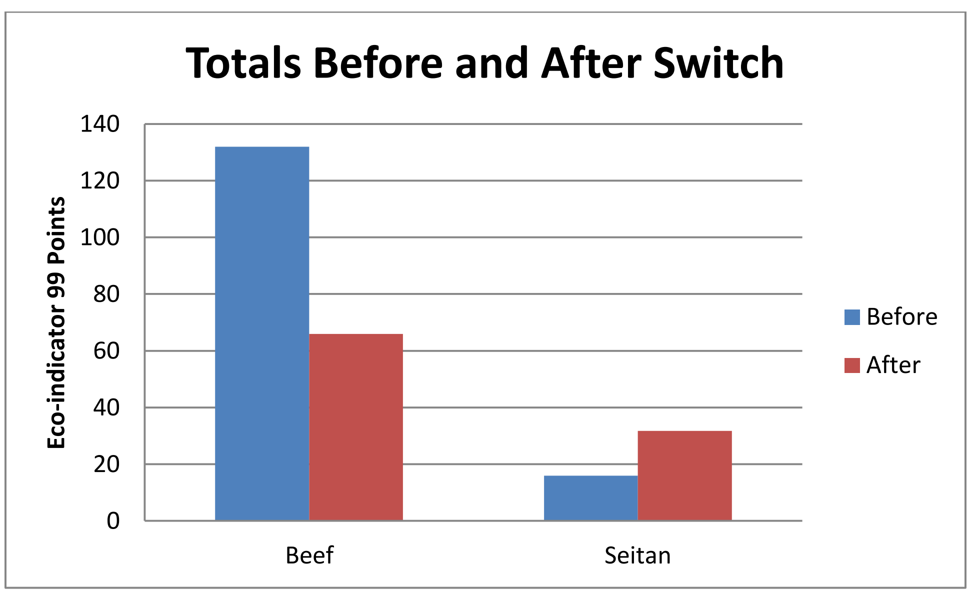


Figure 3 - Environmental Damage Before and After Switch

Several factors may contribute to the uncertainty of the results presented here. This LCA considers beef and seitan to be equivalent products in terms of the needs and desires of consumers that are fulfilled. However, it is questionable whether the quality of the protein provided by seitan is comparable to that provided by beef when used as the primary source of protein in a diet. Additional nutrients provided by beef or by seitan may not be provided by the other food product, so consumers seeking other nutrients specific to those products may not view them as comparable. It is possible that a consumer eating seitan would need to have other foods to get the same nutrients as beef, or that a consumer eating beef would need to have other foods to get the same nutrients as seitan.

Despite the best efforts of the manufacturers, seitan is not a perfect substitute for beef in terms of flavor, texture, or versatility in cooking, but these are all ignored in this study. Consumer preference is also largely ignored, as some may purchase beef or seitan for cultural, health, religious, ethical or social reasons. However, a brief discussion of other issues influencing diet is warranted. My study, "Motivations for Dietary Preference in Vegans and Non-Vegans," performed in 2010, includes a survey of attitudes towards food as well as interviews to determine what really mattered to people when choosing what to eat (Berardy, 2010). I find that vegans are likely to place higher importance on the categories of health, ethics, and environmental impact as "extremely important factors in diet," while non-vegans are likely to place higher importance on the categories of taste and what others eat as "extremely important factors in diet." Vegans also have a higher concern on average than non-vegans for categories including environmental impact, animal welfare, moral considerations, what they read or see, and health. Non-vegans have a higher concern on average than vegans for categories including convenience, necessity, friends, family, pop culture, choices of those around them, and money. Finally, vegans are far less likely to become omnivores than omnivores are to become vegans. That is, 60% of vegans surveyed would not go omnivore to save their lives, but 83% of omnivores surveyed would go vegan to save their lives. The theoretical change presented here therefore seems fairly plausible, especially because it is not a full commitment to a vegan lifestyle, but simply a switch from 1000 servings of beef to 1000 servings of seitan, with everything else remaining the same.

It is also assumed that it is possible to have 1000 people switch from beef to seitan, and that the effect of the switch would result in an increase in seitan production by 1000 servings and decrease beef production by 1000 servings. However, this is not realistic or likely to be the case. In addition, this assumption also ignores scale, meaning that the next marginal unit of production is considered to be the same as all others in terms of impact. With sufficient growth, it is likely that seitan production processes would improve significantly, yielding greater efficiency. It is also likely that with sufficient decline, beef production processes would suffer and become less efficient.

While data quality for beef is assumed to be fairly robust, it is based on the peculiar Danish beef industry. Assumptions for the data provided for beef minced meat are available in the meta-data at http://www.lcafood.dk/ under “Cattle” in the “Meat” section (Dall, et al, 2002). Unfortunately this data is from Danish production, which is determined by milk production, which is in turn determined by a quota system. This means that marginal demand does not influence cattle production, but rather the products which they substitute for. Expensive cattle meat displaces imported cattle meat, whereas cheap cattle meat displaces cheap pig meat. Beef minced meat is considered cheap cattle meat. Cattle in this system are fed primarily soy meal. Cattle meat is produced by slaughtering the cattle. This process includes delivery to a slaughterhouse, processing, packaging, and storage until time for delivery to market. Data from this source may not be representative of US industry processes, possibly resulting in higher or lower environmental impacts than actuality reported. The US beef industry is significantly different since it is not often linked to quotas, and portions of the beef industry are strictly beef with no connection to dairy.

The data quality for the materials for seitan is assumed to be fairly robust, but it is not all from US sources. In addition, not all components of the recipes used to approximate the industrial process of making seitan are represented in the analysis. For instance, salt is not considered. The seitan assembly is constructed from scratch, as no pre-existing data is available from SimaPro or other sources. No published academic papers or industry data is available, industry representatives are either unable or unwilling to provide data to support the analysis, and it is unfeasible to attempt collection of data at a processing facility even if granted permission given the timeframe of the analysis. Therefore, the assembly for seitan is built with representative materials and processes available in SimaPro following recipes available online for making homemade seitan. This also means that the assumption is made that the industrial processes for making seitan are not significantly different from a homemade recipe in terms of ingredients and processes used. Data for all of these components is available through SimaPro, though some data such as the flour is from a Danish source while only soybeans are from US data. The process of boiling water on the stove is also from a Danish source. These data availability and quality issues may result in lower or higher environmental impacts than actuality reported.

Data quality issues are significant enough that it would be unwise to base any policy decisions on this analysis or cite this analysis in academic papers. However, if treated as a "screening" LCA, the difference in environmental impacts between beef and seitan found are likely sufficient to demonstrate that overall, and especially in the category of land use, seitan is the less environmentally impactful food product.

Interpretation and Discussion

Clearly there can be environmental benefits from a shift in production from beef to seitan. Overall environmental impact is reduced by 50 points for just 1000 servings of beef replaced by seitan. Obviously, a larger scale replacement would yield greater environmental benefits, though it is not clear how such changes would affect environmental benefits.

However, the environmental benefits are the reflection of assumptions that may not be true in reality. A shift this small would likely have no effect on the broader system of beef production, but might result in an increase in seitan production. The reason for this is that if beef cannot be sold domestically, there is a large international market which will purchase it. So, in this way, it might be that additional production or consumption of seitan would be detrimental to the environment overall, not because of higher environmental impact of seitan, but because of how little it would affect beef production.

There is still potential for an overall environmental benefit if system expansion is used to look at the broader picture. If a foreign market purchases beef not sold in the US due to decreased demand, it is likely to displace beef within that market, thereby avoiding beef production and resulting environmental impacts in that country. For example, if US beef is sold to a Swedish market, Swedish beef production is avoided, and environmental benefits are had. There are other questions that come into play however, such as additional environmental impact from transport, the reality of what US beef displaces, and shifts in consumer behavior if beef becomes cheaper due to imports. There is also the potential, as demonstrated by the Danish system, that cheap beef will not displace local beef, but rather a different, possibly less environmentally impactful meat such as pork, resulting in an higher overall environmental impact.

It is not fair to assume that beef production will decrease overall or even that environmental benefits will accrue if such a small change is made. In fact, if no change in total beef production is attributable to the consumers switching from beef to seitan, the short term effect of this would be an increase in environmental impacts from the seitan production as noted above, without the benefit of reduced beef production. The end result therefore could be greater overall environmental impact, since beef production remains constant (and consumers may be further away, actually increasing environmental impact from beef) and seitan production increases, therefore increasing environmental impact.

However, if seitan demand increases, the small scale of its production means that it is more likely to be responsive to this demand, especially as the time scale is extended and alternatives to beef and other intensive foods become more popular. A long-term sustained pattern of a large proportion of consumers choosing seitan or other substitutes for beef would be more likely to result in a decrease of beef production. Consumer purchasing power should not be underestimated. For example, the “pink slime” incident proves that consumers can be effective in creating change in the food system through vocal outrage and refusal to purchase a product. Several processing plants producing “lean, finely textured beef” or “pink slime” were shut down and at least one beef processor was bankrupted after several grocery stores and restaurants decided not to carry beef containing “pink slime” in response to consumer concerns regarding the product (Kearns, 2012; Velasco, 2012).

Implications for policy makers from this study are primarily relevant to land use change, as that is where the largest impact is seen, although other benefits exist. However, the focus should be on reducing beef production rather than increasing seitan production, because as discussed above, it is only through reducing beef production that environmental benefits can be realized. It is also worth noting that beef production need not be displaced specifically by seitan for a reduction in overall impact. It is likely that many other meats and plant-based proteins are less impactful than beef and can serve as environmentally preferable alternatives if beef consumption is reduced.

The significance of this study for individuals seeking to reduce their environmental impacts is unclear. From an attributional standpoint, if an individual is only concerned with ensuring that their personal environmental impacts are minimized, seitan is a lower impact food than beef. However, from a consequential standpoint that takes into account the complex systems involved in food production, consuming seitan does not necessarily reduce demand for or production of beef, but may increase demand for and production of seitan, therefore increasing overall environmental impact. The best action the consumer can take to reduce systemic environmental impacts is to attempt to influence policy or overall market demand to decrease beef production.

Recommendations for Further Study

The largest piece of missing information, as well as the largest source of uncertainty in this analysis, is actual data regarding materials and processes for creating seitan on an industrial scale. Given more time, as well as the proper permissions and resources, collection of this data would greatly enhance the quality of this study.

The system boundaries considered here do not include use and disposal phases, which may be significant to the total environmental impact and differ between seitan and beef. In addition, transport from processing facility to storefront is not included, and may be much further for seitan than beef in some cases. Expanding the system boundaries to capture all phases from cradle to grave would improve accuracy and reduce uncertainty in the assessment.

Consideration of factors other than environmental concerns would enhance understanding of the overall impacts associated with a switch from beef to seitan. In addition, expanding the foods considered would prove useful for categorizing other plant-based protein products in terms of environmental impacts. Alternatively, examining common base components of plant-based animal product alternatives would enable a wider array of screening LCA’s for such foods to answer whether or not they are environmentally preferable to the products they are intended to replace.

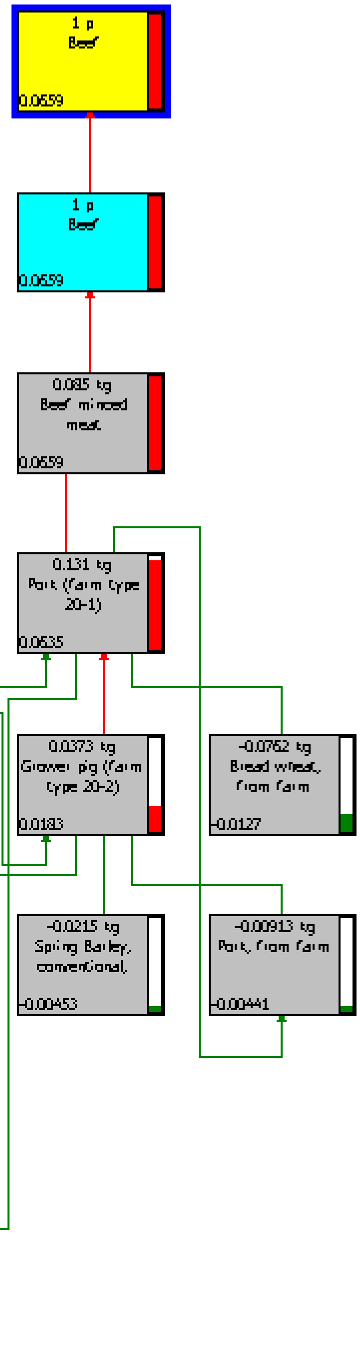
Conclusion

Efforts to encourage sustainable consumption must be backed by accurate analyses if effective policy decisions are to be made. The analysis presented here should not be taken as a definitive quantitative basis for policy makers, but provides a rough guideline and a confirmation that certain processed plant-based foods are less environmentally impactful than the animal-based foods they are intended to replace. It is recommended that a more thorough investigation be performed if a certain environmental goal is intended or if other meats are to be compared with other plant-based foods. However, based on this analysis, it is clear that seitan has far lower impacts than beef, especially in land use change. From a consequential perspective though, seitan production is unlikely to influence beef production, meaning that an increase in seitan production may simply result in increased overall environmental impact. Further study should focus on expanding system boundaries, obtaining accurate industry data, and widening the scope of analysis to include other products.

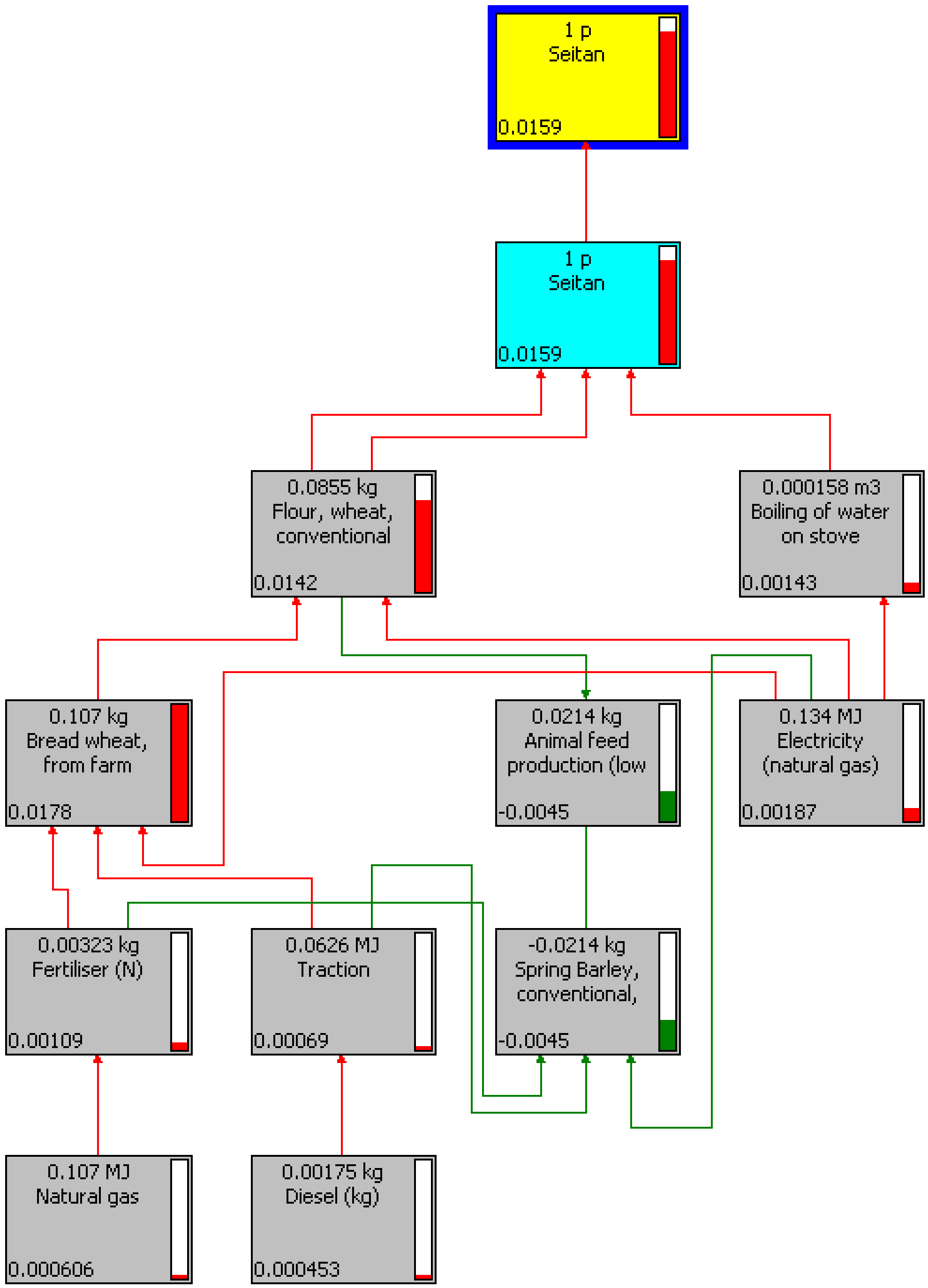
Appendix A – Life Cycle Diagrams

SimaPro life cycle diagrams are presented here. Enlarged or more detailed diagrams are available upon request.

A.1 – Beef



A.2 – Seitan



1 p
Seitan
0.0159
1 p
Seitan
0.0159
0.0855 kg
Flour, wheat,
conventional
0.0142
0.000158 m3
Boiling of water
on stove
0.00143
0.107 kg
Bread wheat,
from farm
0.0178
0.0214 kg
Animal feed
production (low
-0.0045
0.134 MJ
Electricity
(natural gas)
0.00187
0.00323 kg
Fertiliser (N)
0.00109
0.0626 MJ
Traction
0.00069
-0.0214 kg
Spring Barley,
conventional,
-0.0045
0.107 MJ
Natural gas
0.000606
0.00175 kg
Diesel (kg)
0.000453

Appendix B – Detailed Assumptions

B.1 – Beef

Beef nutrition information is collected from http://nutritiondata.self.com/facts/beef-products/6200/2. 1 serving of beef is equivalent to 85 grams and contains 21 grams of protein.

Beef life cycle data is obtained from SimaPro, which obtained data from http://www.lcafood.dk. This website notes that beef production is a side product to milk production. The system boundaries start at growing feed and end at the slaughterhouse.

B.2 – Seitan

Seitan nutrition information is collected from http://nutritiondata.self.com/facts/cereal-grains-and-pasta/7738/2. 1 serving of seitan is equivalent to 85 grams and contains 21 grams of protein (Westsoy cubed seitan box).

Seitan life cycle data is computed using a recipe and available data in SimaPro. The recipe used for seitan ingredients is accessed from http://www.vrg.org/recipes/vjseitan.htm. High gluten flour is needed in a 1 to 1 ratio with seitan (1 cup flour is needed for 1 cup seitan). The system boundaries for high gluten flour include soil cultivation, sowing, weed control, fertilization, pest and pathogen control, irrigation and harvest, machine infrastructure, machine sheltering, inputs of fertilizers, pesticides and seed, as well as transport to the farm and direct emissions on the field. The system boundary is at the farm gate. Water is needed in a 1 to 2 ratio with seitan (1 cup water is needed for 2 cups seitan). Soy sauce is needed in a 0.1875 to 2 ratio (3 tablespoons of soy sauce are needed for 2 cups seitan).

A mini-LCA to find the inventory for soy sauce is performed as this is not readily available in SimaPro. A recipe from http://www.wikihow.com/Make-Your-Own-Soy-Sauce is the basis for this analysis. Ingredients for soy sauce include soy beans, flour, salt and water. Based on conversions to the proper quantity from the recipe, 3 tablespoons of soy sauce requires roughly .22 ounces of soybeans, .17 ounces of flour, .11 ounces of salt, and 1.78 ounces of water. Salt is not considered in this analysis as it is not available in SimaPro and is expected to contribute a negligible amount to the overall inventory.

Data for boiling water is used to approximate the processing of seitan (which is boiled in the recipe for seitan used in this analysis). 2/3 of a cup of water is needed to boil 1 serving of seitan and this data is taken from SimaPro.

Appendix C – Inventory Data

SimaPro inventory data is summarized here. Complete printouts of SimaPro inventory data are available upon request.

1000 servings of beef has a total environmental impact of 5.2178 eco-indicator points from energy including diesel, gas and oil heat, coal, natural gas, electricity mix and various other sources. Eco-indicator points from greenhouse gas emissions are not available, but 1000 servings of beef results in the emission of 92.3 kg of CO_2 and 1.73 kg of methane. Land use change includes conversion from type II to III of .238 m2a, type II-III sea floor of 1.59 m2a, type II-IV of 979 cm2a, type II-IV sea floor of .164 m2a, type III-IV of .164 m2a and type IV-IV of 174 cm2a.

1000 servings of seitan has a total environmental impact of 3.2176 eco-indicator points from energy, including natural gas, diesel, gas heat, electricity mix and various other sources. Eco-indicator points from greenhouse gas emissions are not available, but 1000 servings of seitan results in the emission of 45.5 kg of CO_2 and 81 g of methane. Land use change includes conversion from type II to III of 616 cm2a, type II-III sea floor of .317 m2a, type II-IV of 558 cm2a, type II-IV sea floor of 327 cm2a, type III-IV of .1 m2a, and type IV-IV of 163 mm2a.

Appendix D – References

Agroscope Reckenholz-Tanikon Research Station. “Proceedings,” in 6th International Conference on Life Cycle Assessment in the Agri-Food Sector, 2008.

American Dietetic Association. “Position of the American Dietetic Association: Vegetarian Diets,” in Journal of the American Dietetic Association, Vol. 109 No. 7, 2009.

Andersson, K. “LCA of food products and production systems,” in International Journal of LCA, Vol. 5 No. 4, 2000.

Baroni, L; Cenci, L; Tettamanti, M; Berati, M. “Evaluating the environmental impacts of various dietary patterns combined with different food production systems,” in European Journal of Clinical Nutrition, 2006.

Berardy, A. “Motivations for Dietary Preference in Vegans and Non-Vegans,” not published, 2010.

Black, K; Lee, J; Petrusa, M; Thoreau, C; Tseung, R. “Conducting a sustainability assessment of UBC food services’ meat and meat alternative food products,” in UBC Social, Ecological Economic Development Studies, University of British Columbia, 2010.

Carlsson-Kanyama, A; Ekstrom, M; Shanahan, H. “Food and life cycle energy inputs: consequences of diet and ways to increase efficiency,” in Ecological Economics, Vol. 00, 2003.

Cole, M; Morgan, K. “Vegaphobia: derogatory discourses of veganism and the reproduction of speciesism in UK national newspapers,” in The British Journal of Sociology, Vol. 62 No. 1, 2011.

Dalgaard, R; Schmidt, J; Halberg, N; Christensen, P; Thrane, M; Pengue, W. “LCA of soybean meal,” in International Journal of LCA, Vol. 13 No. 3, 2008.

Dall, O; Toft, J; Andersen, TT. “Environmental impacts of Danish household,” in Danish Environmental Protection Agency Arbejdsrapport 13, 2002.

Davis, J; Sonesson, U; Baumgartner, D; Nemecek, T. “Veggie versus meat – environmental analysis of meals in Spain and Sweden,” in Proceedings of the 6th International Conference on LCA in the Agri-Food Sector, 2008.

Heller, M; Keoleian, G. “Life cycle-based sustainability indicators for assessment of the US food system,” in Center for Sustainable Systems, University of Michigan, 2000.

Kearns, Richard. “’Pink Slime’ maker cuts down production,” in The News-Herald, April 2, 2012. Accessed online on April 2, 2012 at: http://www.thenewsherald.com/articles/2012/04/02/news/doc4f7a1357e8bff665033068.txt

Jungbluth, N; Tietje, O; Scholz, R. “Food purchases: Impacts from the consumers’ point of view investigated with a modular LCA,” in International Journal of LCA, Vol. 5 No. 3, 2000.

Risku-Norja, H; Kurppa, S; Helenius, J. “Dietary choices and greenhouse gas emissions – assessment of impact of vegetarian and organic options at national scale,” in Progress in Industrial Ecology, Vol. 6 No. 4, 2009.

Risku-Norja, H; Kurppa, S; Helenius, J. “Impact of consumers’ diet choices on greenhouse gas emissions,” in Future of the Consumer Society, 2009.

Roy, P; Nei, D; Orikasa, T; Xu, Q; Okadome, H; Nakamura, N; Shiina, T. “A review of life cycle assessment (LCA) on some food products,” in Journal of Food Engineering, Vol. 90, 2009.

USDA SR-21. “Nutrition Facts and Analysis for Beef, ground, 85% lean meat,” in Self Nutrition Data, accessed online April 2, 2012 at http://nutritiondata.self.com/facts/beef-products/6200/2

Velasco, Schuyler. “Pink Slime Bankruptcy: After the backlash, what’s next for beef?,” in Christian Science Monitor, April 2, 2012. Accessed online on April 2, 2012 at http://www.csmonitor.com/Business/2012/0402/Pink-slime-bankruptcy-After-the-backlash-what-s-next-for-beef

Weber, C; Matthews, H. “Food-miles and the relative climate impacts of food choices in the United States,” in Environmental Science and Technology, Vol. 42 No. 10, 2008.

Weidema, B; Wenzel, H; Petersen, C; Hansen, K. “The Product, Functional Unit and Reference Flows in LCA,” in Environmental News, No. 70, 2004.