Life Cycle Management: Project Work

Life Cycle Assessment of Three Tropical Fruits (Avocado, Banana, Pineapple)



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Introduction

As the concern for global warming rises, many people try to reduce their footprints in different ways. Driving less, trying to reduce the usage of electricity, eating foods with less impacts on the environment are just a few examples. Consumers have great power to make a difference if they are educated to know about the footprints of different types of foods. This life cycle assessment (LCA) study compares three tropical fruits and their impact on the environment. The fruits chosen are avocado, banana and pineapple. The impacts of each fruit have been calculated with the help of the LCA-software *openLCA*.

With the recent rise in awareness about global warming, research has already been done on impacts of most fruits on our environment.

Avocado has been ranked as one of the fruits with the highest water footprint by many researchers. Just as a comparison: One kilogram of avocado uses four times more water than one kilogram of oranges (Cuéllar, A., 2018). With the increasing avocado production, deforestation and natural land transformation become pressing issues as well. Mexico is one of the main producers of avocado all year round, nearly supplying half of the worlds avocados (Workman, D., 2018).

Bananas are the fourth most produced fruit in the world. With such high demand for bananas, Ecuador still manages to have nearly a quarter of the market share as of 2017 (Workman, D., 2018). According to Iriarte & Almeida (2014) CO_2-emissions of bananas can be divided into three categories: on farm, post harvest fruit handling and packaging. CO_2-emissions arising from the production of bananas on the farm are the highest, followed by fertilizer production and fuel and electricity. For post harvest fruit handling, electricity takes the lead in terms of CO_2-emissions, having four times more impact compared to fungicides, chlorine and aluminum sulphate productions. In the packaging category, packing cardboard and kraft paper production has about eight times more impact compared to electricity and plastic bag production.

Costa Rica is one of the biggest exporters of pineapples, covering nearly half of the worldwide market (Workman, D., 2018). According to W. Ingwersen (2012) the carbon footprint of pineapples is composed as follows: 56% of the CO_2-emissions come from farming stages, including the application of N-fertilizers, fertilizer and pesticide production and the burning of fuel. Box production used as packaging for bananas takes up to 24%. The rest is transport with 15% and storage with 5% (W.Ingwersen, 2012).

Despite the fact that this research is detailed and informative, it will not be sufficient for a consumer in Freiburg to decide what tropical fruits to choose to have the smallest CO_2-footprint. The research of this paper will provide a comparison of three tropical fruits available in a supermarket in Freiburg.

Goal and research question

The goal of this LCA is to determine the different impacts of the three tropical fruits avocado, banana and pineapple and compare them. The study provides information to an environmentally conscious consumer in Freiburg who wants to buy a tropical fruit. Which one should he/she choose in order to have the least environmental impact? How big are the shares of CO_2eq-emissions for production, packaging and transportation for each fruit?
In a second step, a sensitivity analysis examines the difference in CO_2-eq emissions depending on the electricity mix used for the production of pineapples.

Methodology

The aforementioned goal of this study is to compare the impact of three different tropical fruits – avocado, banana and pineapple – and show respective differences in the following impact categories: *agricultural land occupation, climate change, natural land transformation* and *water depletion*. The defined functional unit is one kilogram of fruit. The three different reference flows *1kg_avocado, 1kg_banana* and *1kg_pineapple* are created in *openLCA*, the LCA-software used in this study. The database *ecoinvent_3.2_cut-off* provides the data for all processes and executed calculations. It already includes default processes for the production and market of the three respective fruits. The authors modified the processes in a way that they include detailed transportation modes and packaging. In order to simplify the choice of country of origin of every fruit, the authors calculated shipping distances from the main exporting countries of every fruit. Visualized in *Figure 1,* they are Mexico (avocado), Ecuador (banana) and Costa Rica (pineapple). For packaging the authors assumed that all fruit would be

transported in cardboard boxes. To conduct the life cycle impact assessment (LCIA) the method *ReCiPe midpoint (H) without long-term* has been used.

Figure 1: *World map with countries of origin; Mexico (avocado), Costa Rica (pineapple) and Ecuador (banana)*

Scope

The scope of the given LCA is shown in *Figure 2.*

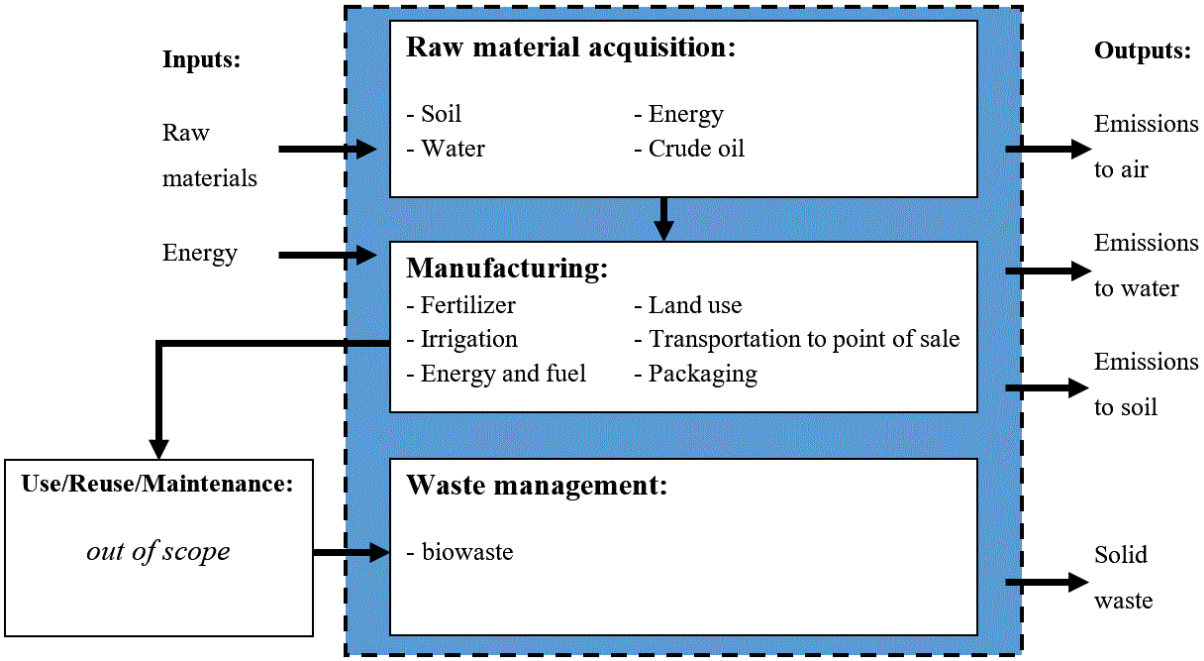

Figure 2: *Scope of the LCA*

System boundaries

The following processes are taken into account:

- Production of fertilizer
- Irrigation
- Land use and land transformation
- Cooling after harvest
- Packaging (cardboard boxes)
- Temperature controlled overland transportation
- Temperature controlled transoceanic transportation
- Biowaste

Out of scope are:

- Production of agricultural machinery
- Use phase of the fruits (consumer)
- Cooling and storage in supermarket
- Infrastructure for production and storage facilities

For transportation, the authors assumed that the fruits would be transported by lorry (temperature controlled, EURO4-diesel) to a sea port in the country of origin, then be shipped on a temperature controlled freight ship to Amsterdam, and be transported by lorry (temperature controlled, EURO6-diesel) to Freiburg. This amounts to the following shipping distances:

Avocado

- 500 km from production site to seaport Tampico (temp. contr. lorry)
- 9600 km from Tampico to Amsterdam (temp. contr. freight ship)
- 700 km from Amsterdam to Freiburg (temp. contr. lorry)

Banana

- 300 km from production site to seaport Guayaquil (temp. contr. lorry)
- 10600 km from Guayaquil to Amsterdam via Panama canal (temp. contr. freight ship)
- 700 km from Amsterdam to Freiburg (temp. contr. lorry)

Pineapple

- 200 km from production site to seaport Puerto Limón (temp. contr. lorry)
- 9100 km from Puerto Limón to Amsterdam (temp. contr. freight ship)
- 700 km from Amsterdam to Freiburg (temp. contr. lorry)

Flow diagram

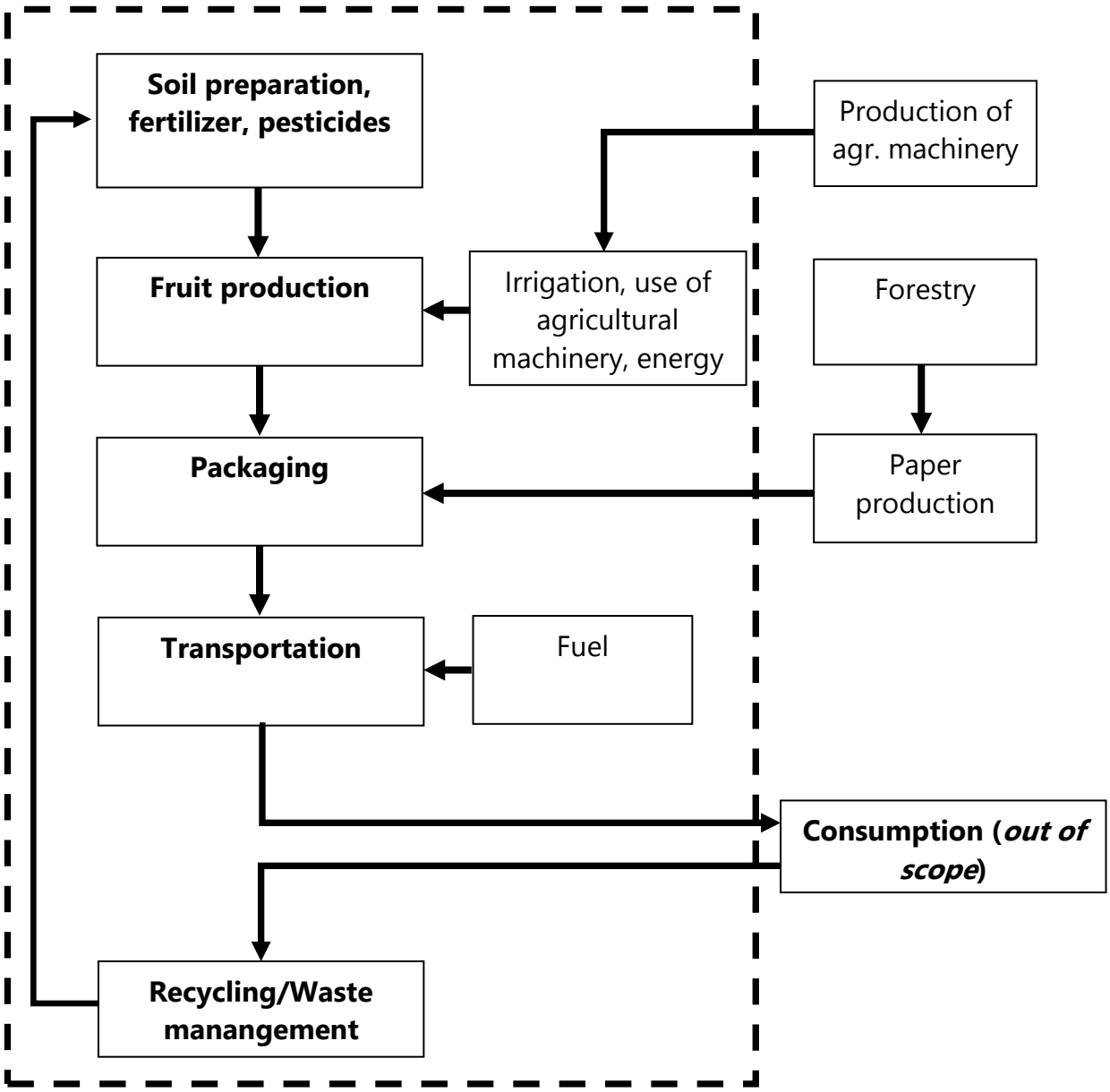

Figure 3: *Flow diagram*

Figure 3 shows a more detailed flow diagram of the conducted LCA. Processes within the system boundary are taken into account in the study, processes outside of it are out of scope.

Results

Figure 4 shows the findings of the four assessed categories *agricultural land occupation*, *natural land transformation*, *water depletion* and *climate change*. In all four categories avocado has the highest impact. Banana has the second highest impact in the categories *climate change*, *natural land transformation* and *water depletion*. Only in *agricultural land occupation* pineapple has the second highest impact.

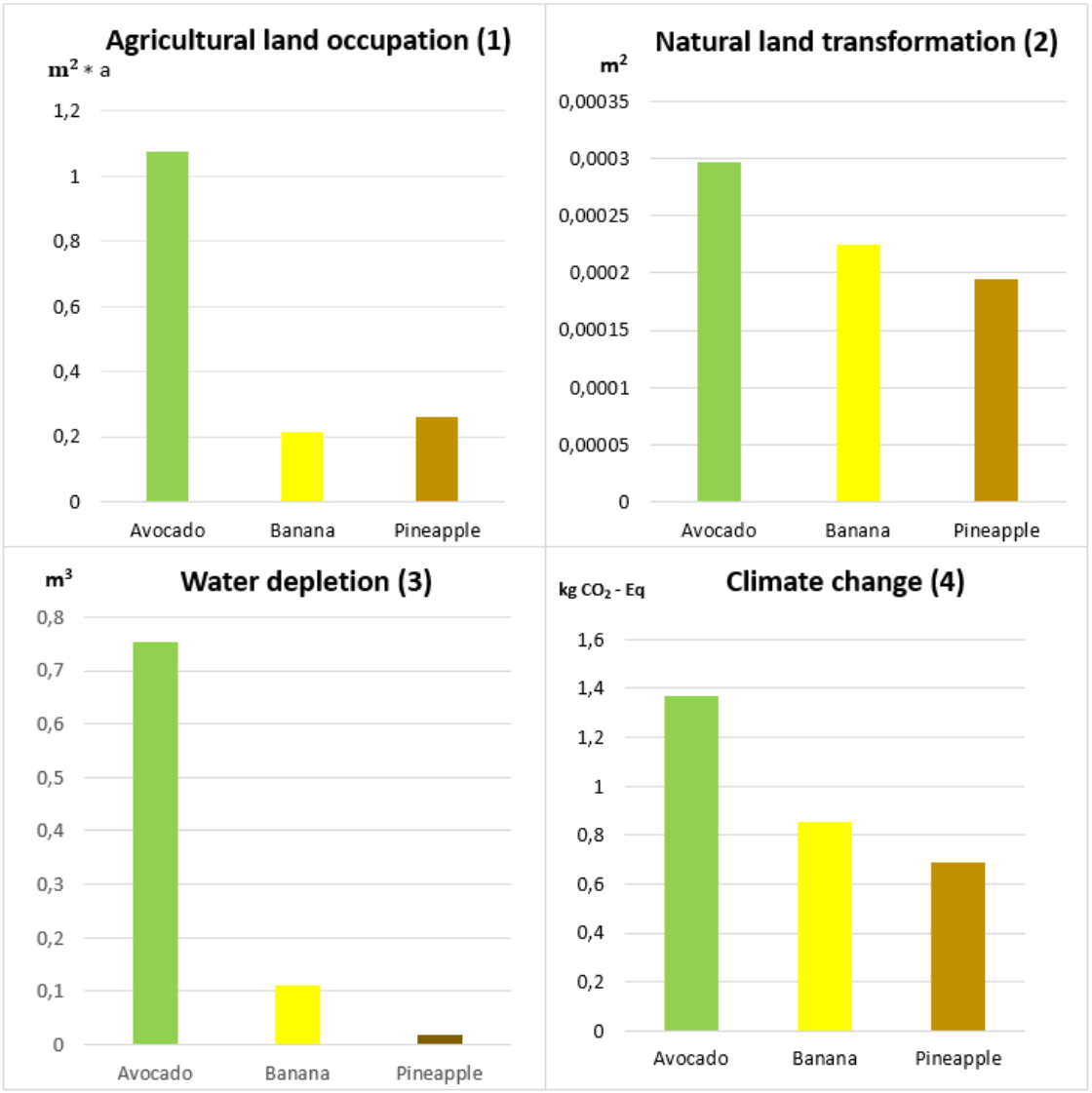

Figure 4: *Results of the LCA: (1) Impacts on agricultural land occupation; (2) Impacts on natural land transformation; (3) Impacts on water depletion; (4) Impacts on climate change*

For one kilogram of avocado in a German supermarket, 1,1 $m^2 *$ a of natural land have to be occupied. That is four times more than for one kilogram of banana or one kilogram of pineapple. The difference between pineapple and banana in this category is only 0,05 $m^2 *$ a and therefore neglectable.

In the impact category *natural land transformation*, impacts of all three fruits are high and the differences between them are low. Avocado has the highest impact with 0,0003 m^2, followed by banana with 0,000225 m^2 and pineapple with 0,00019 m^2. That means the impact of avocado is only 1.53 times higher than the impact of pineapple.

The category *water depletion* shows the biggest differences between the fruits. One kilogram of avocado needs 0,75 m^3 of water, using about seven times more water than needed for one kilogram of bananas. For the production of one kilogram of bananas nearly six times more water than for one kilogram of pineapple is needed. In other words, for every kilogram of avocado almost 40 times more water is needed compared to every kilogram of pineapple.

In the *climate change* category the ranking of the impacts is as follows: For one kilogram of avocado, 1,38 kgCO_2-eq are emitted, followed by banana (0,84 $\frac{\text{kg}CO_2\text{eq}}{kg_{fruit}}$) and pineapple (0,69 $\frac{\text{kg}CO_2\text{eq}}{kg_{fruit}}$). It can be seen that every kilogram of avocado emits two times as much CO_2-eq compared to every kilogram of pineapple and 1.6 times more CO_2-eq compared to every kilogram of banana.

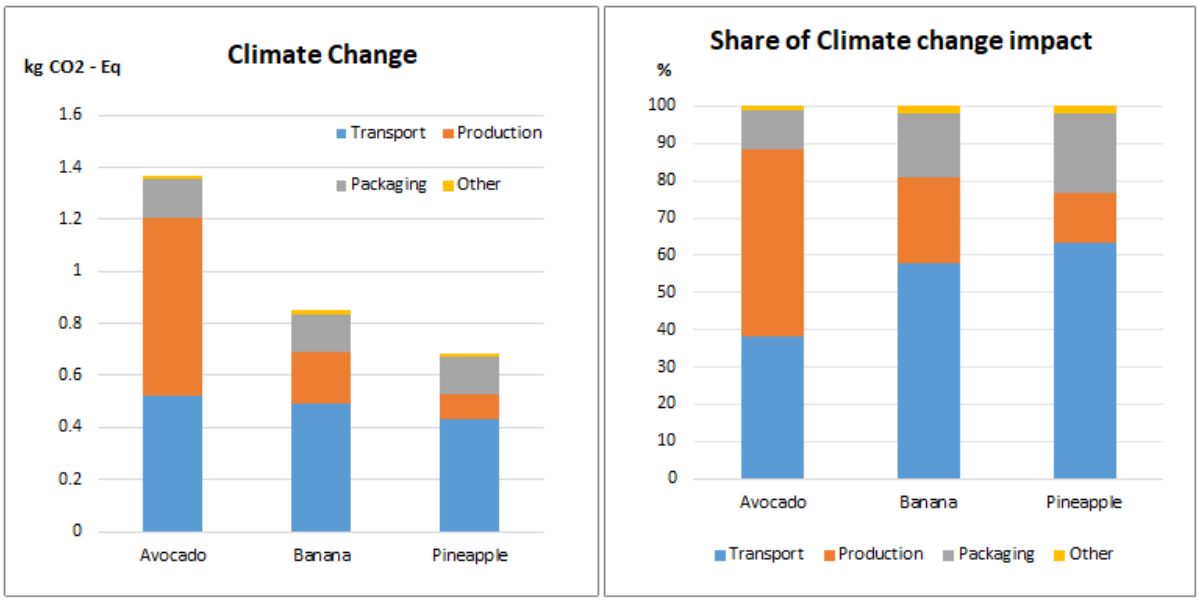

Figure 5: *Share of impact on climate change*

In *Figure 5* the composition of the climate change impact for all three fruits is shown. The four main CO_2-eq emitting categories are *transport*, *production*, *packaging* and *other*. The share of emitted CO_2-eq from packaging is roughly the same for all three fruits. The same holds true for the category *other*. The impact from *transport* differs depending on the transport distances and ranges between 0,42 - 0,52 kgCO_2-eq. The biggest difference between the fruits can be seen in the impact resulting from *production*. Producing one kilogram of avocado leads to 0,7 kgCO_2-eq, one kilogram of Banana equals 0,2 kgCO_2-eq and one kilogram of pineapple only amounts to 0,09 kgCO_2-eq. That means for every kilogram of avocado produced, seven times as much kgCO_2-eq is emitted compared to one kilogram of pineapple and 3,5 times as much kgCO_2-eq compared to one kilogram of banana.
If we look at the shares in percent, categories that have a similar impact in absolute numbers carry different weight in percent. As mentioned before, the impact from *transport* is almost the same for each fruit but it is 63% of the whole impact for pineapple, 58% for banana and just 38% for avocado. For pineapple and banana the *production* has a relatively small share of climate change impact. The most damage is done by *transport* and *packaging*. However, as avocados have a great impact during the *production*, it takes up to 50% of the emitted kgCO_2-eq. *Transport*, *packaging* and other take up the other 50%.

Sensitivity analysis:

From the results it becomes clear that pineapples have the lowest impact on climate change. An uncertainty in this study, however, is what future inputs will be and how the used processes will change. One example will be the electricity mix. So far, the electricity for the production of the fruits included a low-voltage electricity mix, mainly based on fossil fuels. It is possible that this electricity mix will change toward a more renewable electricity supply in the future. Therefore, the authors decided to conduct a sensitivity analysis by changing the electricity mix from fossil-based to 100% PV-based. This has only been done for the pineapple since it is the fruit with the lowest impact on climate change.

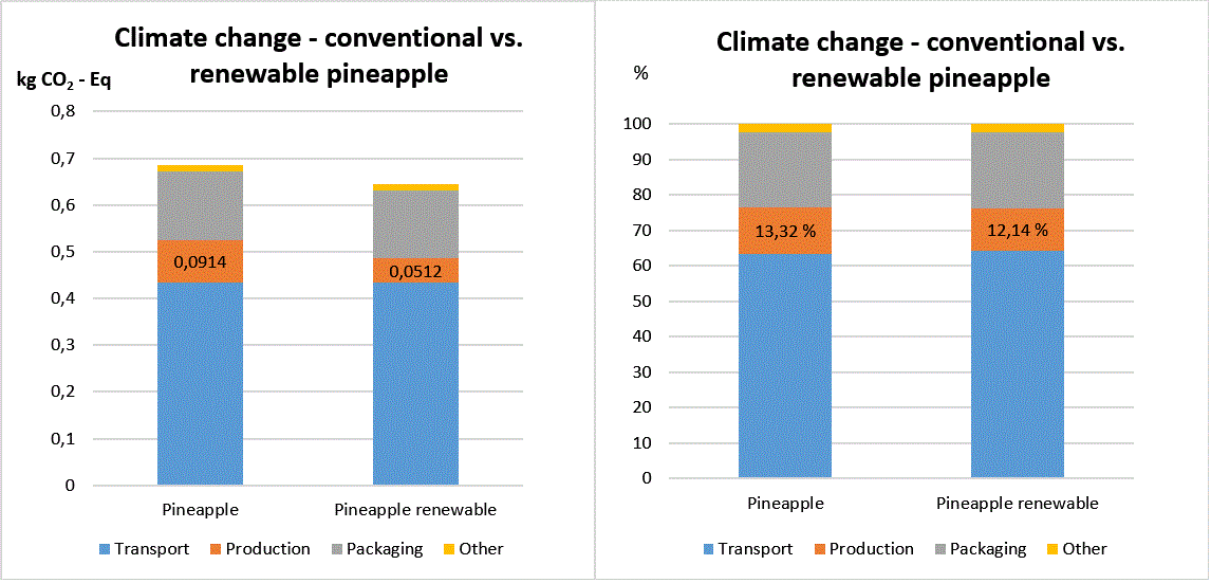

Figure 6: *Share of impact on climate change for pineapple, depending on electricity mix*

Figure 6 shows the difference in climate change impact between one kilogram of pineapple produced with the fossil-based electricity mix and one kilogram of pineapple produced with the PV-based electricity mix. The only category that is impacted is *production*, because only in this phase electricity is being used. The absolute number of kilogram of CO_2-eq emitted changes from 0,0914 kgCO_2-eq to 0,0512 kgCO_2-eq. Even though this is a reduction of 44% within the production process it only amounts to a reduction of 1,35% of the overall CO_2eq-emissions. For a local consumer in Costa Rica, the change of the electricity mix to PV-based electricity greatly affects the emissions from consuming one kilogram of pineapple. For a consumer in Europe, however, this reduction is neglectable. More than 60% of the pineapples CO_2eq-emissions in a German supermarket still stem from the transportation of the fruit.

Discussion

Based on the results presented above it was possible to give the environmental conscious consumer in the local market of Freiburg a clear buying decision guideline, when he/she decides to buy a tropical fruit with a low impact. Pineapple was found to have the lowest impact in all assessed categories except for agricultural land occupation. Avocado was found to have the worst effect in all categories, followed by banana. Furthermore, it could also be confirmed that the production of avocado has a high water consumption as shown in other literature (Cuéllar, A., 2018) (Mekonnen, 2010).
Also, it could be shown that transportation has a significant impact on the resulting climate change footprint. Except for avocados transportation made up more than 50% of the climate change impact. The lower impact of avocados is explained by its higher footprint in the production phase.

Even though the research question could be answered clearly there are still uncertainties, which need to be mentioned.
As the biggest producer of a given tropical fruit was chosen as the only exporter, the impact of transportation is different in reality. Other countries which export their fruits to Germany should be taken into account to get more precise values for transportation.
Also, for the production of the fruit only global and not country-specific fruit production data was used. Having that field of uncertainty in mind for further and deeper research local fruit production data should be used, combined with detailed transportation data.
These two interlinked processes should then be calculated for each fruit-exporting country, delivering to Germany. As a last step the calculated data for each country has to be put together in a mixed class for each fruit and weighted according to the amount of fruit imported from that country. Through this step the fruit and impacts are allocated proportionally through the overall import-country-mix to the countries of their origin. When further research is carried out within this frame, uncertainties in the biggest contributing categories *transport* and *production* affecting climate change, can be significantly reduced (*Figure 5*). The described steps could not be addressed in this study due to a lack of time.
For *packaging* simple cardboard boxes were chosen. To generate more precise LCA results in the future, a detailed analysis has to be carried out how much and what kind of materials are

used to pack the fruits. This could include plastic bags, plastic wrapping foil, the usage of pallets, and so on.
Out of the scope of this study is also the use phase of the different fruits. This includes storage in the supermarket, the transportation from the supermarket to the consumer, storage in the consumer's home and the actual use of the fruit when preparing food with it. Due to an increased complexity when taking all of these aspects into account, they were excluded from this LCA. However, future LCAs should also take this into account to obtain more precise results.

From a purely scientific point of view, the functional unit used in this LCA could be changed to 1000 kcal of fruit. Avocados, bananas and pineapples have very different energy contents and therefore calorific value. Naturally, a fruit with a higher calorific value (like the avocado) uses up more resources to grow and impacts the ecosystem accordingly. Using 1000 kcal of fruit as the functional unit would result in a relative decrease of the impacts of avocados and bananas compared to pineapple as they have a higher calorific value. Even though it would be interesting to look at the evolving numbers, hardly any consumer in Europe chooses food for its high calorific value.

As the sensitivity analysis shows, a change in the electricity mix used for the production of one kilogram of pineapple will have a neglectable influence on the overall CO_2-eq emissions for a European consumer. To actually reduce the impact of the fruits, the transportation modes have to be changed. Tropical fruits will continue to have a high impact on climate change for as long as they are being shipped by lorry and freight container ship with diesel engines.

Conclusion

The presented LCA sufficiently answers the research questions. It provides guidelines to an environmentally conscious consumer in Freiburg who wants to buy a tropical fruit in the supermarket. It shows that buying one kilogram of avocado has a seven times higher impact on CO_2-eq emissions than buying one kilogram of pineapple.

The sensitivity analysis clarifies that changing the electricity mix for the production of pineapples will impact the overall CO_2-eq emissions only very slightly. The biggest shares of emissions still come from packaging and transportation.

The authors recommend to buy pineapples or bananas rather than avocados in order to reduce the CO_2-eq footprint of the consumers diet. However, due to very high CO_2-eq emissions from transport and packaging, buying local and seasonal fruits will always trump a tropical fruit in terms of CO_2-eq emissions.

References

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(22.01.2019, 15:44)

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Appendix

Inputs/Outputs: Providing_1kg_avocado

Inputs

Flow	Category	Amount	Unit
avocado | avocado production - GLO	012:Growing of perennial...	1.00000	kg
biowaste | market for biowaste - RoW	382:Waste treatment and ...	-0.11838	kg
carton board box production, with gravure printing | carton board box production service, with gravure printing - RoW	170:Manufacture of pape...	0.20000	kg
operation, reefer, cooling | market for operation, reefer, cooling - GLO	292:Manufacture of bodi...	0.09580	kg*d
transport, freight, lorry with refrigeration machine, 7.5-16 ton, EURO4, carbon dioxide, liquid refrigerant, cooling | transport, freight,...	492:Other land transport/...	0.50000	t*km
transport, freight, lorry with refrigeration machine, 7.5-16 ton, EURO6, carbon dioxide, liquid refrigerant, cooling | transport, freight,...	492:Other land transport/...	0.70000	t*km
transport, freight, sea, transoceanic ship with reefer, cooling | transport, freight, sea, transoceanic ship with reefer, cooling - GLO	501:Sea and coastal wate...	9.60000	t*km

Outputs

Flow	Category	Amount	Unit	Costs/Reven...	Uncertainty	Avoided pr...	Provider	Data quality...	Description
1kg_avocado	**_MyFlows**	**1.00000**	**kg**		**none**				

Figure 1: *openLCA process Providing_1kg_avocado; inputs and outputs*

Inputs/Outputs: Providing_1kg_banana

Inputs

Flow	Category	Amount	Unit
banana | banana production - GLO	012:Growing of perennial...	1.00000	kg
biowaste | market for biowaste - RoW	382:Waste treatment and ...	-0.11838	kg
carton board box production, with gravure printing | carton board box production service, with gravure printing - RoW	170:Manufacture of pape...	0.20000	kg
operation, reefer, cooling | market for operation, reefer, cooling - GLO	292:Manufacture of bodi...	0.42494	kg*d
transport, freight, lorry with refrigeration machine, 7.5-16 ton, EURO4, carbon dioxide, liquid refrigerant, cooling | transport, frei...	492:Other land transport/...	0.30000	t*km
transport, freight, lorry with refrigeration machine, 7.5-16 ton, EURO6, carbon dioxide, liquid refrigerant, cooling | transport, frei...	492:Other land transport/...	0.70000	t*km
transport, freight, sea, transoceanic ship with reefer, cooling | transport, freight, sea, transoceanic ship with reefer, cooling - GLO	501:Sea and coastal wate...	10.60000	t*km

Outputs

Flow	Category	Amount	Unit	Costs/Reven...	Uncertainty	Avoided pr...	Provider	Data quality...	Description
1kg_banana	**_MyFlows**	**1.00000**	**kg**		**none**				

Figure 2: *openLCA process Providing_1kg_banana; inputs and outputs*

Inputs/Outputs: Providing_1kg_pineapple_renewable

Inputs

Flow	Category	Amount	Unit
biowaste | market for biowaste - RoW	382:Waste treatment and ...	-0.11838	kg
carton board box production, with gravure printing | carton board box production service, with gravure printing - RoW	170:Manufacture of pape...	0.20000	kg
operation, reefer, cooling | market for operation, reefer, cooling - GLO	292:Manufacture of bodi...	0.09580	kg*d
pineapple_production_renewable	_MyFlows	1.00000	kg
transport, freight, lorry with refrigeration machine, 7.5-16 ton, EURO4, carbon dioxide, liquid refrigerant, cooling | transport, freig...	492:Other land transport/...	0.20000	t*km
transport, freight, lorry with refrigeration machine, 7.5-16 ton, EURO6, carbon dioxide, liquid refrigerant, cooling | transport, freig...	492:Other land transport/...	0.70000	t*km
transport, freight, sea, transoceanic ship with reefer, cooling | transport, freight, sea, transoceanic ship with reefer, cooling - GLO	501:Sea and coastal wate...	9.10000	t*km

Outputs

Flow	Category	Amount	Unit	Costs/Reven...	Uncertainty	Avoided pr...	Provider	Data quality...	Description
1kg_pineapple	**_MyFlows**	**1.00000**	**kg**		**none**				

Figure 3: *openLCA process Providing_1kg_pineapple_renewable; inputs and outputs*