Environmental analysis of hydroponic farming systems for Morocco using comparative life cycle assessment (LCA)

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INTRODUCTION

Horticulture is one of the main drivers of the economy in Morocco and the reason why agriculture is the most important sector in the Moroccan economy accounting for 12% of the GDP (The World Bank, 2021) and employing over 30% of its population (La Banque Mondiale, 2019). However, horticulture is also responsible for the overexploitation of natural resources which, in case of water, are alarmingly scarce. Due to climate change, the country is increasingly suffering from longer draughts and higher temperatures (Lionello et al., 2008) which, added to a rapidly growing population, exerts a mounting amount of pressure on the environment.


Figure 1. Moroccan farmer facing drought. S: Atalayar.com

In Souss Massa region, the most important agricultural region in the country, horticulture accounts for 90% of freshwater consumption. Despite its hyperarid climate, 44% of the cultivated land is irrigated, being flooding the most common technique. This mismatch between environment and practices not only cause the depletion of water resources but also its pollution, as well as that of the soil, with chemical fertilizers and pesticides. At national level, it is estimated that 1500 tonnes of nitrates leach each year into the soil, while 7500 tonnes of pesticides are applied (Malki et al., 2017). Furthermore, the overexploitation of groundwater wells is allowing marine water to intrude, threatening the quality of ecosystems. An increasing trend is to satisfy the demand with desalinated water, which is not free of impacts due to its energy intensity extraction and the residues that it generates.


Figure 2. Canarian greenhouse, Agadir (Morocco)

In order to increase productivity, local farmers have moved their production into greenhouses that now occupy 6500 ha of Souss Massa (Hirich et al., 2017). Nevertheless, the greenhouses currently being used in Morocco are still primitive. Their poor construction and ventilation, lack of climate control, high humidity, low CO_2, bad insulation, and weak light radiation lead to very limited yields of modest quality, pests and generation of plastic waste that is defficiently collected. Furthermore, farmers still grow their crops in the ground increasing the risk of pests, consuming more water and polluting the soil.

Therefore, it is undisputed that more efficient agricultural techniques are required in the region. High-tech greenhouses, as those in the Netherlands, can grow crops with minimal water footprint, as well as a lower consumption of fertilizers and essentially no use of chemical pesticides thanks to hydroponic cultivation. These systems are characterized by climate control, heating, active ventilation, CO_2 inyection, soil-less cultivation, and closed irrigation and fertilization (fertigation), features that are combined with natural pest control and pollination practices.

Despite their multiple benefits, hydroponic cultivation is barely present in Morocco. This is expected to change as Moroccan horticultural sector grows. However, the deployment of new technologies needs to be addressed with sustainability in mind. Although it is clear that high-tech greenhouses can help to reduce environmental impacts, an analysis needs to be conducted to adapt this technology to local conditions, optimizing its environmental performance. This study aims at anticipating the main impacts that of transfering hydroponic systems from the Netherlands to Morocco and explores the main adjustments that need to be implemented.

LCA MODEL

Life Cycle Assessment (LCA) is the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle, including from the extraction of resources, through the production of materials, product parts and the product itself, and the use of the product to the management after it is discarded, either by reuse, recycling or final disposal (Guinée, J.B., 2002).

In this case, this tool is applied to tomato production using hydroponic cultivation in Morocco. The product system includes all processes from seed production to the harvest of tomatoes (before packaging) and the auxiliary activities with their supply chains.

In addition, the study looks at two alternative hydroponic systems. First, the conventional system (Figure 4) represents the most common techniques used in the Netherlands, where indeterminated plants are grown on coir substrate bags for a long season that lasts 40 weeks approximately. The second alternative is called Futagrow (Figure 5), an innovative system tested in Westland whose main differences are as follow:

1. Distanced between rows of plants is halved to maximize space and light use.
2. Plants are replaced after 18 weeks so they are younger,and healthier.
3. Plants can be lifted to allow access and control sun exposure.
4. Extra lighting is supplied to middle branches, maximizing control.
5. Nutrient Film Technique (NFT) is used instead of coir substrate, reducing cost and waste
6. Propagation is carried out from sideshoots, avoiding the need of nursery.

The study used ReCiPe to conduct the impact assessment phase looking at a total of 18 categories. However, global warming, terrestial ecotoxicity, freshwater eutrophication and use of freshwater (shown here) were selected for further analysis as they are considered the most critical issues in Morocco.

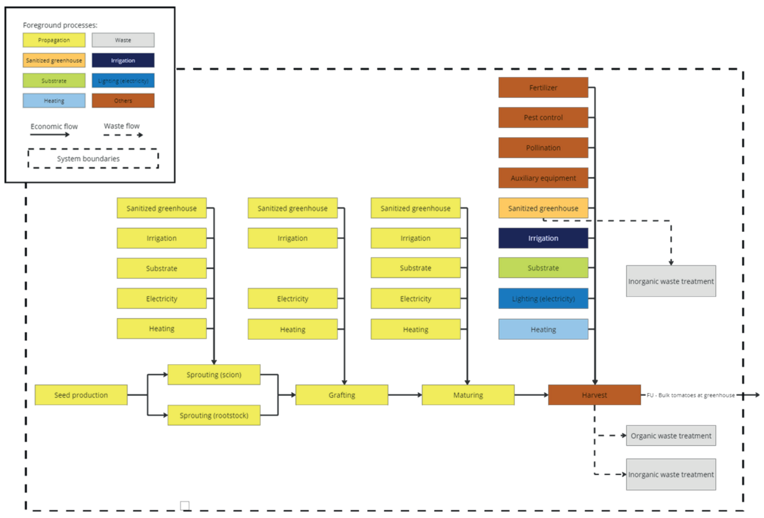


Figure 3. LCA flowchart and system boundaries. Colors indicate the groups in considered for the contribution analysis

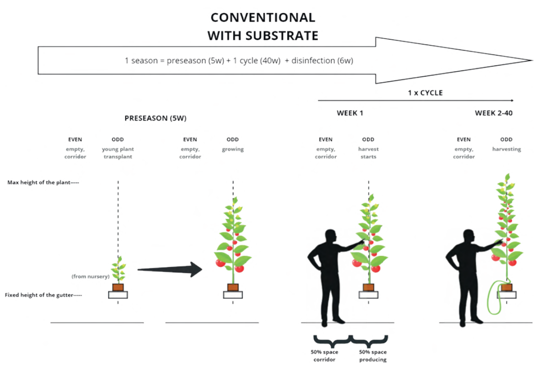


Figure 4. Schematic representation of conventional tomato cultivation in the Netherlands

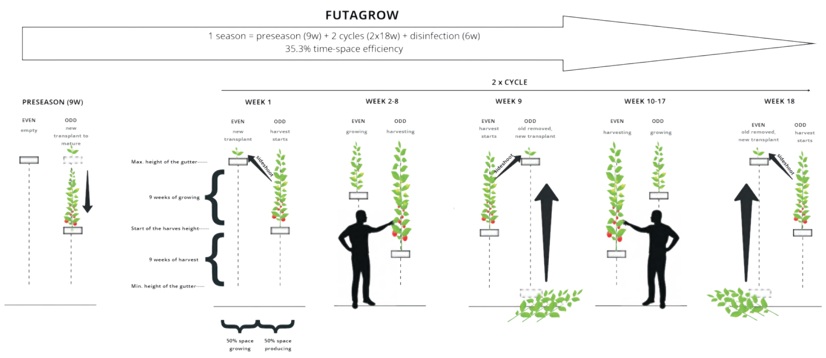


Figure 5. Schematic representation of Futagrow tomato cultivation as it was tested in Westland (van Staalduinen, 2015)

RESULTS

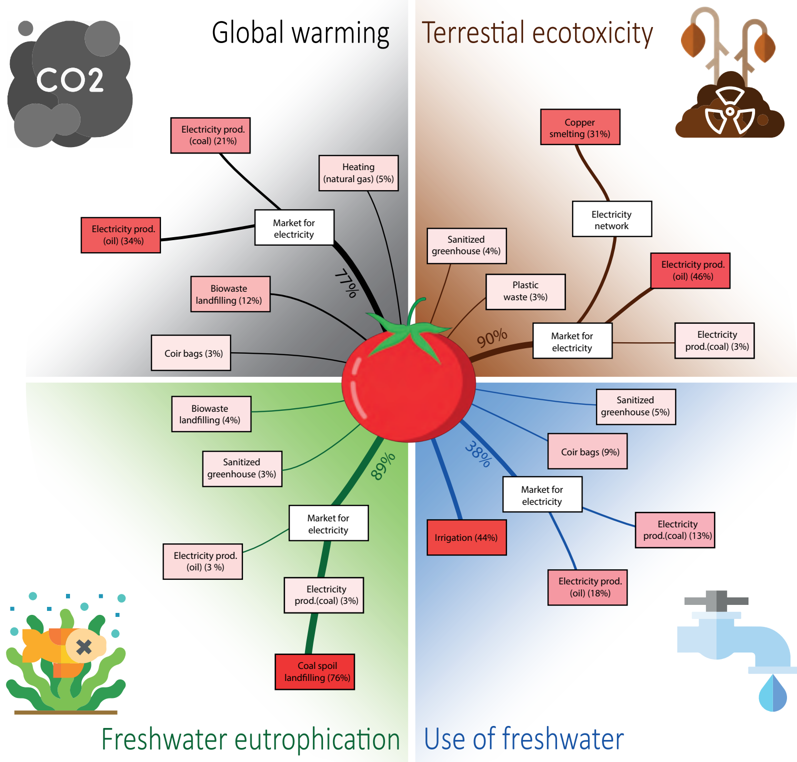


Figure 6. Process contribution analysis of conventional (Dutch) tomato production in Morocco.

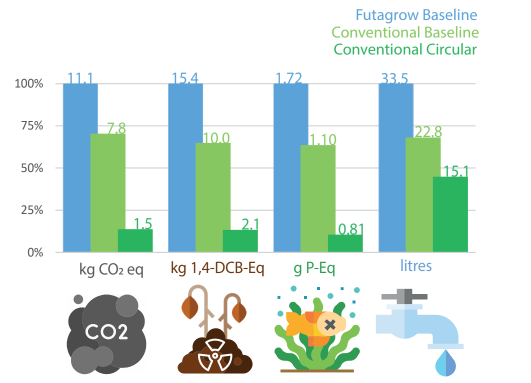


Figure 7. Impact assessment results of conventional and Futagrow, baseline, and conventional cirular

First, an individual analysis of the conventional system was conducted and the results showed that electricity, used for lighting, was the main source of environmental impacts of all processes (Figure 6). Its high contribution is due to the large share of fossil fuels in the Moroccan energy mix (oil 55%, coal 32%, IEA (2020)). Other processes that deserved to be metioned were biowaste landfilling, plastic waste landfilling, heating, sanitized greenhouse and substrate.

Secondly a comparation between futagrow and the conventional system was carried out. Additionally, a new scenario (called *Circular*) was created based on the previous results in which energy for the conventional system was sourced from renewable sources (wind for electricity and solar for heating) and plastic waste was partially recycled. The scores, shown in figure 7, illustrate how futagrow performes worse in all categories, while the implementation of renewables and recycling significantly reduces the impacts.

Finally, a new contribution analysis was conducted on the improved systems to evaluate the new distribution (Figure 8) . Both Futagrow and the conventional system were analyzed. Overall, the gap between both systems was drastically reduced, being now futagrow a better option looking at global warming.

Waste remains the main contributor for global warming which indicates that more efforts have to be addressed to reduce residues and improve waste treatment, especially of biowaste. Heating becomes an important contributor of terrestial ecotoxicity and freshwater eutrophication, so new options need to be considered instead of thermosolar energy. The impact of the greenhouse construction is reduced thanks to plastic recycling but more can be done to extend its life cycle. Finally, irrigation expectedly is the main contributor of freshwater leading to the conclussions that implementing water management policies could significantly reduce the water footprint of Moroccan tomatoes grown in hydroponic systems.

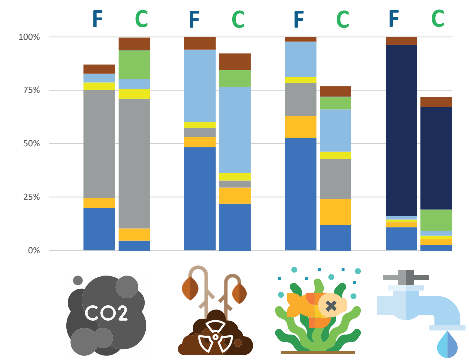


Figure 8. Impact assessment results with contribution analysis for Futagrowand conventional, circular

RECOMMENDATIONS

The environmental analysis of future hydroponic systems conducted using Life Cycle Assessment has revealed some important warnings that need to be considered to minimize the impact of transfering this technology to Morocco. First of all, electricity from the national grid needs to be avoided as it is generated from fossil fuels. To keep the artificial lighting running it will be necessary to install cleaner sources of energy such as windmills. Solar or geothermal energy can also be deployed althought thier performance has not been modelled in this study.

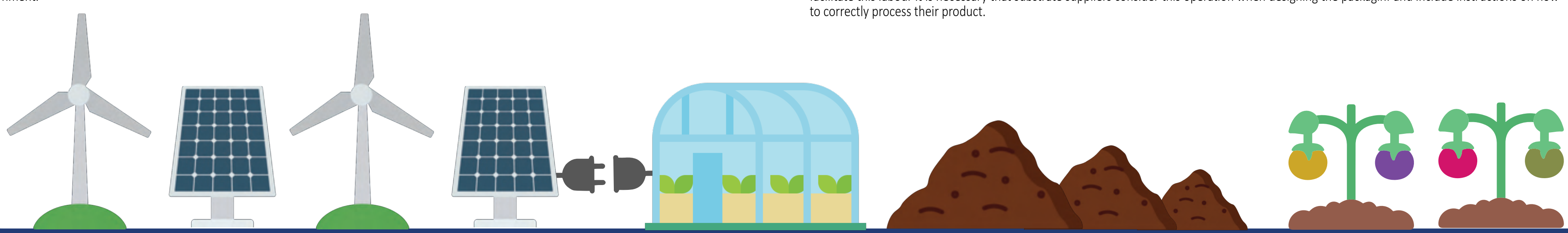
For the specific case of heating, it is difficult to find an alternative to natural gas. However, the climate of Morocco allows for cultivation with minimum or no additional heating support.This is factor that need further evaluation to find a balance between environmental performance and yield productivity.

The high costs of installing new windmills, solar panels or opening a geothermal plant can be subsidized or afford by cooperatives working together. However, this type of collaboration is unprecendented in the case of Morocco and might need some organizational support from the government.

Another hotspot of environmental impacts that has been detected is waste. Currently there are some initiatives pushing to formalize the recycling of agricultural plastic waste. However, it is still mostly under the control of the informal sector. Furthermore, despite the extensive area of films covering greenhouses, plastic is only a small material flow compared to organic waste which nowadays is being dumped on a regular basis next to farms. This pollutes the soil with substances and materials mixed in the stream.

Plant and substrate wastes are a valuable material load with nutrients that should be recirculated. Firtst option must be look to systems using NFT instead of substrate. If these systems are too complex or unfeasible for any other reasons and substrate becomes the only alternative, it should be preserved in use for as long as possible, extending its use life longer than the now common 1-year lifespan.

After their use phase, substrate can be composted together with plant waste and used to grow other crops . Alternatively, coir has also been used to grow mushrooms, which brings an opportunity to diversify the economic activity of farmers with a rather uncommon product in Morocco. To facilitate this labour it is necessary that substrate suppliers consider this operation when designing the packaginf and include instructions on how to correctly process their product.



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