
# Summary Report:

# Environmental Life Cycle Assessment of GrowOff Modular Vertical Farm

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# Background

This study was developed together with Grönska Stadsodling 365. Grönska is vertical farming company that started in 2015 and has developed a large-scale vertical farm in Stockholm and modular vertical farms which are in place nationwide. Since the start, Grönska has worked to reduce the resource and energy demands in order to promote more sustainable food provisioning. This summary report provides a brief review of the environmental life cycle assessment conducted during 2022 with Grönska on their modular cabinet vertical farms, i.e. the GrowOff system. The work was conducted within the FORMAS project "Assessing and Improving the Sustainability of Urban Vertical farming Systems," grant 2019-02049 in order to help Grönska identify hotspots and understand the sustainability of the offerings.

# GrowOff

The GrowOff cabinet was designed to be employed in different environments to produce e.g. lettuce and herbs. The GrowOff systems are currently in place around Sweden in cafeterias, restaurants, and supermarkets. The case was selected as to provide a life cycle analysis to evaluate the viability of vertical farming in smaller systems, such as cabinet-based vertical farms, while also taking into account the general absence of comparable studies in the literature. It also provides further analysis of the environmental implications of new business models, such as growing service-systems (GSS), highlighted recently in a previous study (Martin and Bustamante, 2021).


**Figure 1: GrowOff Vertical Farm Cabinet (Credit: Grönska)**

# Methodology

To examine the environmental performance, a life cycle assessment (LCA) was employed following guidance provided in Martin and Orsini (2023). A cradle-to-grave approach was used to perform the study, which covered the modular farm infrastructure, inputs for cultivation and packaging, energy, material transportation, and waste management from the end-user. One kilogram of edible product was chosen as the functional unit for the assessment, which were used to show the impacts of a GrowOff system producing lettuce or basil. This functional unit is frequently employed in other evaluations of controlled environment agricultural products.

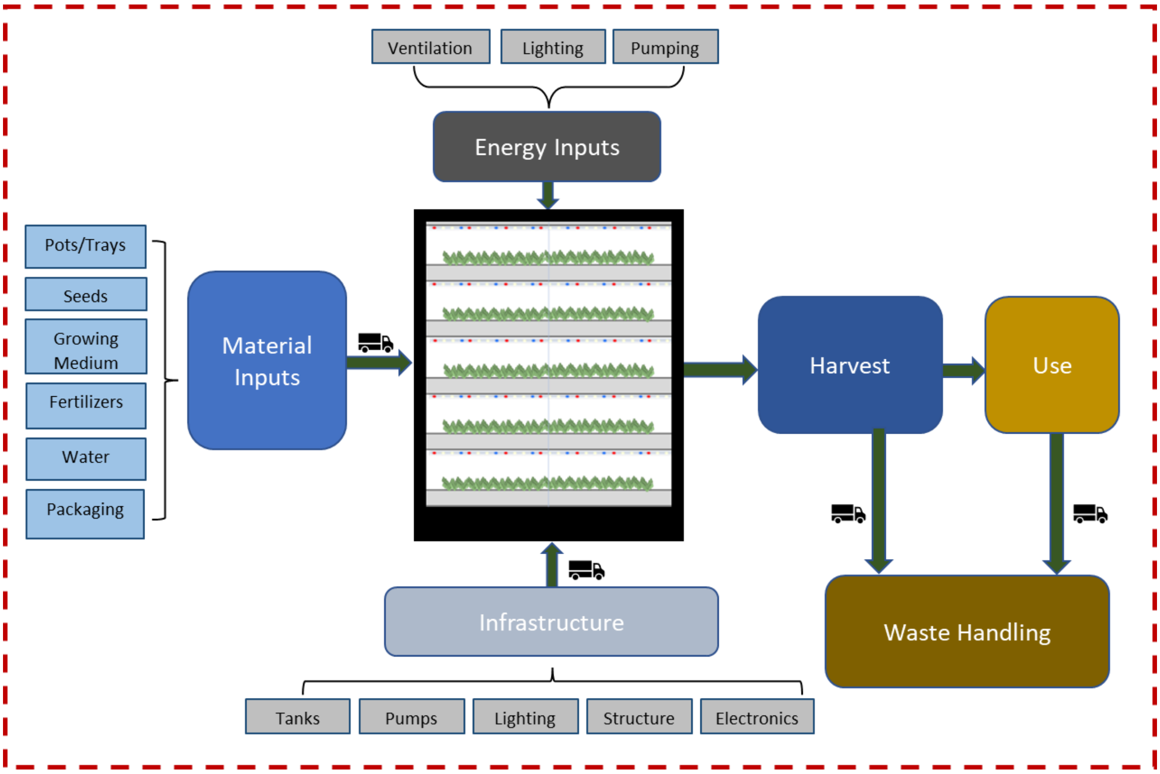


**Figure 2: Simplified system boundaries and processes included in the life cycle assessment**

The LCA was conducted employing the OpenLCA v1.10.3 (2022) software and Microsoft Excel. For the life cycle impact assessment (LCIA) method, the Environmental Footprint v. 3.0 method (EC, 2019) was employed as it is a robust method and recommended for products on the European market. This summary report highlights primarily greenhouse gas (GHG) emissions (measured in kg $CO_2$-eq) although the forthcoming scientific article and associated supplementary material provide further environmental impact categories included in the EF 3.0 method.

# Assessed systems

The life cycle assessment was conducted for two separate GrowOff systems producing 1) lettuce and 2) basil. These systems are labeled Lettuce and Basil respectively. As the LCA was found to be sensitive to methodological choices, the influence of the electricity system and how the environmental impacts from the GrowOff system cabinet infrastructure are included were also studied.

For the baseline scenarios for lettuce and basil, the Swedish average electricity mix was employed. However, as the GrowOff systems may be placed at end-users who purchase certified electricity from renewable sources, two additional scenarios are included. One of these includes only employing hydropower (labeled Hydro El) and the other where a mix of hydro and wind power (labeled Hydro/Wind El) are included.

Finally, the baseline scenarios for lettuce and basil assume that all impacts from the GrowOff infrastructure are included (also taking into account their lifetime). However, as the GrowOff system is a leased module, it may be fair to assume that the end-user and the provider (i.e. Grönska), share the burden of the GrowOff infrastructure (labeled Split Infra). As such, only 50% of the infrastructure impacts are allocated to system. Furthermore, it should be noted that not all impacts are allocated to the annual production, as the GrowOff system is assumed to be in operation for a number of years and the different parts have varying assumed lifetimes. For example, the main cabinet structure is assumed to have a lifetime of at least 20 years. An overview of the different scenarios for lettuce is provided below; note the same scenarios are also conducted for the GrowOff producing basil.

**Table 1: Review of GrowOff lettuce scenarios**

| Scenario | Electricity System | Infrastructure |
|---|---|---|
| **Lettuce** | Swedish Electricity Mix | All allocated to end-user |
| **Lettuce-Hydro El** | Hydropower | All allocated to end-user |
| **Lettuce-Hydro/Wind El** | 50% Hydro, 50% Wind | All allocated to end-user |
| **Lettuce-Split Infra** | Swedish Electricity Mix | Half allocated to end-user |
| **Lettuce-Split Infra-Hydro El** | Hydropower | Half allocated to end-user |
| **Lettuce-Split Infra-Hydro/Wind El** | 50% Hydro, 50% Wind | Half allocated to end-user |

# Results

As illustrated in Figure 3, the energy demand accounts for the largest share of impacts in nearly all impact categories for lettuce. Similar results were found for the basil. However, the infrastructure and fertilizers also account for a significant share of environmental impacts in many of the impact categories, including contributions to GHG emissions, acidification, eutrophication, ecotoxicity, and resource depletion.

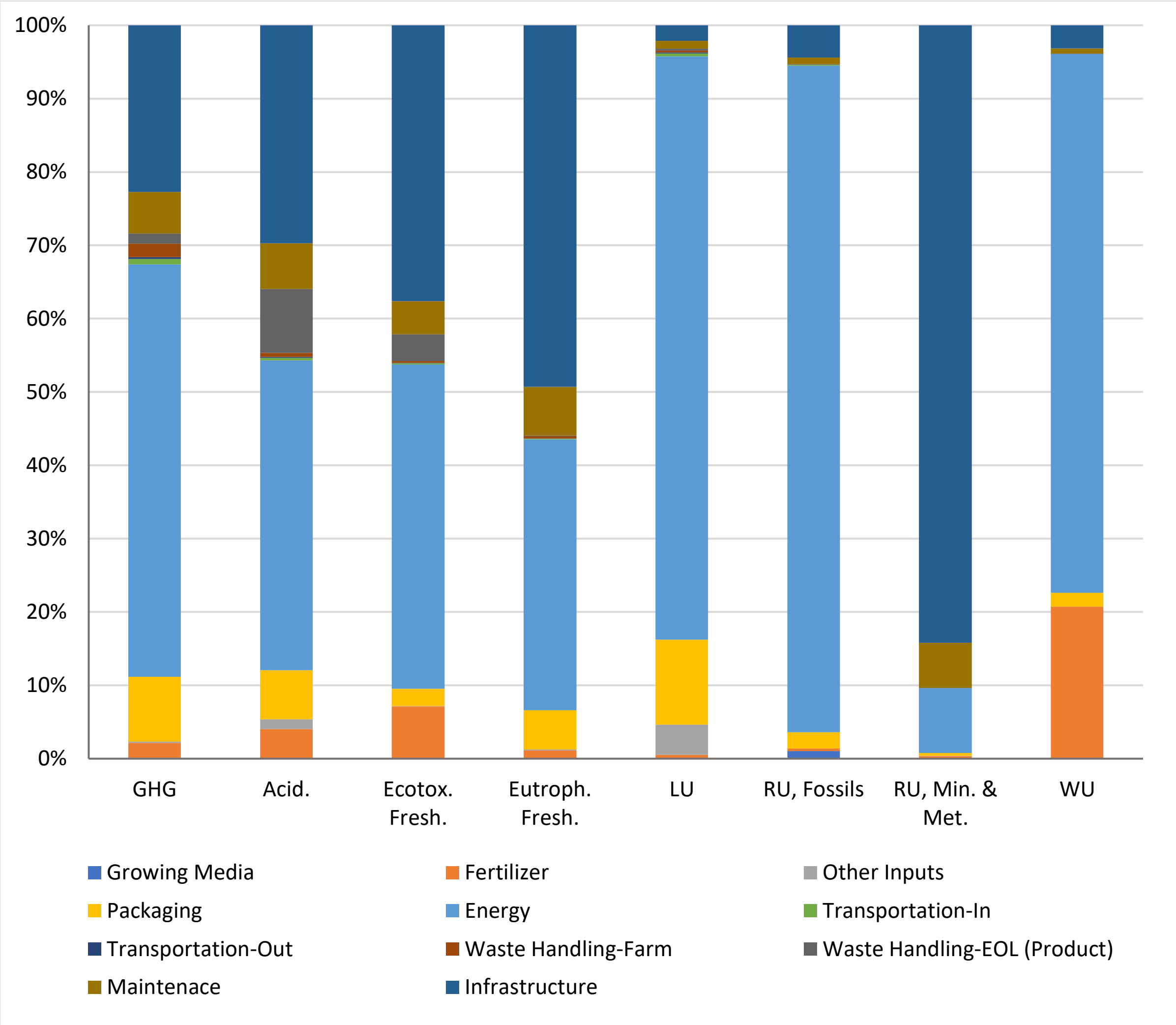


**Figure 3: Contribution of inputs and processes to the impacts for producing 1 kg of lettuce for the baseline Lettuce scenario (GHG-Greenhouse gases, Acid.Acid.-Acidification, Ecotox. Fresh.- Ecotoxicity Freshwater, Eutroph. Fresh..–Eutrophication Freshwater, LU-Land Use, RU fossils -Resource Use Fossils, RU min. & metals- Resource Use-Minerals and Metals, WU-Water Use)**

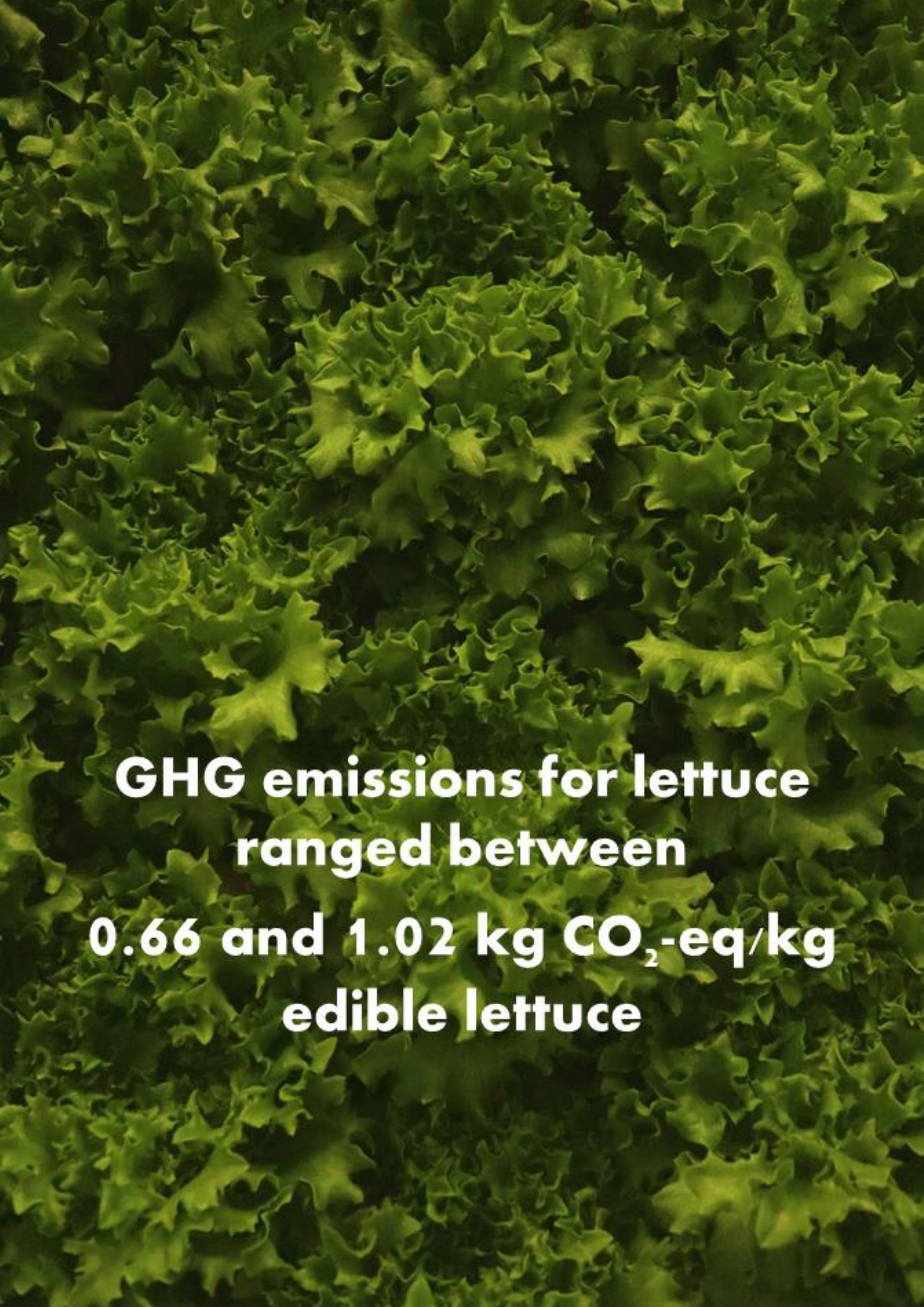
GHG emissions for lettuce
ranged between
0.66 and 1.02 kg $CO_2$-eq/kg
edible lettuce

Figure 4 illustrates the influence of the different methodological considerations for the production of lettuce. As shown the GHG emissions range between 0.66 and 1.02 kg $CO_2$-eq per kg edible lettuce depending upon the scenario. Renewable energy was illustrated to have large GHG emissions reductions compared to the baseline lettuce scenario. In addition, allocating only half the GrowOff infrastructure impacts also leads to large emissions reductions.

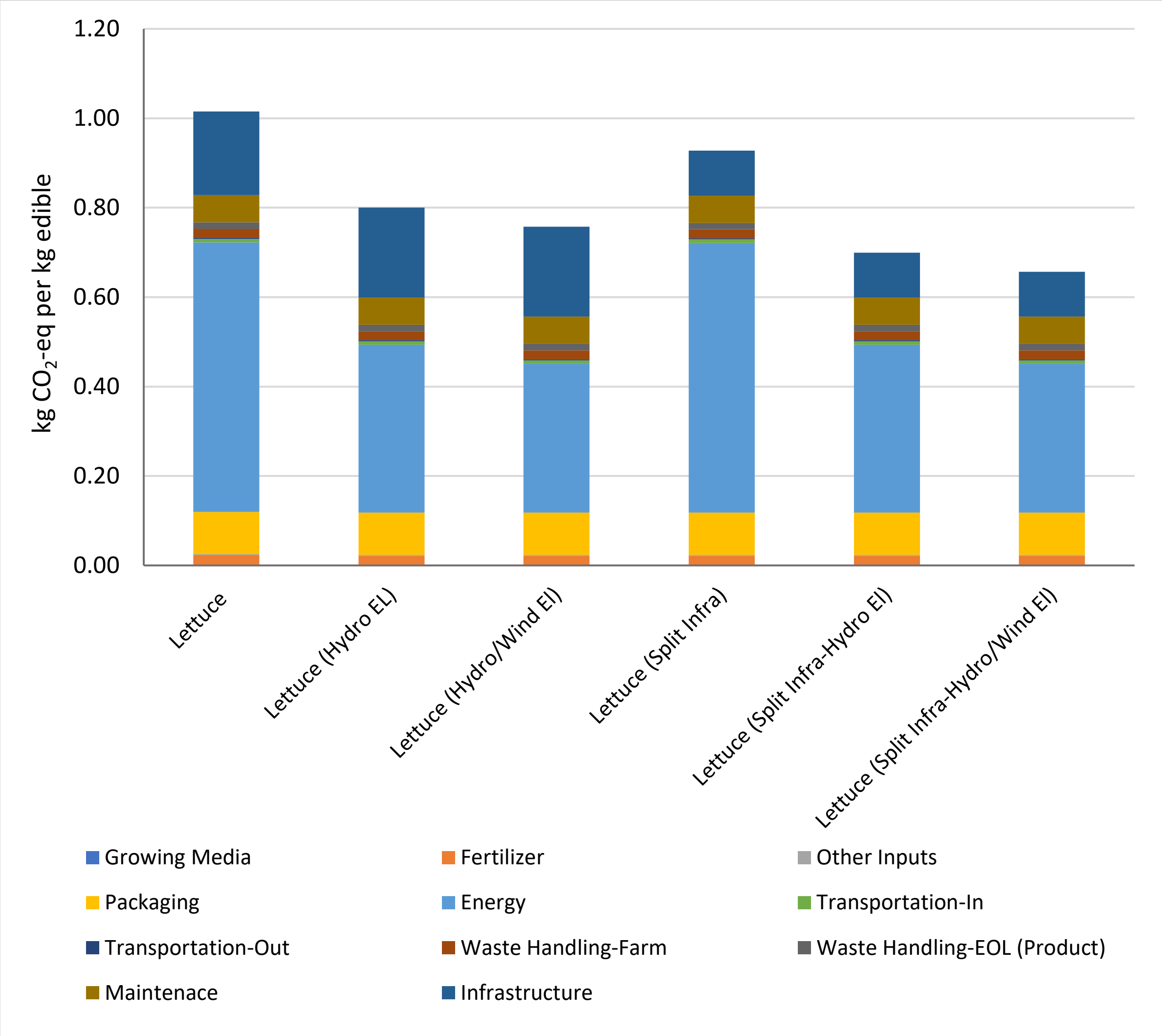


**Figure 4: Illustration of the influence of the selection of energy sourcing and infrastructure allocation for 1 kg of edible lettuce for GHG emissions (shown in kg $CO_2$-eq per kg edible).**

Similar results are found for the basil production, where renewable energy and splitting the infrastructure impacts lead to large GHG emissions reductions, see Figure 5. However, as basil takes longer to produce and has less edible mass, the emissions are higher than lettuce, ranging between 1.3 and 2.1 kg $CO_2$-eq per kg edible basil.

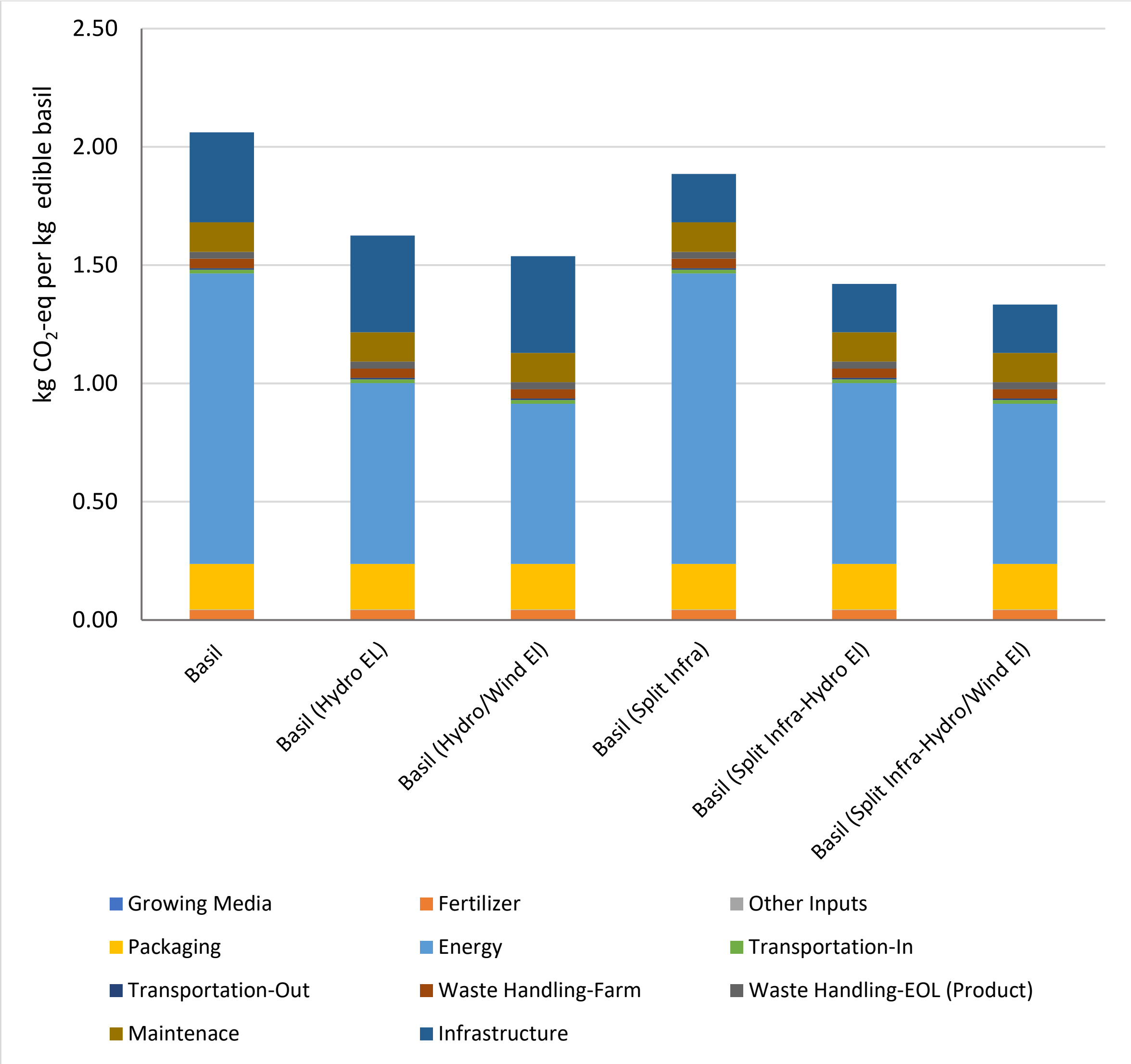


**Figure 5: Illustration of the influence of the selection of energy sourcing and infrastructure allocation for 1 kg of edible basil**


GHG emissions for basil ranged between
1.3 and 2.1 kg $CO_2$-eq/kg edible basil

# Comparisons to conventionally sourced lettuce and basil

Figures 6 and 7 illustrate that both lettuce and basil produced through the GrowOff system have comparable or lower emissions than conventionally sourced products. For example, while the production impacts are lower for imported field-based production of lettuce and basil, the distribution may be significant. Open-field and tunnel produced lettuce from Sweden were illustrated to have lower GHG emissions, although their availability is seasonal. Furthermore, sourcing of lettuce and other crops may also vary seasonally, and may come from Spain, Italy, Sweden, Denmark, or the Netherlands throughout the year. As such the 'average' impacts for imported lettuce and basil may vary monthly. Furthermore, GHG emissions for small vertical farms in the literature (UK and the Netherlands) have significantly higher impacts due to regional energy systems, roughly 8 kg $CO_2$-eq per kg lettuce; see e.g. Casey et al. (2022) and Blom et al. (2022)

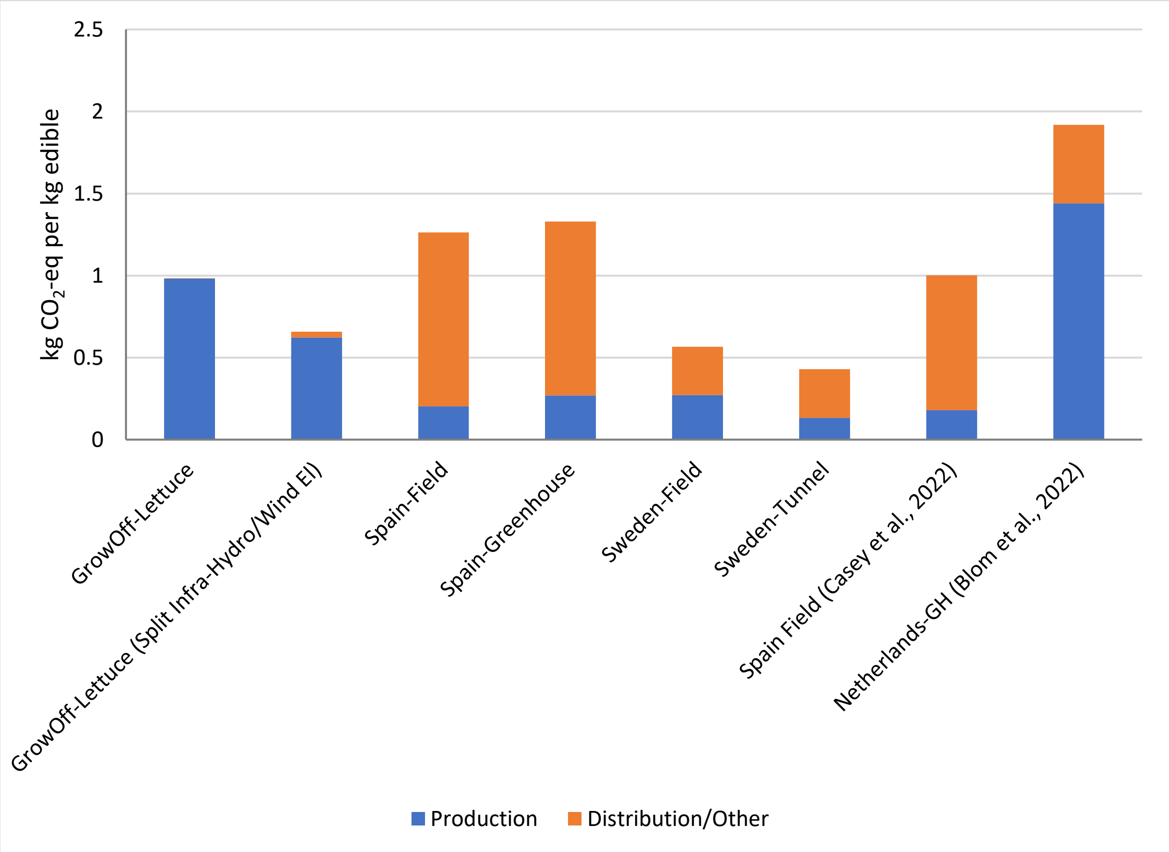


**Figure 6: Comparison of the GHG emissions for the GrowOff produced lettuce with imported and domestically produced lettuce from field and greenhouse farms. GrowOff scenarios labeled with 'GrowOff'**

GHG emissions for basil are also compared with conventionally produced basil from open-field production in Italy and for basil produced in a Swedish greenhouse, based on a recent study by Martin et al. (2023). The results from this study are again lower than the conventionally sourced varieties.

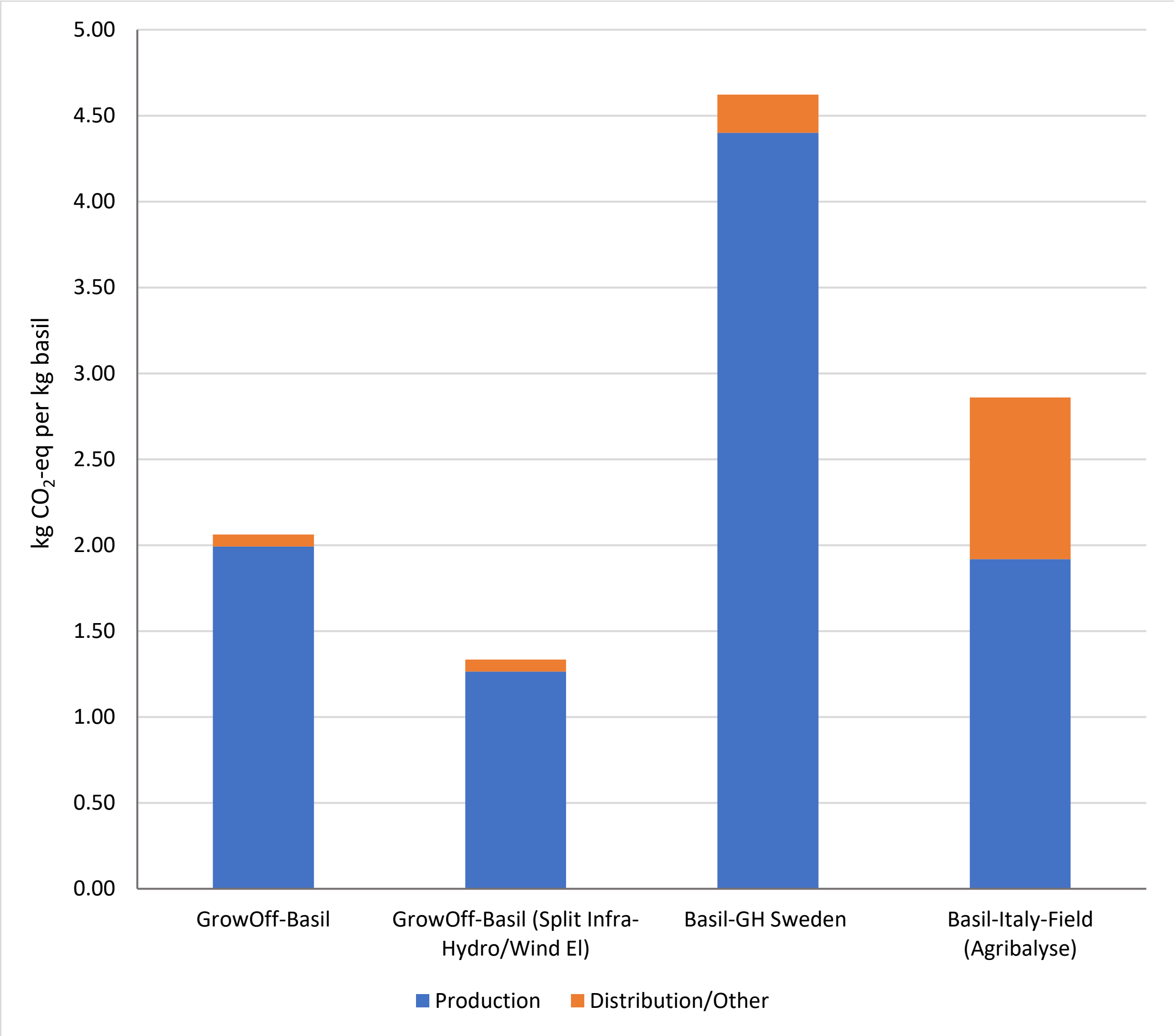


**Figure 7: Comparison of the GHG emissions for the GrowOff produced basil with imported and domestically produced basil from field and greenhouse production**

# Conclusions

This study has assessed the environmental performance of lettuce and basil production the GrowOff modular vertical farm by Grönska. It was found that the GrowOff modular vertical farm can provide a sustainably viable option for provisioning of local lettuce and herbs. The impacts for lettuce production were between 0.6 and 1 kg $CO_2$-eq per kg edible lettuce, which is competitive to imported and domestically sourced lettuce. Furthermore, the basil impacts were between 1 and 2 kg $CO_2$-eq per kg which are also below those of imported and domestic production.

The results provide insights to both producers of vertically farmed products in modular and local production systems on the potential sustainability of these systems. It also highlights the sensitivity to methodological choices made in the environmental life cycle assessment. Furthermore, it stresses the importance of the energy system for the overall impacts of the system, which gives further support to end-users of the GrowOff modules.

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