LIFE CYCLE ASSESSMENT

NEXT GENERATION DELIVERY

HIVED

SUSTAINABLE LAST MILE DELIVERY
&
CIRCULAR LOGISTICS MODEL

As the first European venture capital fund, Planet A relies on its own scientific team to assess the environmental and climate impact of an innovation. Prior to an investment, a life cycle assessment, like this one, is conducted and integral part of the investment decision. All assessments as well as the methodology are published for maximum transparency.

This report consists of two parts.

Part I: LCA on HIVED's last mile delivery (p. 3 to 20 of this document). The LCA study conducted pre-investment by Planet A covers HIVED's sustainable delivery service.

Part II: LCA on HIVED's circular logistics model (p. 21 to 41 of this document). The LCA study assesses a new circular logistics model introduced by HIVED in 2025.

LIFE CYCLE ASSESSMENT

NEXT GENERATION DELIVERY

HIVED

SUSTAINABLE LAST MILE DELIVERY

As the first European venture capital fund, Planet A relies on its own scientific team to assess the environmental and climate impact of an innovation. Prior to an investment, a life cycle assessment, like this one, is conducted and integral part of the investment decision. All assessments as well as the methodology are published for maximum transparency.

Terminology and abbreviations

B2C	business-to-customer
CED_f	Cumulative fossil energy demand
CO_2-eq.	Carbon dioxide equivalents
Functional unit	Quantified performance of a product system for use as a reference unit
GHG	Greenhouse gas
GWP	Global warming potential
ICE	Internal combustion engine
LCA	Life Cycle Assessment
UK	United Kingdom

About HIVED

HIVED offers the next generation of efficient delivery services and logistics, reducing costs and congestion while drastically reducing delivery time and lowering emissions. The London-based startup offers a vertically integrated end-to-end approach for parcel delivery using decentralized sorting mini-hubs. HIVED additionally developed a proprietary AI-powered last-mile routing software.

Summary

The quantity of delivered parcels has been increasing in recent years and is predicted to substantially increase in the coming years. Incumbent players try to lower their environmental impact, but research shows that efforts are insufficient to meet climate targets. Aside from climate change, cities face additional challenges arising from ever increasing volumes of parcels: traffic congestion, local tailpipe emissions and noise. HIVED offers an alternative, more sustainable business model. HIVED's last mile delivery alleviates these pressures and our LCA shows that HIVEDs approach **can result in a net reduction in GHG emissions of 0.13 to 0.17 kg CO_2-eq. and a reduction in fossil energy demand of 2.14 to 2.85 MJ per parcel delivered. The individual methods of parcel delivery offered by HIVED result in a net decrease in GHG emissions ranging from 56 to 76%.** In addition, HIVED's business model includes strategies to enable circular business models. A literature review reveals that this approach will ultimately result in a further reduction in GHG emissions as well as resources needed and wastes to be handled.

About this study

This study assesses the impact of last mile parcel delivery. In Part I, the status quo of last mile delivery is discussed. In Part II, a life cycle assessment (LCA) is presented assessing the impact of switching from conventional parcel delivery to a more sustainable parcel delivery model. Lastly, additional aspects of HIVED's business model affecting sustainability of last mile parcel delivery are discussed in Part III.

Table of content

1. Part I: Current status of the parcel delivery system and last mile delivery

1.1. Current status of parcel delivery

Over the last years the global parcel delivery market has increased significantly, with 159 billion packages being shipped across 13 major markets in 2021 (Pitney Bowes 2021), with a forecast of 256 billion packages shipped globally by 2027 (Statista 2022). Europe saw a 13% revenue growth in 2021 (Effigy Consulting 2021), reaching 88 billion euros with the B2C (business-to-customer) segment soaring. A combined growth in internet based services and an increase in international trade across regions has led to an exploding demand for delivery services. One of the factors contributing to this increase has been the Covid-19 pandemic, which has caused the e-commerce sector to see a substantial rise in parcel shipping volumes.

Large courier companies are now trying to cut emissions in every step of the delivery process, to meet net zero targets by 2050. Achieving net zero operations involves increasing alternative fuels for heavy goods vehicles, generating and purchasing 100% renewable electricity, reducing heating fuel usage, as well as fleet electrification and route delivery efficiency increases. Big industry names like Amazon and UPS have purchased over 100,000 (Amazon 2022) and 10,000 (UPS 2020) electric vehicles respectively. Many other players have also pledged to become net zero by 2050, however their lack of rapid EV adoption and clean energy consumption indicates otherwise. Current efforts are insufficient to meet climate change targets and to alleviate other pressures exerted by last mile delivery (Somo 2021; World Economic Forum 2020). Royal Mail (UK), DPD (EU) and DHL (global) report an increase in net GHG emissions of 28, 11 and 17% from 2020 to 2021, respectively. At the same time, Royal Mail and DPD managed to reduce the carbon intensity by 1.9 and 2.6% only (DPD Group 2021; Royal Mail plc 2020, 2021). The carbon intensity of DHL goods delivered as well as absolute carbon emissions increased; the latter by 17% from 2020 to 2021[1] (Deutsche Post DHL Group 2023). These numbers indicate that despite efforts to reduce emissions, absolute GHG emissions are increasing.

1.2. Last mile delivery

In the past decade e-commerce has risen significantly due to several factors such as urbanization and a wider range of products available to be bought online. Combined with a growth in the space of delivery services, demand for last-mile delivery is soaring and is expected to grow by 78% globally by 2030 (World Economic Forum 2020). Last mile delivery refers to the last step of the delivery process in which a parcel is delivered to its final destination from the transportation hub. Compared to the total journey of a parcel, the last mile portion of delivery logistics covers a fraction of it. However, it represents 40 - 50% of a shipment's total cost and is the most time consuming step (Greg Higgs 2022). Moreover, last mile emissions can account for up to 50% of total GHG emissions of parcel delivery. Using fossil-fueled vehicles with internal combustion engines (ICE) combined with inefficient route planning, outdated technologies and reverse logistics, exacerbates emissions.

The negative impacts of last mile delivery are more severe in urban areas and large cities. Due to traffic congestion and increase of delivery vehicles, they face increasing greenhouse gas (GHG) emissions. Interventions and different delivery strategies implemented will play a major role in reducing the total emissions of last mile delivery. Changing to electric vehicles and involving customer movements such

[1] Most recent numbers show a decrease from 2021 to 2022 in absolute terms. However, the 2022 emission level is still about 10% higher than 2021 and 11% higher than the 2019 level.

as using lockers are potential interventions that can reduce impact. Last mile delivery allows the use of electric vehicles due to shorter distances required to be traveled. Specifically, electric cargo bikes have become popular in the last mile delivery, with the electric cargo bike market expected to achieve 1,935 million Euros by 2030 (Acumen Consulting 2022). Also, last leg changes also affect economics and impacts of last mile deliveries. One option is centralized dispatching in which deliveries are dispatched from a single hub location. In this strategy, delivery vehicles usually follow a singular route in which parcels are dropped off consecutively. Even though this system lowers operation costs, it can lead to high delivery times for destinations that are further away. Another mode of delivery is that of decentralized dispatching, which involves several depots and dispatchers in multiple locations. This strategy can lower delivery times significantly and if combined with optimized routes, lowers overall GHG emissions by using greener transportation such as bikes. Decentralized dispatching is optimal in high population density areas, where there are many deliveries per stop and the distance between stops is short.

Large retail, e-commerce and parcel delivery companies have become aware of the negative environmental effects of their business models and have set their own emissions targets. Fleet electrification, adoption of two wheel and three wheeler vehicles and investing in logistical planning have been the most common actions taken. Royal mail has set a net zero emission target by 2040 and has plans on rolling out more electric vans for final mile deliveries, with 5,500 vans by spring 2023 (Royal Mail 2022). Deutsche Post DHL Group works on electrifying its fleet. By the end of 2020, the company's fleet comprised just over 15,000 electric vehicles, equalling 14.5 percent of their entire fleet (Somo 2021). DPD has achieved an all electric fleet in 10 UK cities (DPD 2022). Hermes falls behind by having ordered 168 fully electric delivery vans and committing to going full electric (Hermes 2021). This indicates that conventional ICE vehicles are still the most common method of last mile delivery and even though efforts are being made, adoption rates and progress is lagging and companies need to accelerate their efforts, if they want to meet their targets (Somo 2021; World Economic Forum 2020). Moreover, there are a number of issues along the sector which are not taken into account such as Scope 3 emissions related to the environmental impact of the production of vehicles and components used.

2. Part II: LCA of last mile delivery

HIVED's last mile delivery system is likely to displace conventional parcel delivery. The aim of this LCA study is to assess the potential systemic changes of switching from conventional parcel delivery to HIVED. This approach follows a consequential LCA approach, seeking to assess (marginal) changes in environmental impact as a consequence of a change in the entire system (Ekvall et al. 2016). To account for marginal changes, marginal data is used wherever possible, e.g. marginal suppliers are identified and the change in their production output is considered (in contrast to using market averages).

2.1. System description

At present, parcel delivery is mainly accomplished using fossil-fueled ICE vehicles. HIVED offers last mile parcel delivery services using only renewable energy and zero emission vehicles. The assessment therefore compares conventional last mile delivery with HIVED's business model and assesses the net benefit of displacing the former by the latter. A key challenge in the assessment arises from the lack of first hand data of incumbent players. There is no data on current last mile delivery, such as location of warehouses and depots, routing, vehicles used, distance per parcel traveled, fuel consumptions under real world conditions etc., available. Therefore, we followed the methodology used by (Shahmohammadi et al. 2020). A literature review was conducted to obtain the most comprehensive sample of the most crucial parameters under real world conditions. Based on these, a parameterized model was developed and a Monte-Carlo simulation was conducted to assess most likely ranges of impacts for each last-mile delivery option. In total, four different options were considered with different vehicles types for each leg of the delivery process (Figure 1):

1) **Conventional last mile delivery**
    - warehouse → local depot: fossil-fueled ICE truck
    - local depot → delivery zone:fossil-fueled ICE delivery van
    - delivery: ICE delivery van
2) **Last mile delivery using electric vans (HIVED)**
    - warehouse → local depot: electric van
    - local depot → delivery zone: electric van
    - delivery: electric van
3) **Last mile delivery using electric vehicles (HIVED)**
    - warehouse → local depot: electric van
    - local depot → delivery zone: electric car
    - delivery: electric car
4) **Last mile delivery using electric cargo bikes (HIVED)**
    - warehouse → local depot: electric van
    - local depot → delivery zone: electric van
    - delivery: electric cargo bike

The functional unit used to assess the impact of HIVED is one parcel delivered in a metropolitan area, such as London. The impact is assessed using the indicators **global warming potential** (GWP) (Masson-Delmotte et al. 2021) and **cumulative fossil energy demand** (CED_f) (Verein Deutscher Ingenieure (VDI) (ed.) 2012). The results are expressed for each individual method of parcel delivery and as a net change in emissions, if conventional parcel delivery (option 1) is replaced by alternative methods (options 2-4 above).

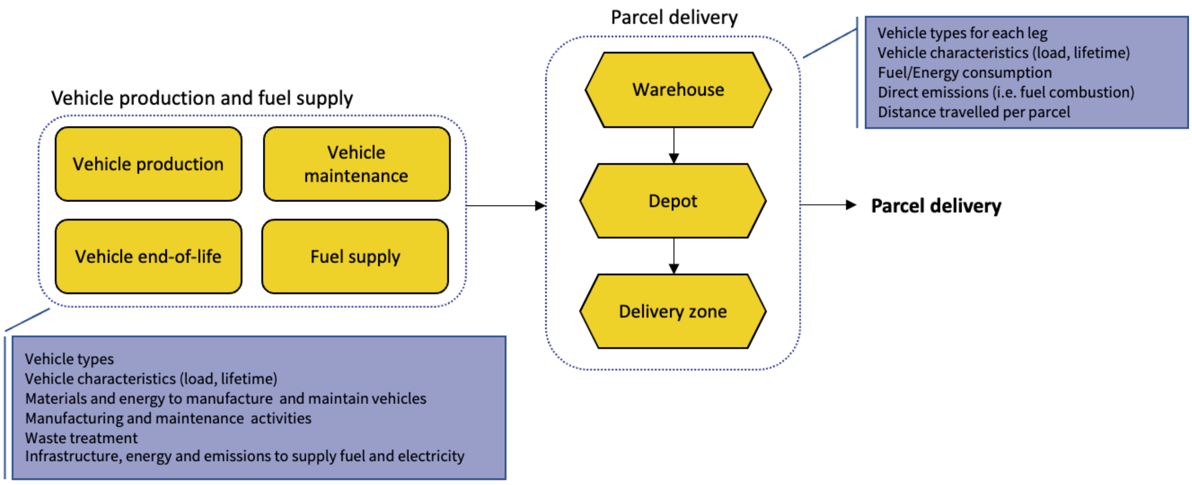


Figure 1 *Assessed system and most important parameters (blue boxes). The key components of the system are the vehicles used to deliver the parcel, fuel supply and the parcel delivery itself. The last mile parcel delivery system consists of transportation from a warehouse to a local depot and from a local depot to the delivery zone where the final parcel delivery takes place.*

2.2. Life cycle inventory

In the following sections, we explain the data used to model the impact of HIVED. Most crucial parameters were defined as probability distributions using most likely parameter ranges. If not stated otherwise, uniform distributions were used. The uncertainty related to input data was modeled using the ecoinvent pedigree matrix in all cases in which no parameter range is specified explicitly in the text (Ciroth et al. 2016).

2.2.1. Vehicles, fuel and electricity supply

Primary vehicle data of commercially available vehicles was used to model the vehicle production of the ICE van, the electric van and the e-cargo bike (Temporelli et al. 2022)[2]. The ICE truck and electric car were modeled using data provided by the ecoinvent database 3.8 (Wernet et al. 2016). The mean lifetime of the different vehicle types is 540,000 km (ICE truck), 240,000 km (ICE and electric vans), 150,000 km (electric car) and 33,620 km (electric cargo bike). All electric vehicles use lithium ion batteries. The energy density of lithium ion batteries is 250 (200 to 300) kWh/kg and a capacity 150 (30 to 300 kWh) and 75 (50 to 100) kWh in case of an electric van and an electric car, respectively (BloombergNEF 2021; Link and Plötz 2022). The fossil fuel supply was modeled with the ecoinvent database (Wernet et al. 2016). The different load capacities of vehicles is accounted for by assuming a parcel weight of 1 kg (0.5 to 10 kg, triangular distribution) and considering the load capacity of each vehicle type as listed in Table 2. Additionally, the distance covered per parcel varies per delivery method. This implicitly includes a difference in transport requirements per parcel to be delivered (e.g. longer distances to be covered with vehicles with lower carrying capacities).

HIVED operates in London (UK) and uses only electricity from renewable sources. The switch from fossil fuels to electricity from renewable sources results in a net increase in demand for electricity from renewable sources. A marginal electricity mix was constructed using current and planned generation capacities of electricity from renewable sources (Table 1).

[2] All data is available in the supplementary material on the journal's website (Temporelli et al. 2022).

Table 1 *Key parameters of the marginal supply mix of electricity from renewable sources. Data obtained from (Forrester 2022; UK Government (ed.) 2022)*.

	Capacity [GW]			
	2022	**2035**	**Load factor**	**Marginal mix**
Offshore wind	11.3	45	40.2%	59%
Onshore wind	14.5	35	26.3%	23%
Solar PV	13.8	54	10.0%	18%

2.2.2. Parcel delivery

The key parameters of parcel delivery depend on many variables, such as the number of parcels delivered, the density of customers, the location of warehouses, depots and customers, the routing, local traffic conditions, etc. Due to a high uncertainty in all of these variables and the lack of first hand data of incumbent parcel delivery companies, a literature review was conducted and parameter ranges for most important parameters were defined (Table 2). Notably, the distance traveled per parcel is longer for electric vehicles. This finding revealed by the literature review is confirmed by other scientific publications, cf. literature cited in (Patella et al. 2020). Based on Shahmohammadi et al. (2020), a transport distance from the warehouse to the depot is 100 (50 to 250) km is assumed.

Table 2 *Key parameters of last mile parcel delivery. Parameter ranges defined based on data obtained from HIVED and* (Shahmohammadi et al. 2020; Elbert and Friedrich 2020; Fraselle, Limbourg, and Vidal 2021; Gonzalez-Calderon et al. 2022; Groot et al. 2017; Krause et al. 2020; Llorca and Moeckel 2021; Nielsen and Jørgensen 2023; Stolaroff et al. 2018; Temporelli et al. 2022; Weiss, Cloos, and Helmers 2020; Browne, Allen, and Leonardi 2011).

	Conventional ICE Van	Electric vehicles	Electric cargo bike
Distance per parcel [km/parcel]			
Min	0.15	0.27	0.42
Max	0.80	1.28	1.00
Average	0.36	0.59	0.71
Fuel/electricity consumption [MJ/ km]			
Min	2.51	0.79	0.03
Max	4.60	1.08	0.34
Average	3.69	0.91	0.11
Weight [t]			
Min	1.35	1.54	0.05
Max	2.80	2.80	0.36
Average	2.10	2.10	0.17
Load volume [m^3]			
Min	3.60	3.00	1.00
Max	12.00	12.00	2.00
Average	7.80	7.80	1.58
Load weight [kg]			
Min	700.00	445.00	18.50
Max	1000.00	1000.00	300.00
Average	875.50	875.50	197.70

2.3. Results

All delivery methods using electric vehicles perform better than conventional parcel delivery using ICE vehicles (Figure 2). **The last mile parcel delivery results in average GHG emissions of 0.22, 0.08, 0.10 and 0.05 kg CO_2-eq. per parcel if the parcel is delivered with conventional ICE vans, electric vans, electric cars and electric cargo bikes, respectively** (Table 3). **Thus, electric parcel delivery emits between 56 and 76% less GHG emissions than conventional parcel delivery.** The average fossil energy required to deliver a parcel is 3.43, 0.66, 1.22, 0.59 MJ per parcel delivered with conventional ICE vans, electric vans, electric cars and electric cargo bikes, respectively. **The displacement of conventional last mile parcel delivery results in net reductions in GHG emissions of 0.13 to 0.17 kg CO_2-eq. and reductions in fossil energy demand of 2.14 to 2.85 MJ per parcel delivered.** The cargo bike performs best among all options despite longer distances covered per bike. The low weight of the bike, very low emissions of the bike manufacturing and low energy consumption are the main reasons for the good performance of the electric cargo bike. The electric car results in the highest emissions among the electric vehicles due to the comparably low load capacity and a higher electricity consumption per parcel delivered and more emissions resulting from the vehicle manufacturing.

It is important to note that in contrast to conventional parcel delivery vehicles, smaller electric vehicles do not emit local tailpipe emissions, such as particulate matter, nitrogen oxides, etc. The noise emitted by electric vehicles is substantially lower than by ICE vehicles. In addition, small vehicles, such as cargo bikes can reduce the curb-side occupation and reduce traffic in urban areas.

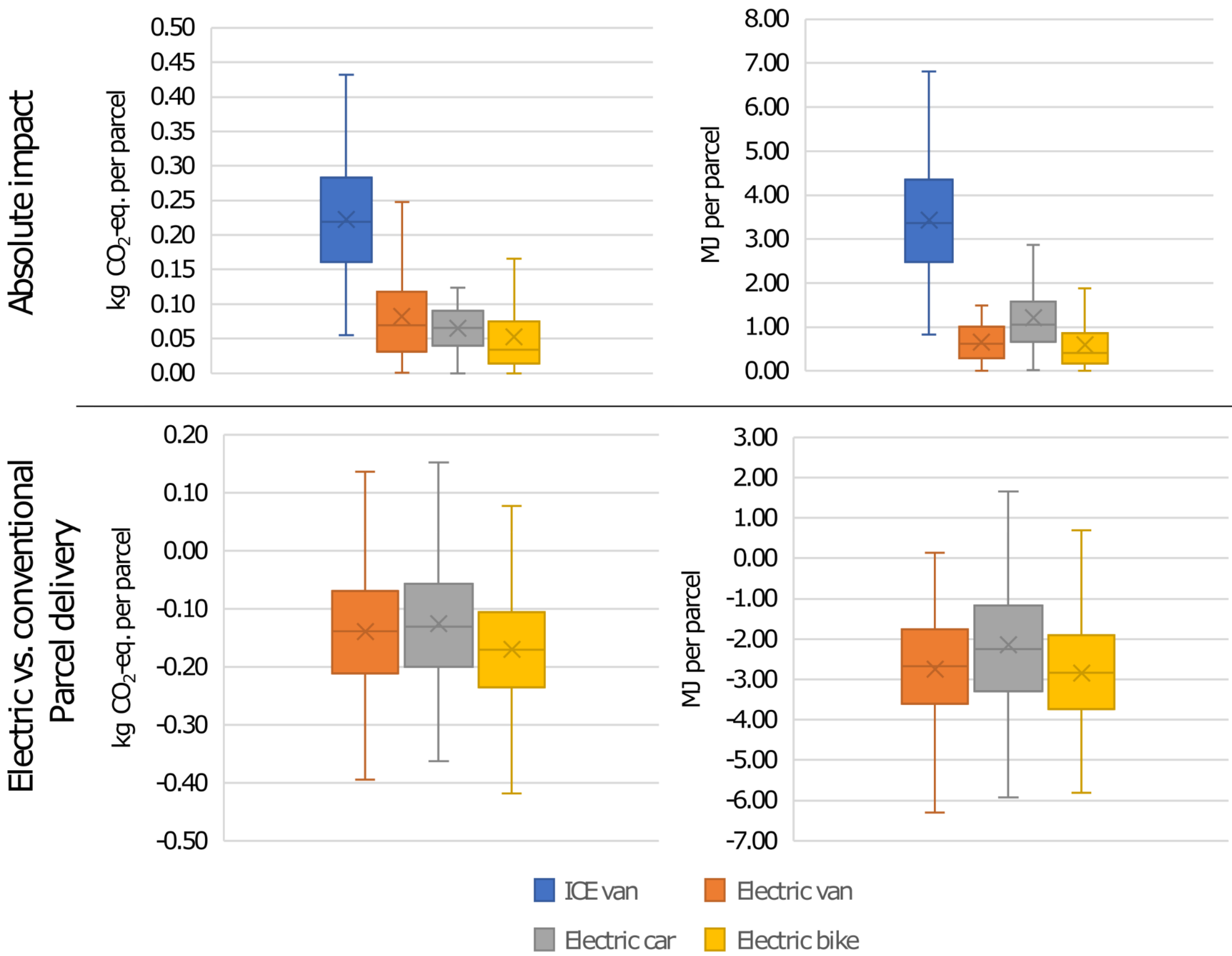


***Figure 2** Top: GHG emissions and fossil energy demand of last mile parcel delivery in kg CO_2-eq. and MJ per parcel. Bottom: Net change in GHG emissions and fossil energy demand if conventional parcel delivery is replaced by electric parcel delivery.*

Table 3 *Results of the Monte-Carlo simulations showing GHG emissions (GWP) and fossil energy demand (CED_f) of last mile parcel delivery. The upper half of the table shows absolute emissions per delivery method. The lower half shows the net change in emissions if conventional parcel delivery is displaced by electric delivery methods.*

	Indicator	**Vehicle**	**Median**	**Average**	**Std. dev.**	**5% Percentile**	**95% Percentile**
Absolute	GWP	Conv. ICE van	0.22	0.22	0.08	0.10	0.36
		Electric van	0.07	0.08	0.06	0.01	0.21
		Electric car	0.08	0.10	0.07	0.02	0.24
		Electric cargo bicycle	0.03	0.05	0.05	0.00	0.17
	CED_f	Conv. ICE van	3.37	3.43	1.24	1.54	5.52
		Electric van	0.63	0.66	0.42	0.04	1.38
		Electric car	1.06	1.22	0.78	0.25	2.79
		Electric cargo bicycle	0.41	0.59	0.56	0.04	1.75
Net change	GWP	Electric van	-0.14	-0.14	0.10	-0.30	0.03
		Electric car	-0.13	-0.13	0.11	-0.29	0.05
		Electric cargo bicycle	-0.17	-0.17	0.09	-0.32	-0.02
	CED_f	Electric van	-2.67	-2.75	1.32	-4.93	-0.78
		Electric car	-2.25	-2.14	2.65	-4.58	0.19
		Electric cargo bicycle	-2.83	-2.85	1.30	-5.08	-0.86

2.4. Limitations

There are several limitations in this study that havent been addressed but influence the final results:

- Data: Data used in this study stems from scientific literature and other reports. It therefore comprises specific case studies on last mile delivery and vehicles. Over time, vehicle characteristics and manufacturing processes change. Additionally, there is no first hand data of routing of incumbent players available. All these parameters change over time. This shortcoming cannot be overcome. In order to account for this uncertainty, the Monte-Carlo simulation was chosen as the most appropriate modeling approach.
- Modeling approach: Due to the lack of first-hand data of last mile parcel delivery accomplished by incumbent players as well as due to the high flexibility of how the future parcel delivery of HIVED and the incumbent players will look like, a Monte-Carlo simulation using a wide range of scientific literature was chosen as the most appropriate approach. The advantage of this approach is that even if the system is largely unknown, impacts can be determined based on the data available. The results show the likely range of potential impacts of last mile parcel delivery. Yet, it is not a representation of the exact system in place at a specific location.
- Several aspects were not considered in this study:

  - Delivery failures: It is estimated that delivery failures amount to up to 14% of parcels delivered (Allen et al. 2018). These parcels require additional delivery attempts or are either returned to the sender or sent to a central facility (e.g., a locker box or a pickup store) to be picked up. Again, data of incumbent players is missing. Thus, this aspect was excluded from the assessment.
  - Efficient routing: HIVED uses efficient routing and microhubs to decrease stem mileage and to allow a more efficient parcel delivery (see below). Since routing of incumbent players is missing, this aspect was not modeled explicitly. Yet, the data used in the model contains studies with microhubs and a wide range of efficiencies. Therefore, these aspects are implicitly included in the model.
  - Calories burned because of manual effort: Walking (in all cases) and cycling (electric cargo bike) require physical activity. The additional physical activity results in an increase in calories needed. The provision of additional nutrition to compensate for the increase in energy expenditure is not accounted for in this study.
- The role of incumbent players: Incumbent players already implement strategies to lower GHG emissions and to alleviate other pressures caused by them. However, research shows that these efforts are insufficient to reach international climate targets. A fundamental shift away from all conventional parcel delivery is required (regardless if this is done by HIVED or the incumbents). The results shown in this study refer to a shift from conventional, fossil-fueled ICE parcel delivery to more sustainable vehicles. If HIVED gains market shares from incumbent players, they will also displace the (small) share of sustainably delivered parcels by these incumbent players. In such a case, the impact depends on the characteristics of each delivery model. Due to the lack of data (see above), such a case cannot be assessed in detail. Instead, the easiest way to get a rough estimate, is to assume a certain share of sustainable parcel delivery conducted by incumbent players and to subtract this share from the net change in impacts estimated in this study. E.g., if a 15% share of parcel delivery by electric vehicles is assumed, the estimated impact is 15% lower than estimated here (neglecting system efficiencies, vehicles used, routing etc., all of which cannot be accounted for due to the lack of data).

3. Part III: Additional aspects of HIVED’s business model affecting the environmental impact of parcel delivery

In addition to the aspects covered by the LCA, HIVED’s business model implements several aspects that improve the status quo of existing last mile delivery.

3.1. Improvements in last mile delivery logistics

HIVED covers a distinct number of contiguous areas with a high delivery density (parcels per km^2). In addition, HIVED uses micro-hubs and sequential routing to allow efficient routing. This allows the use of small electric vehicles, such as cargo bikes and reduces stem journeys. Additionally, microhubs can be replenished at night or in times of low traffic. All these methods combined result in less traffic and lower emissions compared to conventional last mile delivery (World Economic Forum 2020).

3.2. Circular economy

HIVED’s long term vision is to enable a truly circular economy by leveraging the density of their network. By building an a logistics network to enable a reliable and cost efficient circular movement of goods and items to and from individual addresses. Our economy is currently dependent on the traditional take-make-consume-dispose approach. This linear model relies on the extraction of raw materials, manufacturing of products and disposal of waste in an unsustainable manner, leading to resource depletion, pollution, waste generation as well as loss of biodiversity. To mitigate the environmental damage caused by this approach, the circular model is able to create a closed loop system that supports sustainable economic growth. Figure 3 below summarizes the two approaches.

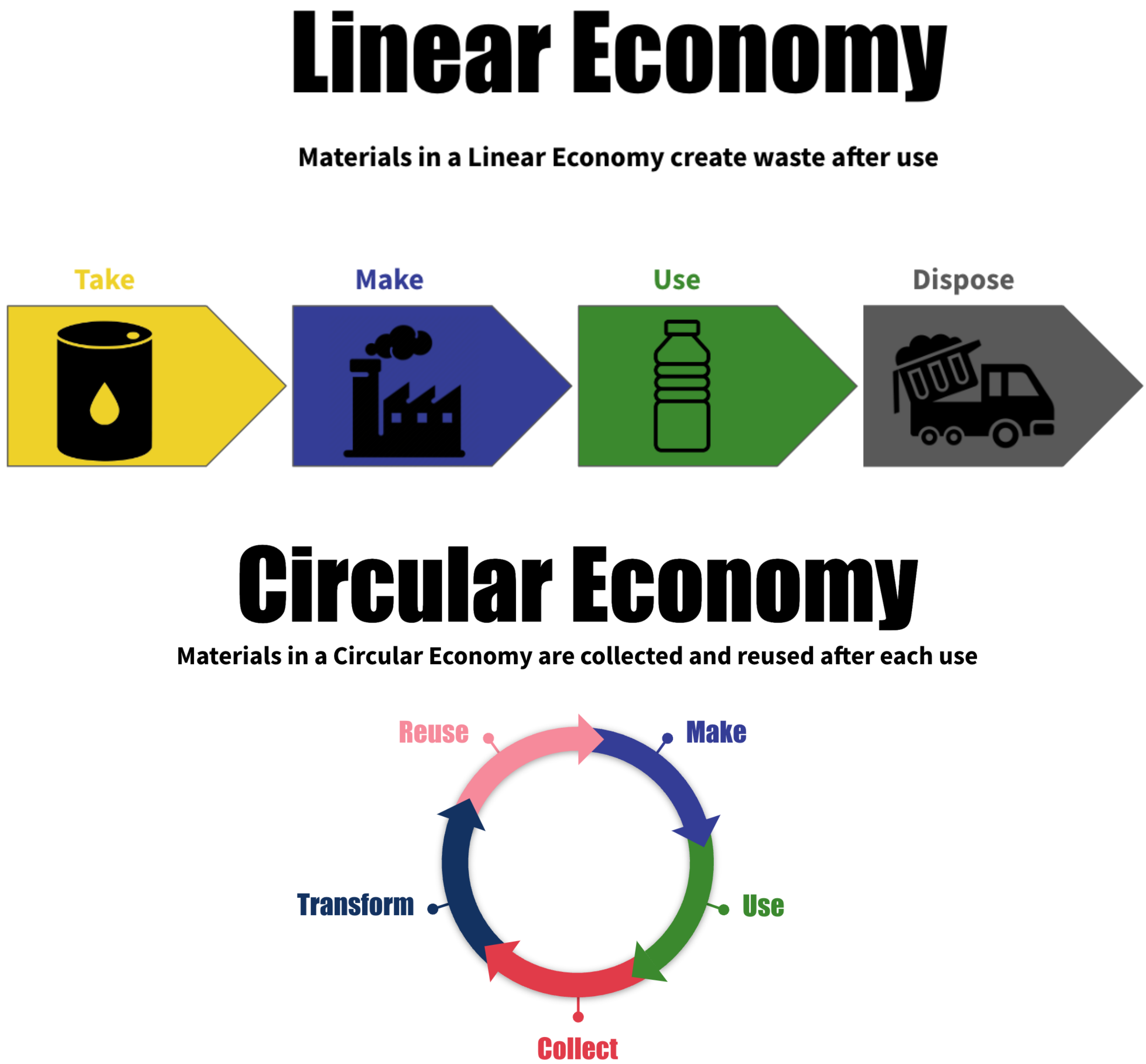


Figure 3 *Linear vs Circular Economy schematics.*

Increasingly more research is undertaken to refine our understanding of the concept of circular economy and demonstrate the possibilities of a sustainable production-consumption culture (Korhonen, Honkasalo, and Seppälä 2018). However, only a limited number of countries have taken action towards adopting more circular economy models and many researchers are expressing the need for stronger commitments (Vania Ivanova and Sonia Chipeva 2019). New policies and players will have to enter the market to enable the adoption of such circular models along the value chain. One of the most important ones is transportation, which plays a critical role and is responsible for the continuous

movement of goods between the different circularity stages. HIVED is positioned well to fit into such a model and tackle different industries.
To date, there is no study available assessing multiple circular business models. This is due to the novelty of the topic, as well as the very case specific conditions resulting from the business models as well as local conditions. Table 4 below summarizes a list of assessments on individual circular business models and comparing them with linear models.

Table 4 *Circular economy case studies.*

Study	Case study	Results
(Emma Johnson 2020)	Rental clothing	Consistent benefit in freshwater, marine and human carcinogenic toxicity
(Schwarz et al. 2021)	Recycling of plastics	80% GHG emission reduction
(Kerdlap, Gheewala, and Ramakrishna 2021)	Pram rental	29-46% lower impact between all environmental impact categories
(Yoon-Young Chun and Kun-Mo Lee 2017)	Water purifier rental	32-37% improvements in selected environmental impact categories
(Pérez-Martínez et al. 2021)	Repurposed electronic equipment	25-80% less environmental impact in selected categories
(Tua, Grosso, and Rigamonti 2020)	Reconditioning glass bottles	30-65% better environmental performance in selected environmental impact categories

HIVED's business model strongly focuses on the enablement of circular business practices. This will enable others to operate circular business models, resulting in lower GHG emissions, lower resource demand and less wastes generated.

4. Conclusion

The volume and quantity of delivered parcels has been increasing in recent years and is predicted to substantially increase in the coming years. Urban environments suffer from noise, GHG emissions and tail-pipe emissions of other pollutants (e.g. particulate matter, NOx, etc.) caused by higher freight volumes and increasing traffic. Alternative business models in the parcel delivery sector are needed to alleviate these pressures. HIVED offers a more sustainable approach to last mile delivery. **The LCA shows that last mile delivery with electric vehicles can result in a net reduction in GHG emissions and fossil energy demand ranging from 0.13 to 0.17 kg CO_2-eq. and 2.14 to 2.85 MJ per parcel delivered, respectively.** HIVED's business model includes additional aspects, such as efficient routing, the use of microhubs and the enablement of circular business models. These aspects result in additional benefits, such as lower GHG emissions, lower emissions of other pollutants as well as less wastes and material use.

5. References

Acumen Consulting. 2022. *Electric Cargo Bike Market Size*. https://www.globenewswire.com/news-release/2022/08/29/2506309/0/en/Electric-Cargo-Bike-Market-Size-Will-Achieve-USD-2-042-Million-by-2030-growing-at-13-7-CAGR-Exclusive-Report-by-Acumen-Research-and-Consulting.html.

Allen, J. et al. 2018. "Understanding the Impact of E-Commerce on Last-Mile Light Goods Vehicle Activity in Urban Areas: The Case of London." *Transportation Research Part D: Transport and Environment* 61: 325–38.

Amazon. 2022. "Amazon's Electric Delivery Vehicles from Rivian Roll out across the U.S." https://www.aboutamazon.com/news/transportation/amazons-electric-delivery-vehicles-from-rivian-roll-out-across-the-u-s.

BloombergNEF. 2021. "Battery-Cell Energy Density." https://cleantechnica.com/2020/02/19/bloombergnef-lithium-ion-battery-cell-densities-have-almost-tripled-since-2010/.

Browne, Michael, Julian Allen, and Jacques Leonardi. 2011. "Evaluating the Use of an Urban Consolidation Centre and Electric Vehicles in Central London." *IATSS Research* 35(1): 1–6.

Ciroth, Andreas, Stéphanie Muller, Bo Weidema, and Pascal Lesage. 2016. "Empirically Based Uncertainty Factors for the Pedigree Matrix in Ecoinvent." *The International Journal of Life Cycle Assessment* 21(9): 1338–48.

Deutsche Post DHL Group. 2023. *We Keep Delivering. 2022 Annual Report*. Bonn.

DPD. 2022. "DPD UK." https://www.geopost.com/en/news/dpduk-electric-delivery/.

DPD Group. 2021. *Sustainability Report 2021*.

Effigy Consulting. 2021. "EUROPEAN CEP MARKET REPORT." https://www.effigy-consulting.com/cep-market-report/.

Ekvall, Tomas et al. 2016. "Attributional and Consequential LCA in the ILCD Handbook." *The International Journal of Life Cycle Assessment* 21(3): 293–96.

Elbert, Ralf, and Christian Friedrich. 2020. "Urban Consolidation and Cargo Bikes: A Simulation Study." *Transportation Research Procedia* 48: 439–51.

Emma Johnson. 2020. "Dressing up the Environmental Potential for Product-Service Systems: A Comparative Life Cycle Assessment on Consumption in Rental Clothing vs. Linear Business Models." https://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=9025941&fileOId=9025943.

Forrester, Chloe. 2022. "Where Will Britain's Future Energy Supply Come from?" *House of Commons Library - UK Parliament*. https://commonslibrary.parliament.uk/where-will-britains-future-energy-supply-come-from/ (May 5, 2023).

Fraselle, Justin, Sabine Louise Limbourg, and Laura Vidal. 2021. "Cost and Environmental Impacts of a Mixed Fleet of Vehicles." *Sustainability* 13(16): 9413.

Gonzalez-Calderon, Carlos A. et al. 2022. "Cargo Bicycles as an Alternative to Make Sustainable Last-Mile Deliveries in Medellin, Colombia." *Case Studies on Transport Policy* 10(2): 1172–87.

Greg Higgs. 2022. *Revealing the Secret of Emissions of E-Commerce*. https://clean-mobility.org/wp-content/uploads/2022/07/SRG_Last_Mile-FINAL.pdf.

Groot, Cornelis Hofstede de et al. 2017. "Users and Deployment of Delivery Vans in the Netherlands."

Hermes. 2021. "Hermes Commits to Electric Vehicles for the Road Ahead." https://www.evri.com/press/hermes-uk-commits-to-electric-vehicles-for-the-road-ahead.

Kerdlap, Piya, Shabbir H. Gheewala, and Seeram Ramakrishna. 2021. "To Rent or Not to Rent: A Question of Circular Prams from a Life Cycle Perspective." *Sustainable Production and Consumption* 26: 331–42.

Korhonen, Jouni, Antero Honkasalo, and Jyri Seppälä. 2018. "Circular Economy: The Concept and Its Limitations." *Ecological Economics* 143: 37–46.

Krause, Jette et al. 2020. "EU Road Vehicle Energy Consumption and CO2 Emissions by 2050 –

Expert-Based Scenarios." *Energy Policy* 138: 111224.
Link, Steffen, and Patrick Plötz. 2022. "Technical Feasibility of Heavy-Duty Battery-Electric Trucks for Urban and Regional Delivery in Germany—A Real-World Case Study." *World Electric Vehicle Journal* 13(9): 161.
Llorca, Carlos, and Rolf Moeckel. 2021. "Assessment of the Potential of Cargo Bikes and Electrification for Last-Mile Parcel Delivery by Means of Simulation of Urban Freight Flows." *European Transport Research Review* 13(1): 33.
Masson-Delmotte, Valérie et al. 2021. 2 *Climate Change 2021: The Physical Science Basis*. Intergovernmental Panel on Climate Change (IPCC).
Nielsen, Lars, and Kaj Jørgensen. 2023. "Electric Vehicles and Renewable Energy in the Transport Sector - Energy System Consequences Main Focus: Battery Electric Vehicles and Hydrogen Based Fuel Cell Vehicles."
Patella, Sergio Maria et al. 2020. "The Adoption of Green Vehicles in Last Mile Logistics: A Systematic Review." *Sustainability* 13(1): 6.
Pérez-Martínez, M.M., C. Carrillo, J. Rodeiro-Iglesias, and B. Soto. 2021. "Life Cycle Assessment of Repurposed Waste Electric and Electronic Equipment in Comparison with Original Equipment." *Sustainable Production and Consumption* 27: 1637–49.
Pitney Bowes. 2021. *Pitney Bowes Parcel Shipping Index*. https://www.pitneybowes.com/content/dam/pitneybowes/us/en/shipping-index/pb_globalshippingindexinfographic_2021stats_final.pdf.
Royal Mail. 2022. *Net Zero*. https://www.royalmail.com/sustainability/environment/net-zero.
Royal Mail plc. 2020. *Corporate Responsibility Report 2019-20*.
———. 2021. *Corporate Responsibility Report 2020-21*.
Schwarz, A.E. et al. 2021. "Plastic Recycling in a Circular Economy; Determining Environmental Performance through an LCA Matrix Model Approach." *Waste Management* 121: 331–42.
Shahmohammadi, Sadegh et al. 2020. "Comparative Greenhouse Gas Footprinting of Online versus Traditional Shopping for Fast-Moving Consumer Goods: A Stochastic Approach." *Environmental Science & Technology* 54(6): 3499–3509.
Shopify. 2022. *The Future of Commerce Trend Report*. https://enterprise.plus.shopify.com/rs/932-KRM-548/images/FOC_PDF_FA.pdf.
Somo. 2021. *Parcel Delivery on a Warming Planet*. https://www.somo.nl/wp-content/uploads/2021/12/Parcel-Delivery-on-a-Warming-Planet_Final.pdf.
Statista. 2022. "Global Parcel Shipping Volume between 2013 and 2027." https://www.statista.com/statistics/1139910/parcel-shipping-volume-worldwide/.
Stolaroff, Joshuah K. et al. 2018. "Energy Use and Life Cycle Greenhouse Gas Emissions of Drones for Commercial Package Delivery." *Nature Communications* 9(1): 409.
Temporelli, Andrea, Paola Cristina Brambilla, Elisabetta Brivio, and Pierpaolo Girardi. 2022. "Last Mile Logistics Life Cycle Assessment: A Comparative Analysis from Diesel Van to E-Cargo Bike." *Energies* 15(20): 7817.
Tua, Camilla, Mario Grosso, and Lucia Rigamonti. 2020. "Reusing Glass Bottles in Italy: A Life Cycle Assessment Evaluation." *Procedia CIRP* 90: 192–97.
UK Government (ed.). 2022. "Digest of UK Energy Statistics (DUKES). Contains Public Sector Information Licensed under the Open Government Licence v3.0." https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes (May 12, 2023).
UPS. 2020. "UPS Invests in Arrival." https://about.ups.com/ca/en/newsroom/press-releases/sustainable-services/ups-invests-in-arrival-accelerates-fleet-electrification-with-order-of-10-000-electric-delivery-vehicles.html.
Vania Ivanova and Sonia Chipeva. 2019. *TRANSITION TO A CIRCULAR ECONOMY MODEL IN THE EUROPEAN UNION – STATE AND OUTLOOK*. http://ijasos.ocerintjournals.org/en/download/article-file/800415.

Verein Deutscher Ingenieure (VDI) (ed.). 2012. “Cumulative Energy Demand (KEA) - Terms, Definitions, Methods of Calculation.” 01.040.27, 27.100(VDI 4600).
Weiss, Martin, Kira Christina Cloos, and Eckard Helmers. 2020. “Energy Efficiency Trade-Offs in Small to Large Electric Vehicles.” *Environmental Sciences Europe* 32(1): 46.
Wernet, Gregor et al. 2016. “The Ecoinvent Database Version 3 (Part I): Overview and Methodology.” *The International Journal of Life Cycle Assessment* 21(9): 1218–30.
World Economic Forum. 2020. *The Future of the Last-Mile Ecosystem*. https://www3.weforum.org/docs/WEF_Future_of_the_last_mile_ecosystem.pdf.
Yoon-Young Chun and Kun-Mo Lee. 2017. *Environmental Impacts of the Rental Business Model Compared to the Conventional Business Model: A Korean Case of Water Purifier for Home Use*. https://link.springer.com/article/10.1007/s11367-016-1227-1.

www.planet-a.com

LIFE CYCLE ASSESSMENT

NEXT GENERATION DELIVERY

HIVED

CIRCULAR LOGISTICS MODEL

As the first European venture capital fund, Planet A relies on its own scientific team to assess the environmental and climate impact of an innovation. Prior to an investment, a life cycle assessment, like this one, is conducted and integral part of the investment decision. All assessments as well as the methodology are published for maximum transparency.

Terminology and abbreviations

CED_{fossil}	Cumulative fossil energy demand
CO_2-eq.	Carbon dioxide equivalents
EOL	End-of-life
EPD	Environmental product declaration
EPP	Expanded polypropylene
Functional unit	Quantified performance of a product system for use as a reference unit
GHG	Greenhouse gas
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
m^2a	Land use: 1 m^2 used for a duration of 1 year
Sb-eq.	Antimon equivalents
UK	United Kingdom

About HIVED

HIVED offers the next generation of efficient delivery services and logistics, reducing costs and congestion while drastically reducing delivery time and lowering emissions. The London-based startup offers a vertically integrated end-to-end approach for parcel delivery using decentralised sorting mini-hubs. HIVED has additionally developed proprietary AI-powered last-mile routing software. Recently, the company introduced a circular logistics model.

About this study

HIVED provides logistics to a circular logistics model that facilitates the use of reusable packaging solutions. This study assesses the impact of switching from a linear logistics model to a circular logistics model using the example of a grocery subscription.

Summary

This prospective LCA study evaluates the environmental impacts of transitioning from a linear logistics model, which relies on single-use cardboard boxes, to HIVED's circular logistics model that utilises reusable Expanded Polypropylene (EPP) boxes for grocery subscription deliveries. The study aims to assess how this shift affects various environmental indicators.

The findings demonstrate a clear environmental advantage for the circular logistics model. Compared to the linear model, the circular model results in a net reduction across all assessed impact categories. Specifically, there is a significant net reduction in Greenhouse Gas (GHG) emissions, ranging from -0.37 to -0.96 kg CO2-eq per delivery. Additionally, the circular model shows net reductions in abiotic resource depletion, land occupation, cumulative fossil energy demand (CED_{fossil}), and water use.

The study considers factors such as the production, cleaning, and refurbishment of reusable EPP boxes, as well as the displacement of single-use cardboard boxes. Sensitivity analyses were conducted to assess the influence of parameters like the number of use cycles for EPP boxes and the return rate of cold packs, further supporting the robustness of the results.

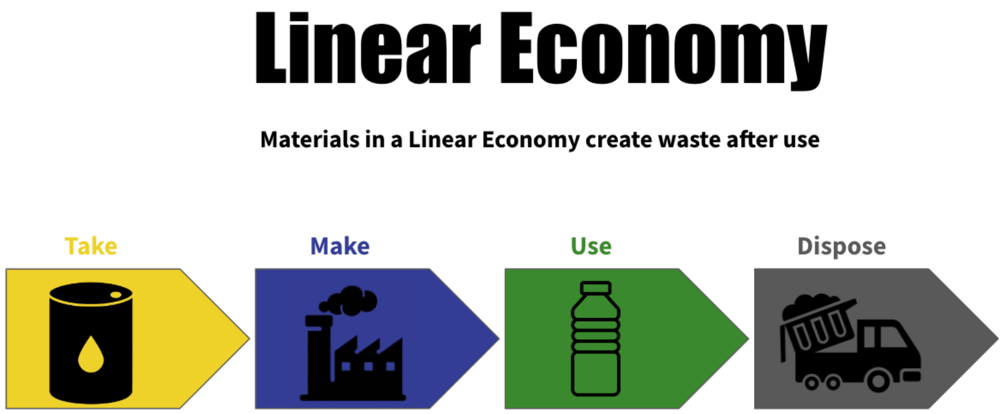
Overall, the transition to HIVED's circular logistics model represents a substantial step towards reducing environmental impacts in the e-commerce and delivery sector. By replacing single-use cardboard boxes with durable, reusable EPP boxes, HIVED minimises waste and contributes to a more sustainable and resource-efficient economy. This study provides evidence for the adoption of reusable packaging solutions as a key strategy for achieving sustainable delivery services.

Table of contents

1. Introduction

The rapid growth of e-commerce and globalised supply chains has led to a substantial increase in parcel deliveries, intensifying the demand for packaging materials. Statistics show that packaging waste amounts to nearly 187 kg per capita per year in Europe (EU27) and 186 kg in the UK (Eurostat 2024; UK Government 2024). Cardboard and paper waste accounts for the largest share of the packaging waste: 41% in the EU and 43% in the UK.

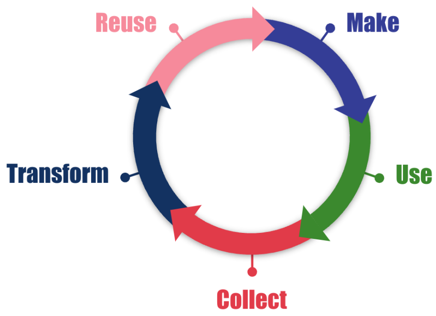
Single-use cardboard boxes, the predominant packaging choice, contribute significantly to resource depletion, greenhouse gas emissions, and waste generation. Currently, **68% and 83.2% of paper and cardboard packaging waste is recycled in the EU and the UK, respectively**, most of the remainder is incinerated. After 5-7 recycling cycles, cardboard fibres are no longer recyclable and need to be disposed of. Only around 40% of cardboard used in packaging is made from recycled fibres (Confederation of European Paper Industries (CEPI) 2024). The production of cardboard packaging is highly resource-intensive, requiring large amounts of **wood, water, and energy**, and is associated with high **carbon emissions from deforestation, pulping, and manufacturing**. In the logistics sector, these challenges are exacerbated by the short-lived nature of single-use packaging, as each parcel requires a new box, leading to a continuous cycle of material consumption and waste. Hence, while involving some degree of circularity, the existing system largely reflects a linear economy approach.



To mitigate the environmental damage caused by this approach, the circular model is able to create a closed loop system that supports sustainable economic growth. Addressing this issue necessitates innovative distribution and collection logistics. **HIVED** has introduced a new business model based on **reusable EPP boxes** to replace single-use cardboard packaging in parcel deliveries. EPP is a lightweight, durable, and highly reusable material.

Circular Economy

Materials in a Circular Economy are collected and reused after each use



To assess the environmental implications of this offering, a **consequential Life Cycle Assessment (cLCA)** is conducted. Unlike attributional LCA, which accounts for the total environmental footprint of a product system, consequential LCA focuses on processes that change due to a decision. In this case, the assessment considers the **production, cleaning, and refurbishment of reusable EPP boxes**. Additionally, the study accounts for the **displacement of single-use cardboard boxes**, ensuring that the environmental trade-offs associated with this transition are adequately captured. By identifying the potential benefits and drawbacks of this new business model, the study aims to support informed decision-making for sustainable logistics operations.

2. System description

2.1. Goal and scope

HIVED's circular logistics offering allows business customers to deliver items to consumers using reusable packaging solutions. The goal of this study is to assess how environmental impacts change in response to a shift from single-use cardboard packaging to reusable boxes. The study is intended to provide insights to Planet A to track the mission alignment and environmental implications of HIVED (one of Planet A's portfolio companies) and to HIVED and potential customers to understand the environmental implications of introducing a circular logistics model.

This study encompasses all processes that are expected to change as a result of the transition from a linear to a circular logistics model (Figure 1). The new business model will increase the demand for the packaging boxes, cleaning of these boxes as well as refurbishment and disposal. The logistics of the delivered items remain unaffected. Yet, the boxes are transported from their point of manufacturing to the depot. A shift to reusable boxes will reduce the demand for cardboard boxes.

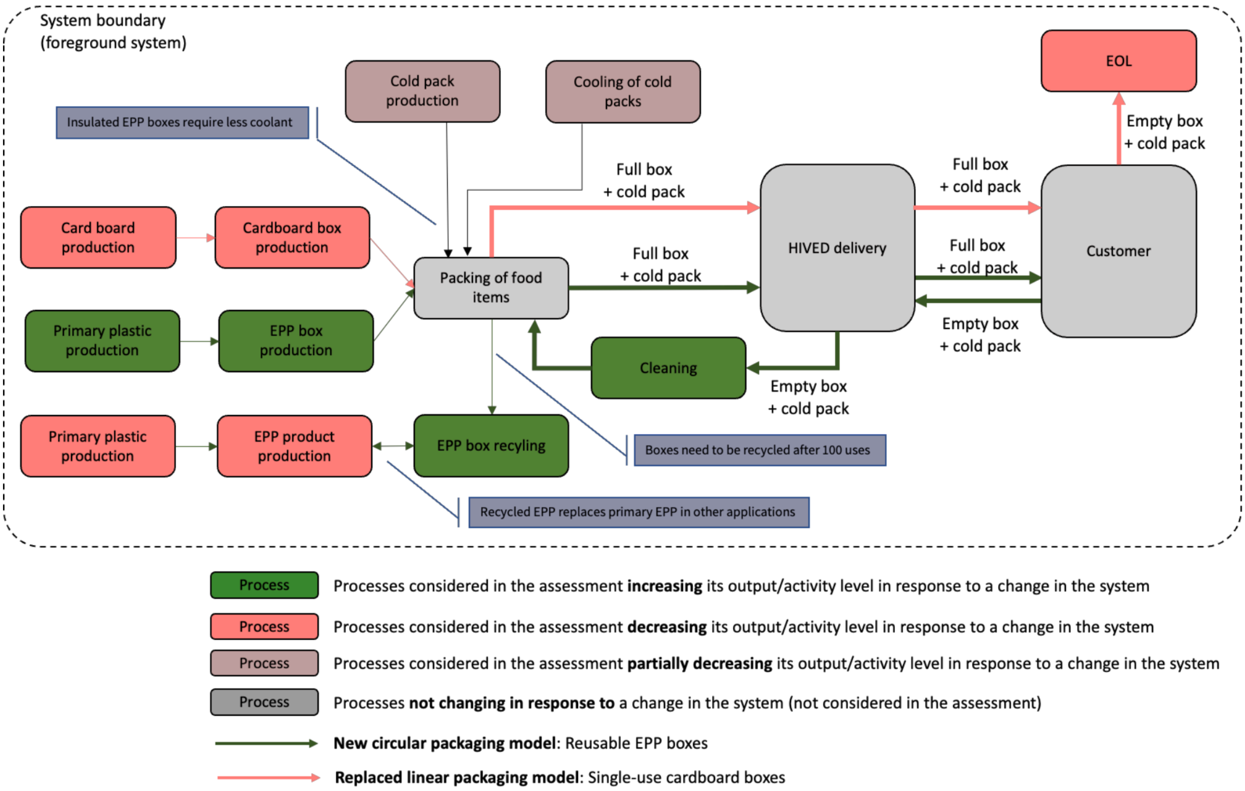


Figure 1 *Assessed system. The key components of the system are new processes facilitating the circular logistics model operated by HIVED and the replaced processes belonging to the linear logistics model. Background processes are not shown.*

2.2. Functional unit and assessed indicators

The functional unit of this study is the delivery of one box to customers of a grocery subscription service. The following impact indicators are assessed:

1. Climate change/GHG emissions in kg CO_2-eq. (Intergovernmental Panel on Climate Change (IPCC) 2014),
2. Abiotic resource depletion in kg Sb-eq. (CML 2001 v. 4.7 2016 (CML - Department of Industrial Ecology 2016),
3. Cumulative fossil energy demand (CED_f) in MJ (Verein Deutscher Ingenieure (VDI) (ed.) 2012),

4. Water demand (WSI) in L (Pfister, Koehler, and Hellweg 2009),

2.3. Data and assumptions

Primary data was used whenever possible. This includes data collected by HIVED and the potential partners implementing the circular business model, from manufacturer's data sheets, peer-reviewed scientific papers and the econinvent database (Moreno Ruiz et al 2024).

2.4. Approach to model circularity

This study assesses the systemic change in environmental impacts as a result of the introduction of a circular business model. The new circular logistics concept facilitated by HIVED is a '*closed loop*' system: empty boxes are returned to the logistics centre by HIVED where they are cleaned before being reused. The boxes can be used on average 100 times before they are recycled. The recycling process produces recycled EPP that replaces EPP made from primary plastics in the market. A re-use in food applications is not possible due to stricter material requirements. The recycled EPP is in all other characteristics functionally equivalent to EPP made from primary plastic. This step is modelled as an '*open loop - same primary route*' system (European Commission - Joint Research Centre - Institute for Environment and Sustainability 2010), i.e.: The recycling step and the displacement of EPP from primary plastic is included. Each delivery with the reusable box replaces a delivery using a single-use cardboard box. If such a box was made from recycled cardboard, this recycled cardboard is available to other users in the market. If the box was made from primary cardboard, the replacement of single-use cardboard boxes by the assessed circular delivery model results in an additional use of cardboard in another product: cardboard fibres can be used 5 to 7 times. Replacing a single-use cardboard box made from primary cardboard, results in a replacement of primary cardboard because primary cardboard manufacturing is the flexible market participant. The total quantity of recycled cardboard supplied to the market remains largely unchanged because it is driven by recycling quotas and other regulatory efforts promoting recycling. On a systemic level, such displacements affect the marginal supplier that can respond to a change in the market, i.e. primary cardboard production.

2.5. Life cycle inventory

In the following sections, we explain the life cycle inventory (LCI) used to model the impact of HIVED' reusable packaging logistics offering. A table summarising the data is provided in section 2.2.3.

2.5.1. The replaced linear logistics model

Current delivery models often rely on linear logistics models, relying on single-use packaging. In this study a shift from such a linear model to a circular logistics model is assessed. The linear model relies on corrugated cardboard boxes that are disposed of by customers. The linear model was modelled in the following way:

- **Manufacturing of corrugated board boxes:** The size of the boxes was determined assuming a similar internal volume as the EPP boxes delivered by HIVED (section 2.5.2, Table 3). The dimensions were determined assuming a similar ratio between width and depth and assuming a wall thickness of the EPP boxes of 20% of the dimensions of reusable EPP boxes used by HIVED. Table 1 shows the resulting dimensions of the corrugated cardboard boxes. The thickness/strength of corrugated board is determined by its design, e.g. number of flutes and thickness of liners. We assumed a typical corrugated box made from 150KT/B corrugated cardboard. Such a box uses liners with a weight of 150 g per square meter (commonly referred to as 'GSM' - g/m^2) and B flutes with a GSM of 105 (Daggar and GWP Group 2024; European Federation of Corrugated Board Manufacturers (FEFCO) 2022). A so-called 'take-up factor' of 1.33 is used to calculate the total weight of the corrugated board per m^2 (FECO 2022). With 5.5 g of glue per m^2, the resulting weight of the cardboard is 445 g per m^2. Cardboard boxes with different shares of recycled cardboard are available. If the circular logistics model replaces the corrugated cardboard boxes, the recycled cardboard will be available to other users. The demand for recycled cardboard exceeds the demand and the supply of recycled cardboard is inflexible, i.e. recycling quotas ensure a supply of recycled materials to the market. Thus, freeing recycled cardboard by replacing cardboard boxes is very likely to affect virgin cardboard production (section 2.4).

Table 1 *Characteristics of the single-use cardboard boxes. Abbr.: Sizes – S - small, M - medium, L - large; Dimensions – H – height, L – length, W – width.*

Size	Internal volume in l	Dimensions in mm			Material weight in g
		L	W	H	
S	20	372	280	192	204
M	30	476	316	199	275
L	45	476	316	299	345

- **End-of-life (EOL) of displaced cardboard boxes:** Cardboard fibres can be recycled 5 to 7 times before they can be recycled any longer. Reducing the number of cardboard boxes by providing reusable EPP boxes will therefore reduce the incineration of cardboard at the end of its lifetime. The most common form of incineration is incineration with energy recovery (Department for Environment 2022).
- **Refrigeration:** Certain food items require refrigeration. The cold pack was modelled with data from a cold pack manufacturer (Polar Tech Industries 2022). The cold pack contains a gel consisting of 98% water and 2% carboxymethyl cellulose. We assume an average temperature change required to cool the coolants from room temperature to the desired temperature. The required total energy that needs to be extracted from the system is calculated using equation (1):

$$Q_{total} = m\, c_{liquid}\, (T_{initial} - T_{final}) \qquad \text{Eq. (1)}$$

where Q_{total} is the total energy that needs to be removed from the system, m is the mass of the coolant, c is the thermal capacity and T the initial and final temperature. Constant c was taken from cold packs available on the market (Eutecma GmbH 2023). Based on Eq. (1). It is assumed that coolants are cooled from room temperature to the temperature in the storage place, i.e. 20°C, to 5°C (Electronic Temperature Instruments Ltd 2025). Per kg of coolant, 63 kJ of heat needs to be removed from the system. With a coefficient of performance (COP) of 5 (United Nations Industrial Development Organization (UNIDO) 2019), the cooling requires 3.5 Wh of electric energy per kg of coolant. The medium-sized cardboard box requires 4 L of coolant. The volume/quantity of coolant needed for the small and large boxes are scaled by the volume of the boxes. The facility operates with energy from renewable sources (Table 2).

Table 2 *Key parameters of the marginal supply mix of electricity from renewable sources. Data obtained from (Forrester 2022; UK Government (ed.) 2022)*.

	Capacity [GW]			
	2022	**2035**	**Load factor**	**Marginal mix**
Offshore wind	11.3	45	40.2%	59%
Onshore wind	14.5	35	26.3%	23%
Solar PV	13.8	54	10.0%	18%

2.5.2. HIVED's circular logistics model

The circular logistics model does not require additional transportation because customers are served on a regular basis anyway. The new logistics model requires a few additional processes:

- **Box manufacturing:** The boxes are made from expanded polypropylene (EPP). The production process was modelled by using an environmental product declaration (EPD) of an EPP bead manufacturer (ARRRO 2021) and a peer-reviewed scientific paper reporting LCA data for the manufacturing of EPP packaging boxes (Casson et al. 2021). Three sizes are evaluated in this study (Table 3).

Table 3 *Characteristics of the reusable EPP boxes. Abbr.: Sizes — S - small, M - medium, L - large; Dimensions — H — height, L — length, W — width.*

Size	**Internal volume in l**	**Dimensions in mm**			**Material weight in g**
		L	**W**	**H**	
S	20	465	350	303	600
M	30	595	395	265	900
L	45	595	395	355	1350

- **Cleaning of returned boxes:** The returned boxes are cleaned by disinfecting and, if required, washed. The washing is accomplished by a crate washer using water and a detergent. The data to model the washer was taken from the manufacturer's datasheet (Riley Industries Ltd. 2019). The logistic center uses electricity to water. The disinfection is accomplished through a UVC disinfection conveyor. The disinfection uses ultraviolet light (UVC, 180 - 280 nm) to inactivate microorganisms. The required energy demand and water use are taken from the datasheets of the machines used (KRONEN GmbH 2022). The facilities are operated using electricity produced from renewable sources. In this study, two scenarios were considered:
    - Scenario C1: Dry food items - 5% of boxes require washing, 100% are disinfected
    - Scenario C2: Fresh food items, e.g. meal kits - 50% of boxes are washed, 100% are disinfected.

  The shift in the business model requires the acquisition of cleaning equipment. It is assumed that the cleaning equipment lasts for 20 years.
- **Box refurbishment and EOL:** The boxes can be reused 100 times (on average) before they need to be refurbished. This is an assumption that can be validated by scientific literature (Sazdovski et al. 2024). Transportation to the manufacturer and back to the logistics centre is included (140 km, return trip). The boxes are refurbished by grinding the boxes into EPP beads and reassembling them using thermal energy and pressure. Conservatively, a similar energy requirement as for primary box manufacturing is assumed. We assumed that 10% of the material/boxes are unsuitable for recycling/not returned and are disposed of (municipal solid

waste incineration). The material is replaced by EPP made from primary plastic. The boxes that need to be refurbished are transported from the logistics center to the box manufacturer. In a sensitivity analysis, the influence of the number of boxes that need to be refurbished on the results is evaluated. A share of the material is unfit for recycling. It is assumed that this share is incinerated in municipal solid waste incineration plants with energy recovery (Department for Environment 2022).

- **Refrigeration:** EPP boxes have much better insulation properties than conventional cardboard boxes, requiring 25% less coolant. This affects the energy required per parcel delivery (less coolant needs to be cooled down). We assumed that 50% of cold packs are returned to the logistics center. The reminder is disposed of. In a sensitivity analysis, the influence of the share of coolant that is returned by customers on the results is evaluated. The disposal and incineration in a municipal solid waste incinerator results in a net reduction of the calorific value of municipal solid waste (98% water). The impact on the emissions and other environmental implications of incinerating the coolants is excluded from this study due to the very low quantities of cold packs in the overall municipal solid waste stream and hence, the small overall net reduction in the calorific value of the municipal solid waste stream.
- **Delivery:** In this study, a shift from single-use cardboard boxes to multi-use EPP boxes is assumed, i.e. consumers receiving food items in a subscription model on a regular basis. No additional delivery services are required. The net change in environmental impacts from changing from conventional parcel delivery to HIVED and the impacts associated with different delivery options are assessed in a separate LCA study.

2.5.3. Summary of life cycle inventory data

Table 4 lists a summary of the inventory data of the circular business model. All processes and LCI data not specifically listed were taken from the ecoinvent consequential database 3.8 without changes.

Table 4 *Summary of LCI data of processes related to the circular business model.*

		Unit	Value	Comment
EPP box manufacturing				Inventory taken from (Casson et al. 2021)
Inputs	EPP beads	kg/kg	1.01	Inventory taken from (ARRRO 2021)
	Electricity	kWh/kg	1.69	
	Heat	MJ/kg	71.97	Provided by natural gas
	Water	L/kg	23.20	
Output	EPP box	kg/kg	1.00	
	Wastewater	L/kg	23.20	
	Waste EPP	kg/kg	0.01	
EPP box washing				Inventory taken from manufacturer datasheet (Riley Industries Ltd. 2019)
Inputs	Electricity	kWh/hr	46.47	Corresponds to full capacity but conservatively used at assumed capacity
	Water	L/hr	100	Corresponds to full capacity but conservatively used at assumed capacity
Equipment	Washing equipment	units/box	$8.56\ 10^{-5}$	Assumed life time 20 years, 2 shifts per day (16 hrs)
	Water pump	units/box	$2.33\ 10^{-6}$	
Output	Capacity	box/hr	6000	Max. capacity according to data sheet: 8000
	Wastewater	L/hr	100	Corresponds to full capacity but conservatively used at assumed capacity
EPP box disinfection				Inventory taken from manufacturer datasheet (KRONEN GmbH 2022)
Inputs	Electricity	kWh/hr	1.2	Electricity from renewable sources used by HIVED's partner Corresponds to full capacity but conservatively used at assumed capacity
Output	Capacity	box/hr	700	Max. capacity according to datasheet: 900
EPP box recycling				
Inputs Outups	Similar to box manufacturing, except for EPP beads: 10% loss assumed that needs to be treated and replaced by primary material			
Cold packs				Inventory taken from manufacturer (Polar Tech Industries 2022)
Inputs	Water	kg/unit	0.98	
	Carboxymethyl cellulose	kg/unit	0.02	
Other				
Transport	Distance	km/unit	70	One way from logistic centre to box manufacturing/recycling

2.5.4. Sensitivity analysis

This is a prospective LCA study relying on a number of assumptions where primary data or no peer-review scientific information is available. In a sensitivity analysis, the influence of the following parameters is assessed:

- Number of use cycles before refurbishment is needed.
- Share of cold packs returned by customers.

3. Results

The shift from a linear logistics to a circular logistics model results in a net reduction in GHG emissions ranging from -0.37 to -0.96 kg CO_2-eq. per delivery (Figure 2, Table 5). The largest net reduction in GHG emissions stems from the replacement of cardboard boxes. The largest contribution to GHG emissions of the circular model comes from the used coolant in the case of the circular model. In the case of the linear model, the coolant is the second greatest contributor to GHG emissions. The impact of coolant was cross-validated by comparing the impact of the most impactful ingredient (carboxymethyl cellulose) modelled in this study with data from the ecoinvent database and an EPD of a manufacturer (SE Tylose GmbH & Co. KG 2024). The GHG emissions associated with the production of carboxymethyl cellulose differ by less than 4%. These results show that the biggest lever to deliver even higher net reduction in GHG emissions is to increase the share of cold packs returned to the logistics center (50% are assumed in this study). This could be accomplished by introducing a deposit. The second biggest leaver is to increase the number of uses of the boxes before they need to be recycled. Careful handling of boxes during handling in the logistics centre and by customers can help to increase the number of uses and could be incentivised.

Notably, the cleaning of the boxes only plays an insignificant role. The technical data used was taken from manufacturer datasheets, and the power consumption corresponds to the full load. The low impact can be explained by the high throughput of boxes (only 75% of the maximal throughput was conservatively assumed while keeping energy and water use as specified in the data sheet). The use of electricity from renewable sources in the facility to power the cleaning devices further reduces the importance of the cleaning step.

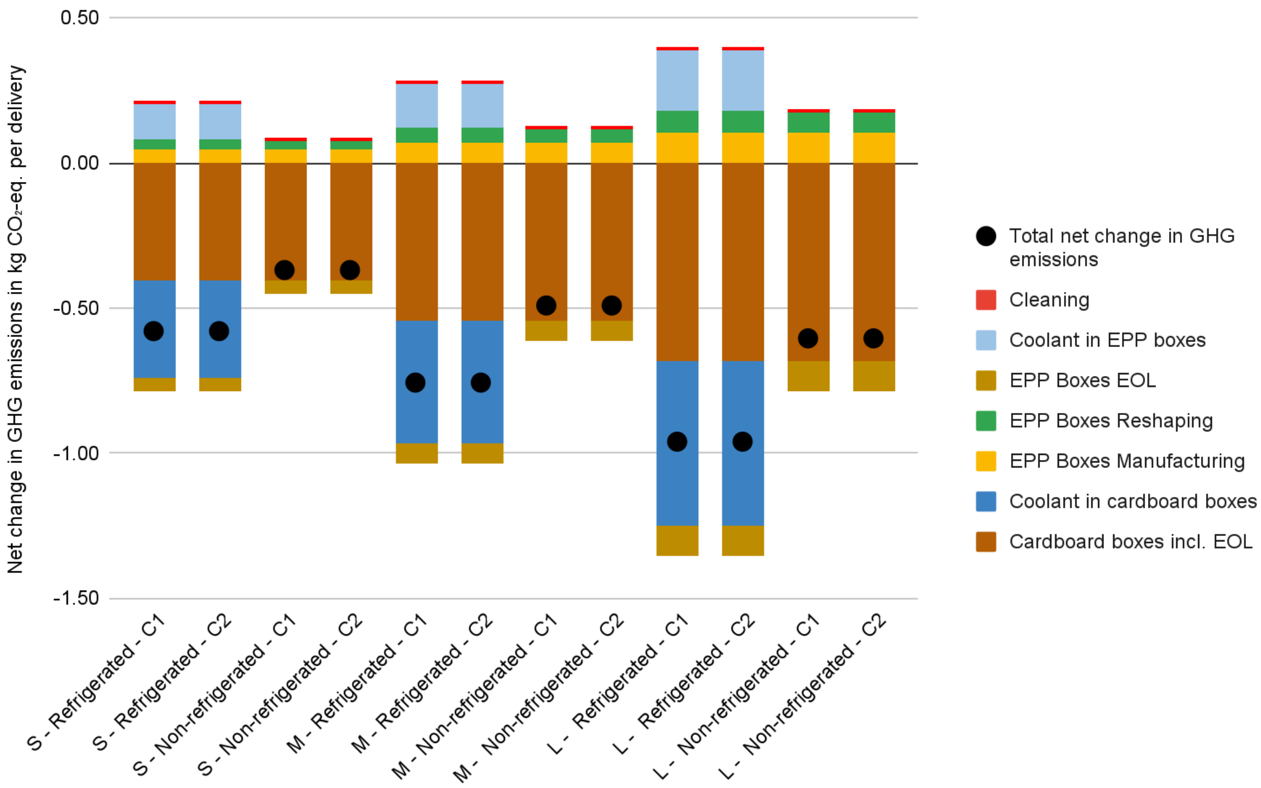


Figure 2 *Net change in GHG emissions arising from the evaluated shift from a linear delivery model to a circular delivery model. Abbr.: Sizes — S - small, M - medium, L - large; Scenarios — C1 - cleaning scenario 1 (5% washing, 100% disinfection), C2 - cleaning scenario 2 (5% washing, 100% disinfection); Other abbr. — EOL - end-of-life, EPP - expanded polypropylene, GHG - greenhouse gas.*

Similar to GHG emissions, the evaluation of the net changes in environmental impacts shows that the shift from a linear to a circular logistics model results in a net reduction across all indicator scores (Table 5). A detailed list of results is presented in Tables A.1 and A.2 in the Annex.

Table 5 *Net change in environmental impacts resulting from a shift from a linear to a circular logistics model. Abbr.: Sizes — S - small, M - medium, L - large; Scenarios — C1 - cleaning scenario 1 (5% washing, 100% disinfection), C2 - cleaning scenario 2 (5% washing, 100% disinfection); Other abbr. — CED_{fossil} - cumulative fossil energy demand.*

		Refrigerated						Non-refrigerated					
		Scenario C1			Scenario C2			Scenario C1			Scenario C2		
Indicator	**Unit**	**S**	**M**	**L**	**S**	**M**	**L**	**S**	**M**	**L**	**S**	**M**	**L**
Abiotic resource depletion	10^{-6} kg Sb eq	-3.88	-5.03	-6.52	-3.87	-5.01	-6.50	-1.64	-2.20	-2.73	-1.63	-2.18	-2.71
Climate change	kg CO_2-eq.	-0.58	-0.76	-0.96	-0.58	-0.76	-0.96	-0.37	-0.49	-0.60	-0.37	-0.49	-0.60
Land occupation	m2a	-1.39	-1.86	-2.34	-1.39	-1.86	-2.34	-1.24	-1.67	-2.09	-1.24	-1.67	-2.09
CED,fossil	MJ	-5.76	-7.37	-9.40	-5.76	-7.37	-9.40	-2.35	-3.07	-3.63	-2.35	-3.07	-3.63
Water use	L	-122.80	-160.32	-207.20	-122.78	-160.30	-207.18	-65.36	-87.78	-110.02	-65.34	-87.76	-110.00

3.1. Sensitivity analysis

This prospective LCA study uses a number of assumptions. Of these, the number of use cycles of EPP boxes and the return rate of cold packs are assessed in a sensitivity analysis. The latter was included because of the importance of the cold pack identified in the results. The results of the sensitivity analysis underline the importance of achieving high return rates of cold packs. Increasing the return rate (or re-use rate) of cold packs to 90%, results in a 18% higher net reduction in GHG emissions (Figure 3). Increasing the number of use cycles before boxes need to be refurbished has a much lower impact. However, a substantially lower number of uses will result in a sharper decrease in the net environmental benefit of using EPP boxes.

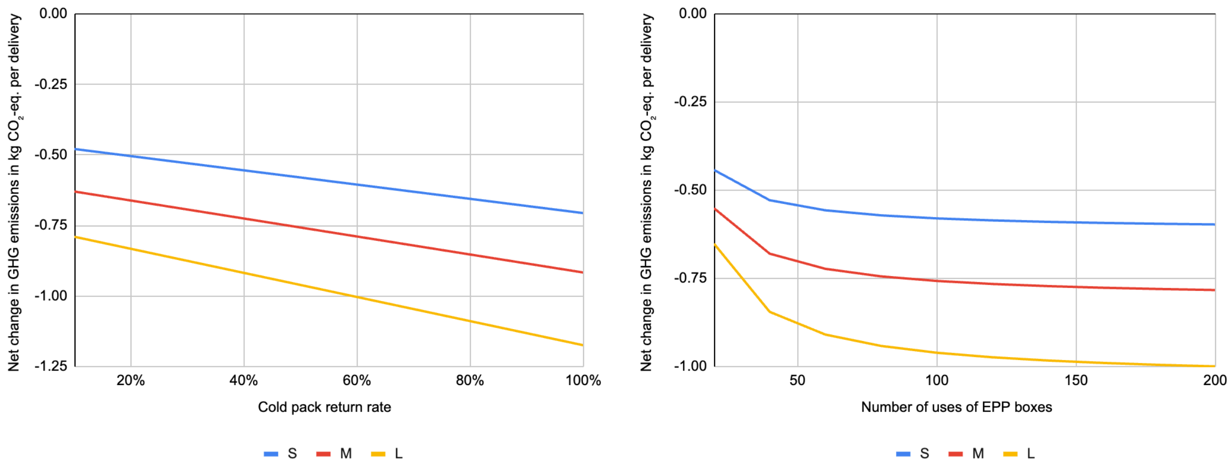


Figure 3 *Sensitivity analysis: Net change in GHG emissions in kg CO_2-eq. per delivery in dependence of the cold pack return rate (left) and the number of uses of EPP boxes before they need to be recycled (right). Abbr.: Sizes — S - small, M - medium, L - large; Other abbr.: EPP - expanded polypropylene, GHG - greenhouse gas.*

3.2. Limitations

This prospective LCA study relies on a number of assumptions where primary data or peer-reviewed scientific information may be limited. Therefore, the results should be interpreted with consideration of these limitations. Key limitations include:

- **Data Availability:** Some data used in this study are based on assumptions and estimations, particularly where primary data from specific processes was unavailable:
  - Conservative assumptions were made in these cases, which may affect the accuracy of the results. The recycling process for EPP boxes is modeled based on the conservative assumption that it requires a similar energy input as primary EPP production. This assumption may overestimate the environmental burden of EPP recycling, as actual recycling processes could be more efficient.
  - Certain crucial data points were estimated, e.g. the number of uses of EPP boxes and the return rate of cold packs. The sensitivity analysis demonstrated how the results depend on these assumptions.
- **Coolant Disposal:** The environmental impact of disposing of non-returned coolant packs is excluded from this study due to their very low quantities in the overall municipal solid waste stream and the ingredients contained in the cold packs (98% water). While this simplification is reasonable, it does mean that a minor impact is not accounted for.
- **Generalisability:** The study focuses on a specific case of a grocery subscription service. The results may vary for other types of products or delivery scenarios. The data was collected from a potential customer of HIVED. The logistics center uses electricity from renewable sources. If another potential customer uses electricity from fossil sources, the net benefit from switching to a circular business model using insulated boxes increases even further (higher net reductions in GHG emissions associated with the cooling of the cold packs).

Despite these limitations, this study provides valuable insights into the environmental implications of shifting from a linear to a circular logistics model using reusable EPP boxes.

4. Conclusion

This prospective LCA study has evaluated the environmental impacts of transitioning from a linear logistics model using single-use cardboard boxes to HIVED's circular logistics model utilising reusable EPP boxes for grocery subscription deliveries. The results demonstrate a clear environmental advantage for the circular model across all assessed impact categories.

The circular logistics model results in a significant net reduction in Greenhouse Gas (GHG) emissions, ranging from -0.37 to -0.96 kg CO2-eq. per delivery, indicating a substantial contribution to climate change mitigation. Furthermore, the circular model also shows net reductions in abiotic resource depletion, land occupation, cumulative fossil energy demand, and water use. These findings highlight the potential of reusable packaging solutions to minimise environmental footprints and promote resource efficiency in the logistics sector. The findings offer strong evidence for the adoption of reusable packaging solutions as a key strategy for achieving sustainable delivery services.

In conclusion, the transition to HIVED's circular logistics model represents a significant step towards reducing environmental impacts in the e-commerce and delivery sector. By replacing single-use cardboard boxes with durable, reusable EPP boxes, HIVED is not only minimising waste but also contributing to a more sustainable and resource-efficient economy. This study underscores the importance of circular business models in achieving environmental sustainability and provides a strong foundation for future improvements and optimizations in the logistics industry.

5. References

ARRRO. 2021. *Environmental Product Declaration for ARPRO Expanded Polypropylene*. EPD International AB. https://api.environdec.com/api/v1/EPDLibrary/Files/ff93f141-8099-4348-9b3b-08da3d5507cb/Data.

Casson, Andrea, Valentina Giovenzana, Alessio Tugnolo, Alessia Pampuri, Ilaria Fiorindo, Roberto Beghi, and Riccardo Guidetti. 2021. "Assessment of an Expanded-Polypropylene Isothermal Box to Improve Logistic Sustainability of Catering Services." *Journal of Agricultural Engineering* 52(2). doi:10.4081/jae.2021.1139.

CML - Department of Industrial Ecology, ed. 2016. "CML-IA Characterisation Factors: 05 September 2016." https://www.universiteitleiden.nl/en/research/research-output/science/cml-ia-characterisation-factors.

Confederation of European Paper Industries (CEPI). 2024. *Key Statistics 2023*. https://www.cepi.org/wp-content/uploads/2024/09/Key-Statistics-2023-FINAL-2.pdf.

Daggar, Jay, and GWP Group. 2024. "Corrugated Board Grades Explained: Different Types of Cardboard." https://www.gwp.co.uk/guides/corrugated-board-grades-explained/.

Department for Environment, Food & Rural Affairs. 2022. "Progress Report on Recycling and Recovery Targets for England 2020." https://www.gov.uk/government/publications/progress-report-on-recycling-and-recovery-targets-for-england-2020/progress-report-on-recycling-and-recovery-targets-for-england-2020.

Electronic Temperature Instruments Ltd. 2025. "Food Storage & Service Temperatures." https://thermometer.co.uk/content/310-food-storage-temperatures.

European Commission - Joint Research Centre - Institute for Environment and Sustainability. 2010. *ILCD Handbook: General Guide for Life Cycle Assessment - Detailed Guidance*. Publications Office of the European Union. https://eplca.jrc.ec.europa.eu/uploads/ILCD-Handbook-General-guide-for-LCA-DETAILED-GUIDANCE-12March2010-ISBN-fin-v1.0-EN.pdf.

European Federation of Corrugated Board Manufacturers (FEFCO). 2022. "Corrugated Board Production." https://www.fefco.org/lca/dscription-of-production-system/corrugated-board-production.

Eurostat. 2024. "Packaging Waste Statistics." https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Packaging_waste_statistics.

Eutecma GmbH. 2023. *ICECATCH Gelpack Data Sheet*. https://eutecma.com/wp-content/uploads/2023/07/ICECATCH-Gelpack-data-sheet-EN.pdf.

Forrester, Chloe. 2022. "Where Will Britain's Future Energy Supply Come from?" *House of Commons Library - UK Parliament*. https://commonslibrary.parliament.uk/where-will-britains-future-energy-supply-come-from/ (May 5, 2023).

Intergovernmental Panel on Climate Change (IPCC), ed. 2014. *Climate Change 2013 - The Physical Science Basis*. Cambridge: Cambridge University Press. doi:10.1017/CBO9781107415324.

KRONEN GmbH. 2022. *UVC Lock Disinfection Lock Datasheet.* Kehl am Rhein.

Moreno Ruiz et al. 2024. "Ecoinvent Version 3.10." https://support.ecoinvent.org/ecoinvent-version-3.10 (June 12, 2024).

Pfister, Stephan, Annette Koehler, and Stefanie Hellweg. 2009. "Assessing the Environmental Impacts of Freshwater Consumption in LCA." *Environmental science & technology* 43(11): 4098–4104. doi:10.1021/es802423e.

Polar Tech Industries. 2022. *Cold Pack Ice-Brix Safety Data Sheet*. https://www.polar-tech.com/wp-content/uploads/2022/06/Cold-Pack-Ice-Brix-POL137-Rev06-21-2022.pdf.

Riley Industries Ltd. 2019. *Newsmith Stainless Ltd. Silver Series S4 Multi-Lane Heavy Duty Industrial Component/Mould/Washer Machine*. https://files.rileysurfaceworld.co.uk/live/machines2/31830.pdf.

Sazdovski, Ilija, Laura Batlle-Bayer, Alba Bala, Maria Margallo, Sahar Azarkamand, Ruben Aldaco, and Pere Fullana-i-Palmer. 2024. "Comparative Assessment of Two Circularity Indicators for the Case of Reusable versus Single-Use Secondary Packages for Fresh Foods in Spain." *Heliyon* 10(6): e27922. doi:10.1016/j.heliyon.2024.e27922.

SE Tylose GmbH & Co. KG. 2024. *Environmental Product Declaration: Methylcellulose*. EPD Norge. https://www.epd-norge.no/getfile.php/1350842-1704275820/EPDer/Kjemikalier/NEPD-5642-4909_Methylcellulose-.pdf.

UK Government. 2024. "UK Statistics on Waste." https://www.gov.uk/government/statistics/uk-waste-data/uk-statistics-on-waste.

UK Government (ed.). 2022. "Digest of UK Energy Statistics (DUKES). Contains Public Sector Information Licensed under the Open Government Licence v3.0." https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes (May 12, 2023).

United Nations Industrial Development Organization (UNIDO). 2019. *TEST Training Kit Case Study: Cooling in Food Industry*. https://www.test-toolkit.eu/wp-content/uploads/2019/09/CS-3-Cooling-in-food-industry.pdf.

Verein Deutscher Ingenieure (VDI) (ed.). 2012. "Cumulative Energy Demand (KEA) - Terms, Definitions, Methods of Calculation." 01.040.27, 27.100(VDI 4600).

A. Annex

Table A.1 *Environmental impacts of processes belonging to the replaced linear logistics model. Abbr.: Sizes — S - small, M - medium, L - large; Scenarios — C1 - cleaning scenario 1 (5% washing, 100% disinfection), C2 - cleaning scenario 2 (5% washing, 100% disinfection); Other abbr. — CED_{fossil} - cumulative fossil energy demand, EOL - end-of-life, EPP - expanded polypropylene.*

		Cardboard boxes incl. EOL			Coolant			Total		
Indicator	**Unit**	**S**	**M**	**L**	**S**	**M**	**L**	**S**	**M**	**L**
Abiotic depletion	10^{-6} kg Sb-eq.	1.78	2.39	3.00	3.65	4.61	6.17	5.42	7.00	9.17
Climate change	kg CO_2-eq.	0.40	0.54	0.68	0.34	0.43	0.57	0.74	0.97	1.25
Land occupation	m^2a	1.24	1.67	2.10	0.24	0.30	0.40	1.48	1.97	2.51
CED_{fossil}	MJ	2.96	3.98	4.99	5.46	6.90	9.24	8.42	10.87	14.23
Water use	L	66.05	88.81	111.55	91.93	116.11	155.55	157.98	204.92	267.09

Table A.2 *Environmental impacts of processes belonging to the new circular logistics model (Cleaning scenario C1). The EOL of EPP boxes contains a recycling step. The material can replace EPP from primary plastics (cf. section. 2.4). As described in section 2.2.1, no data was found on the recycling of EPP. Conservatively, the same effort as the primary production was used, therefore the values of EPP boxes manufacturing and EOL are similar (a negative sign needs to be assigned to the value). Abbr.: Sizes — S - small, M - medium, L - large; Other abbr. — CED_{fossil} - cumulative fossil energy demand, EOL - end-of-life, EPP - expanded polypropylene.*

		EPP boxes manufacturing / EOL			EPP boxes re-shaping			Coolant			Cleaning			Total		
Indicator	**Unit**	**S**	**M**	**L**	**S**	**M**	**L**	**S**	**M**	**L**	**S**	**M**	**L**	**S**	**M**	**L**
Abiotic resource depletion	10^{-6} kg Sb eq	0.11	0.17	0.25	0.11	0.17	0.25	1.41	1.78	2.38	0.02	<0.01	<0.01	1.54	1.97	2.66
Climate change	kg CO_2-eq.	0.05	0.07	0.10	0.03	0.05	0.08	0.13	0.16	0.21	<0.01	<0.01	<0.01	0.16	0.21	0.29
Land occupation	m^2a	0.00	0.01	0.01	0.00	0.01	0.01	0.09	0.11	0.15	<0.01	<0.01	<0.01	0.09	0.12	0.16
CED_{fossil}	MJ	1.02	1.52	2.29	0.61	0.91	1.36	2.05	2.59	3.47	<0.01	<0.01	<0.01	2.66	3.50	4.83
Water use	L	0.67	1.00	1.50	0.68	1.01	1.52	34.50	43.57	58.37	0.01	<0.01	<0.01	35.18	44.59	59.90

www.planet-a.com