hivenet

Hivenet, the green cloud

An in-depth analysis of Hivenet's sustainable cloud for storage and compute services

There is no doubt that, today, how we store and process data has become as crucial as the data itself. With vast amounts of information being generated every second, finding efficient storage and compute solutions is essential. But efficiency is no longer just about reliability, speed and storage space—it's also about its impact on our environment. That's where Hivenet comes into the picture.

In this whitepaper we delve deep into Hivenet's approach to sustainable cloud, with a focus on storage. Instead of massive centralized data centers, Hivenet uses p2p technologies to build a distributed network of devices upon which storage and compute capabilities are offered.

But what does this mean for energy use? What is the carbon footprint of such a cloud as compared to centralized clouds we use everyday in our lives?

We'll explore these questions and more. We'll dive into the methods used to store and compute in Hivenet and analyze the environmental benefits of such solutions. From understanding the nuts and bolts of data management to the carbon footprint of servers and personal computers, here is a comprehensive look at our sustainable storage solution.

Before we begin, did you know that the energy consumed by Information and Communication Technologies (ICT) has grown so much that it now accounts for 3.7% of global greenhouse gas emissions? (1) That's more than the combined emissions of the aviation and shipping industries, which each contribute 2%! (2) It is probably not a surprise to you that a third of these emissions is from data centers, the invisible infrastructure behind our online activities. (3)

Why are data centers such energy hogs?

Data centers form the backbone of the cloud infrastructure.
They are responsible for:

1. **Storing** vast amounts of data.
2. **Processing** information.
3. **Transmitting** data across the globe.

To achieve this, they use:

- Powerful servers that require vast amounts of energy.
- Redundancy to provide reliable services 24/7.
- Industrial air conditioning.
- Vast amounts of water for cooling.
- Extensive IT equipment.

What's our hypothesis with Hivenet?

We anticipate that Hivenet's carbon footprint will be significantly reduced compared to centralized clouds. This is because it doesn't rely on centralized data centers that use vast amounts of energy with their powerful, often underutilized servers and extensive cooling systems.

These data centers and their dozens of millions of servers also generate significant electronic waste. In contrast, Hivenet leverages existing equipment, providing a more energy-efficient and sustainable storage solution.

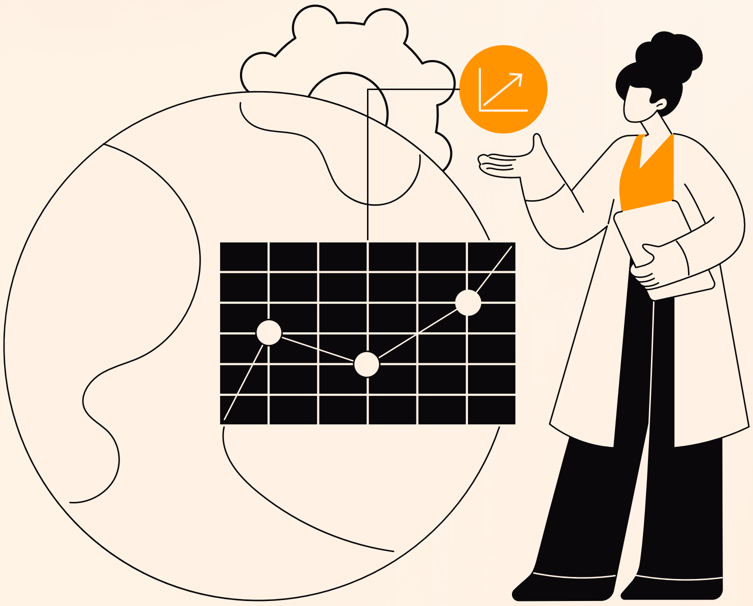
In the sections that follow, we will delve deeper into this, analyzing the evidence to substantiate our hypothesis. It's our unwavering commitment to not only highlight these footprint concerns but also to actively seek and champion alternatives that address them.

Understanding cloud emissions: a deeper and transparent review

Centralized cloud service providers keep their carbon footprints under wraps. It's difficult to understand where these emissions are coming from, which makes it challenging for consumers, businesses, and regulators to make informed decisions about their digital storage choices.

The Greenhouse Gas (GHG) Protocol, which includes cloud provider usage, currently does not provide clear guidelines for reporting Scope 3 emissions (ref). This makes it hard to truly understand the environmental impact of different cloud storage providers. Our aim is to clear up this ambiguity.

Table of contents



How do we measure carbon footprints?

Breaking down emissions: Operational and Embodied

We use a straightforward equation:

$$\text{Total } CO_2 = \text{Operational Emissions} + \text{Embodied Emissions} \quad (1)$$

1. **Operational Emissions:** These are the emissions resulting from daily operations, such as running servers and cooling servers.
2. **Embodied Emissions:** These include emissions from the manufacturing IT equipment and end-of-life impact.

By pulling usage data (like compute, storage, networking) from major cloud providers, we estimate their energy use and greenhouse gas emissions. These are then expressed as carbon dioxide equivalents (measured in metric tons CO_2e).

We express these yearly emissions in the unit $kgCO_2e/TB/y$, where:

- **kg** stands for kilograms
- **CO_2e** is Carbon Dioxide equivalent
- **TB** is Terabytes
- **y** is years

Operational Emissions: These are the greenhouse gasses released because of the daily functioning of cloud storage systems.
They include:

1. **Cloud storage energy conversion factors:** This measures in kWh the energy consumption of 1TB of data stored on hard-disks due to:
   a. Disks
   b. Computing
   c. Networking
2. **Replication Factor:** This factor refers to the amount of data actually stored for 1 TB of original user data. Traditional storage systems typically replicate the user data on multiple servers and disks (and often multiple locations) to ensure its availability and reliability.
3. **Cloud Provider Power Usage Effectiveness (PUE):** This measures how efficiently a cloud provider's data center uses energy. It is the ratio between the total energy consumption used by the data center and the energy consumed solely by the IT equipment.
4. **Grid Emissions Factors:** This assesses the carbon footprint of the electricity used, which depends on how the electricity is produced.

The result is the following equation:

Operational Emissions = Cloud Usage x Cloud Energy Conversion factors x PUE x Grid Emission Factors

where "Cloud Usage" is the number of TB of user data stored times the replication factor:

Operational Emissions per TB = Replication Factor x Cloud Energy Conversion factors x PUE x Grid Emission Factors

Reference: cloudcarbonfootprint.org/docs/methodology

Embodied Emissions: These emissions emerge from the entire life cycle of the equipment used in cloud storage.

When considering hiveNet embodied emissions in comparison with centralized cloud embodied emissions, the equipment to consider is more diverse. Like centralized cloud, there are some servers that are powered 24 hours a day, dedicated to the service. But hiveNet also uses capacity contributed form the devices of its users (called Hivers). By nature, these devices are very heterogeneous: mobile devices, laptops, gamer desktops, NAS (Network-Attached Storage), small servers, and more.

So, generally speaking, we consider the following category of devices:

- Personal Computers, contributing some of their unused space to the service while they are powered up.
- Mobile devices, while they are connected to power and consuming Wi-Fi resources.
- Servers, powered on 24 hours a day, dedicated to the service.

Embodied Emissions can thus be broken down as follows:

- E1. **Personal Computer Emissions:** The carbon footprint from the manufacturing, transport, use and disposal of personal computers.
- E2. **Mobile devices:** The carbon footprint from the manufacturing, transport, use and disposal of mobile devices.
- E3. **Server Emissions:** Emissions from the servers' entire lifecycle, from manufacturing, transport, use and end-of-life of servers.
- E4. **Data Center Building:** The emissions associated with the construction and maintenance of data center buildings.

For a given category of device (personal computers or servers), these emissions (in the unit $kgCO_2e/TB/y$) are computed as follows:

$$\text{Embodied Emissions per TB} = \frac{(\text{Manufacturing} + \text{Transport} + \text{Use} + \text{EndOfLife})}{\text{Storage Capacity per Device} \times \text{Expected lifespan}} \times \text{Fair share LCA} \times \text{Replication Factor}$$

And overall for yearly embodied emissions:

Yearly Embodied Emissions per TB = Data Center Building + Personal Computer Emissions + Server Emissions

Hivenet specifics and impact on carbon footprint

To assess the operational and embodied emissions, we need to first look at some specific features and aspects of Hivenet that impact its carbon footprint.

Indeed, Hivenet is different.

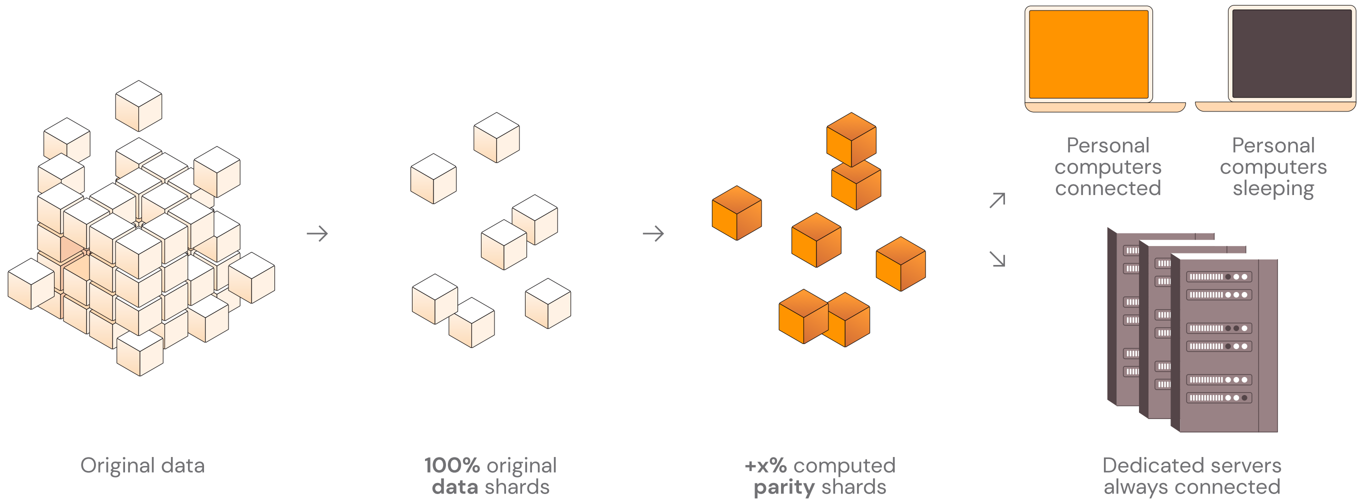
Data Replication on Hivenet

- Hivenet does not rely on servers which are online 24/7 in a data center, but on our community's **unreliable** machines, which we call hiver nodes.
- Hivenet depends on its users' devices, which are **intermittent** and not consistently reliable. These devices frequently connect and disconnect from the network, either going into sleep mode or when users opt out.

To deal with unreliability and intermittence, Hivenet uses:

1. **Erasure coding:** user data is compressed and divided into small shards, and additional redundant data known as parity shards are generated, and spread over many personal machines. Any missing original data shard can be recovered by any parity shard.
2. **Data repair algorithm:** ensures that, on average, 200% of the original data shards remain available **at all times** by regenerating unavailable shards when needed.
3. **Garbage collection:** ensures the deletion of redundant data by deleting from hiver nodes to keep the data replication factor at 200%, on average.

These advanced computing and data processing technologies make Hivenet robust to nodes disappearing, whether temporarily or permanently, while keeping an optimum level of availability for when a user needs their data.



To compute our carbon footprint emissions, we consider a mix of two types of storage devices:

- **Personal devices,** including mobile phones, home NAS, professional and personal desktop computers or laptops, etc. These are used for other purposes than being a specialized device for Hivenet. Their owners share some of their unused hard disk space and compute capabilities without changing their daily usage patterns. On average, a laptop is typically connected 8-10 hours per day, while a mobile phone or a NAS will be connected 24 hours a day. We consider our personal devices to be connected 12 hours a day, a conservative value.
- **Dedicated servers,** adding always-on capacity dedicated to Hivenet. We model these as data center servers, always on and connected 24 hours a day.

While we assume that most of our hiver nodes will be intermittent as described above, some of our Hivers will install dedicated devices to provide predictable SLAs to the Hivenet community. In these early days, Hive is the entity that acts as these nodes to bootstrap Hivenet. As the network grows, personal devices will outnumber these dedicated servers. For our CO_2 emission model we consider that in two years from now, out of the 200% of shards available on active devices (evenly split today between the two categories), 50% will be hosted on dedicated servers and 150% on personal computers.

Impact on carbon footprint

Replication factor

Centralized cloud storage also uses data replication to ensure reliability and availability. Think of it as keeping a backup passport copy in your basement in case you lose the original. The infrastructure and energy needed to provide a specific amount of storage are typically **tripled**, often in different geographical locations. This is to ensure copies are stored across the network, safeguarding against system failures. For a service such as the one provided by Hivenet, **replication factor is 3** (ref).

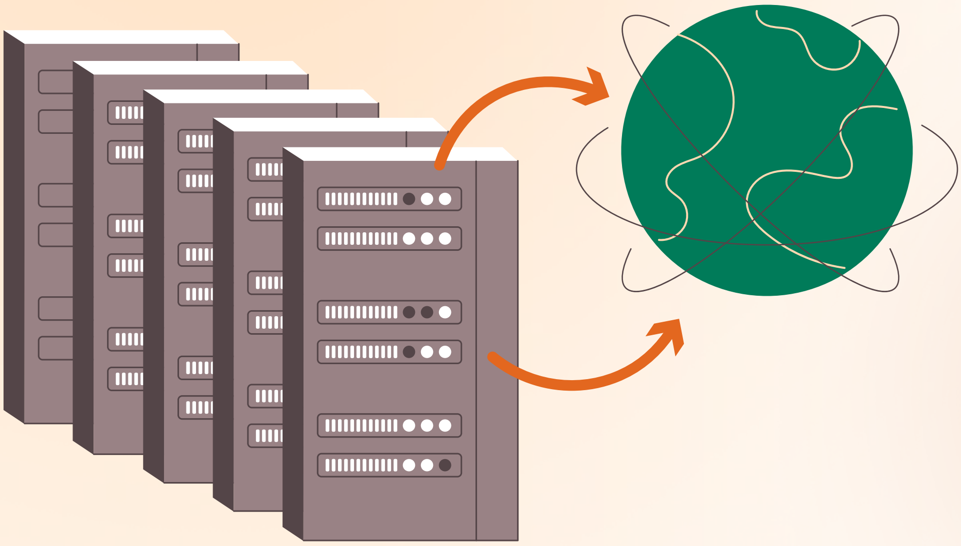
For Hivenet, when considering replication factor, we distinguish:

- Operational emissions: only Hivenet-connected active devices are considered. Replication factor is 2, as explained above. As our algorithms performance increases with the growth of hiver nodes, this replication factor will decrease providing more efficient energy consumption.
- Embodied emissions for dedicated servers are computed with a **50% replication factor** (part of the 200% shards stored on dedicated servers), using the same server characteristics as traditional cloud providers.
- Embodied emissions for personal devices are taken into account, as we consider that the use of the Hivenet software on these devices has no or negligible impact on its lifetime. Moreover, the service relies on existing resources that have been manufactured specially for Hivenet as it is the case for servers composing centralized data centers. However, to be conservative, we assumed an LCA contribution for Hivenet of 5%.

Power Usage Effectiveness (PUE) and Data Center Building

In the absence of a data center, no additional equipment is deployed other than our users' IT equipment (it doesn't mean these do not consume energy). By definition, the Power Usage Effectiveness (PUE) is equal to 1. In other words, all the energy involved in our service is in the user's personal computer.

Likewise, there are no emissions linked to Data Center Building as there are no data centers, nor do we assume the energy cost of air conditioning or water consumption.



Operational emissions

Operational emissions can be broken down into:

1. Cloud energy conversion factors (in kWh), adding:
    a. Disk Power Consumption
    b. Compute Power Consumption
    c. Networking Power Consumption
2. Power Usage Effectiveness (PUE)
3. Grid emissions factors (in metric tons CO_2e)

Operational Emissions per TB = Replication Factor x Cloud Energy Conversion factors x PUE x Grid Emission Factors

Disk Power Consumption

This factor provides the power consumed for each unit of data stored on disk:

Watts per TB = Watts per disk x TB per disk

Let's break this down:

1. HDD (Hard Disk Drive) Energy Usage:
    - Average Capacity: 10 Terabytes per disk
    - Average Wattage: 6.5 Watts per disk
    - Average Watts per TB: 0.65 Watts per TB
2. SSD (Solid State Drive) Energy Usage:
    - Average Capacity: 5 Terabytes per disk
    - Average Wattage: 6 Watts per disk
    - Average Watts per TB: 1.2 Watts per TB

Since cloud storage typically uses a mix of HDD and SSD storage types (assuming a 50-50 split), we get an average energy usage of 0.925 W/TB equivalent to 0.000925 kW/TB. This figure is representative for both Hivenet and centralized cloud storage platforms, making it a useful benchmark for comparison.

[O1a] Disk Power Consumption = $9.25 \cdot 10^{-4}$ kW / TB

Amount of data processed vs. stored

Computation and networking power consumption are evaluated based on the data in transit, in other words processed and transported among the different computers and servers.

Every file stored undergoes a number of file operations: it is uploaded and downloaded a number of times every year. Data repair on a portion of the file is equivalent to combined download and upload operations.

The ratio between data in transit (processed and moved between the users and the cloud) and data at rest (stored on the servers) is mainly dependent on the service and user behaviors. It corresponds to the number of cycles for a given file: how many times that file is uploaded or downloaded every year.

For our cloud storage use case, we define that number of cycles to be on average:

For upload, downloads, and data repair from personal computers:

Cycles per year = 3 or Cycles per hour = $3.4 \cdot 10^{-4}$

From dedicated servers:

Cycles per year = 1 or Cycles per hour = $1.13 \cdot 10^{-4}$

Compute Power Consumption

Additional power consumption for Hivenet

The use of our different algorithms (ECC, encryption, data repair) for a TB of data entails additional consumption for CPU and memory. We estimated this by performing file operations on a personal computer or a dedicated server for a 1-TeraByte transfer:

- Complete file upload (leading to 1TB of Encrypted shard)
- Complete file download (leading to 1TB of decrypted shards)
- Complete file repair, which can be considered equivalent to upload+download

Watts per TB = Cycles per hour x (Max Watts - Min Watts) x Running Time x CPU usage

For personal computers (using Dell Latitude 7300 as a reference):

- Max Watts - Min Watts = 60 W
- Running Time =20 h
- CPU usage = 10%

Personal Computer Power Consumption = 4.1 · 10-5 kW / TB

For dedicated computers (using Dell PowerEdge R740 as a reference):

- Max Watts - Min Watts = 60 W
- Running Time =20 h
- CPU usage = 10%

Server Power Consumption = 1.4 · 10-5 kW / TB

For Hivenet, we consider the average between the two based on their replication factor:

[O1b] Compute Power Consumption = 5.5 · 10-5 kW / TB

Networking Power Consumption

As explained in the linked study (ref), we assume that the electricity used for networking is negligible relative to the electricity required to power servers in data centers.

A precise evaluation would highlight the fact that energy consumption used by the corresponding traffic would depend on (1) access media, fiber, 5G, Wifi, etc., (2) data usage patterns, (3) end-user behaviors, (4) layers of services used (including CDN providers), (5) geographical footprints of the different providers. The studies using different methodologies end up with results with significant differences.

To be conservative, we can, however, reasonably estimate that centralized cloud services and Hivenet have similar networking power consumption. A highly distributed Hivenet will retrieve data from nearby computers, minimizing the route for such traffic. Centralized cloud providers would achieve similar results with CDNs (adding an additional energy footprint though). Long distances, with fiber and submarine cables, as well as networks within data centers with transfers above 100 Gbps can be considered quite energy efficient.

We have used the recommended coefficient: 0.001 kWh/Gb for both Hivenet and centralized cloud providers.

[O1c] Network Power Consumption = Cycles per hour x 1 kWh / TB = $4.6 \cdot 10^{-4}$ kW / TB

Replication Factor

The replication factors used are explained in the section above. They are dependent on the service studied here, which is hot storage (example AWS S3 or Azure Blobs).

For traditional cloud providers

[O2] Replication Factor = 3

For Hivenet (for operating emissions)

[O2] Replication Factor = 2

Power Usage Effectiveness (PUE)

PUE is a vital metric for understanding the energy efficiency of a data center. It measures the relationship between total energy consumption and the energy consumed solely by IT equipment. It is evaluated as follows:

$$\text{PUE} = \frac{\text{Total Data Center Energy (kWh)}}{\text{IT Equipment Energy (kWh)}}$$

Where:

- Total Data Center Energy is the product of Electrical Energy and an Electrical Weighting Factor.

For a typical data center, the energy for IT equipment does not represent the total energy consumption. There are other significant contributors, such as cooling systems (chiller plant energy consumption) and energy losses during distribution.

For an average cloud provider, PUE is estimated at 1.32, based on public data regarding Dropbox's PUE (ref)

[O3] PUE = 1.32

In contrast, Hivenet boasts a PUE of 1, as explained above. The absence of traditional data centers means there is no energy consumed other than that of the personal computer or the dedicated server.

[O3] PUE = 1

Grid emissions factors

The carbon footprint of electricity varies based on the region and its energy mix:

- **Emissions Factors:** These numbers indicate the carbon intensity of electricity. For instance, Norway, which gets 98% of its electricity from renewable sources (mainly hydropower), has
- an emissions factor of just 17 gCO_2 per kWh. On the other hand, South Africa, heavily dependent on coal, has an emissions factor of 786 gCO_2 per kWh.

We will favor hosting data in regions getting their electricity from renewable sources, such as Norway. This will lead to an overall reduced emission factor. For the time being, we considered, for both centralized cloud providers and Hivenet, the world's combined average grid emission factor.

[O4] Grid Emission Factor = 0.4 $kgCO_2e$ / kWh

Other operational factors

While not directly influencing the Operational Emissions formula, it's essential to consider several operational factors for a comprehensive view of a cloud storage platform's carbon footprint:

- **Water Cooling Effectiveness (WUE):**
  Much like PUE gauges the efficiency of power usage in data centers, WUE measures the amount of water required for cooling. Given in m3/MWh, it's calculated as:

$$\text{WUE} = \frac{\text{Data Center Water Consumption}}{\text{IT Equipment Energy}}$$

For the same as the PUE, Hivenet also has a benefit in water cooling effectiveness.

Operational emissions

When summing all these and applying the different factors:

For centralized cloud providers:

Operational Emissions per TB = 208.49 $kgCO_2e$ / TB / y

For Hivenet:

Operational Emissions per TB = 34.75 $kgCO_2e$ / TB / y

Embodied emissions

Embodied emissions, often referred to as embedded emissions, represent the greenhouse gas emissions tied to the production and disposal of hardware components in cloud storage systems.

Personal computers emissions

Unlike centralized cloud storage platforms, Hivenet's embodied emissions also account for personal computer emissions.

We use the Dell Latitude 7300 laptop from a 2019 Life Cycle study as a reference. The total emissions encompass:

- [E1] Personal Computer Emissions
  - [E1a] Manufacturing Emissions
  - [E1b] Transport Emissions
  - [E1c] Use Emissions
  - [E1d] End-of-Life
  - [E1e] Other factors

Manufacturing Emissions:
These emissions account for production: raw material extraction processing (metals, electronics, paints, adhesives, etc.), assembly and packaging of the laptop.

For the Dell Latitude 7300, the manufacturing emissions total **109.9 kgCO_2e.**

[E1a] Manufacturing Emissions = 109.9 kgCO_2e

Transport Emissions:
These include the emissions from:

1. Component Transport: Our methodology assumes that manufacturing and production occur at the same location, so no additional emissions are attributed here.

2. Transport to Customers: This involves moving the laptop from the factory to distribution centers and then to the end user. Specifically, for the Dell Latitude 7300, it's assumed that the laptop travels entirely **by air** from China (ChengDu) to the Netherlands (Amsterdam/Tilburg), covering a distance of 8000 km. Then, the laptop typically undergoes road transport, covering an average distance of 942 km, resulting in **13.5 kgCO2e**.
3. End-of-Life (EoL) Transport: The transport to end-of-life facilities is estimated at a distance of 680 km. This reflects the average distance from primary locations to major electronics recyclers in Europe, relying solely on road transport. This contributes an additional **0.1 kgCO2e**.

[E1b] Transport Emissions = 13.6 kgCO_2e

Use Emissions:
These include the emissions from:

- The emissions resulting from the use of the Dell Latitude 7300 laptop over its lifetime is estimated to be **35 kgCO_2e**.

[E1c] Use Emissions = 35 kgCO_2e

End-of-Life (EoL) Emissions:
These emissions relate to the disposal of the laptop once it's no longer in use.

- For the Dell Latitude 7300, end-of-life emissions are actually negative. With a recycling rate of 41.2%, these emissions offset **-11.7 kgCO2e**.

[E1d] End of life emissions = -11.7 kgCO_2e

Other factors
We used the following factors to compute the personal computer emissions for Hivenet only:

- Expected lifespan (as per Dell Latitude 730 LCA analysis): 5 years
- Replication factor (which includes sleeping devices): 3
- Storage capacity: 0.5 TB
- Faire share of the service LCA impact: 5%

Total Personal Computer Emissions:

For centralized cloud providers:

Personal Computer Embodied Emissions per TB = 0

For Hivenet:

Personal Computer Embodied Emissions per TB = 8.81 $kgCO_2e$ / TB / y

Dedicated Server emissions

Both centralized cloud storage and Hivenet rely on dedicated server emissions. The part of data stored on these devices decreases as Hivenet grows, soon to represent a smaller portion of the embodied emissions.

For the server emissions, the Dell PowerEdge R740 server from a Life Cycle study is taken as a reference. The breakdown is as follows:

- [E2] Server Emissions
  - [E2a] Manufacturing Emissions
  - [E2b] Transport Emissions
  - [E2c] Use Emissions
  - [E2d] End-of-Life
  - [E2e] Other factors

Manufacturing Emissions:
These emissions account for production: raw material extraction, processing (metals, electronics, paints, adhesives, etc.), assembly and packaging of the server.

For the Dell PowerEdge R740, the manufacturing emissions total **4288 $kgCO_2e$**.

[E2a] Manufacturing Emissions = 4288 $kgCO_2e$

Transport Emissions:
These emissions account for the distances and modes of transport for raw materials, operating materials, and auxiliary materials to production and assembly facilities. Specific transport scenarios for the Dell R740 materials are detailed.

- Component Transport: Emissions associated with moving components and parts to production and assembly facilities.
- Transport to Customers: It's assumed that the server travels primarily by air from its manufacturing location to its designated installation site.
- End-of-Life (EoL) Transport: This involves the movement of the server to end-of-life facilities for recycling or disposal.

After considering the above factors, the total transport emissions for the Dell PowerEdge R740 server amount to **3 kgCO_2e**.

[E2b] Transport Emissions = 3 kgCO_2e

Use Emissions:
Given that servers are typically active round the clock, the Dell R740's emissions are substantial:

- 24/7 Operation: The Life Cycle Assessment for the Dell R740 assumes the server is connected to the electricity supply 24/7 throughout the year.
- Global Warming Potential (GWP): This measure captures the impact of greenhouse gasses on climate change. For the Dell R740, GWP from its use emissions totals 4526 kgCO2e.

[E2c] Use Emissions = 4526 kgCO_2e

End-of-life (EoL) Emissions:
EoL emissions involve the management and disposal of the server once it's no longer in use:

- **Reprovisioning Process:** This process can include reuse, redeployment, dismantling for parts, recycling, and final disposal. For the Dell R740, recycling results in a credit of **-199.34 kgCO_2e**. This offset represents 1.8% of the server's total life cycle impact.

[E2c] End of life Emissions = -199.34 kgCO_2e

End-of-life (EoL) Emissions:
EoL emissions involve the management and disposal of the server once it's no longer in use:

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[E2c] End of life Emissions = -199.34 kgCO_2e

Other factors
We used the following factors to compute the personal computer emissions for Hivenet only:

- Expected lifespan (as per Dell R740 LCA analysis): 4 years
- Replication factor:
  - For Hivenet: 50% (only part of the data is stored on dedicated servers)
  - For traditional cloud providers: 3
- Storage capacity: 31 TB
- Faire share of the service LCA impact: 100% (entire server used
- for the service)

Total Server Emissions:

For centralized cloud providers:

[E2] Server Embodied Emissions per TB = 208.49 kgCO_2e / TB / y

For Hivenet:

[E2] Server Embodied Emissions per TB = 34.75 kgCO_2e / TB / y

Conclusion

Combining the various emission categories for both Hivenet and centralized cloud providers :

Centralized Cloud Provider Emissions per TB = 283.37 $kgCO_2e$/ TB / y

hiveNet Emissions per TB = 63.41 $kgCO_2e$/ TB / y

Hivenet is an opportunity to significantly reduce the carbon footprint emissions of a typical cloud storage service by a factor of 4.5.

The main factors explaining such a difference are:

- Embodied emissions are significantly lower due to the fact that Hivenet relies heavily on existing resources that would simply be wasted if not used by Hivenet. Reducing waste and limiting the build of new equipment is a way to reduce carbon footprint:
  - 80% in embodied emissions.
- Hivenet distributes its data on personal devices across the world. It avoids the concentration of large data centers leading in large cooling systems (reflecting in the PUE):
  - 30% in operational emissions
- By spreading the data in hundreds of geographical locations and relying using on ECC and data repair algorithms), Hivenet produces similar reliability with a lower replication factor for operational emissions (200%) than traditional cloud providers:
  - 66% in operational emissions

Our planet matters

Hivenet is changing the game in digital storage. Unlike the usual cloud storage services, we are doing things differently by using a system where many devices are connected. This is good for the planet and makes storing data more efficient.

All our efforts to study and reduce our carbon footprint are a work in progress towards not further harming our planet. We use clever tools like erasure coding to keep data safe and easy to get. This tech-savvy approach means less energy is used, and that's a win for everyone.

And the cherry on top? As more people use Hivenet, it gets even better. The system needs less extra help and uses less energy. So, as it grows, it becomes even friendlier to the earth.

Hivenet is a glimpse into a future where cloud tech cares about the planet.

		Unit	Central Cloud	Hivenet 2023	Hivenet 2025
0	**Equipment Mix**				
	Personal Computers				
	Hours connected per day	Hours	12	12	12
	Storage Capacity	TB	0.5	0.5	0.5
	Fair share of the service LCA Impact	%	-	5%	5%
	Years in Operations	Years	-	-	-
	Expected Lifespan	Years	5	5	5
	Dedicated Servers				
	Hours connected per day	Hours	24	24	24
	Storage Capacity	TB	31	31	31
	Fair share of the service LCA Impact	%	100%	100%	100%
	Years in Operations	Years	3	3	3
	Expected Lifespan	Years	4	4	4
	Cycle per year (personal computer)	3			
	Cycle per year (dedicated servers)	1			
1	**Operational Emissions (Electricity Consumption)**	**$kgCO_2e/TB/y$**	**74.88**	**19.86**	**19.86**
O1	**Cloud Storage Energy Conversion factors**	**$kgCO_2e/TB/y$**	**18.91**	**9.93**	**9.93**
O1a	**Disk Power Consumption**	**kW/TB**	9.3E-04	9.3E-04	9.3E-04
	HDD average capacity in 2023	TB/Disk	10	10	10
	Average wattage per HDD disk for 2023	Watts/disk	6.5	6.5	6.5
	SDD average capacity in 2023	TB/Disk	5	5	5
	Average wattage per SDD disk for 2023	Watts/disk	6	6	6
O1b	**Computing**	**kW/TB**	**0.0E+00**	**5.5E-05**	**5.5E-05**
	Personal Computers	kW/TB	0.0E+00	4.1E-05	4.1E-05
	Dedicated Servers	kW/TB	0.0E+00	1.4E-05	1.4E-05
O1c	**Networking**	**kW/TB**	**4.6E-04**	**4.6E-04**	**4.6E-04**
O2	**Replication Factor (exc. sleeping devices)**	**Ratio**	**3**	**2**	**2**
O3	**Power Usage Effectiveness (Cooling & Other)**	**Ratio**	**1.32**	**1**	**1**
O4	**Grid emissions factors**	**$kgCO_2/kWh$**	**0.4**	**0.4**	**0.4**
2	**Embodied Emissions (Lifecycle Assessment)**	**$kgCO_2e/TB/y$**	**208.49**	**75.37**	**43.56**
E.1	**Personal Computer Emissions per TB**	**$kgCO_2e/TB/y$**	**0**	**5.87**	**8.81**
	Replication factor (inc. sleeping devices)	Ratio	0	2	3
	Personal Computer Emissions (over lifetime)	**$kgCO_2e/TB/y$**	**146.8**	**146.8**	**146.8**
	Manufacturing	**$kgCO_2e$**	**109.9**	**109.9**	**109.9**
	Transport	**$kgCO_2e$**	**13.6**	13.6	13.6
	Transport to customer	$kgCO_2e$	13.5	13.5	13.5
	Transport to end-of-life	$kgCO_2e$	0.1	0.1	0.1
	Use	**$kgCO_2e$**	**35**	35	35
	End-of-life	**$kgCO_2e$**	**-11.7**	9.93	9.93
E.2	**Server Emissions per TB**	**$kgCO_2e/TB/y$**	**208.49**	**69.5**	**34.75**
	Replication factor (inc. sleeping devices)	Ratio	3	1	0.5
3	**Total Emissions**		**283.37**	**95.23**	**63.41**

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