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Sustainability of the Home LAN

An operator-led ecosystem approach to understanding and managing the environmental impact of the home LAN

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I. Executive Summary

This white paper uses the French market as an example with use cases from Orange France. A **home LAN** is a network of devices within a single home. Its environmental impact is measured by its energy consumption and the CO2e emissions of home devices.

Device manufacture and refurbishment are also discussed (for example, Orange France already recycles **85%** of its home gateways) and will be covered in greater detail in future papers.

Why it's important & why you should care

In the case of Orange France, the power consumption of the Set Top Boxes and home gateway together is 100 kWh/year in magnitude. This represents:

- **twice** as much as the IP network used to supply them with data,
- about **one-tenth** of all of Orange France's total carbon emissions.

What we can do in the short term

Idle-time power consumption represents around **77%** of the total. Better **sleep modes** are critical for reducing the home LAN's environmental impact. Leveraging **subscriber engagement** can also help alleviate short-term pressure, for example, by spreading load outside of peak demand.

> ***A plan to reduce the home gateway's energy consumption using currently deployed devices can achieve ~10% savings without significant Capex.***

In the longer-term

Chipset evolution is needed to save significant power on wasted radio resources at home. Better efficiencies in video streaming, innovations to extend CPE **shelf-life**, and further customer education promoting digital **sobriety** are crucial here.

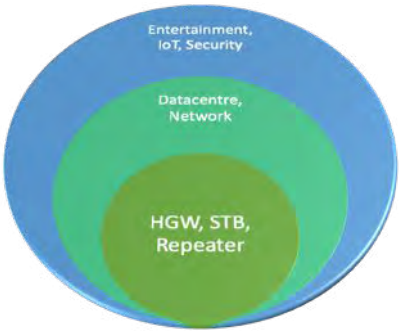
> ***~ 80% of energy could be saved with devices built on next-gen components. For the overall carbon impact to approach such targets, devices must be kept in the field beyond ten years.***

How a better home LAN can help in the broader context

A feature-rich home LAN, propelled by growing fibre deployments, enables more **work-from-home**. The Cloud and Wi-Fi offload can reduce emissions globally. We explore Cloud/local optimisation for storage and processing. Benefits for ecosystem players include:

- Meeting your own ESG goals and helping to save the environment,
- Being proactive with regulators,
- Delighting employees & customers.

Despite explosive traffic growth, operators like Orange have been able to lower their scopes 1 & 2 carbon footprint by over 10% at a group level in the last four years and will achieve 30% by 2025. Net zero, including scope 3, is on target for 2040[1].



1 Core focus of this white paper

1 Christelle Heydemann: https://www.europeanfiles.eu/digital/circular-economy-in-the-ict-sector-call-for-a-more-comprehensive-european-approach

II. ISP checklist: starting on home LAN sustainability

If the environmental sustainability of the home LAN is a new endeavour for your organisation, this one-page checklist will give you a quick idea of where to start.

Now is the time to start

- ☐ Saving power saves the planet and has the secondary benefit of saving money
- ☐ The home LAN, the core of our digital identities, is at the heart of building better

Not just technology, marketing input is needed too

- ☐ Although much will happen "under the hood", customer acceptance is critical, so you need a strategy to encourage it; educating users – including about overconsumption - is needed
- ☐ A "wattmeter functionality" (in Wh/y) can help onboard users with tangible results

  Sincerity, trust, and transparency are central tenets to avoid greenwashing

Commercial aspects

- ☐ Much wastage comes from too many devices, but unlimited data access can also encourage irresponsible customer behaviour
- ☐ Fibre improves LAN performance, and better LANs encourage mobile network offload, lowering the overall footprint
- ☐ Work From Home offers a win-win opportunity with reduced travel

Architecture

- ☐ Always look at end-to-end consumption (local savings can worsen overall consumption)
- ☐ Lowering peak capacity requirements is critical, optimising Cloud vs local storage and processing for different features, as some resources cannot be switched off
- ☐ Promote solutions where power requirement is proportional to usage (not just on/off)
- ☐ Electronic components (SoCs, boards) must evolve to support low-power modes better
- ☐ Middleware needs to be modular and optimised for low-power modes

User Experience

- ☐ Services adaptation: "good enough" can be better than "best" (e.g., reduce radio capacity during quiet times – remove auto-play & lower resolution for video services)
- ☐ Exiting sleep modes must be quick (load suitable software modules first, e.g., UI)

Quick wins

- ☐ A black casing is best for extended CPE shelf-life
- ☐ Turning off unused radio frequencies in Wi-Fi Access Points has a measurable energy impact
- ☐ Having an e-ink screen on the home gateway can lower truck rolls as it can permit clients to auto-diagnose their problems
- ☐ Accelerating the transition to streaming to reduce video delivery complexity

III. The environmental impact of the home network

To focus on the environmental impact of the home network itself in this section, we look at the home network in the context of our overall digital carbon footprint. We'll define CO2, CO2e, and Wh/year, look at scopes, zoom in on idle time, consider device build vs run, and investigate energy mixes. Note that a very brief history of ESR and CSG is provided in the annexe "A Very Brief History of ESG". Further white papers may focus on other essential phases of the life cycle, such as manufacturing, logistics and end-of-life, and other impacts, including material resource consumption and pollution.

For many, addressing sustainability – the ability to do something perpetually - started as a politically correct thing one just needed to do. But for some, it is already a core strategy requirement spreading to all company stakeholders.

Benefits vary but often include cost-saving, 'green' communication, and employee motivation/recruitment. Cost-saving is achieved by more efficient processes and the reduction in the use of resources and energy and can be an effective driver; however, if looked at in the short-term instead of the big picture, it can lead to increased environmental impact. ISPs are reorganising supply chains and maintenance for improved recycling. For example, in 2022, Orange reached over 85% recycling of home gateways; by specifying devices that allow for re-use and a longer shelf life, CAPEX is reduced in the long term.

The CO2e emissions from transportation and storage are easily measurable. An ISP with a strong local presence will want smaller stocks kept closer to users, although our financial models don't yet have the finesse to cater for such details. Similarly, the CO2e cost of salvaging rare earth minerals from recycled hardware is not yet well understood. Manufacturers have, for example, only been able to recuperate the aluminium from discarded chipsets fully.

1. The home network in the context of our overall digital carbon footprint

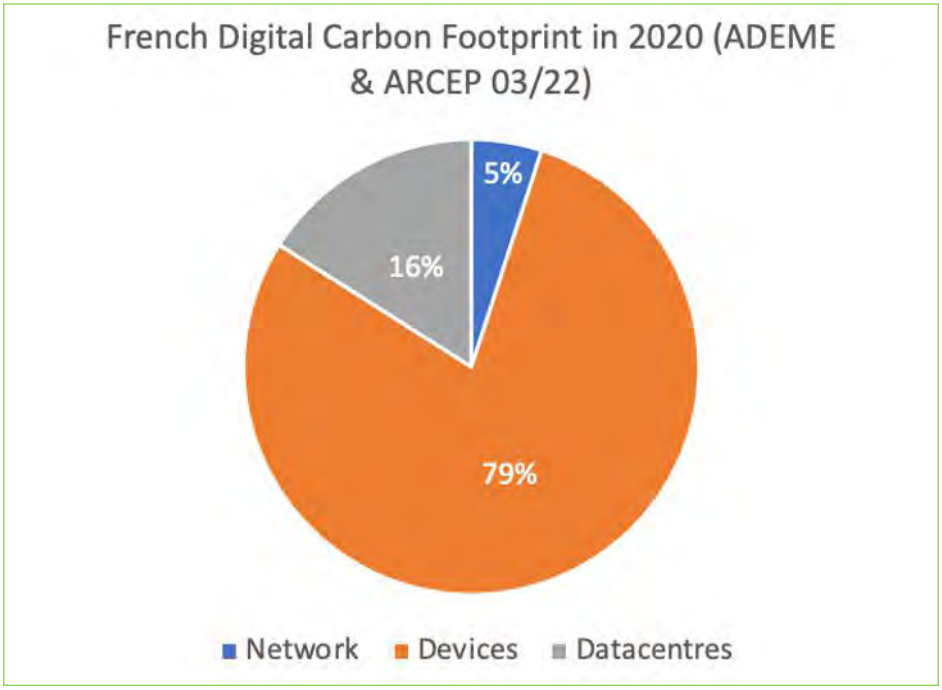
In France, 10% of electricity consumption and 2,5% of all CO2e emissions come from our digital lives (ADEME & ARCEP[2]). Globally, this is estimated to be between 2% and 4%[3], potentially rising to up to 15% within five years[4]. As we see in the last chart of this document "Home LAN CO2e emissions", operator devices such as the home gateway

2 Agence de l'Environnement et de la Maîtrise de l'Énergie (ADEME): https://www.arcep.fr/uploads/tx_gspublication/note-synthese-au-gouvernement-prospective-2030-2050_mars2023.pdf

3 SHIFT Project etc.

4 Draft BEREC Sustainability Report: Assessing BEREC's contribution to limiting the impact of the digital sector on the environment 03/20

or the STB account for about half of the carbon footprint that broadband providers can directly affect.



2 French Digital Carbon Footprint in 2020 (ADEME & ARCEP 03/22 2

We see "Where energy is consumed in our digital homes and idle time" that a home with a home gateway and an STB will use just over 100 kWh/y for those two operator CPE (in France, this represents just under 6 kg of CO2e) [CHECK DATA] but has a significant impact on other devices like the TV that consumes almost twice as much energy. Note that when electrical heating is used in the home, the consumption of all home LAN use cases is dwarfed in comparison; heating consumes, on average, thirty times more than the home gateway, STB combo for just one person.

2. Scoping the problem

The CO2e emissions from any organisation are classified into three scopes.

- Scope 1 includes direct emissions from company resources, such as burning gas or fuel.
- Scope 2 indirect emissions come from the generation of bought energy (to power the telecom network with electricity). These emissions are also called upstream.
- Scope 3 includes remaining up and downstream indirect emissions, the hardest to measure and influence. For the telecom industry, these include CO2e from the fabrication of purchased equipment and client usage of the organisation's products and services.

Scope 3 emissions offer the most challenging target to reach and the most promising

rewards as we begin our journey towards sustainability. For example, from a company like Apple, over 98% of emissions have been coming from scope 3 since 2015, and the current situation is no different.

> ***For Orange Group in 2022, scopes 1 and 2 were 1.30 Mt CO2e, which is between 10% and 14% of all emissions, including scope 3***[5].

Based on confidential data from other operators, the ratio of 90% of scope 3 emissions is typical of the sector.

3. CO2, CO2e or Wh/year

CO2 is the chemical formula for carbon dioxide, the principal greenhouse gas responsible for global warming. CO2e (equivalent) includes CO2 plus other gases that play prominent roles in the greenhouse effect, such as methane (CH4). There is an excellent description of CO2e here.

Global warming is one of the principal environmental impacts of the home LAN; therefore, in this white paper, we convert energy use where possible to CO2e to compare like with like.

However, converting home LAN power consumption into CO2e requires us to make significant assumptions, such as the network's "Managing peaks" or the energy mix of its power provider. These assumptions change at different points in the white paper requiring a lengthy explanation to adapt each time.

However, talking about energy consumption instead of CO2e has the advantage that client subscribers fully understand the former, not yet the latter. Energy is also directly measurable. We recommend that ISPs supply a wattmeter functionality in their devices wherever possible.

To discuss the relationship between a device's environmental impact during its build and the power it consumes to run, we will use CO2e. Still, we'll measure using kWh/year in many places, representing the number of hours a kilowatt of power was used during a year.

> ***Measuring is a critical part of any sustainability initiative.***

5 https://rai2021.orange.com/wp-content/uploads/sites/47/2022/05/orange_rapportannuelintegre_2021_fr.pdf (page 26), and https://www.orange.com/fr/engagements/orange-s-engage/pour-l-environnement

For energy consumption, it is critical to differentiate instantaneous consumption (W or Watts) from total energy consumption over time – W-hour (Wh) or W-year (Wy). For example, whereas a TV may consume over ten times more than a home gateway if measured instantaneously, the average TV uses only twice the amount of a gateway over a year. So, wherever possible, we will measure in kilo Watt hour per year (kWh/y).

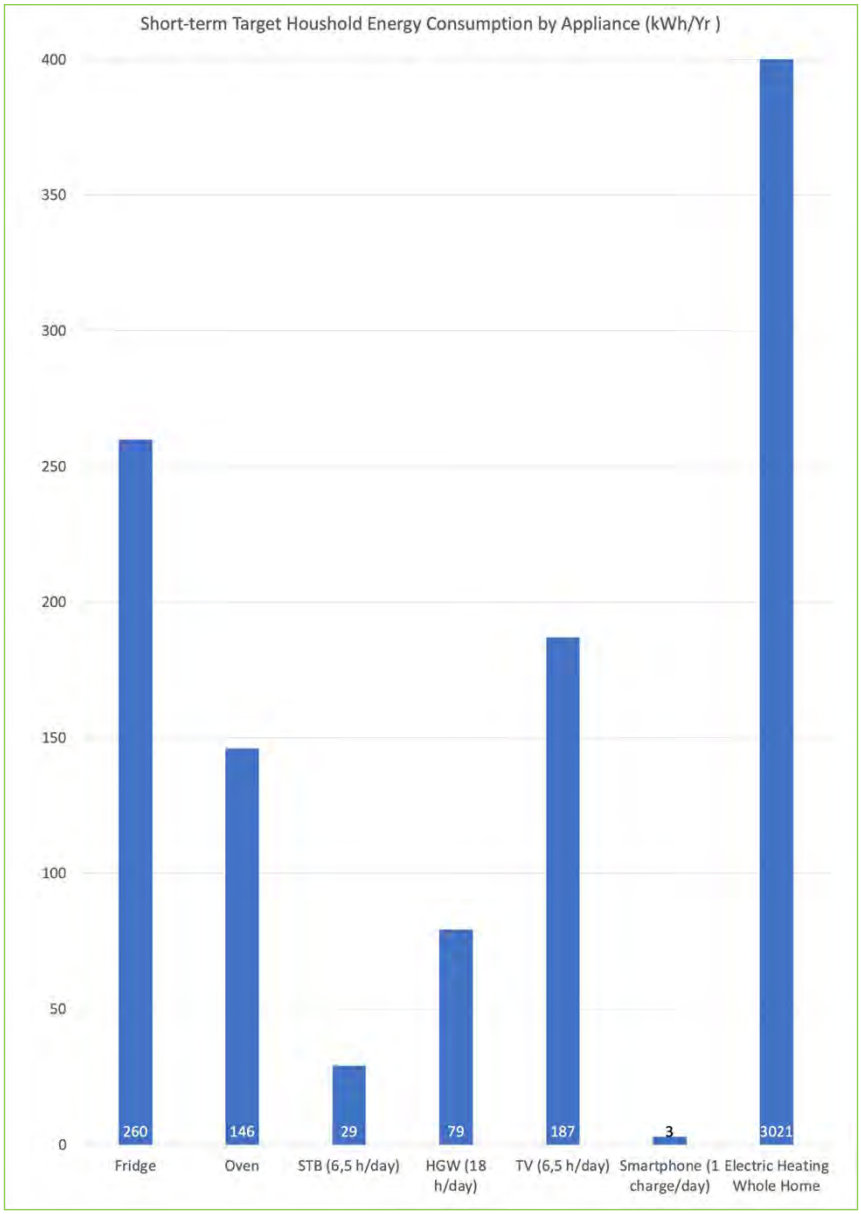
4. One sustainable home network size doesn't fit all

Homes are where families are raised; they are central to people's identities. We want our homes to reflect who we are. In this digital age, the network within the home caries part of that identity. Even if there is something universal in basic IP connectivity, the home network must be personalised. Services will be differentiated as users have different requirements. The home network's power consumption and CO2e emissions can be addressed "under the hood". But when the subscriber's explicit acceptance is required, operators must provide personalised services that address privacy concerns.

5. Where energy is consumed in our digital homes and idle time

EU privacy directives forbid operators from analysing home LAN traffic except for routing purposes, so traffic analysis doesn't help us understand where energy is consumed.

So, how do the energy requirements of our digital home and its LAN fit into our overall digital lives?



3 Household appliance annual energy consumption[6]

In adapting some ADEME data, we consider that the STB is only turned on when the TV is too, which is only the case with operator-controlled devices and that a home gateway is switched off for six hours every evening. The chart with the original ADEME data in the annexe "A Very Brief History of ESG" is provided for reference. Other studies assume the home gateway is on 24/7[7].

For a device manufacturer like Sagemcom, typical home gateway power consumption for devices shipped in 2022 will range from 10W to 15W. More extreme cases range from 8W to 30W. Using the 18 hours per day average uptime, we see from this source that home gateway power consumption is in the range below.

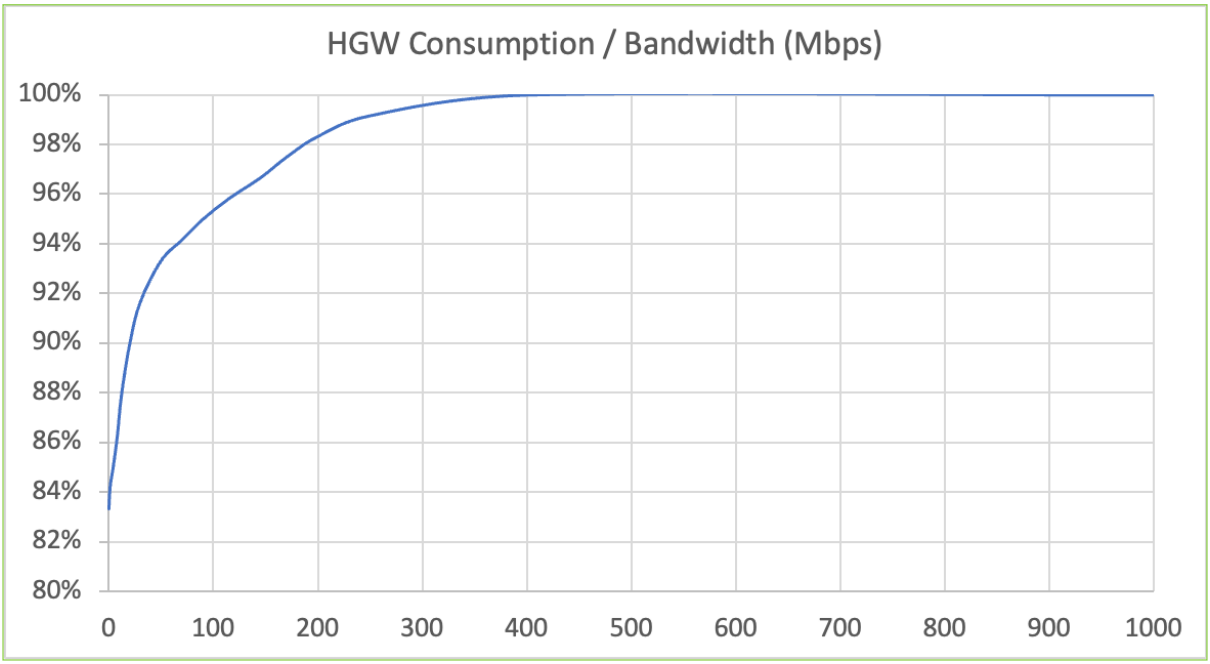
6 Source ADEME data & Orange usage patterns

7 E.g., Investigating the Energy Use of Video Delivery and Consumption 2022-2027 (Faultline Research, December 2022)

A home gateway consumes between 50 and 200 kW/year without sleep modes.

A network's peak capacity also influences the energy cost to deliver things, even outside peak times. However, the difference in power consumption of the overall network between idle time and, say, when delivering a video session to the TV is still controversial. Industry groups such as "Greening of Streaming" are actively working on this critical question.

Looking solely at the home network, the home gateway consumes 90% of its full power requirement during idle time. This seems to be low-hanging fruit to reduce energy.



4 home gateway power consumption according to load[8]

Idle power consumption using current-generation home gateway chipsets - when keeping all features available (i.e., all radio frequencies active) – is only 17% lower than at peak performance. Low-bandwidth services cost more per bit proportionally. Focusing on the home network, transporting two 75 Mbps 8K streams over home Wi-Fi consumes only fractionally more energy than doing the same in HD; we transport twenty times the data for less than ten per cent more energy cost. To address this challenge, chipsets must evolve, as we discuss "Sleeping intelligently".

When a Wi-Fi radio session stays open, devices have an active connection with a few Watts of power going to the antennas. Whether data is transmitted or not, the power consumption varies little. Above 100 Mbps, the correlation between energy requirement

8 Source Orange France

and throughput almost disappears; below 100 Mbps, only a low correlation exists.

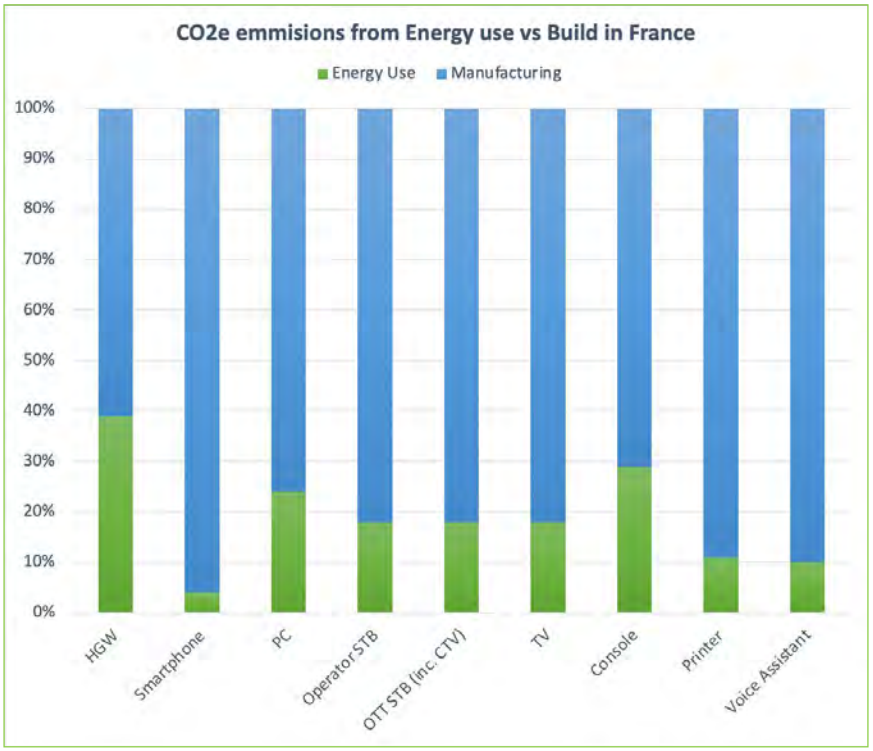
In earlier sections, we saw a clear hierarchy in power consumption, with the home gateway consuming over twice as much annually as an STB (other credible models show a factor of five).

EU regulation is more stringent for the STB than for the home gateway; Advanced Configuration and Power Interface (ACPI) defines five activity levels, and an STB must support more advanced energy modes. Regulators consider the gateway as a "highly available" network device, so it must answer queries from both LAN and WAN instantaneously.

There is a huge potential in addressing idle time, which we discuss below.

Home gateway idle-time consumption is ~77% of all power usage, representing a low-hanging fruit, but will require a new chipset architecture to be fully addressed.

6. Device build vs. Energy consumption



5 CO2e generated during device run vs build in France[9]

CO2e emissions from home devices in France are shown above from the build (manufacturing) and usage phases of life. Reliable data is not yet available for end-of-life

9 Source SoftAtHome and Orange

emissions. Note that this is atypical because of the country's lower-carbon energy mix, as discussed "How energy mix influences the home's path to sustainability"; for countries with a higher-carbon energy mix, the % of CO2e from the usage phase can be much higher.

The chart above doesn't illustrate how "good" or "bad" a device's energy efficiency is. Instead, it shows the CO2e generated from the power used during a device's lifetime as a proportion of all the manufacturing CO2e generated.

Eco-designed home gateway models have been around in France since at least circa 2009[10]. Most operator boxes launched since 2020 in the French market include eco-design principles. Orange is committed to reaching 100% eco-design by 2025[11].

This chart already points to a central conclusion of this white paper that operator-managed devices are run more efficiently. The smartphone's meagre use/build ratio also stands out, mainly due to its rapid renewal rate and higher use of rare earth materials.

Focusing on the home gateway's energy usage, we can segment it into three main parts.

Segment	Components	Saving opportunity	HW dependency	Typical consumption*
Main	SoC and WAN modem (copper/ fibre)	Low	High	4-6W
Wi-Fi	RF bands and number of active antennas	High	Moderate	3-5W
Other	DECT, ethernet, ...	Low	N/A	0.5-2W

*Source SoftAtHome

6 Three parts of the home gateway from an energy-saving perspective

Integrating several devices can save components, casing, and power supplies. An ONT can be integrated into the home gateway or a sound box into an STB, for example. There can be adverse side effects if the combo device is used when just one of its features is needed.

One simple solution to reducing energy consumption at home is to reduce the number of devices connected to the home gateway.

10 FR announced a reduced CO2e footprint for its home gateway of 36 Kg. https://ile-de-france.ademe.fr/sites/default/files/eas-me-sfr.pdf

11 https://www.orange.com/fr/engagements/orange-s-engage/pour-l-environnement/notre-engagement-pour-la-planete-net-zero-carbone-dici-2040

7. How energy mix influences the home's path to sustainability.

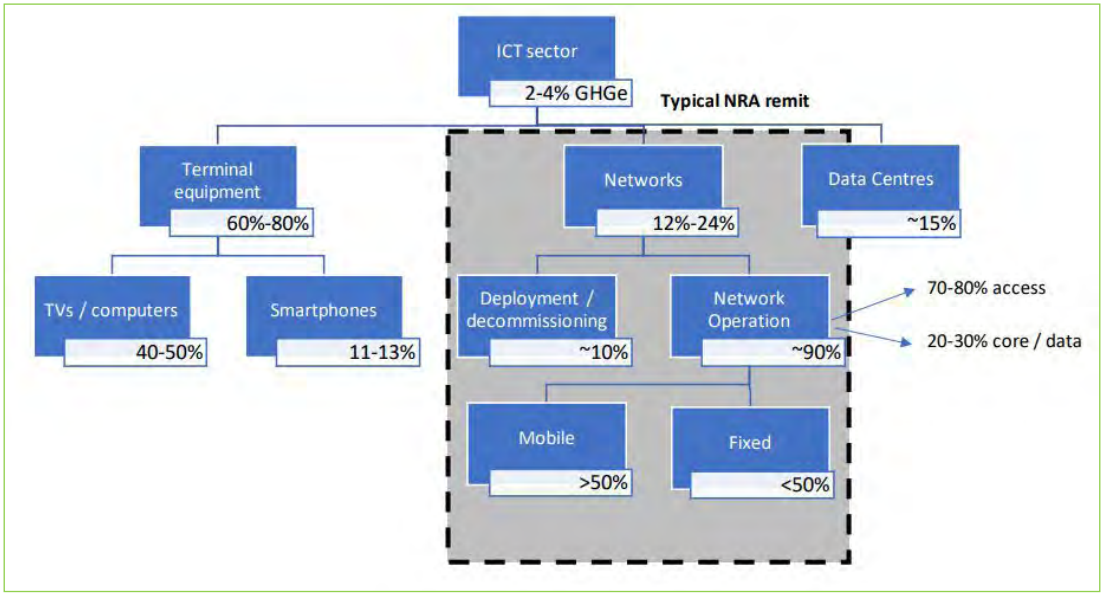
Fossil fuels dominate the global energy mix in most markets. In the Annex "Energy mix", we describe the international, French, and Polish situations. France has one of the least carbonated energy mixes in Europe, while Poland has one of the most. In a simplified theoretical scenario, we show how a French operator is incentivised to keep devices in the field even if more efficient ones are available. In our example, the Polish operator can justify changing devices every three years if each generation needs 40% less energy. In France, an operator would need to wait up to ten times longer between device generations.

Energy mixes will improve over many years, so a long-term vision is required here.

Energy mix - What this means for:	
a manufacturer	fine-tune sustainable offerings to each market
an operator	
a subscriber	change for a more efficient device in carbonated energy mix markets

8. Towards a Home LAN energy/carbon model

No agreed model exists for how to slice and dice all the components and their contribution to CO2e emissions. International industry bodies and regulators are an excellent place to look for a framework that could gain industry consensus. In 2022, the Body of European Regulators for Electronic Communications or BEREC captured this way of looking at energy consumption from which we can derive the home LAN's consumption.



7 BEREC: Breakdown of ICT sector contributions to Greenhouse Gas emissions

The chart above is from the BEREC website. In this paper, we have used the approach captured in this diagram and internal Orange data to determine what impact an operator can have on the end-to-end CO2e emissions. The calculations of the previous chapter and the result in the final chart, 17 show this.

Managing peaks

The peak capacity of almost any network is a critical driver for its energy efficiency. This constraint is valid for the whole operator network and the home LAN alone. The recent energy cost spike has brought to light the risk of blackouts, even in the most developed markets. Peak consumption periods are the most difficult, and peak network usage directly correlates with peak power consumption. That is why operators like Orange have significantly improved their power consumption during peak usage times (see here in French).

The influence of peak capacity over overall energy requirements will slowly lessen as devices in the end-to-end architecture adapt power requirements to their load.

Managing peaks - What this means for:	
a chipset maker	Make processing proportional to load
a manufacturer	Where possible, promote broad/multicast
an operator	
a subscriber	Avoiding peak times when possible is good for the planet

Top-down, bottom-up, regulation and why failure isn't an option

Top-down initiatives come from law and regulation, while bottom-up pressure comes from citizens. Both are needed, but for an ISP in competitive markets, being a step or two ahead offers more room to differentiate. If everyone in the market does the same thing simultaneously, the only differentiator can be price, leading to a race to the bottom. Operators need to anticipate regulation in areas such as sustainability. Otherwise, implementing new rules in a rush is costlier and can lead to unsustainable solutions.

IV. Lowering the home LAN's footprint

1. Sleeping intelligently

Turning the home gateway off when Internet access isn't required seems promising. For example, Orange's latest home gateway, the LiveBox 6, has a "light" sleep mode where telephone services are maintained and a "deep" sleep mode where all services are suspended. The latter method reduces power requirements by 95%. However, turning the home gateway off or into a deep sleep without Wi-Fi is not a solution for all cases. For example, even if home IoT is still a nascent market, half of the people with IoT devices have an alarm. The operator often does not manage these devices that require Wi-Fi.

Also, turning off Wi-Fi can have other adverse side effects. In France alone, one undesirable outcome if all operators defaulted to a sleep mode with no Wi-Fi at night, up to a hundred million mobile devices would be "sleeping" on cellular networks instead of Wi-Fi.

The power consumption ratio between Cellular and Wi-Fi + fibre is around 10X in favour of Wi-Fi + fibre[12].

There are at least three ways of getting the home LAN components into reduced power modes.

1. Manually
    a. Via App or on Web UI, locally or remotely (CPU and WAN are up and running)
    b. On the home gateway, through the screen menu or button
2. Scheduled
    a. At repeated times (nights, weekends)
    b. During calendar events
3. Automatically
    a. On inactivity timer (15mn, 30mn, 1h, 2h, 4h, 8h … 48h)

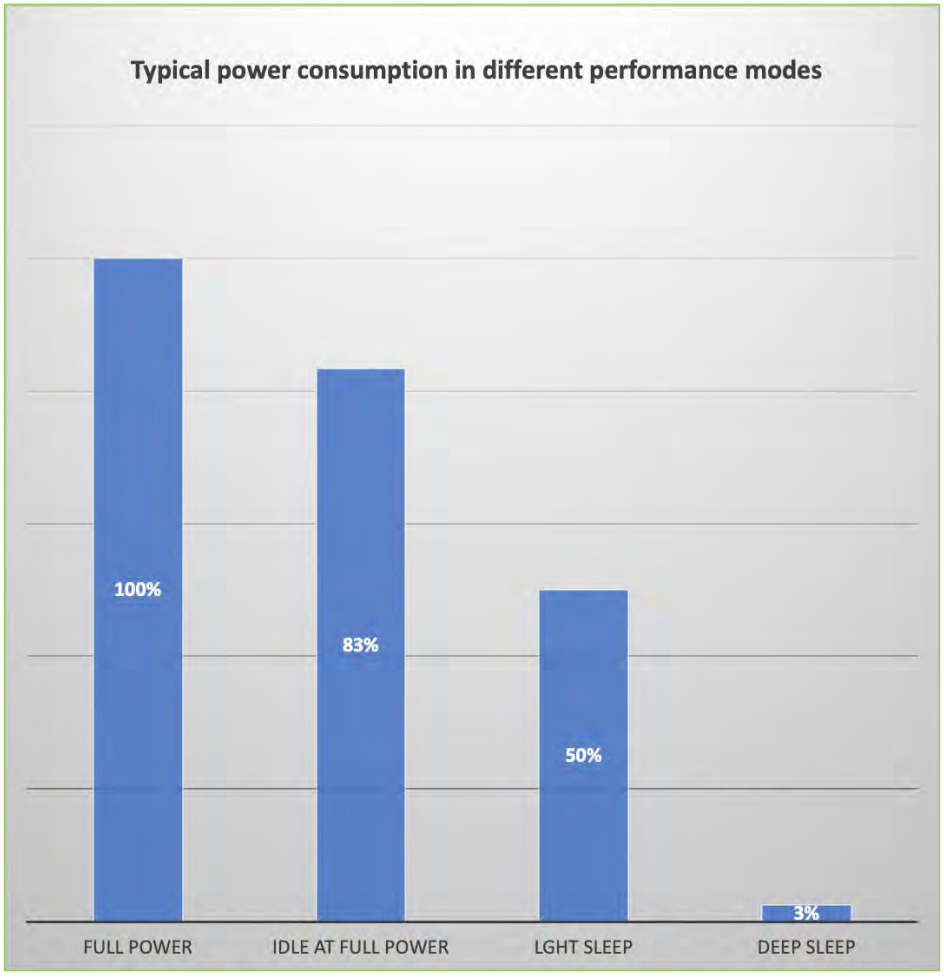
Smart middleware can already achieve quite a lot on its own, even without dedicated hardware support, but with such support, savings are more significant.

12 https://www.arcep.fr/uploads/tx_gspublication/rapport-pour-un-numerique-soutenable_dec2020.pdf

Segment	Components	Saving opp	Resume time	No HW support	With HW support	Typical consumption
Main	SoC and WAN modem (copper/ fibre)	Low	High	0-5%	>90%*	4-6W
Wi-Fi	RF bands and number of active antennas	High	Medium	~25%	~40%	3-5W
Other	DECT, ethernet, ...	Low	Low	N/A	0-5%	0.5-2W

8 Power saving opportunities in the home gateway

* Orange's LiveBox 6 uses a PCB feature to turn the whole SoC on or off, but this is not workable for all users, for example, those with security home systems using Wi-Fi.



9 Power consumption depending on power mode [UPDATE]

As described "Chipsets must support low-energy features", future HW support is needed to reach significant savings while keeping acceptable service levels. The alarms mentioned above must still work even in reduced power modes.

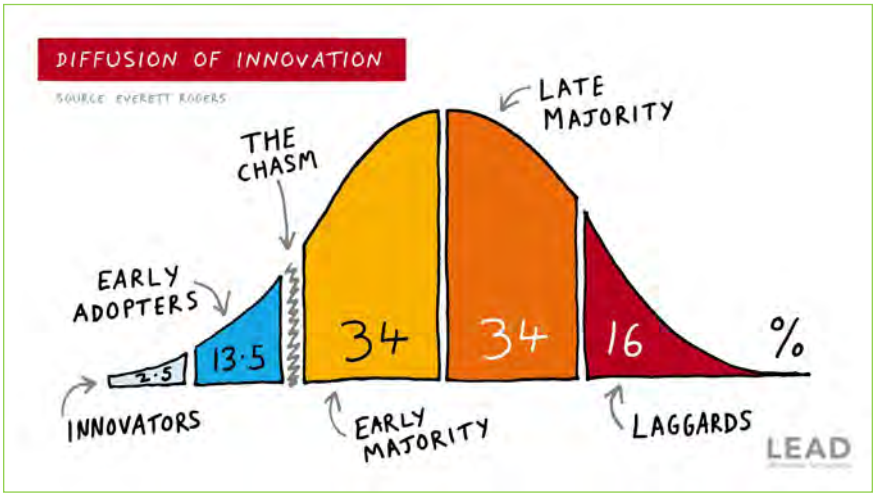
Note that technologies and features have hindered the implementation of sleep modes. The TR069 that was used to manage CPE by many operators until recently would often ping devices every 40 ms. App stores by Google or Apple can specify that certain apps must be able to receive push notifications preventing many forms of sleep.

2. Leveraging user engagement towards sustainability

> ***Stakeholders from a technology background tend to say energy savings should happen under the hood, while marketing people see a need to involve the user, albeit minimally.***

In any market, subscribers can be segmented into three groups. We can call the early adopters those who will avidly accept any change that can help the planet. Then followers are the group potentially open to change if they understand the impact on their experience. Then the third sustainability resistors' group is made up of those that want the best service for the lowest price and will churn if they feel they are no longer getting that.

Sustainability resistors probably still represent the largest segment of US consumers. In contrast, French consumers (and we presume most European consumers) break down into 20% early adopters, 60% followers and 20% sustainability resistors (source Orange France).



10 Diffusion of innovation

Acceptance

User acceptance is influenced by education and knowledge. Device middleware is getting more intelligent in this respect so that changes that reduce power consumption have the least possible impact on user experience. Trade-offs need to be precise. For

example, with current chipsets, if the home gateway switches off completely the Wi-Fi when it's unused, a 2 W saving is achieved, but up to two minutes may be required to start everything back up, according to SoftAtHome. If Wi-Fi is instead put on standby, only about 1 W is saved, but getting back up can take as little as a second.

A helpful metaphor is that of the automobile's start/stop feature. Drivers wouldn't accept a two-minute delay for the car to start when a traffic light goes green. In the home LAN, energy-saving features must also have minimal impact. An intelligent middleware could turn off all Wi-Fi at night, returning to standby before people wake up.

Common sense in marketing and recent customer focus groups show that many users will deactivate energy-saving features if their impact is too high.

Communicating to users

Some things Orange can achieve by working behind the scenes include:

- Improving CPE with features to lower consumption
- Helping subscribers reduce their overall number of devices
- Lowering consumption of unneeded resources

Some things Orange is considering doing to get users more involved:

- Educate clients to take decisions the operator cannot. Such limitations may be due to legal or regulatory frameworks or when the user experience impact is significant.

Some other ideas being explored include:

- Gamifying green issues so that it's also fun,
- Creating a club effect so subscribers feel valued for their efforts towards sustainability,
- Where appropriate, offer financial incentives when the greener way also creates cost savings that the operator can pass back to the subscriber,
- Producing a report on all devices connected to the LAN,
- Leveraging Wi-Fi sensing to detect when no one is in front of the TV.

Customer-facing eco-labelling is beginning to take root in some places. Germany, for example, with the TuvGreenMark label. This is also starting to arrive in France, where operators already communicate on the environmental aspects of their home LAN products.

Political will is needed for any stringent regulations

The rollout of smart electricity meters in Europe and, more recently, the virulent online reactions to French government communication on turning home gateways off at night show how touchy the subject can be with users.

Measuring how people feel about compulsory measures is hard to gauge as the most active on social media are often the change resistors.

We are getting outside the scope of what operators and their ecosystems can do here, but it seems clear that they must remain highly sensitive to consumer attitudes that vary from market to market.

Shifting goalposts

The regulatory framework is rapidly shifting. Today, operators like Orange are generally ahead of regulation, but we can expect regulators to move forward faster on sustainability. Operators always want to stay ahead and see that being a leading sustainability player in their market can become an asset to their brand.

3. Chipsets must support low-energy features

Improvements from the middleware that runs devices based on today's hardware could reduce power requirements by 10% to 20%, according to SoftAtHome. Going further at this time would overly degrade the user experience. The most effective way to address the remaining 80% will be with a new chipset and SoC architectures with improved support for low-power modes. However, as semiconductor manufacturing processes move from 40 nm at the outset to 7 nm and below, opportunities for lowering power consumption will continue to arise.

In the same way, the iPhone 14 has an "always on" screen feature that is only refreshed once a second to save power. ISPs will need to enable new sleep modes that, for example, still let security cameras wake up the system when movement is detected or are polled often enough to raise a timely alert.

Hardware must support short periods of reduced Wi-Fi when there is no activity while reaping the energy-saving benefits.

Critical power-hungry hardware accelerators within current designs must constantly be on to manage radio transmissions or video decoding. New architectures are needed where power usage is proportional to load at all parts of an end-to-end architecture, including the chipset. Most electricity would only be consumed to render services addressing the idle-time issue.

Until then, processing should occur where power consumption is most proportional to usage.

A standard way of communicating a required service level between devices, e.g. "I need

to be woken up on the network once every two seconds", would help maximise power savings while minimising user impact. The emergence of open ecosystems discussed "The promise of open ecosystems" will facilitate this.

4. Codecs and more efficient streaming

Video services are a central part of the home network. This chapter was written after speaking to Jean-Louis Diascorn, senior innovation manager at Harmonic Inc. This discussion is at the edge of this paper's scope, as much video processing happens within the TV.

The chipsets used to decode video in the wired devices of the home network behave as if they are either « On », consuming power or "Off", whether they are decoding a simple low-res video or an 8K one or even doing nothing. Optimising power consumption is, therefore, not an effective strategy today. Mobile devices, where energy conservation has always been critical, show us that other hardware approaches could be possible. The ARM architecture on recent MacBooks is an excellent example of mobile technology coming to the desktop and bringing massive power savings.

Is it cheaper to decode lower-resolution video?

Major codec generations occur around once per decade.

MPEG2 → H264 → HEVC → VVC

Each new codec is generally twice as efficient as its predecessor and requires at least four times the processing power. The situation was workable with a healthy Moore's law and little regard for power consumption. However, neither of these is still the case.

Despite all the changes from MPEG2 to VVC, all codecs use similar building blocks. Each generation sees refinements and more tools but still uses a similar process.

> ***Once chipset power consumption becomes genuinely proportional to the decoding effort, we can ask for "simpler" encoding. Even if only milliwatts are saved, the billions of devices mean we are still talking megawatts.***

What about HDR and brightness?

The jury is still out for other video features like High Dynamic Range (HDR). Estimates of the extra power required vary from just a few percentage points to 100 % to decode and

display HDR. One reason for this considerable gap is the variability in video brightness. A consensus is forming on HDR being calibrated at 203 Nits (a measure of luminance or brightness); simultaneously, Standard Dynamic Range grading is moving from 100 Nits to 200 Nits. So, it's not an HDR issue per se, but one of luminance. HDR is about contrast, not overall luminance, so in the end, supporting HDR shouldn't change energy requirements in the home in a measurable way. In dark scenes, HDR could even consume less. Although several organisations are working on it, there has yet to be any valid data on the potential extra processing required by HDR.

Dynamic Resolution Encoding is a new approach that lowers resolution on the fly in video parts without significantly impacting user experience. It will affect decoding consumption, although it's too early to say whether the savings will be measurable.

5. Optimising Wi-Fi topology (more repeaters than needed?)

The fewer devices in the sustainable home LAN, the better. The primary device should be at the centre of people's homes. We must ensure installation engineers can spend enough time bringing the fibre to the right place. Installation technicians are often paid by installation and want to do whatever is quickest. Well-meaning regulation that requires a full Ethernet setup will lead to the primary Wi-Fi access point being set up at the building entrance rather than its centre.

The home gateway must also be elegant so people will readily set up in a visible place in the sitting room. Orange France discovered that their latest LiveBox 6 requires fewer repeaters, not only because of better radio but also because it's a vertical device that is more elegant than previous versions. Hence, users are happy to keep it visible rather than hidden away.

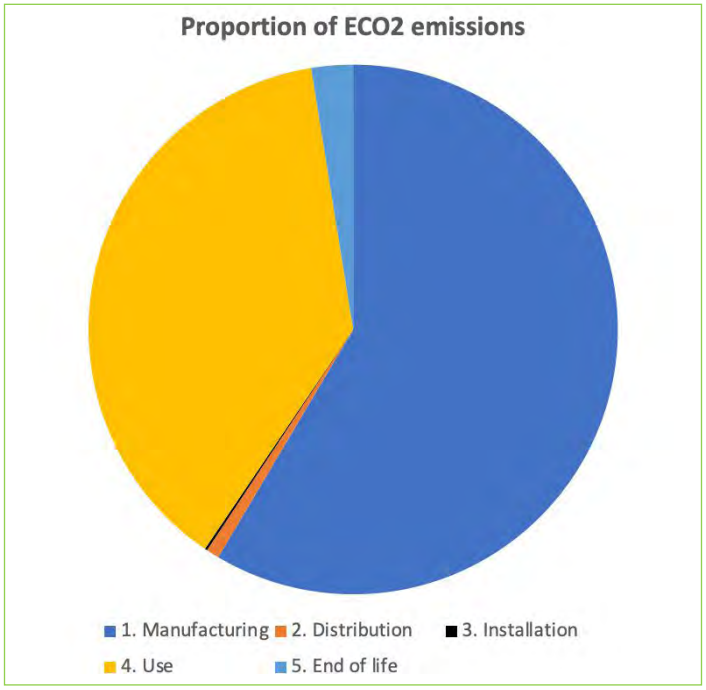
Adding a repeater improves the Wi-Fi experience in almost all situations. However, the effects on overall power consumption are more complex to analyse. Adding more repeaters should only be recommended case-by-case. In some cases, subscribers should be advised about partial sleep modes when available.

Is the future wired or wireless?

- In France, most subscribers no longer use ethernet,
- When coverage issues occur, Wi-Fi repeaters are often cascaded beyond reason,
- Ethernet is becoming more present through regulation; for the last decade, all new homes in France must have ethernet, a rule that is only sometimes followed.

6. Device Manufacturing

The hardware impact on a device's cradle-to-grave CO2e emissions can be significant, especially in countries with a low-carbon energy mix. For example, in France, CO2e emissions from hardware alone can account for over half of the overall impact of a device's complete lifecycle.



11 Simplified lifecycle of a Sagemcom device modelled with EIME

The evolution of energy mixes in all markets, which must continue to evolve to meet Paris Agreement goals, will decrease the relative importance of the use phase in the long term.

It is, therefore, evermore important to also work on the manufacturing phase beyond energy consumption, looking into multiple aspects:

- Use local manufacturing wherever possible
- Optimise manufacturing processes
- Find alternative materials (plastics, metals and others)
- Integration functions (one chip instead of 2, 3, 4… with potential drawback on energy efficiency) and miniaturisation
- Implement materials traceability
- Design upgradability into the manufacturing process

Assembly methods also affect a product's ability to be refurbished and recycled, enhancing its shelf-life. Ideally, the assembly method will integrate reversibility to separate different materials during recycling effectively. Such an approach enables waste streams that can

be recycled with optimal output quality, making it possible to use this secondary material for new production.

7. Reducing consumption and renewal of individual devices

In the short term, we still need new hardware

Sustainability awareness has been growing for several years. Hardware design and build cycles, particularly for SoCs, have traditionally taken several years. We are temporarily in a unique position where, although we want device shelf lives to lengthen, we need a new generation of devices in the short term to improve our drive to effective low-power modes.

Extending shelf-life

Technology agnosticism future-proofs devices, for example, adding XGSPON to a GPON box. Tech maturity helps too. The core components of fibre are here to stay for many years.

> ***If the trend for more home services continues, devices delivered today must be over-specified to support future services; alternatively, we must stop adding features.***

Device manufacturers have a role to play in extending shelf life through innovation. A more flexible device architecture could enable them to be physically updated at home rather than changed.

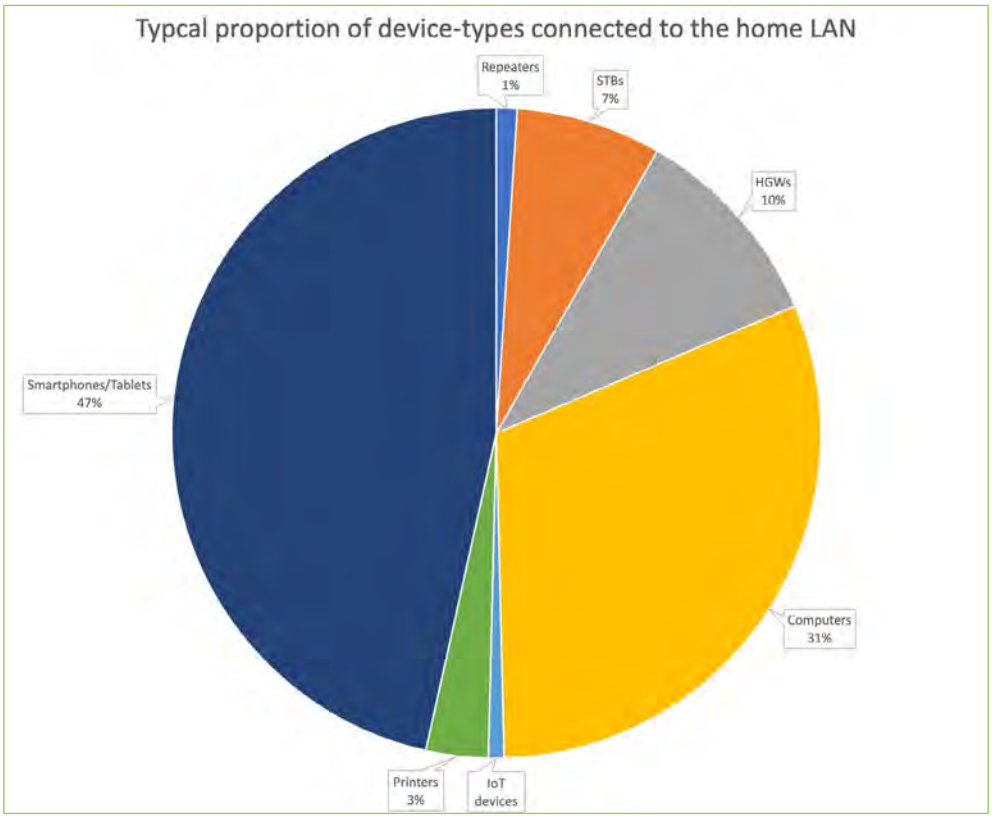
> ***The maturity of XGS-PON and Wi-Fi enables operators to give devices a longer shelf life.***

Operators can extend shelf life by adopting technology early on (like Orange did with Wi-Fi 6e). The corollary to this is the ability to retire others once they are no longer critical. Examples of this are the removal of Bluetooth and DECT from Orange's latest gateway.

Optimising the power usage of existing devices

ISPs can identify "always-on" devices that need not be, such as printers. The home gateway can find such devices and determine how often data gets sent to them. The operator's companion apps can easily offer this functionality. There are privacy concerns

to be addressed with users and regulators.



12 Device types connected to the home LAN

The considerable proportion of smartphones is not surprising, but the low ratio of IoT devices is disappointing for the smart home industry. The devices managed by operators (repeaters, home gateways, and STBs) represent 18% of devices connected to home LANs, leaving 82% of retail devices.

We've only just started turning off unused features; there's plenty of room for improvement. From Wi-Fi 6 onwards, APs control other devices and will be able to turn their radios off.

Moore's law is waning for CPE, too

Many ISPs have been successfully lengthening device shelf-life from five to eight years. A central aim of eco-design is to go beyond ten years. So, is Moore's law (stating that processing power doubles every 18 months) losing its integrity in our space?

- It is losing its sense in the world of the PC, with computer obsolescence lessening,
- Bandwidth was a leading industry driver for decades; fibre deployment has put an end to that,
- Latency might have become the next driver, but we're already down to 1 ms, and it's

not clear whether average users need further reductions,

- Chipset and other component improvements lessen from one generation to the other.

Irrespective of ISPs' intentions, the points above show a natural tendency towards longer shelf lives. Devices will, however, need to be built with enough quality. It is interesting to note that Orange's devices have moved from white casings to black, which retains a "new" look for longer. Ten years can be a long time for white or coloured plastic.

It may seem counter-intuitive, but Orange estimates that adding an e-ink screen to the home gateway has lessened its carbon footprint. Indeed, for a marginal extra build cost, it significantly reduces customer calls and, more importantly, lowers truck rolls (technician after-sales visits).

A quick win with multiple radio frequency bands?

Wi-Fi access points shipped today will often have three frequency bands of 2.4, 5 and 6 GHz.

A longer-term goal is for interoperable devices to collaborate to optimise radio usage within the home.

These bands each require antennas that consume energy. Still, in the short term, a gateway can turn off unused frequencies by default, as with Orange's latest device and the 6 GHz frequency.

Vendors like Sagemcom have their own sustainability roadmaps, such as solar farms for factories, transport optimisation using waterways rather than roads or improved repairability. The vendor's lifecycle analysis goes from design to end-of-life, defining priorities for lowering carbon footprint and taking the local energy mix into account at all parts of the workflow.

Refurbishment

The benefits of CPE that is refurbishable by design can be highly significant.

Refurbishing a device means cleaning, re-cabling, possibly changing broken shell components, re-flashing the firmware, testing, and repackaging into a new cardboard box. Doing this avoids producing a new device, and the most impactful parts from a sustainability perspective, the electronic boards, are reused.

Considering a home gateway with a manufacturing impact of 37 kg CO2e, its refurbishment requires spare parts (plastic parts, packaging and transport) representing a CO2e impact of only 2 to 3 kg eCO2. The total emissions for two cycles are 40 kg CO2e, while two new

products would produce 74 kg CO2e. In this example, the refurbishment decreases the impact of the manufacturing phase by 46%.

An operator like Orange France has two top-level indicators.

- The proportion of devices that get back - currently over 80% - that Orange is always looking to improve.
- The proportion of collected devices that are indeed refurbished. The initial build quality is critical here. Orange France currently refurbishes 95% of collected CPE.

Improving the customer journey with better information is the most cost-effective way of improving the proportion of devices returned. It's the operators' responsibility to make sure customers know. Maintaining the "stick" of subscribers having to pay for non-returned devices is costly. Orange attributes the 25% improvement in returned devices over the last five years to better communication. Having a responsive backend system with reliable and granular data on which devices are in which homes is critical here.

Note that end-of-life management is a different issue. Once the OEM no longer makes a device, operators will gradually retire them. These devices can be resold to other operators or dismantled within the ecosystem by specialist firms such as Pena.

Eco-design avoids permanent bonds between parts and materials, enabling their separation.

V. A better home LAN to reduce the overall footprint

This chapter looks at several other Home LAN-related issues and technologies that can impact the overall environmental footprint.

A more open, standardised home LAN can simplify overall architectures, reducing redundancies and inefficiencies and future-proofing the end-to-end delivery of network services for our digital lives.

We also discuss how open-ecosystem initiatives like RDK-B or prpl address this in a chapter below. A future standard to communicate energy requirements and capabilities, where devices could communicate their connectivity needs, could let a home Gateway optimise Wi-Fi power consumption.

1. The Wi-Fi offload opportunity

What Wi-Fi offload is

13 Hyper-simplified Wi-Fi Offload

"Wi-Fi Offload" means offloading mobile device traffic from cellular networks **to** Wi-Fi using fixed internet access. Dean Bubley describes this well in a LinkedIn post. Mobile networks generally use more energy than fixed networks and can be more expensive to operate. Wi-Fi Offload can therefore reduce energy consumption and cost for operators of mobile networks.

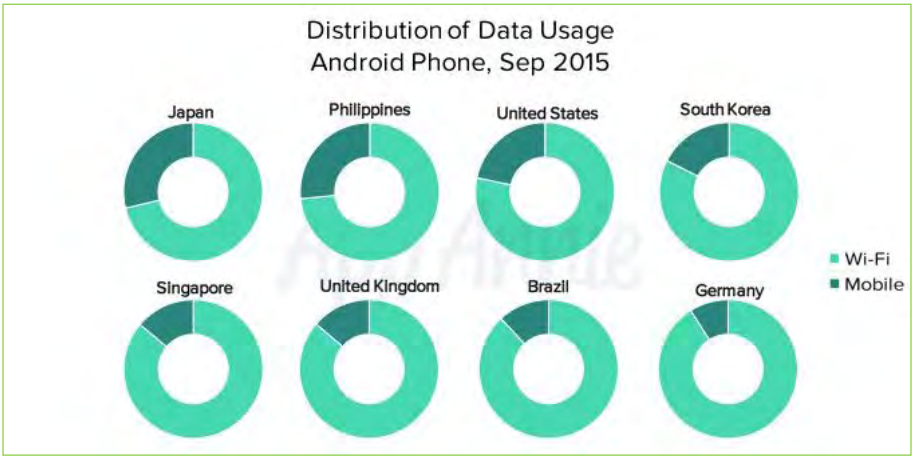
Offload occurs:

- by the user's explicit choice, activating Wi-Fi on the smartphone when at home,
- automatically by the device reactivating Wi-Fi when close to a trusted Wi-Fi hotspot,
- with the operator's help using Wi-Fi zones, network-controlled authentication, and balancing mechanisms.

How much traffic is offloaded?

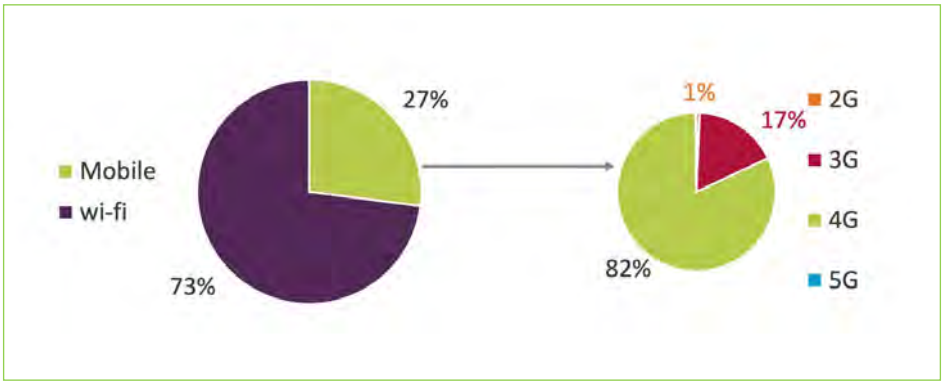
The proportion of smartphone traffic carried over Wi-Fi varies significantly between different parts of the world. Three critical factors for this variance are:

- Mobile network coverage and quality,
- Wi-Fi availability in subscribers' homes,
- The cost of mobile subscriptions.



14 Global Mobile Data Trends: A Special Report for Operators and OEMs[13]

A more recent Ofcom study[14] shows more detail for the UK Market. We cannot read anything into the apparent lowering of the proportion of offloaded traffic as the two studies use different methodologies.



15 Ofcom analysis of crowdsourced Android data. 1 January to 31 March 2021

Orange's data is consistent with others

« For Spectrum Mobile, about 80% of data traffic occurs over Charter's Wi-Fi, which is typically faster than cellular networks."[15]

13 https://www.data.ai/fr/insights/market-data/global-mobile-data-consumption-trends-special-report-operators-oems/
14 https://www.ofcom.org.uk/__data/assets/pdf_file/0015/224070/mobile-matters-2021-report.pdf
15 https://www.fiercewireless.com/operators/charter-claims-fastest-wireless-speeds-due-to-benefits-wi-fi

Orange confirms this order of magnitude (70% to 80%), with variations among clients, due to the type of access technology, quality of Wi-Fi at home, or the density of the cellular network.

How much does offload save?

With 80% of traffic offloaded to Wi-Fi, losing just 1% (i.e., if the ratio of offloaded traffic goes from 80% to 79%), 5% more traffic is generated on the cellular network.

This loss of offload traffic would require significant cellular investments and a major jump in CO2e emissions, showing that Wi-Fi offload is virtuous: saving money also offers better service and lower CO2e emissions. This data proves that maximising offload lowers energy impact.

Home insulation makes offloading even more critical

Building insulation makes it harder for radio transmissions to enter the home. Wi-Fi offload will become even more critical as sustainability and the ongoing energy crisis drive more mass insulation projects. Currently, 15% of homes in France are classified as *Haute Qualité Énergétique* (HQE). This was expected to reach 35% by 2030[16], before the current energy crisis hit. In marginal cases, this could reduce Wi-Fi coverage, for example, in gardens.

A better LAN for better offload

Offload rates are higher when the home LAN's performance is better, i.e. with a fibre connection and excellent Wi-Fi coverage.

Investing in a better home LAN lowers cellular network costs and reduces the overall energy footprint.

The issue with the mobile OS

Operators don't have many tools to keep traffic offloaded to Wi-Fi. The mobile device's operating system decides which network to prioritise. When smartphones started in the late noughties, Wi-Fi, when available, would invariably be better than the mobile networks circa 2008. iOS and Android have so far mainly kept this priority on Wi-Fi. However, the algorithms that choose the network could change at any time. If this happens, offload will

16 Scenarios from The Shift Projet / NégaWatt : https://theshiftproject.org/article/logement-points-communs-scenarios/

probably get lower as there is always a part of the home where Wi-Fi coverage leads to poorer network performance than cellular. Emerging "booster modes" can try to benefit from both Wi-Fi and cellular simultaneously, muddying the water further. Operator initiatives to prioritise Wi-Fi have not yet been successful.

Deep indoor mobile gets more complex as buildings are made more sustainable; a LAN reduces the mobile phone's carbon footprint.

Wi-Fi offload - What this means for	
a manufacturer	devices with cellular and Wi-Fi capabilities always prefer Wi-Fi
an operator	Wi-Fi offload is cost-effective in the long run
a subscriber	Become aware that Wi-Fi is more sustainable than 3/4/5G

2. Cloud vs. local (for storage and processing)

Latency, idle time, and power

Energy models of the trade-off between the time it takes to access services and carbon footprint are still purely conceptual. Let's constrain customer experience to the delay between asking for something and receiving it. It could then be traded for a reduction in energy consumption. The "Greening of Streaming" (GoS) industry group is currently working on such models based on the hypothesis that some elements in the delivery chain consume less power when the demand is lower.

GoS is trying to confirm if there is a relationship between traffic and energy since there appears to be more of a correlation between capacity and energy.

One of the group's early assumptions is that if we can get the traffic and energy to correlate (by improving service/capacity orchestration in line with demand), THEN we can start to explore the effect of better managing traffic. Indeed, there is little point in traffic management if it doesn't make any difference, which appears to be the case in non-computer network distribution.

So, in the Cloud, as in the home LAN, when a significant difference in power consumption occurs between idle and busy times, the trade-offs on quality of experience will be possible, and there is scope for energy savings and, therefore, CO2e emission reductions.

Leveraging Cloud technologies usually lowers local processing and storage requirements but can also degrade the user experience and increase bandwidth requirements.

We discuss video decoding in the home LAN "Codecs and more efficient streaming".

Ongoing market dynamics change how home LAN components access services. For video, the move towards streaming services, away from legacy IPTV, is ongoing and opens the door to delivering all operator video services from a single platform.

Simplicity reduces the number of devices

As video streaming continues its inexorable ascent, the overall video architecture is simplified, and some of this simplification is carried over to the home LAN.

An ISP network with optimised content and service delivery is also an enabler for a simpler LAN.

Architecture simplification brings opportunities to reduce the number of devices, a vital requirement.

Regarding sustainability, it is critical to avoid replicating processes unnecessarily. For example, video transcoding should happen only once for many viewers; however, the Cloud's real benefits come with volatile workloads, not 24/7 ones.

The same goes for video storage, for example, when subscribers record content. The 'Personal Video Recorder' (PVR) application typically stores recordings on local hard drives inside the STB provided by the operator. These local PVRs have been replaced over the last ten years by 'network PVR' propositions, where recordings are mutualised across users and stored centrally in ISP networks. As we show in more detail in this annexe below, Broadpeak argues that the sum of local storage in STBs to offer local PVR functionality will always be several orders of magnitude greater than any network implementation of PVR (nPVR).

A local storage architecture for a million subscribers can require 500 PB of local storage. A Cloud solution providing each of the same users with their own exclusive storage space would require 100 PB of Cloud storage. A fully shared storage solution would only need 1 to 3 PB (details "Detailed Sagemcom CO2e emissions").

So can we find the best local/Cloud mix for processing and storage?

- Cases where "local" is best:
  - Bandwidth-intensive applications lowering peak requirements, for example, targeted ads,
  - Popular assets that can be preloaded using a multicast stream,
  - When low latency is critical, like for targeted Ad preloading,

    - IoT communications between local devices (video surveillance delivered to the STB),
    - Local services with personal data generated locally or local maintenance,
    - ISPs must avoid data duplication, caching content only when performance is affected.
- Cases where Cloud or centralised approaches make the most sense:
    - For the same content, such as for transcoding or nDVR (storage, encoding),
    - For more personal data requiring similar operations and maintenance for a better proportionality of resources vs actual usage,
    - For critical data that must be backed up redundantly.

When considering sustainability, we must balance the physical infrastructure required for a specific traffic volume and the cost of devices to manage local processing and storage.

Our earlier discussion on idle time also relates to the Cloud, as servers also use energy in idle states. A server's peak usage in a typical datacentre is 75%, whereas mean usage will typically be 25%. The spare capacity of 50% is mainly wasted for a single server blade. However, unlike in the home LAN, where there is only a single device, the Cloud's container-based architecture, with multiple all-purpose servers, allows for the capacity to be changed, reused, or turned off. As discussed above, the GoS industry group investigates to what extent measures from the field back up this theoretical assumption.

Datacentres

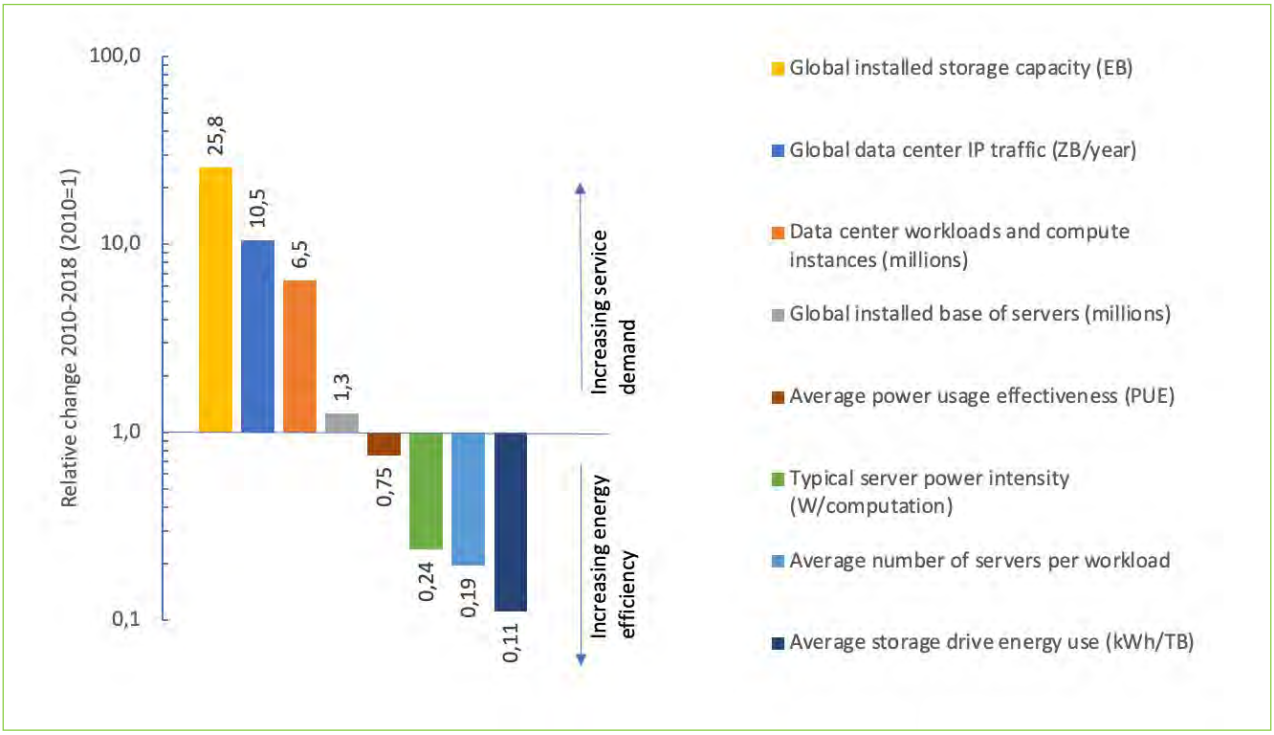
More and more home LAN services rely on the Cloud at some point. Cloud services are delivered from datacentres, so it is worth having a quick look at their ongoing journey towards sustainability.

APL Data Center, a French consulting and engineering specialist in datacentre design, build, and sustainable IT, helped us with this section.

Datacentres are often considered the villains in CO2e emissions linked to our digital lives. It's an easy misconception as they bear the brunt of the Internet's incredible growth, which has been above 30% per annum over the last decade[17]. But this perception is exaggerated for two reasons at least. As models such as the BEREC one "Household appliance annual energy consumption" show, data centres account for only up to 15% of the ICT's overall impact. Different ways of framing or scoping

17 https://www.iea.org/reports/data-centres-and-data-transmission-networks#reference-2

the problem create a variance. The French regulator has put the figure at 10%[18] . The business model of companies that operate data centres motivates them to be as cost-effective as possible with energy consumption which is a significant part of their costs. So, they constantly improve their energy efficiency practices which become close to their business productivity. Cooling is critical, and they also use highly optimised hardware, often implementing aspects of the Open Compute Project (OCP) and hyperconverged infrastructures. Monitoring is also a crucial part of datacentre efficiency. The big three Cloud hosting companies spend millions every year on R&D to further optimise their datacentres, a critical competitive feature for them. Areas of research include better ways of harvesting intermittent renewable energy sources. One way is by delivering services from a solar-powered data centre with spare capacity when it's in the sunshine, even if it's further away.



16 Recalibrating global data centre energy use estimates[19]

The encouraging chart above shows that in almost a decade, storage capacity has multiplied by 25 for all datacentres worldwide. During the same time, the energy cost for storage has been reduced by 90%. In other words, storing 25 times more data requires less than three times as much power.

We must be wary of the rebound effect or Jevons' paradox. This counter-intuitive behaviour occurs when the use of a resource (coal in the case of Jevons, electricity for us) is made drastically more efficient by technological disruption (improvements in steam engine technology for Jevons, disk storage in datacentres for us). In the nineteenth century, Jevons found that the falling cost of use increases demand to the extent that

18 https://www.arcep.fr/uploads/tx_gspublication/rapport-pour-un-numerique-soutenable_dec2020.pdf

19 "Recalibrating global data center energy use estimates." Masanet, E., Shehabi, A., Lei, N., Smith, S., and J.G. Koomey (2020). Science, Vol 367, Iss 6481

more resources are needed.

> ***Datacentres may offer lessons on how their energy consumption is growing at a far slower rate than overall internet traffic[20].***

Datacentre stakeholders have been addressing energy consumption for several decades, even if concerns about CO2e emissions are as new to them as to the rest of the ecosystem. As opportunities for the "Edge CDNs, mutualisation to the home LAN" of devices or device features appear, the operator can play a central role.

3. More sustainable service delivery mechanisms

Evolution towards 100% streaming

When home devices are network-aware, they can benefit from the most sustainable delivery mechanism available for a given service at a given time. This awareness may require some processing. For example, Broadpeak's nano CDN agent uses no more than 5% of a home gateway's CPU.

Much live video content distribution to large audiences in France uses legacy IPTV (MPEG video delivered over IP multicast to an STB). Orange France, for instance, had almost 8M IPTV subscribers at the beginning of 2022.

But as audiences shift to streaming (Adaptive Bit Rate video delivered to any device), growing amounts of video are served in formats such as Apple HLS or MPEG-DASH over HTTP.

We know that streaming has two significant consequences when it comes to video delivery:

1. Simplification of the receiving aspects, as content can playback across many devices and on any IP network.

2. Decoupling video delivery from the operator network makes it possible to deliver OTT content. This delivery relies on CDN caching and unicast distribution.

The first aspect positively affects the environment as the operator STB becomes leaner. Across Europe, we are seeing exponential growth of 'streaming-only STB' like the Sky Stream in the UK and Ireland or the LGI 'Mini TV Box' in Poland, Switzerland and the UK. These two STBs are marketed as bringing a more sustainable approach than earlier

20 For another source, Faultline Research estimates in December 2022 that video traffic within Data Centers will grow from 138 TWh in 2022 to 149 TWh in 2027, while their consumption rises by just 1 TWh across the period to 192 TWh in 2027.

generations, with IP-only capabilities and no broadcast stack. The veracity of such claims will depend on many factors, especially audience sizes for linear content.

As streaming supersedes IPTV gradually, the old boxes are replaced by streaming-only STBs, allowing some legacy components in the network to be retired. Multiple head-end platforms still encode and package live channels on one platform for IPTV and another for streaming. Security is another example, as Digital Rights Management (DRM) replaces IPTV's Conditional Access.

The simplification of the STB moves the complexity to the home gateway or the network, where scaling distribution becomes essential.

Multicast Adaptive Bit Rate (mABR)

Scalability remains challenging with streaming. Distribution problems occur when demand exceeds the CDN or the network capacity. This is where multicast ABR technology can help by delivering one stream over the network to address millions of viewers compared with one stream per viewer in a traditional streaming scenario.

The concept is for the home gateway to receive popular live content over multicast and to serve it in a unicast stream to the playback devices. This delivery mechanism is an example of a smart home LAN leveraging network optimisation, which will likely also result in better quality for the consumer.

With multicast ABR implemented on the home gateway, video service providers address all connected home devices and reach massive audiences without increasing their CDN footprint. This is one of the challenges of the transition to streaming, where we must remain acutely aware of the Jevons paradox described above, where 'over delivery', a generic ABR problem, could be further enabled by mABR.

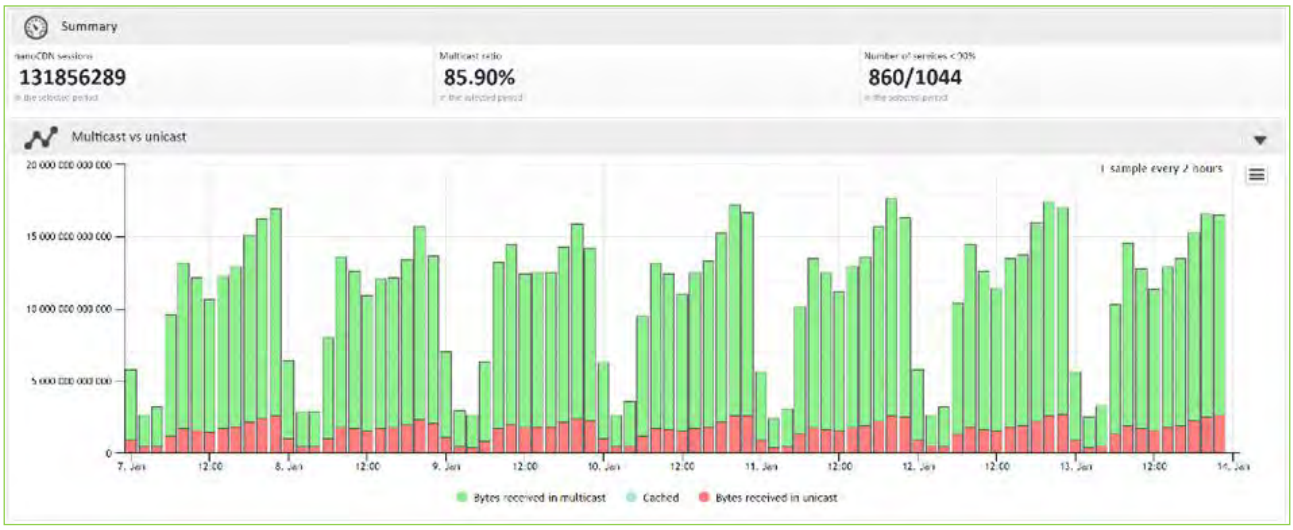
Awareness of processing capacity avoids unnecessary processing repeated in many homes; this could be when an AI algorithm is used once on a group of users instead of repeatedly for each one.

Storage awareness enables practical cost-benefit analysis avoiding unusual cases of never-watched content stored for many years.

Home devices must also be network and bandwidth-aware; for example, always favour a wired connection over the radio whenever possible. Intelligent content and service delivery from a multi-CDN environment require device awareness. Home devices can also lower peak capacity requirements in the LAN and the overall network. Multicast ABR helps in prime time for the most popular linear channels.

As illustrated below, a typical effect seen in a network where mABR is implemented is that 85 to 95% of live-streaming uses multicast, reducing video traffic in the core by

between 5 and 20-fold.



17 Multicast vs unicast use[21]

The challenge of targeted advertising

Another example of functionality that migrates from the STB to the Operator Network is targeted advertising.

The rise of ad-funded services, where targeted ads are inserted in the video being watched, creates a scaling challenge. Targeted advertising was introduced in the French IPTV ecosystem in 2020 and is ramping up quickly, with 600 million impressions estimated for 2022[22].

Today the primary delivery method for targeted advertising in France is Client-Side Ad Insertion (CSAI). Typically used in IPTV STB, the CSAI approach inserts a pre-downloaded advert on the playback device.

Streaming uses a more recent Server-Side Ad Insertion (SSAI) approach stitching the ad directly into the viewing session. SSAI video service providers can use a single advertising system to address all the playback devices, again mutualising resources in the network rather than inside the individual devices in the home.

GoS cofounder Dom Robinson pointed out to us that the 'engagement' economics of advertising encourage streams to be left running. FAST revenues are higher if a user turns a stream on and leaves it on - so the economic incentives are contrary to subscriber models where the longer a stream runs, the more cost is taken from the sub-revenue - Economic alignment between 'engagement' and 'environment' are typically orthogonal - and are thus an anticipated problem.

21 Source Broadpeak

22 Source AF2M - Association Française pour le développement des services et usages Multimédias Multi-opérateurs

Leveraging multicast beyond live video

A significant volume of WAN traffic comes from game and OS updates. That, too, could use a multicast path just like mABR. As with video, quality is improved, i.e., the update requiring multiple GBs could occur in a few seconds. Pure local storage can be used, or a P2P protocol, if storage requirements are too high.

In the same spirit, a multi-CDN agent within the home LAN can prioritise speed vs cost vs sustainability by using a greener path. A smart service like this is yet another way for operators to keep out of the dumb pipe model.

Edge CDNs, mutualisation to the home LAN

Taking these ideas further, one can imagine a more distributed CDN, with some storage in the home LAN, implying that traffic goes over less network equipment, reducing footprint. However, this needs to be balanced with the multiplication of "datacentres" in the network. The model could only create savings if the CDN feature is deployed dynamically at the edge, i.e., when the demand is high. Indeed, having many CDN servers doing nothing in the middle of the night defeats the purpose! A 'mutualised' approach to the CDN could offer a solution here. ISPs cannot deploy hundreds of CDN extensions (Google Global Cache, Netflix OpenConnect, DAZN edge, Prime Video Sye streamers, ...). They could instead offer a single edge-based video delivery service for all OTT services and possibly leverage a single stack running in the home LAN.

AWS illustrates some sustainability advantages of having more smaller servers in this video.

4. Work From Home (WFH)

By reducing travel, WFH brings opportunities for a more sustainable lifestyle.

> ***A better work environment at home enables workers to do more complex tasks wherever they are, reducing business trips.***

The situation is still very fluid, but as we write this, large organisations like Orange can reclaim about 30% of office space with seven desks for ten people. However, the energy impact here needs to be fully understood, with significant consumption transferred to the home. In contrast, some energy at the office must be maintained, even for an empty desk. Indeed, in winter, both places will be heated.

ISPs wanting to encourage and facilitate WFH can:

- create dedicated services with traffic prioritisation so that data for Zoom calls are

prioritised over gaming,

- improved QoE guarantees on home LAN performance,
- bring the home LAN's security up to corporate standards,
- optimise data synchronisation between home LAN storage and office servers with a flexible approach allowing for collaborating on a shared document with others in real time while only backing up individual work once every few minutes.

5. The promise of open ecosystems

One open-source initiative standardising embedded software for the broadband market is the "Reference Design Kit for Broadband" A.K.A. RDK-B, whose primary purpose is to create a standardised software stack to manage broadband.

The prpl Foundation is another telling example of an open-source, community-driven, collaborative, non-profit initiative that aims to enable the security and interoperability of embedded devices.

The keyword for us here is interoperability, enabling the home gateway to orchestrate energy savings without degrading customer experience in unacceptable ways. As devices learn to interoperate better, redundancies can be avoided.

prpl's EasyMesh, for example, is a standardised open-source implementation of a Wi-Fi Mesh protocol. Its inclusion in prplWare enables retail devices to work out-of-the-box, potentially lowering the number of required devices in the home.

In the future, standard protocols will enable open ecosystems to let devices expose their energy requirements.

So, for example, a security camera could tell the Wi-Fi Access Point it uses how often it needs to be polled. Indeed, an intrusion notified within a few seconds may be good enough to allow the network to microsleep.

VI. The role of the operator moving forward

1. The road to net zero CO2e emissions by 2040

At the corporate level, Orange Group is committed to reducing CO2e emissions,

- by 30% in 2025 vs 2015 for scopes 1 and 2,
- by 14% in 2025 vs 2018 for scope 3.

The operator's net zero carbon pledge by 2040 represents a 90% reduction of CO2e emissions compared to 2015. This commitment is made within the Science-Based Targets initiative (SBTi) guidelines, which, for example, state, in line with the Paris Climate accords, that no more than 10% of CO2e emissions can be offset.

From a corporate perspective, Marie-Noelle Jégo-Laveissière, Deputy CEO for Orange in Europe, said, "In today's increasingly digital world, our networks and services have become a critical element of our society and economies. However, we also believe we must minimise our impact on the planet. We are determined to continue to find creative ways to improve our energy consumption efficiency and encourage sobriety while ensuring the resilience of our network and sites"[23].

Zooming in to the home LAN Ecosystem, a mid-term vision embracing sustainability that Orange, Broadpeak, Sagemcom and SoftAtHome are looking to foster could include the following:

23 https://telecoms.com/518711/orange-wants-to-somehow-reduce-energy-consumption-with-5g/

1. Lowering energy requirements per device, aiming for it to become as proportional to load as possible.
2. Merging devices wherever possible, leveraging mutualisation.
3. Improving product lifecycles and using future-proof technologies for longer shelf lives.
4. Continuing to deliver routing functionality within the home and maybe in the longer term within the building, taking legitimate Wi-Fi privacy concerns into account.
5. Encouraging circular economies where rare materials get recycled, and devices refurbished.

2. Reporting instead of doing is greenwashing

The journey towards sustainability has begun and will affect how we organise our businesses. But for now, core tenets such as profit and growth are still with us. In a rush to become the best in ESG financial reporting, we must avoid confusing the tools with the end goal. Otherwise, today's ESG hype will undoubtedly disappoint by overpromising.

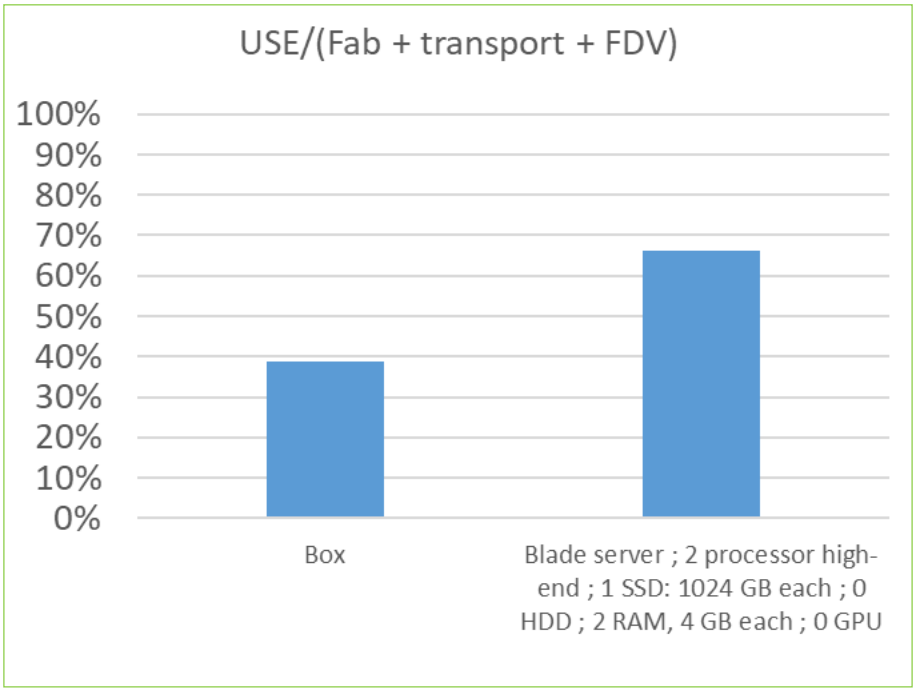
Greenwashing negatively affects all stakeholders. An example of greenwashing can be just changing a product's packaging and stopping there, addressing less than 1% of the problem. Consumers lose trust, regulators get more punitive, and the absence of impact on CO2e levels is a failure.

French regulation requires operators to communicate the LAN and WAN carbon impact per Gb by 2024. It's not yet clear how the communication will happen. In our case, this data will probably be provided by the box manufacturer, e.g. Sagemcom.

3. Operators manage devices more sustainably than consumers

Even as sustainability enters deeper into our organisations' core value system, ISPs, like most, remain financially driven. When a service provider has been competing for decades, it will have optimised its resource management to the absolute limits. Indeed, when such an organisation has millions of devices to run, there are no lengths it will not go to lower Opex costs, even by fractions of a per cent. Managing resources is their core business, after all.

Contrast that with an end-user. Firstly, consumers tend to think in the shorter term. So, if the real-time consumption of their home gateway is, say, 10 W and their kettle is 1500 W, it's challenging to motivate them to take action to save 10% of their home gateway consumption, i.e. in real time just 1 W. Yet for the operator with 10 million boxes, that's a 10-megawatt opportunity.



18 APL analysis comparing CO2e of use vs run server blade to CPE

The APL chart above extends the earlier discussion on "Device build vs. Energy consumption".

Devices are far more efficient when managed by operators rather than by users[24].

Then on the Capex side, ISP will do all they can to extend the shelf-life of devices. They are immune to vendor marketing campaigns or fashion trends, making the latest must-have object desirable.

The finance team pressures operations to get each device's last bit of value.

One can easily imagine market conditions soon where a home gateway using less energy or having cost less CO2e to build could be a decisive competitive advantage.

The ISP is also better positioned to optimise service delivery aspects that most subscribers will not want to be aware of. Say a playback device, such as an STB, has

24 APL estimates that without taking idle time into account, the optimisation of a server blade is such that its processor is 20% more energy efficient than a home gateway.

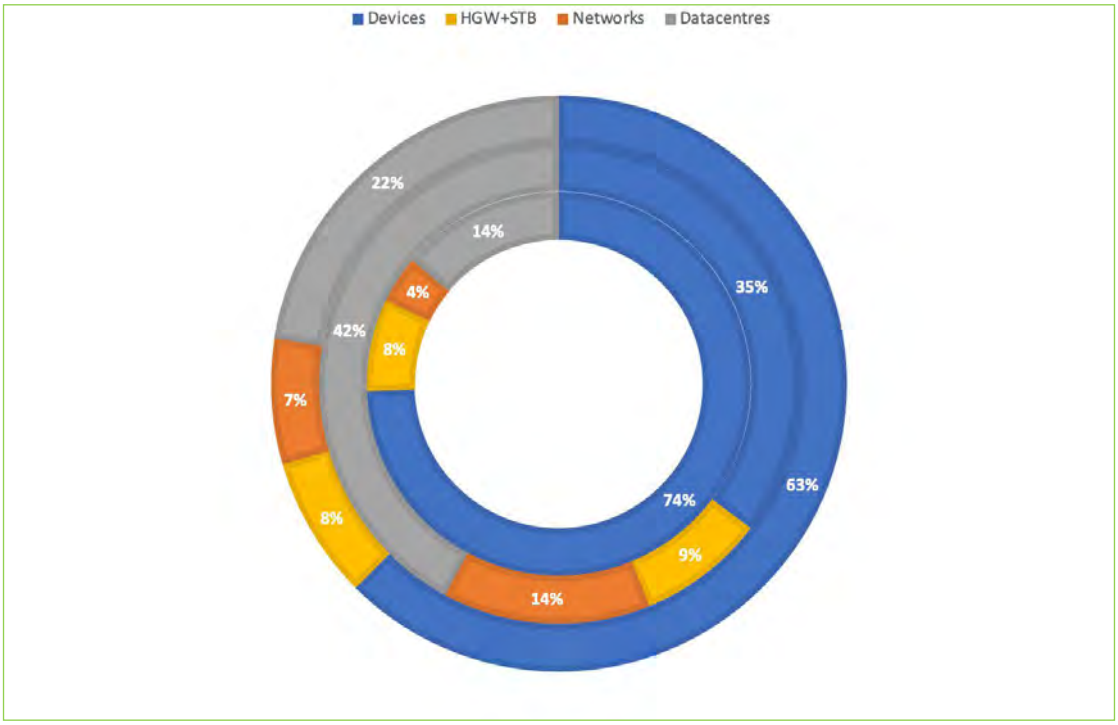
a wireless connection to the home gateway and a wired one to the TV; downloading can save energy over streaming. Savings can be achieved even if regulations limit such "local caching" to short periods. If a video asset takes 90 minutes to stream, a point-to-point connection must be maintained from the server to the STB for the entire duration. In the case of download and play, the active link needs only be kept for a minute or so. This example shows how the core network and home Wi-Fi can collaborate to free up resources.

4. Operators can drive the whole ecosystem towards sustainability

The ISP is in an ideal position to identify when the user has more devices than needed.

> ***As sustainability becomes more crucial for society, the home LAN will play its central role.***

The home LAN was critical in getting us through pandemic-induced lockdowns. The chart below shows where operators have control or at least influence power consumption in the home LAN, i.e., in the yellow and orange segments representing the CPE and the network.



19 Home LAN CO2e emissions

Consumer education towards sobriety

Part of the solution will be to educate and accompany users into digital sobriety using fewer, more efficient devices. With the rise of fibre connections and lockdowns, ISPs have gradually taken more responsibility over the home LAN. Yet operators will need to bring users on board so they become active participants.

> ***A device that is not procured has no carbon footprint.***

Operators manage devices most efficiently.

Unlike subscribers, operators are driven by a business imperative to manage devices as efficiently as possible. They directly influence at least 15% of the home LAN's CO2e emissions. They can impact the remaining 85% through other scope-3 initiatives.

It's the operator's role to initiate ecosystem cooperation

Only practical cooperation throughout the ecosystem can significantly improve the sustainability of the home LAN. Some suppliers focus only on the price performance of their solutions. Operators are in the best position to evangelise and educate here.

> ***There used to be RFP boxes to tick and reports to write - that few read.***

> ***Now, it is challenging to go through the procurement process without actual audits; suppliers must prove credentials with third-party validation.***

Ambitious sustainability goals are set within RFPs, and collaboration is picking up speed within industry organisations.

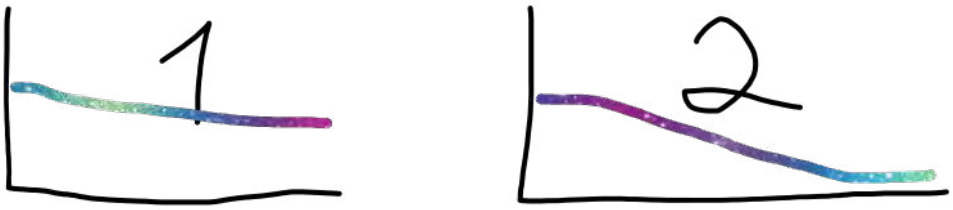
Shifting goalposts compound this challenge. In just a few months of writing this white paper, we have seen significant changes in regulation and a growing level of commitment from all stakeholders.

Low-hanging fruit

We have identified idle time as low-hanging fruit. Better sleep modes are critical but mustn't degrade user experience too much. The local operator providing internet connectivity can aspire to orchestrate intelligent sleep modes throughout the home.

A mid-term strategy

A mid-term 2025 strategy for operators (1) is to optimise device consumption, especially when there is little/no load. A realistic reduction in home LAN power requirements is 10% here. The longer-term strategy (2) will see some router functionality moving to the network edge. This evolution might break the hegemony of the one-to-one model for the home LAN, although there will probably still be indoor coverage with individual Access Points. This second objective could reach energy reductions of up to 80%.



Despite explosive traffic growth, operators like Orange have been able to lower their scopes 1 and 2 carbon footprint by over 10% in the last four years and will achieve 30% by 2025. Net zero, including scope 3, is on target for 2040.

Towards the home radio network

As operators look for a more sustainable architecture in weighing their options, the home LAN offers an opportunity to become THE radio network within the home. This approach leads to better financial and CO2e emission savings than densifying their mobile networks.

Working together!

As a closing note, we each feel thrust into the journey towards a sustainable home LAN by peer pressure, hype, regulation, or anything else. But as we become more deeply involved, we have developed a holistic and collaborative approach. There may never be an arrival point of this journey in our working lifetimes as sustainability eventually becomes the norm; for now, it's an ongoing iterative process that we are just beginning. It's an opportunity and a hopeful, fun, rewarding and exciting journey towards a future where we can achieve our goals using today's resources without compromising our children's.

VII. Annexes / Notes

1. Main contributors

Many people helped me write this White Paper; key contributions were from:

- **Orange**: Jean-Benoît Besset, Christian Gacon, Ollivier Courtel, Frank Payoux, Roger Dunlop
- **SoftAtHome**: David Viret-Lange, Arnaud Bensaid, Yves Kerlou
- **Broadpeak**: Xavier Leclercq, Damien Sterkers, Elodie Levrel
- **Sagemcom**: Ahmed Selmani, Valérie Spriet, Florian Tremblay
- Thanks also to JL Diascorn (Harmonic), G. Ouffoué (APL), D. Robinson (GoS)

2. A Very Brief History of ESG

Fifty years of CSR

CSR, or Corporate Social Responsibility, has been around for decades. It was usually about giving back to society and considering that companies were responsible to their community. The idea that companies have responsibility can be traced back to the Industrial Revolution. The planet still seemed to offer endless resources in the mid to late 18th century. The concerns then were only social, as the new factories created harsh working conditions, especially for women and children. However, it wasn't until 1953 that Howard Bowen coined the term CSR in the book *Social Responsibilities of the Businessman*. In the following 50 years, the idea spread and was often promoted by academia.

The Club of Rome to face the 'predicament of mankind'

A 1965 speech by Italian industrialist Aurelio Peccei on the long-term future of humanity and the planet is acknowledged as the inspiration for the club of Rome. The international think-tank began circa 1970 and challenged the belief in the benefits of unbridled exponential economic growth. It remains influential to this day, still striving for objective, scientific assessment of the impact of humanity's behaviour and use of resources.

The concerns of the Club of Rome have retained their relevance[25].

25 https://www.clubofrome.org/history/

Towards ESG

Initiatives have proliferated since, like the Carbon Disclosure Project (CDP), which began in 2000. Still, we'll focus on the more recent ESG (Environmental, Social and Governance). The term is credited to the 2006 UN Principles for Responsible Investment (PRI) report, requiring such criteria in the financial evaluations of companies for the first time. ESG was initially a financial reporting concept, with some companies reporting physical, liability and transition risks in their annual reports.

> ***Setting goals is a critical early step in the sustainability journey.***

The 2006 PRI report covered $6.5 trillion in assets, rising to over $80 trillion in 2019, a whopping 13-fold increase in only as many years. There's a good Forbes history of ESG here. In recent years, ESG has become mainstream. As highlighted at Davos in 2020, ESG is not only needed to achieve the UN's 2030 Sustainable Development goals but is also seen as intrinsically good for business. Countries have passed laws and regulations like the French PACTE[26] law, which lets companies incorporate CSR or ESG aspects into their statutes[27] [Mission-Driven Company]. This French law will probably become an example followed in other markets. There are now countless resources for companies wanting to manage their CO2e emissions, such as the Green House Gas Protocol.

20 UN sustainability goals

26 PACTE: Plan d'Action pour la Croissance et la Transformation des Entreprises (Action plan for growth and modernisation)
27 https://www.strategie.gouv.fr/english-articles/pacte-act-monitoring-and-evaluation-committee-summary-first-report

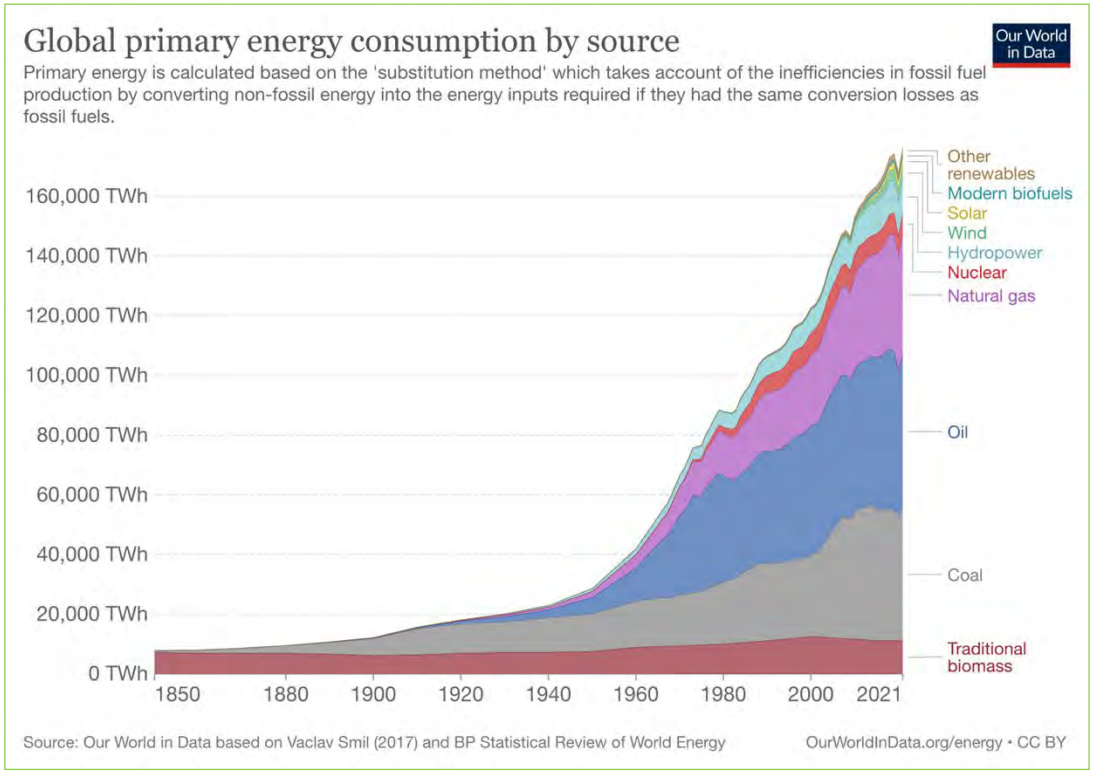
Towards a Circular Economy

With the same impetus, the industry is also looking to make our economy more circular.

In the recent "Strategy Paper for Circular Economy (Network equipment)", the GSMA identified four challenges.

1. To reduce the impacts on the environment from manufacturing products and components and mining raw materials
2. To make it easier to source, reuse and repurpose existing network equipment
3. To better understand the environmental impacts of network equipment through more comparable methods of evaluation
4. To accelerate the shift to more circular principles in the design of the supply chain for network equipment. Orange CEO Christelle Heydemann made a recent plea to European regulators for this[28].

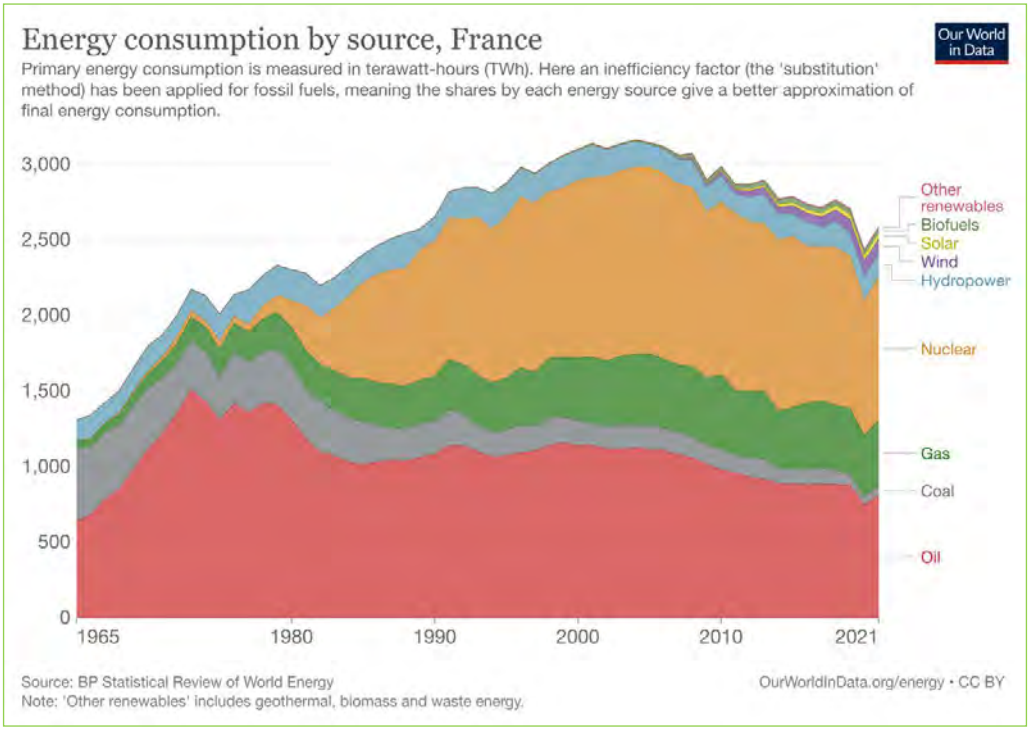
3. Energy mix



21 Global Energy Mix

With its high proportion of nuclear power, the French energy mix has become very distinctive over the last half-century.

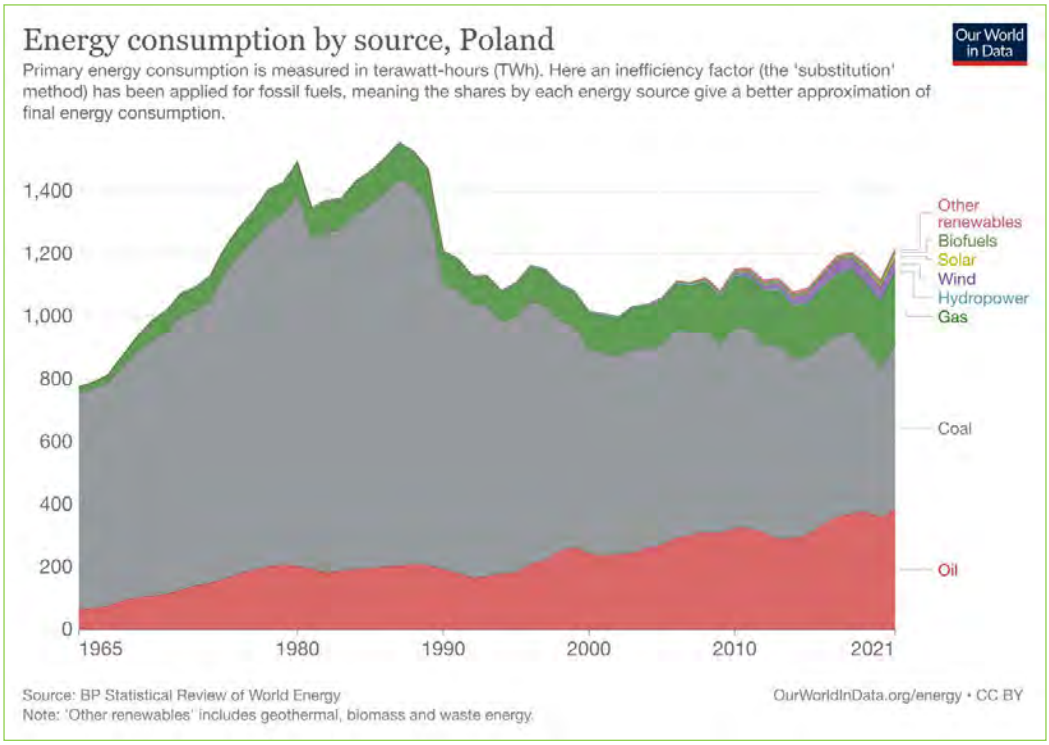
28 https://www.europeanfiles.eu/digital/circular-economy-in-the-ict-sector-call-for-a-more-comprehensive-european-approach



22 French Market Energy Mix

As nuclear energy is generally considered clean, over half of the energy mix in France can be regarded as carbon neutral. This significantly influences operator decisions when considering whether to extend the shelf-life of old equipment that isn't very energy-efficient or replace it with new optimised equipment.

Compare, for example, with Poland for the same period.



23 Polish Market Energy Mix

Here we see that most energy is fossil-based. So, an operator in Poland would address the previous question differently and introducing more energy-efficient devices will be a much higher priority. Let's do some simple maths to find out ("Towards a Home LAN energy/carbon model" to the next chapter if you're allergic).

Note that the calculations below look exclusively at two variables, the device's power consumption and the local energy mix, and they are not at all realistic. We are only trying to illustrate the impact of the energy mix. Here is our scenario:

An operator has a home gateway in the field that consumes 90 kWh per year

The 70 kg of CO2e29 for its cradle-to-grave lifecycle is a sunk cost we won't use30

A new device also costs 70 kg of CO2e but consumes 40% less power at 55 kWh/year

Scenario A, in France, a kWh generates 58 g of CO2 (source IEA)

a. The old device generates 5,22 kg of CO2e/year (A*D)
b. The new device would generate 3,13 kg of CO2e/year (C*D)
c. The new device would save 2,08 kg of CO2e/year (a-b)
d. To offset 70 kg of CO2e, the new device needs a shelf-life of 30+ years (70/c)

Scenario B, in Poland, a kWh generates 728 g of CO2 (source IEA)

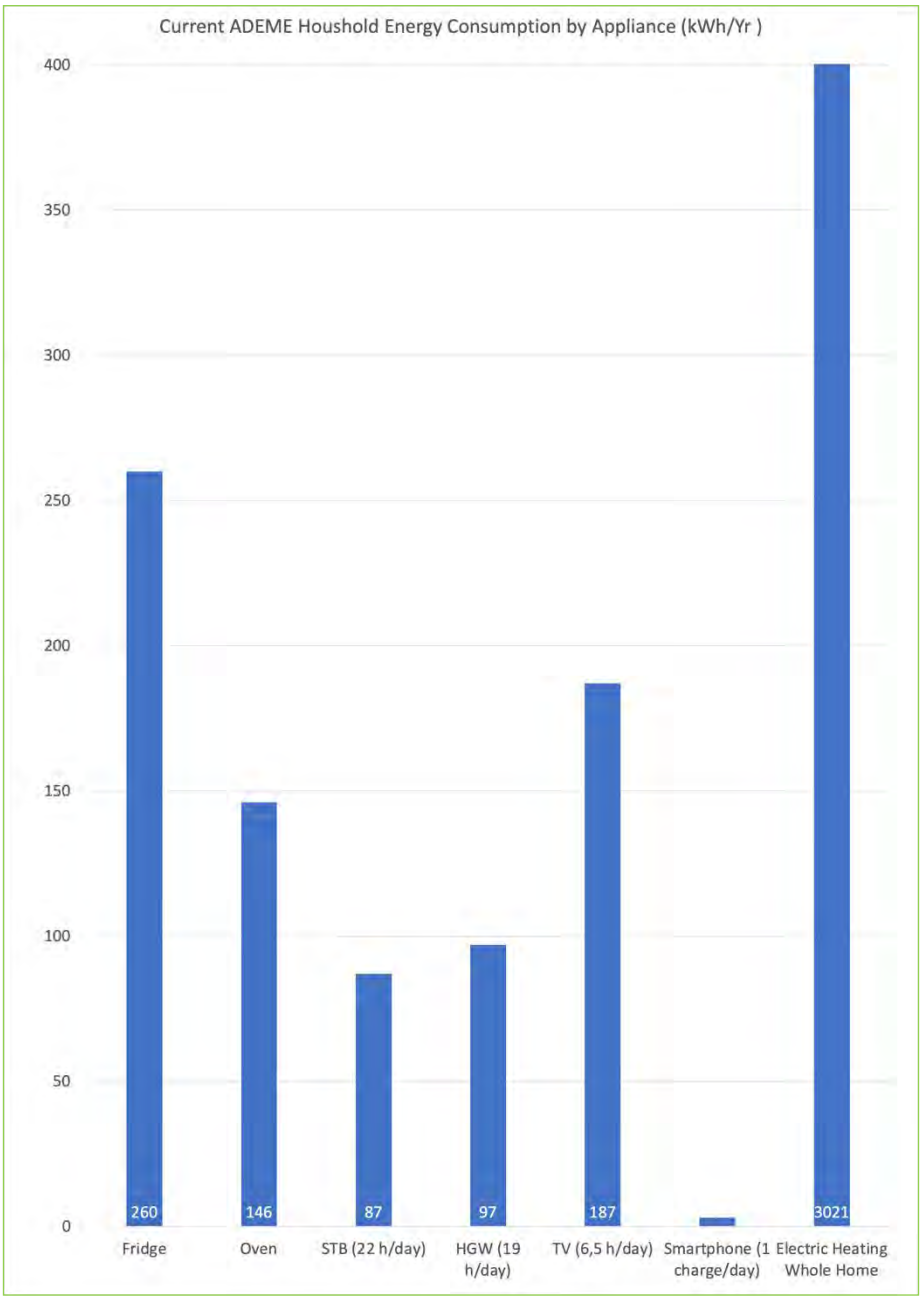
e. The old device generates 65,52 kg of CO2e (A*E)
f. The new device would generate 39,31 kg of CO2 per year (C*E)
g. The new device would save 26,20 kg of CO2e per year (a-b)
h. To offset 70 kg of lifecycle cost, the new device needs a ~3-year shelf-life (70/c)

This result of three years vs thirty+ years unsurprisingly shows a greater than tenfold difference, in line with the difference between the two markets' energy mix.

In practice, many other factors come into play. So, in the real world, the example of a new, more energy-efficient generation of home gateway could only shine when a lot of data is used, concerning just top-tier consumers.

29 Data from: https://bilans-ges.ademe.fr/documentation/UPLOAD_DOC_EN/index.htm?electromenager.htm
30 20% is dependent on the energy mix of the country of production (20% OEM, 80% parts)

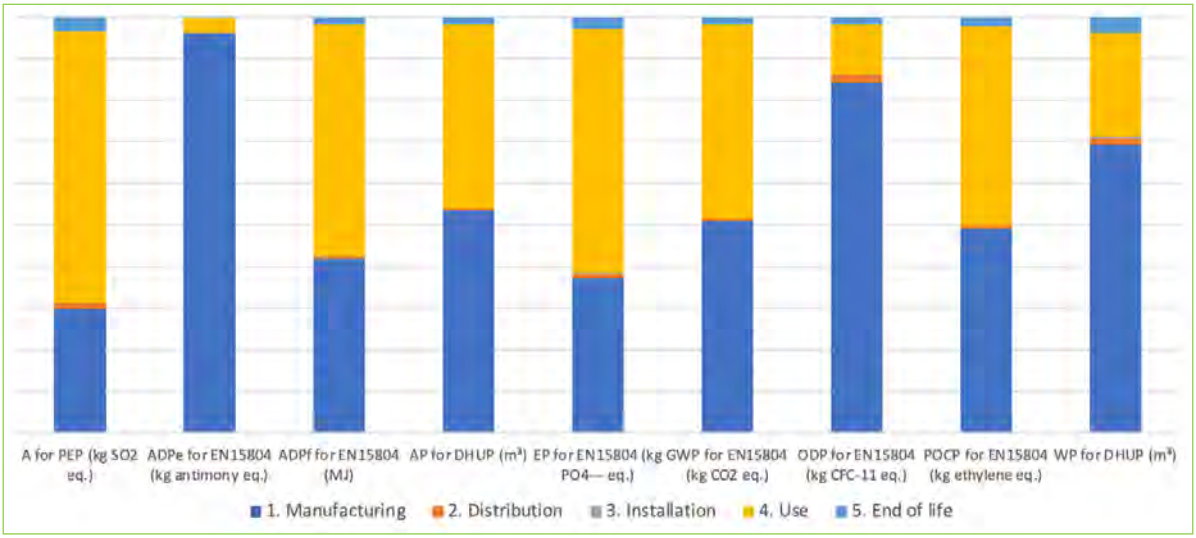
4. Original ADEME data on relative household appliance consumption



24 Household appliance annual energy consumption

(unmodified ADEME data)

5. Detailed Sagemcom CO2e emissions



25 Life cycle analysis of device manufacture by Sagemcom using EIME

- GWP, global warming (in kg CO2-eq): This indicator makes it possible to calculate the contribution to global warming of the planet through the emission of greenhouse gases. The calculation methodology comes from the IPCC (International Panel of Climate Change, US, 2007), we have considered a 100-year horizon (IPCC 2007 method via CML, GWP 100).
- ODP, ozone depletion (in kg CFC11-eq): This indicator is used to calculate the contribution to the depletion of the stratospheric ozone layer by atmospheric emissions. The calculation methodology comes from the WMO (World Meteorological Organization, CML 2012).
- AP, acidification of soil and water (in kg SO2-eq): This indicator allows the calculation of soil and water acidification. The calculation methodology is developed by Huijbregts (CML, 2012).
- EP, eutrophication (in kg PO43- -eq): This indicator allows the calculation of eutrophication (nutrient enrichment) of oceans and lakes by effluents. The eutrophication of a watercourse results from an excessive input of nutrient molecules (organic molecules) into the environment. Phosphorus, nitrogen, carbon, and potassium are elements that allow the development of algae and aquatic species that can lead to a decrease in oxygen levels and an imbalance in the biocenosis. The calculation methodology is developed by Heijungs et al. 1992 (CML, 2012).
- POCP, photochemical ozone creation (in kg C2H4-eq): This indicator is used to calculate the quantity of ozone produced in the tropospheric layer by the action of solar radiation on oxidising gas emissions (called summer SMOG; cf summer ozone peaks). The calculation methodology is developed by Jenkin & Hayman - Derwent et al (CML, 2012).
- ADPe, depletion of abiotic resources (elements) (in kg Sb-eq): This indicator allows the calculation of the depletion of non-renewable mineral resources by taking into

account the size of natural reserves. The calculation methodology is developed by Oers et al (CML, 2012).

- ADPf, depletion of abiotic resources (fossil) (in MJ): This indicator allows the calculation of the consumption of non-renewable fossil resources. The calculation methodology is developed by Oers et al (CML, 2012).
- WP, water pollution (in m3): This indicator makes it possible to calculate water pollution by taking into account the authorised limit concentrations of effluents. The methodology is derived from the DHUP according to the recommendations of the AIMCC.
- AP, Air pollution (in m3): This indicator allows the calculation of ambient air pollution (tropospheric layer), taking into account the authorised limit concentrations of atmospheric emissions. The methodology is derived from the DHUP according to the recommendations of the AIMCC.

6. Detailed calculation of Cloud vs local storage scenarios

A quantum leap in requirements continues to occur in markets needing an implementation of the "private copy" principle, where there is a separate digital copy for each home that requests a recording. To show the order of magnitude, one Tier 1 operator currently adds 5M USD / year to cater for the additional storage requirements that private copy brings.

Looking deeper into architectures for delivering a PVR functionality, let's consider a reference TV deployment of 500 live channels and one million users and give an approximate comparison in terms of storage requirement. There are three types of architecture.

The traditional STB DVR that records on local storage,

- All users have an STB with HDD for local storage, even if they do not use it. Typically, 50% of subscribers never use their capacity storage,
- With, for example, a 500 GB capacity, this represents ~500 PB of storage,
- There is an alternative where external drives are bought by users, potentially reducing the storage to ~250 PB,
- This model is fading away, especially in developed markets.

Cloud DVR with private copy mode (aka RS-DVR or Remote Storage DVR),

- Each user is provided with a "virtual storage disk" requiring much less hardware than any local storage option,
- No hardware at all is needed when the service isn't used,
- As the solution is managed from the network, expiration dates can be added to

recordings. Typically, less than 1% of viewing of a given asset occurs after one month has passed, less than 10% after a week, and about 50% of recorded assets are never watched,

- For our reference deployment, this represents ~100 PB of storage
- The choice between private and shared copy is driven by licensing and legal constraints. It is possible to optimise storage depending on the country's legislation. For example, some markets allow for long-term shared storage with duplication of the content only at the time of delivery to a customer (if the content is ever streamed). In this case, the overall storage requirements resemble the shared-copy model described below.

Cloud DVR shared copy mode.

- Required storage is only based on the total number of programs ingested and no longer on the number of subscribers,
- One major European ISP says that ~80% of programs are recorded by at least one person, and so 20% don't ever need to be recorded,
- As mentioned above, expiration dates are added to recordings,
- In our reference model, with a one-month expiration date for recordings, the storage amounts for typically 1-3 PB,
- further optimisation comes from allowing recordings only on popular content. Regular feedback from the field is that by recording 10% of the most popular channels, an operator can cover 90% of cPVR viewing requests.