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Master's Thesis

Energy and Environmental Impact of Digital Games and Gaming in Sweden

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Abstract

This thesis examines the operational energy use and associated greenhouse gas emissions of digital gaming using a bottom-up quantitative modelling approach, with Sweden as an illustrative case and comparisons to European average electricity conditions.

The analysis considers three interacting dimensions: device characteristics, user behaviour, and electricity system characteristics. Gaming PCs, gaming laptops, and modern consoles are evaluated through scenario-based and sensitivity analyses representing different usage patterns, performance assumptions, and gameplay intensities.

The results show substantial variation in electricity demand across platforms and usage scenarios. Gaming PCs exhibit the greatest variation and highest energy use, while consoles remain comparatively standardised. User behaviour, gameplay duration and performance-related choices, strongly influences annual electricity consumption, in some cases as much as or more than device category alone. Electricity system characteristics also significantly affects greenhouse gas emissions, with identical electricity demand producing dramatically different outcomes.

The thesis concludes that the environmental impact of digital gaming is shaped by the interaction between technology, user behaviour, and electricity infrastructure rather than by device category alone.

Populärvetenskaplig sammanfattning

Två personer kan spela exakt samma spel lika länge och ändå orsaka helt olika klimatpåverkan. I vissa fall kan skillnaden vara över tjugo gånger större. Den här studien visar att digitalt spelandes miljöpåverkan inte går att härleda till en enskild faktor. Istället beror påverkan på en kombination av vilken hårdvara som används, hur mycket man spelar och hur den el produceras som driver utrustningen.

Resultaten är viktiga eftersom digitalt spelande idag är en av världens största fritidsaktiviteter. Miljarder människor spelar regelbundet på datorer, spelkonsoler eller mobiltelefoner. Samtidigt diskuteras digitaliseringens klimatpåverkan allt oftare. Trots detta har spelande fått betydligt mindre uppmärksamhet än exempelvis datacenter, artificiell intelligens och videostreaming.

För att undersöka denna frågeställning utvecklades en beräkningsmodell som uppskattar hur mycket elektricitet olika typer av hårdvara använder under ett år. Modellen omfattar moderna spelkonsoler, bärbara speldatorer och stationära speldatorer. Beräkningarna bygger på tidigare forskning, tekniska specifikationer och statistik om svenska spelvanor.

Uppsatsen undersöker flera olika scenarier. Exempelvis jämförs personer som spelar några timmar i veckan med personer som spelar många fler timmar i veckan. Även skillnader mellan olika typer av datorer och spelkonsoler analyseras. Dessutom inkluderas videostreaming eftersom många spelar samtidigt som de tittar på videor eller livesändningar.

Resultaten visar att stationära speldatorer står för den största variationen i energianvändning. En energieffektiv dator kan använda relativt lite elektricitet medan en kraftfull speldator med avancerade komponenter kan använda flera gånger mer. Spelkonsoler uppvisar mindre variation eftersom hårdvaran är mer standardiserad.

En av de tydligaste slutsatserna är att användarens beteende spelar en mycket stor roll. Hur många timmar som läggs på spelande påverkar ofta energianvändningen lika mycket som valet av hårdvara. En person som spelar länge på en energieffektiv enhet kan därför använda mindre elektricitet än någon som spelar kortare tid på en mer energikrävande enhet.

Studien visar också att elsystemet och dess elmix har stor betydelse för klimatpåverkan. Samma mängd elektricitet kan ge mycket olika utsläpp beroende på hur elen produceras. Sveriges elproduktion består till stor del av energikällor med låga utsläpp, medan genomsnittet i Europa innehåller en större andel fossila bränslen. Därför kan samma spelvanor ge ungefär 27 gånger högre utsläpp under europeiska genomsnittsförhållanden än under svenska.

Det innebär att diskussionen om digitalt spelandes miljöpåverkan inte bara handlar om vilken hårdvara människor köper. Även spelvanor och landets energisystem spelar även det en avgörande roll. Uppsatsen bidrar med kunskap om vilka faktorer som har störst betydelse och kan användas som underlag för framtida diskussioner om digitalisering, energi och hållbarhet.

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Chapter 1

Introduction

We are approximately 8.3 billion people on Earth, and over 3.32 billion actively play digital games (Exploding Topics, 2026). While only a very small share engage with gaming professionally, the vast majority use digital games as a form of leisure and recreation.

As digital gaming continues to grow globally, its environmental implications become increasingly relevant. Although the electricity use of an individual gaming session may appear relatively small in isolation, cumulative impacts become more significant when scaled across billions of users and repeated over long periods of time. Digital gaming therefore represents an increasingly important form of electricity consumption within broader patterns of digitalisation and digital leisure.

At the same time, global greenhouse gas emissions remain one of the central drivers of climate change and environmental degradation. Rising temperatures, extreme weather events, biodiversity loss, and increasing pressure on energy systems have intensified the need to better understand how different forms of consumption contribute to environmental impact. While transport, industry, and energy production are often central to climate discussions, the environmental impact of digital activities has received increasing attention as digital infrastructures continue to expand globally.

Gaming is particularly relevant in this context because it combines widespread adoption with increasingly demanding hardware and longer periods of online engagement. Modern gaming is no longer limited to isolated gameplay on a single device, but increasingly exists within broader digital routines involving communication platforms, media consumption, and connected online services. This creates environmental impacts that extend beyond the gaming device itself and into wider digital infrastructure.

Previous research has shown that gaming related environmental impact depends on several interacting factors. (Mills et al., 2019) demonstrated that user behaviour, including gameplay duration, framerate choices, and performance settings, can be just as important for electricity demand as device type itself. (Marsden et al., 2020) highlighted the role of downloads, updates, and supporting network infrastructure, while (Aslan, 2020) emphasised the importance of broader digital system boundaries when assessing environmental impact.

At the same time, the environmental impact of gaming remains less well understood than many other digital activities, particularly when it comes to how multiple influencing factors interact. Existing studies often rely on fixed electricity assumptions, average usage

patterns, or specific regional contexts, making it difficult to assess how environmental outcomes change under different behavioural and infrastructural conditions.

Another limitation is that several foundational studies were conducted under technological and behavioural conditions that differ from today's gaming environment. Gaming hardware has developed rapidly, with increasingly power-intensive GPUs, higher graphical expectations, and performance enhancing technologies that may significantly affect electricity demand. Gaming habits have also evolved, with longer online engagement and more integrated digital routines. This creates a need to revisit operational gaming electricity use using updated assumptions that better reflect contemporary conditions.

The importance of understanding operational electricity demand becomes clearer when digital emissions are considered alongside sectors more commonly associated with environmental impact. According to the Swedish Transport Agency, newly registered passenger cars in Sweden emitted an average of 53.92 grams of CO_2 per kilometre during 2025 (Transportstyrelsen, 2025). While gaming emissions occur through fundamentally different systems and should not be interpreted as directly equivalent, such comparisons help illustrate how everyday digital activities can collectively become environmentally relevant when scaled across millions of users domestically, or billions globally, over long periods of time.

Sweden provides a particularly relevant illustrative case due to its widespread gaming culture, high levels of digital adoption, and comparatively low carbon electricity system. Several studies and theses have contributed valuable insights into related areas, including GPU workload in modern games (Berg, 2024), sustainability practices in the Swedish game industry (Lonnqvist, 2022), and updated global gaming emissions estimates (Mahmood, 2025). However, there remains limited work that systematically examines how device choice, user behaviour, and electricity system characteristics interact to shape operational environmental impact.

A clearer understanding of which factors most strongly influence gaming related electricity use is important for researchers, policymakers, and other actors seeking to reduce the environmental impact of digital services. Identifying the relative importance of device efficiency, usage behaviour, and electricity system characteristics can help inform both technological development and broader sustainability strategies.

The thesis aims to address these issues by analysing the operational energy use and environmental impact of digital gaming using a generalised modelling approach. The thesis focuses on estimating electricity use across common gaming platforms and examining how device types, user behaviour, and electricity system characteristics influence operational greenhouse gas emissions. Although Sweden is used as one illustrative case due to data availability and its low carbon electricity system, the analysis is structured to provide insights applicable beyond a single national context by varying key assumptions related to gameplay behaviour, hardware use, and electricity emission intensity.

To ensure a consistent analytical structure throughout the thesis, the analysis is organised around three interacting dimensions that jointly determine the energy use and environmental impact of digital gaming:

- **Device characteristics** - hardware performance, platform type, and energy efficiency

- **User behaviour** - playtime, performance related choices, and the use of parallel digital services
- **Electricity system characteristics** - represented through electricity carbon intensity

These three dimensions form the common analytical thread throughout the thesis and are used to structure the literature review, methodology, and analysis. Rather than treating these factors independently, the thesis examines how their interaction shapes overall energy use and environmental impact.

Rather than aiming to produce precise absolute emission estimates, the thesis is designed to identify dominant factors, relative differences, and sensitivities related to device choice, user behaviour, and electricity system characteristics.

Chapter 2

List of abbreviations and units

gCO_2e = Gram of carbon dioxide equivalent

$kgCO_2e$ = Kilogram of carbon dioxide equivalent

PC = Personal computer

Operational energy = Energy consumed during system / device use

kWh = Kilowatt-hour

ICT = Information and Communications Technology

MMORPG = Massive Multiplayer Online Role-Playing Game

MOBA = Multiplayer Online Battle Arena

Chapter 3

Related Work

The literature reviewed in this chapter is organised around the three central analytical dimensions of the thesis: device characteristics, user behaviour, and electricity system characteristics. These dimensions are used throughout the thesis to analyse how operational electricity use and greenhouse gas emissions from digital gaming are shaped. Existing research provides valuable insights into each of these dimensions, but they are often studied independently or within different methodological boundaries. The thesis builds on these contributions by integrating them into a unified bottom-up modelling framework focused on operational electricity use.

3.1 Environmental impact of ICT and digital activities

The environmental impact of information and communication technologies (ICT) has received increasing attention as digital services have become deeply integrated into everyday life. Activities such as video streaming, online communication, cloud computing, digital entertainment, and gaming all rely on electricity-intensive infrastructures, including end-user devices, communication networks, and data centres. As a result, the broader ICT sector has become increasingly relevant within climate and sustainability discussions.

Large scale assessments suggest that ICT may account for a significant share of global greenhouse gas emissions, although estimates vary considerably depending on methodology, scope, and assumptions. (Belkhir and Elmeligi, 2018) estimate that ICT could represent a rapidly growing share of global emissions due to increasing device ownership, data traffic, and digital infrastructure expansion. Their work places ICT within a broader environmental context by arguing that continued digital growth may offset technological efficiency improvements if overall consumption continues to increase.

However, this perspective is not universally accepted. (Malmodin and Lundén, 2018) present a more moderate assessment, arguing that improvements in infrastructure efficiency and hardware performance have contributed to stabilising parts of ICT-related emissions despite continued growth in digital services. This contrast illustrates an important issue within the ICT sustainability literature: environmental impact estimates are highly sensitive to assumptions regarding boundaries, infrastructure allocation, and technological development.

This has led to increased scrutiny of ICT emissions modelling itself. (Freitag et al., 2021) critically examine existing ICT emission studies and identify recurring methodological issues, including inconsistent system boundaries, double counting, outdated assumptions, and insufficient transparency in data selection. Their work is particularly relevant because it demonstrates that digital environmental impact assessments are not only influenced by technical data, but also by modelling choices. This reinforces the importance of clearly defining analytical scope.

Within this broader ICT context, gaming represents a particularly relevant case because it combines high performance consumer hardware, long usage durations, online connectivity, software distribution, and often simultaneous use of other digital services. Gaming therefore differs from many other ICT activities in that it involves both locally intensive electricity consumption and broader digital ecosystem interactions.

Reports on internet traffic and digital media trends further support this perspective. (Cisco, 2020) identify gaming as part of a broader pattern of growing internet traffic driven by increasingly connected digital lifestyles, digital distribution, and media integration. Although traffic projections alone do not provide direct environmental estimates, they reinforce the broader point that gaming should not be understood purely as isolated device use.

For the thesis, the broader ICT literature provides important framing. It demonstrates that digital environmental impacts emerge through interactions between technical infrastructure, usage behaviour, and modelling boundaries. At the same time, it also justifies a narrower analytical focus. Rather than attempting to estimate the full environmental footprint of all gaming-related digital systems, the focus is specifically on operational electricity use during the usage phase, allowing a more detailed analysis of user behaviour, device characteristics, and electricity system characteristics.

3.2 Operational perspectives on gaming energy use

A central distinction within the environmental assessment literature concerns the difference between operational electricity use and broader lifecycle emissions. Operational electricity use refers to the electricity consumed during the active use phase of a device or service, while lifecycle perspectives also include upstream and downstream impacts such as manufacturing, transport, material extraction, and end of life treatment.

Lifecycle perspectives remain important because they demonstrate how strongly total impact estimates depend on analytical boundaries. (Aslan, 2020) examine the climate implications of gaming products and services through a lifecycle perspective, including consoles, gaming PCs, online infrastructures, and supporting systems. One of the key contributions of this work is its transparent treatment of system boundaries. Aslan demonstrates that inclusion choices substantially influence environmental estimates, particularly when infrastructure components and peripheral systems are considered. This highlights the methodological importance of clearly defining scope rather than treating environmental assessments as neutral or universally comparable.

In a similar fashion, (Buonocore, 2016) compare environmental impacts associated with digital entertainment systems and show that operational electricity use can represent a major share of total emissions depending on usage intensity. Their analysis demonstrates

that frequent use over long periods can make operational emissions highly significant, even when broader lifecycle impacts are acknowledged. This is particularly relevant for gaming, where repeated and long-duration use may substantially increase cumulative electricity demand.

At the same time, manufacturing-focused studies show that embodied impacts in ICT hardware can be considerable. (Williams, 2004) highlight the substantial energy intensity associated with semiconductor manufacturing, demonstrating that complex electronic devices can carry significant upstream environmental burdens. This broader literature reinforces the importance of recognising lifecycle impacts when discussing digital sustainability.

However, the thesis does not attempt to conduct a lifecycle assessment. Instead, it adopts a narrower operational perspective. This decision is both methodological and analytical. Operational electricity use can be directly linked to the variables examined in the thesis, including gameplay duration, hardware performance, device category, and electricity carbon intensity. This creates a clearer connection between assumptions, calculations, and findings. It also improves transparency and replicability compared with broader assessments requiring manufacturing allocations and a broad spectra of data.

The operational perspective adopted here therefore reflects both practical scope limitations and a deliberate analytical focus on understanding the usage phase drivers of gaming related greenhouse gas emissions.

3.3 Electricity use in gaming systems

A substantial amount of literature has examined electricity use in gaming systems, particularly gaming consoles and PCs. This research demonstrates that gaming electricity consumption varies considerably depending on device type, technical configuration, and patterns of use.

One of the earlier detailed studies in this field is presented by (Hittinger et al., 2012), who examine electricity consumption from video game consoles in U.S. households. Their study combines measured device power consumption with household usage patterns in order to estimate electricity demand. A particularly important finding is that electricity consumption is not determined only by active gameplay, but also by inactive states such as standby and idle operation. This demonstrates that behavioural patterns, not only hardware specifications, significantly influence total energy demand.

A broader empirical assessment is provided by the California Energy Commission (California Energy Commission, 2019), which evaluates electricity use across gaming consoles, gaming PCs, and virtual reality systems. Their report uses measured electricity consumption data across representative user profiles and demonstrates substantial variation between casual, moderate, and intensive gaming users. The study also evaluates opportunities for efficiency improvements and policy interventions. One of its key contributions is showing that average values can conceal substantial behavioural variation, reinforcing the value of scenario based modelling approaches.

More recent work has also demonstrated that electricity use within gaming systems is increasingly influenced by technical complexity beyond simple hardware comparisons.

(Berg, 2024) empirically evaluate the electricity implications of modern performance-enhancing gaming technologies such as upscaling and frame generation. Using controlled experimental measurements, the study shows that technologies marketed as efficiency improvements do not necessarily reduce electricity consumption. In some cases, GPU demand increases due to altered rendering behaviour and performance expectations. This is particularly relevant because it demonstrates that technical innovation does not automatically translate into reduced environmental impact.

In a similar fashion, (Pérez et al., 2024) shows that software level design choices can influence electricity use. By comparing the Unreal and Unity game engines under similar gameplay conditions, they demonstrate measurable differences in runtime energy consumption caused by software architecture rather than hardware alone. This reinforces the idea that electricity use per gaming hour is not a fixed universal value, but depends on multiple interacting technical factors.

One of the most methodologically important contributions to gaming electricity modelling is provided by (Mills et al., 2019). Their study remains one of the most comprehensive quantitative assessments of gaming electricity use. Using a bottom-up modelling framework, they combine measured device-level power consumption, ownership statistics, and usage assumptions to estimate national electricity demand associated with gaming in the United States. Their methodology is particularly relevant because it explicitly links device characteristics and user behaviour to electricity consumption through transparent assumptions. Rather than relying on aggregate estimates, their approach enables behavioural sensitivity analysis and platform comparison.

More recently, (Mahmood, 2025) expand this type of bottom-up modelling approach by estimating global greenhouse gas emissions from video gaming using updated market data and emissions conversion methods. Their work combines gamer population estimates, behavioural assumptions, and electricity carbon intensity factors to estimate emissions at larger scales. This is particularly relevant because it demonstrates how operational electricity modelling can be extended from device-level analysis to emissions estimation through carbon intensity conversion.

Together, these studies provide the methodological backbone for the operational modelling approach.

3.4 User behaviour, demand, and digital media practices

While device characteristics determine baseline electricity demand during gameplay, user behaviour determines how frequently, how intensively, and under what conditions devices are used. Behaviour therefore represents one of the most important variables in operational energy modelling.

Previous studies consistently show that gameplay duration strongly affects total electricity demand. (Hittinger et al., 2012) demonstrate that usage patterns significantly influence household gaming electricity consumption, while (Mills et al., 2019) similarly show that behavioural assumptions substantially affect total estimated energy demand at larger scales. These studies reinforce the idea that user behaviour must be treated as a dynamic modelling variable rather than a fixed background assumption.

Gaming behaviour is also shaped by broader digital media practices. (Lee et al., 2025) examine how live streaming affects player engagement and gaming activity. Their findings suggest that exposure to gaming related media can increase engagement, reinforce participation, and extend gameplay duration. This supports the interpretation of gaming as part of a broader digital ecosystem rather than a purely isolated leisure activity.

Behavioural studies in broader digital sustainability research also highlight the importance of rebound effects. (Lange et al., 2020) argue that efficiency improvements in digital technologies do not necessarily reduce overall energy demand, since improved efficiency may enable increased activity, higher performance expectations, or entirely new patterns of use. This is particularly relevant to gaming, where improved hardware efficiency may be accompanied by longer sessions, more demanding games, or increased concurrent digital activity.

A broader consumption perspective is provided by (Akenji et al., 2021), who examine lifestyle-based emissions and household carbon footprints. Their work emphasises the importance of everyday practices in shaping environmental outcomes, arguing that repeated small-scale activities can collectively contribute substantially to emissions when scaled across populations. This perspective is particularly useful for gaming, which may appear individually insignificant but becomes environmentally relevant through scale and frequency.

Altogether, this literature supports the thesis treatment of user behaviour as a central analytical variable.

3.5 Swedish gaming and industry context

Although a generally applicable modelling framework is developed, Sweden is used as an illustrative case due to data availability and electricity system characteristics.

Swedish gaming behaviour is particularly relevant because the country demonstrates high digital adoption, widespread gaming participation, and relatively early uptake of digital technologies. Behavioural statistics provide useful empirical grounding for scenario assumptions.

Previous Swedish thesis work also provides contextual insight. (Lonnqvist, 2022) examine sustainability awareness within the Swedish gaming industry, highlighting a gap between environmental ambitions and implemented practices. Although their work focuses on industry perspectives rather than operational electricity modelling, it provides valuable sociotechnical context.

Sweden is therefore relevant both as a behavioural case and as an electricity system case.

3.6 Research gap

The reviewed literature demonstrates that gaming related environmental impact is shaped by interactions between device characteristics, user behaviour, and electricity system characteristics.

Device-level studies provide detailed measurements of electricity demand. Behavioural studies demonstrate the importance of gameplay intensity and digital media practices. Broader ICT literature provides environmental framing and methodological reflection. Electricity system studies show that operational energy and its emissions vary significantly depending on electricity carbon intensity.

However, these different dimensions are often studied separately. Fewer studies integrate detailed device-level electricity modelling, behavioural variation, and electricity system characteristics within a single operational modelling framework.

This gap is particularly relevant in low carbon electricity systems such as Sweden, where the relative importance of operational variables may shift compared with higher carbon electricity systems in other countries.

By applying a bottom-up operational modelling framework to addresses that gap, the framework systematically examines how device type, user behaviour, and electricity carbon intensity interact in shaping gaming related electricity use and greenhouse gas emissions.

Chapter 4

Aim and Research Questions

4.1 Aim

The aim of this thesis is to analyse the operational energy use and environmental impact of digital gaming, with a focus on how device type, user behaviour, and electricity system characteristics influence the results. The study applies a generalised bottom-up energy modelling approach to estimate and compare electricity use across common gaming platforms, including gaming PCs, laptops, and consoles.

The analysis examines how user related factors, such as weekly playtime, performance related choices, and concurrent digital activities, influence operational electricity use and greenhouse gas emissions, and how these effects compare with differences in device efficiency and electricity system characteristics. Differences in reported gaming behaviour between demographic groups, such as gender and age, are also considered in an exploratory manner to assess how variations in usage patterns may influence model outcomes.

Although the modelling framework is intended to be generally applicable, Sweden is used as an illustrative case due to the availability of data on gaming habits, device ownership, and electricity generation. In addition to comparative scenario analysis, exploratory population-scaled scenarios are used to contextualise how operational gaming related emissions may accumulate at a national level under Swedish conditions.

The primary purpose of the study is not to produce a precise national emissions inventory, but rather to identify which factors most strongly influence the operational environmental impact of digital gaming under different behavioural, technical, and infrastructural conditions.

The analysis is structured around the interaction between device characteristics, user behaviour, and electricity system characteristics, which together form the core analytical framework of the thesis.

4.2 Research Questions

1: What factors most strongly influence the operational energy use and greenhouse gas emissions of digital gaming, considering device type, user behaviour, and electricity system characteristics?

Supporting subquestions:

> 1a: What differences in operational electricity use and greenhouse gas emissions can be identified between common gaming platforms such as gaming PCs, laptops, and consoles under different electricity system characteristics?
>
> 1b: 1b: How sensitive are operational electricity use and greenhouse gas emissions to user related choices such as gameplay duration, performance related settings, and simultaneous digital activities, compared with differences in device efficiency?
>
> 1c: How might differences in reported gaming behaviour between demographic groups have on estimated operational energy use and greenhouse gas emissions from digital gaming?

4.3 Scope and Delimitations

The thesis focuses on analysing the operational energy use and environmental impact of digital gaming through a generally applicable bottom-up modelling framework demonstrated using Sweden as an illustrative case. Rather than producing a precise national footprint assessment, the purpose of the study is to identify the main factors influencing operational electricity use and greenhouse gas emissions under different assumptions related to device type, user behaviour, and electricity system characteristics.

The scope of the thesis includes:

- Estimation of operational electricity use for digital gaming across common gaming platforms including gaming PCs, laptops and consoles.
- Analysis of user related factors, such as weekly playtime, gameplay intensity, and performance related choices connected to graphical settings and hardware usage.
- Representation of electricity system characteristics through electricity carbon intensity, which is treated as an adjustable parameter in order to reflect different national, regional, or global electricity system characteristics.
- Inclusion of associated digital activities, such as video streaming and simultaneous media consumption, within selected behavioural scenarios.

Although the modelling framework of the thesis is intended to be generally applicable, Sweden is used as one illustrative scenario. The choice of Sweden is motivated by the availability of reliable data regarding electricity generation, gaming habits, and the comparatively low carbon intensity of the Swedish electricity system. Using Sweden

as an illustrative scenario makes it possible to examine how operational greenhouse gas emissions from gaming change under relatively low carbon electricity conditions.

The same modelling framework can be applied to other countries or regions by modifying electricity carbon intensity values and behavioural assumptions.

A number of limitations and delimitations are acknowledged.

No primary measurements of power consumption were conducted within the study. Device power draw, electricity consumption values, and performance assumptions are instead based on previously published studies and datasets.

Detailed modelling of network infrastructure, data centre operation, and internet traffic dynamics is outside the scope of the thesis. Electricity use related to broader digital infrastructure is instead represented through values obtained from previous literature and reports.

The thesis focuses on operational electricity use during the usage phase of gaming systems. Broader environmental impacts related to hardware manufacturing, supply chains, raw material extraction, and end of life processes are therefore outside the scope of the analysis.

By treating key variables such as device type, user behaviour, and electricity carbon intensity as adjustable parameters, the thesis aims to generate insights that remain relevant across different countries, regions, and future electricity system characteristics, rather than being tied to a single national context.

Only consoles, PCs and gaming laptops are studied as platsforms in the thesis. Mobile gaming is not taken into account.

Chapter 5

Background

This section introduces data and statistics that is needed to understand the broader context of Swedish gaming patterns, media usage, gender distribution and demographics.

5.1 Gaming behaviour and digital media use in Sweden

To ground the modelling assumptions in observed behaviour, this section examines available data on gaming habits and digital media use in Sweden. Sweden has a population of approximately 10.6 million inhabitants (Statistics Sweden, 2025). Of the total population, as of 2026, there is a 67.35% video game penetration. This is projected to reach 71.52% by 2030 (Statista, 025f). Particular attention is given to gameplay duration, demographic usage patterns, and the broader digital context in which gaming often occurs, as these factors influence the behavioural scenarios used in the analysis.

5.1.1 Gaming intensity is widespread but primarily moderate

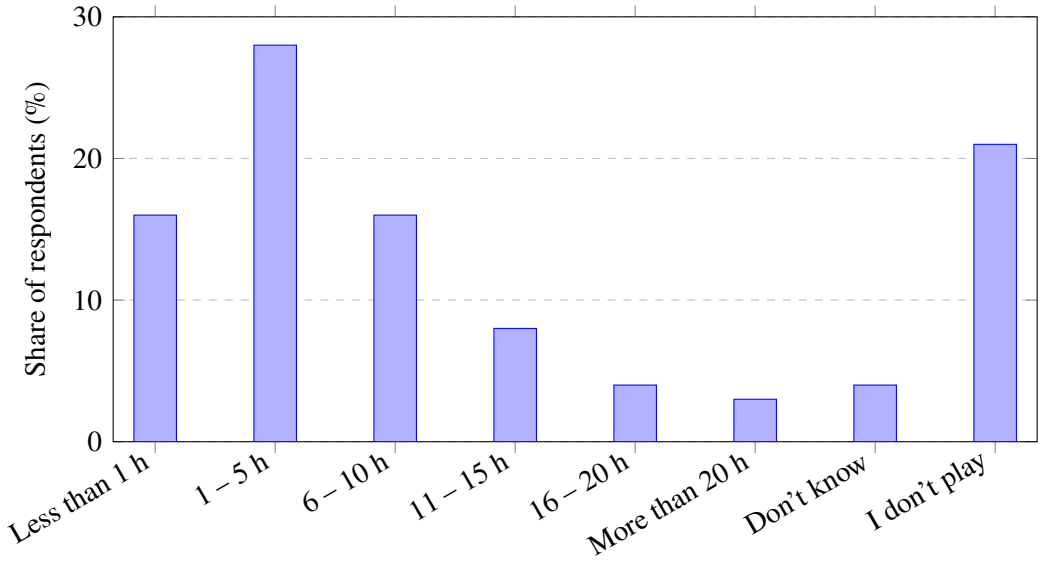


Figure 5.1: *Weekly hours spent playing video games in Sweden as of June 2025, 2018 respondents* (Statista, 2025c)

A central observation from the data is that gaming is widely present across the Swedish population, but typically at relatively low to moderate intensity. The most common category is 1–5 hours per week (28%), followed by both less than 1 hour (16%) and 6–10 hours (16%) Statista (2025c). Together, these categories account for approximately 60% of respondents, indicating that gaming is predominantly a moderate activity rather than a high-intensity one.

The average gaming time was estimated at approximately 4.7 hours per week. This value is representative of typical gaming behaviour in Sweden and therefore provides an important point of reference for understanding the potential energy demand associated with gaming activities.

At the same time, only a limited share of users report very high levels of gameplay. Around 3% of respondents indicate more than 20 hours per week, and even when including the 16–20 hour category, the total share of high-intensity users remains relatively small Statista (2025c). This suggests that extreme gaming behaviour exists but is not representative of the majority of users.

From an energy perspective, this distribution is particularly relevant because gameplay duration directly influences electricity consumption. While individual high intensity users may consume considerably more electricity than average, the overall environmental impact of gaming is likely to be driven primarily by the large number of users engaging in moderate amounts of gameplay. As a result, understanding typical gameplay duration is important when assessing the operational energy demand associated with gaming activities.

5.1.2 Gaming is distributed across adult age groups

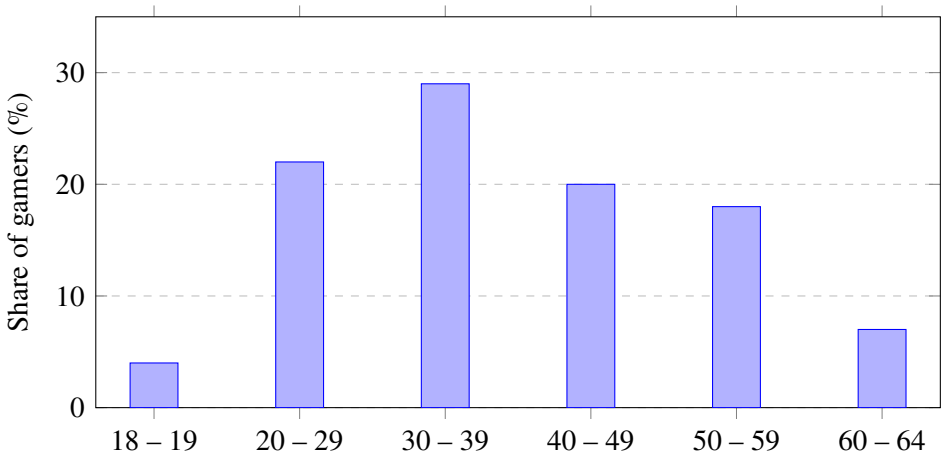


Figure 5.2: *Distribution of video game users in Sweden by age group, March 2025, 1489 respondents* (Statista, 2025a)

The data further shows that gaming in Sweden is not concentrated among younger populations, but rather distributed across multiple adult age groups. The largest share of gamers is found in the 30 – 39 age group (29%), followed by 20 – 29 (22%) and 40 – 49 (20%) Statista (2025a). Even older groups such as 50 – 59 (18%) and 60 – 64 (7%) represent a non-negligible portion of the gaming population.

This distribution indicates that gaming is a mainstream activity embedded in everyday life across a wide demographic range. The relatively high share in the 30 – 39 group is particularly significant, as this group typically has stable income levels and access to more energy intensive gaming hardware such as high performance PCs or modern consoles.

This implies that gaming electricity use should be understood as a population wide phenomenon rather than something limited to specific demographic segments. This strengthens assumptions related to total demand scaling and supports the inclusion of broad population level scenarios in the modelling. This has implications for scaling behaviour across the population and therefore influences total energy demand in the modelling framework.

5.1.3 Gender distribution suggests a general population activity

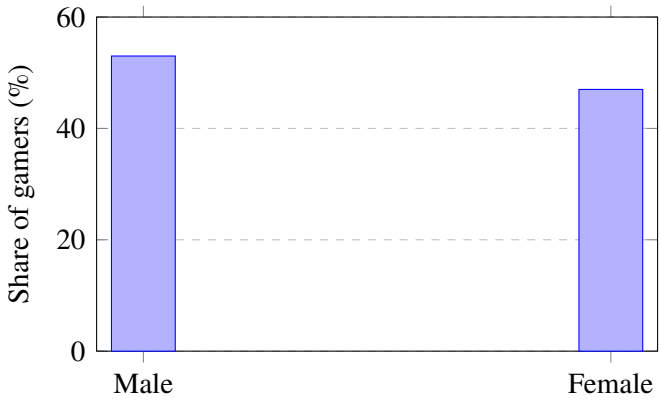


Figure 5.3: *Distribution of video game users in Sweden by gender, March 2025, 2031 respondents* (Statista, 2025b)

The gender distribution of gamers in Sweden is relatively balanced, with 53% male and 47% female users Statista (2025b). This challenges earlier assumptions of gaming as a strongly male dominated activity and instead reinforces the view of gaming as a general form of digital leisure.

This has implications for modelling assumptions. Since participation is relatively evenly distributed, it is less appropriate to rely on strongly gender differentiated usage patterns without additional supporting data. Instead, aggregate behavioural parameters are likely to provide a more accurate representation of overall electricity demand.

The near parity in gender distribution further supports the interpretation of gaming as a socially embedded and widely adopted activity.

5.1.4 Game genre preferences indicate heterogeneous energy demand

Table 5.1: *Gaming genres and typical gameplay characteristics*

Genre category	**Typical gameplay characteristics**	**Potential hardware intensity**
Action / Shooter	Fast-paced gameplay, often multiplayer, high frame rate requirements	High graphical load and strong GPU demand
Adventure / Open world	Large environments, exploration, narrative-driven gameplay	Moderate to high graphical load depending on complexity
Role playing games	Character progression, complex worlds, long play sessions	Moderate graphical demand but long continuous usage
Simulation and strategy	System management, slower gameplay loops	Lower graphical intensity but extended runtime
Casual and puzzle games	Short sessions with simple mechanics	Low hardware intensity and low power demand

The data on preferred game genres shows a wide distribution of player preferences amongst 1589 respondents. The most popular genres include adventure (33%), action-adventure (31%) and strategy (26%), followed by action and shooter games Statista (2025e). Less common genres such as MMORPG and MOBA games still represent a smaller but relevant share of users.

This diversity is important because different game genres are associated with different computational and graphical demands. For example, visually intensive action and shooter games often require higher GPU utilisation, while strategy or casual games may involve lower and more stable processing loads.

As a result, electricity consumption per hour of gameplay cannot be assumed to be constant across all users. Instead, the variation in genre preferences supports modelling approaches that incorporate ranges or scenario based assumptions for energy use. This strengthens the realism of the operational electricity estimates used. This also connects behavioural patterns to device level energy demand, as different genres place varying loads on hardware performance.

5.1.5 Gaming should be understood within a broader digital media context

When contextualising gaming within the broader media landscape, it becomes clear that it is part of a broader ecosystem of digital consumption. Among 689 respondents, the most widely used media services in Sweden include television (85%), music streaming (73%) and video streaming (69%) Statista (2025d). In addition, a large share of the population uses online television services frequently, with 36% reporting daily use and 58% using such services at least weekly Statista (2023).

This indicates that gaming is one component within a highly digitalised lifestyle where multiple forms of media consumption coexist. From an energy perspective, this is important because total electricity demand from digital activities is cumulative. Even if gaming itself is moderate at the individual level, its contribution becomes significant when combined with other digital services and scaled across the population.

This supports analysing gaming not as an isolated activity, but as part of a broader system of digital energy use. It also strengthens the argument that growth in digital consumption more generally may lead to increased electricity demand, even if individual activities appear relatively modest.

5.2 Detailed power consumption assumptions for consoles and gaming systems

A requirement for the thesis is to establish realistic power consumption values for gaming devices under actual use conditions. This is necessary because operational electricity use is calculated directly from device wattage and usage time, and the reliability of the modelling therefore depends heavily on the quality of the wattage assumptions. Earlier work in gaming energy research has already shown that gaming electricity demand varies

substantially across devices, software conditions, and player behaviour. However, more recent manufacturer and platform specific baseline data also make it possible to refine console assumptions beyond what was previously available in the literature.

This subsection therefore combines three types of material. First, it uses empirical gaming energy research from Berg (2024), the California Energy Commission (2019), and Mills et al. (2019), which together provide a strong foundation for understanding variability in gaming power use across PCs and consoles. Second, it incorporates recent PlayStation ecodesign measurements, which provide official power consumption values for a large number of PlayStation 3, PlayStation 4, and PlayStation 5 models under several distinct modes of use Sony Interactive Entertainment (2026). Third, it incorporates Xbox sustainability baselines, including mode-specific and genre-specific estimates for Xbox Series X and Xbox Series S Microsoft (2026b,a). Taken together, these sources provide a more complete picture of console gaming electricity demand than could be obtained from any single source.

The overall conclusion from this combined material is that console power consumption is more structured and predictable than gaming PC power consumption, but still highly dependent on generation, mode of use, display output, and software context. The most important distinction is not only between platforms, but also between active gameplay, menu or constrained states, media playback or streaming, and rest or standby modes. For this reason, modelling based only on a single "gaming wattage" would miss important parts of the duty cycle and would risk underestimating annual electricity consumption for some users.

5.2.1 Literature basis for updated wattage assumptions

(Mills et al., 2019) remains one of the most important sources in this area because it measured 26 gaming systems and found that energy use varied widely not only across hardware but also across games and user conditions. The article shows that mid-range and high end desktops were among the highest per-unit energy users, but it also demonstrates that many consoles consume as much or more power than lower-end PCs and laptops in some cases. One particularly important conclusion is that user behaviour is often a stronger driver of total annual electricity use than hardware category alone. This point is essential for the thesis, because it justifies using scenarios rather than using single value modelling framework.

(Mills et al., 2019) also shows that gameplay power varies substantially by title, by system, and by duty cycle. The study reports that average power during gameplay varied by a factor of approximately 12 across desktop systems, by 10 across laptops, and by 15 across consoles. It also notes that some consoles used as much or more power than all but the highest-performance laptops and entry-level desktops. In addition, non-gaming modes for some consoles could still be relatively power intensive, which makes it necessary to distinguish active use from menus, connected standby, and other low interaction states.

(California Energy Commission, 2019) supports this broader view by showing that gaming PCs, consoles, and VR systems all exhibit substantial differences depending on usage pattern and hardware type. (Berg, 2024) adds an especially important contribution for gaming PCs by showing that upscaling and frame generation do not automatically reduce electricity use, and that improvements in rendering performance can instead coincide

with increased GPU load and increased power demand. In other words, technological development can shift where electricity is consumed, but does not necessarily reduce total consumption.

While these three sources provide a strong scientific basis, the newer PlayStation and Xbox sources are particularly valuable, because they offer recent, platform specific wattage values under clearly defined modes of operation. These can be used not only to validate older console assumptions from the literature, but also to update them.

5.2.2 Overview of platform categories

A more in depth overview of console wattage can be seen in Appendix C.

Table 5.2: *Broad power consumption ranges across gaming platforms*

Platform category	**Typical power (W)**	**Upper range (W)**	**Main basis**
Gaming PC	150 – 350	400 – 700+	Mills et al. (2019), Berg (2024), CEC (2019)
Gaming laptop	100 – 250	300+	Mills et al. (2019), CEC (2019)
PlayStation 5	200 – 219	220+	PlayStation ecodesign values
PlayStation 4	75 – 158	160+	PlayStation ecodesign values
Xbox Series X	108 – 154	154+	Xbox platform baselines
Xbox Series S	61 – 77	77+	Xbox platform baselines

This table suggests several important patterns. First, modern flagship consoles such as PlayStation 5 and Xbox Series X operate at wattage levels that overlap with lower and moderate gaming PC scenarios. Second, lowerpower modern consoles such as Xbox Series S use markedly less power, often closer to older PlayStation 4 levels. Third, the difference between active gaming and other console modes remains large enough that mode-specific assumptions are necessary.

These values make the implications for annual modelling very clear. A PlayStation 5 at approximately 215 W consumes around 0.215 kWh per hour of active gaming. If a user plays 10 hours per week, this alone would correspond to approximately 2.15 kWh per week or about 112 kWh per year from active gameplay alone, before streaming, menus, downloads, standby, or related digital services are added.

Similarly, an Xbox Series X at approximately 154 W consumes 0.154 kWh per hour. At 10 hours per week this gives roughly 80 kWh per year for active gameplay alone. In contrast, an Xbox Series S at roughly 74 W would consume roughly half that amount, around 38 kWh per year at the same weekly playtime.

Table 5.3 presents representative active gameplay electricity consumption values for selected modern gaming consoles, expressed both as power demand in watts and as equivalent hourly electricity use in kWh. These representative values were selected based on current generation console performance data and are intended to provide transparent benchmark assumptions for the comparative modelling conducted in the results section. The hourly electricity consumption values presented here are used in subsequent scenario calculations

to estimate annual electricity demand and associated greenhouse gas emissions under different gameplay assumptions.

Table 5.3: *Representative active gameplay electricity consumption values for selected modern gaming consoles, used as benchmark assumptions in the results section for annual electricity use and greenhouse gas emissions modelling*

Console platform	**Power demand (W)**	**Electricity use (kWh/hour)**
PlayStation 5	215	0.215
Xbox Series X	154	0.154
Xbox Series S	74	0.074

5.2.3 Video streaming

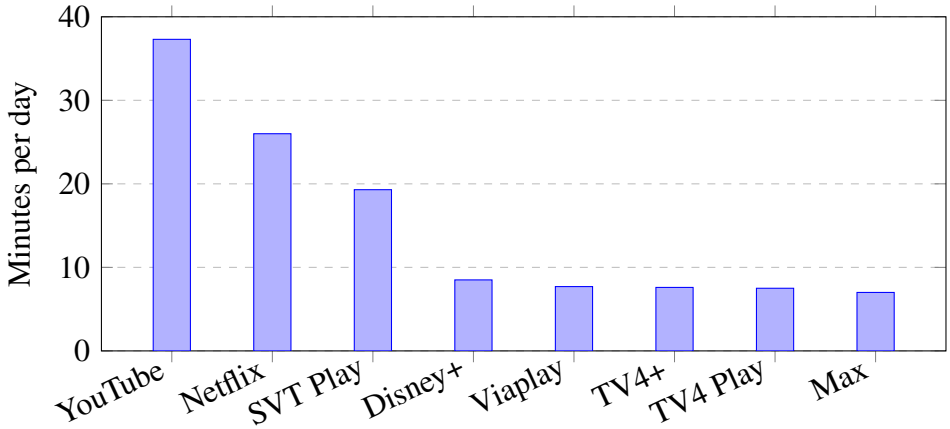


Figure 5.4: *Average daily viewing time of video streaming services in Sweden, 4th quarter*(Statista, 2023)

Figure 5.4 presents average daily viewing time across major video streaming platforms in Sweden. The data shows that streaming media consumption is a significant part of everyday digital activity, with YouTube representing the highest average daily usage at approximately 37.3 minutes per day, followed by Netflix at 26 minutes and SVT Play at 19.3 minutes. Other services such as Disney+, Viaplay, TV4+, TV4 Play, and Max show lower but still measurable levels of daily engagement.

These figures are relevant because gaming often takes place within a broader digital media environment rather than as an isolated activity. Users may combine gaming with parallel or adjacent digital activities such as watching video content, listening to music, or engaging with other online services. While these activities are not directly included in the core gaming electricity model, they provide important contextual information regarding the wider electricity demand associated with digital leisure.

To provide a simple benchmark for comparison, previous work by the International Energy Agency suggests that streaming video can involve approximately 80 W of electricity

demand at the device level, depending on the viewing setup and assumptions used (International Energy Agency, 2020). This corresponds to roughly 0.08 kWh per hour of streaming activity. While exact electricity demand varies depending on screen type, resolution, and connected equipment, this provides a useful reference point when comparing gaming electricity demand with other forms of digital entertainment.

Chapter 6

Methodology

This study uses a desk-based quantitative modelling approach combined with a structured literature review and scenario analysis in order to evaluate the operational energy use and environmental impact of digital gaming. The methodology was developed iteratively throughout the project, where the collection of literature, previous theses, technical reports, and quantitative datasets continuously informed the structure of the analytical model and the final scenario design.

The purpose of the methodology was not only to gather relevant information about gaming-related electricity use, but also to construct a transparent and reproducible modelling framework that connects directly to the calculations and results presented later in the thesis. The overall methodological process therefore consisted of four interconnected stages:

1. collection and review of relevant literature and previous research
2. identification and selection of suitable modelling methods
3. collection and categorisation of quantitative data
4. construction of a bottom-up scenario-based analytical model

The methodological structure was designed so that each stage informed the following stage. The literature review informed the selection of modelling methods, the selected methods determined what type of data needed to be collected, and the collected data was then organised into the scenarios and calculations used in the Results section.

6.1 Bottom-up modelling approach

This thesis applies a bottom-up quantitative modelling approach to estimate the operational electricity use and associated greenhouse gas emissions of digital gaming activities.

In energy systems research, bottom-up modelling refers to an approach where system level outcomes are estimated by modelling individual technical components or end use activities and then combining these results to represent the wider system. Rather than relying on high level combined historical consumption data, bottom-up models use micro

level technical and behavioural inputs to estimate energy demand (Dineen, 2014; Swan and Ugursal, 2009).

As described by (Dineen, 2014), bottom-up models focus on the energy demand of individual units or end use categories, which are then scaled upward to estimate broader system behaviour. (Swan and Ugursal, 2009) similarly describes bottom-up energy models as approaches that explicitly represent technical energy consuming components, allowing detailed modelling of how technological characteristics and user assumptions influence overall demand.

This differs from top-down modelling approaches, which typically rely on combined macro level indicators such as historical energy demand, economic growth, population trends or national consumption statistics to estimate more broad energy patterns (Dineen, 2014; Swan and Ugursal, 2009). While such approaches are useful for large-scale forecasting and economic trend analysis, they offer less transparency when the objective is to isolate the influence of specific technical or behavioural variables.

A bottom-up approach was considered particularly appropriate for this thesis because the objective is not simply to estimate a single total environmental footprint for gaming, but to understand which factors drive variation in operational electricity use and emissions. Since my thesis focuses explicitly on device characteristics, user behaviour, and electricity system characteristics, a modelling framework that allows these variables to be represented individually and varied systematically is required.

6.2 Literature review and method selection

The first stage of the study consisted of conducting a broad literature review in order to establish an understanding of existing research related to gaming energy consumption, digital carbon emissions, operational electricity use, and user behaviour in digital environments.

Literature was collected primarily through Google Scholar, ScienceDirect and the Uppsala University library database. The following search terms were used: “gaming energy consumption”; “gaming electricity use”; “operational energy ICT”; “gaming carbon footprint”; “video streaming electricity consumption”; “gaming hardware power consumption”; “digital emissions”; “ICT environmental impact”.

The literature review included peer-reviewed journal articles, technical reports, environmental assessments, statistical reports, and previous theses related to digital sustainability and gaming energy analysis. Previous theses were especially useful during the early stages of the project since they provided examples of how similar modelling based studies structured their methodology, presented calculations, and connected assumptions to findings.

Rather than directly reproducing the methodology from a single source, the study adopted and combined methodological elements from several previous studies depending on their relevance to the research aim. Particular attention was given to studies that used transparent quantitative modelling approaches and clearly documented assumptions, calculations, and scenario structures.

Several methodological approaches identified during the literature review became central to the final analytical framework.

The first major methodological choice was the use of a bottom-up operational energy model. This approach was selected primarily from studies such as Mills et al. (2019), Mahmood (2025), and Hittinger et al. (2012), where electricity consumption is estimated at device level rather than through aggregated national statistics. In particular, Mills et al. (2019) provided a methodological foundation by combining device-level power measurements, ownership data, and usage patterns within a bottom-up modelling framework. Similarly, Mahmood (2025) demonstrated how operational electricity demand can be translated into greenhouse gas emissions through behavioural and platform-based scaling assumptions. The work by Hittinger et al. (2012) further highlighted the importance of gameplay duration, standby modes, and user activity patterns when estimating operational electricity demand. This bottom-up approach was considered most appropriate for the thesis since it allows the analysis to directly connect user behaviour, device type, and hardware performance to estimated electricity consumption and emissions.

The second methodological choice was the use of scenario analysis. Multiple previous studies used scenario-based approaches to compare how changes in behaviour, technology, or electricity systems influence environmental outcomes. Studies such as Buonocore (2016), California Energy Commission (2019), and Lange et al. (2020) demonstrated that energy use and emissions can vary substantially depending on assumptions regarding gameplay intensity, hardware efficiency, and broader digital consumption patterns. Scenario analysis was therefore adopted because the study does not aim to predict exact future values, but instead aims to compare how different assumptions influence operational electricity use and greenhouse gas emissions under varying conditions.

Another important methodological element adopted from previous work was the inclusion of behavioural factors within the modelling process. Multiple studies emphasised that user behaviour significantly affects operational electricity consumption in digital systems. For example, Mills et al. (2019) identified gameplay duration and device usage patterns as major drivers of electricity demand, while Lee et al. (2025) demonstrated how external digital media consumption, such as live streaming, may influence gameplay behaviour and increase engagement time. In addition, Akenji et al. (2021) and Lange et al. (2020) highlighted the importance of everyday consumption practices and rebound effects when analysing digital energy demand. As a result, the analytical model incorporates behavioural variables such as gameplay duration, hardware performance level, simultaneous use of streaming services, and platform specific usage patterns.

Gaming is therefore treated not as an isolated activity, but as part of a broader digital ecosystem where multiple digital services may be used simultaneously. This perspective became important throughout both the modelling and scenario development process, particularly when analysing how broader digital consumption patterns may contribute to operational electricity demand.

The literature review therefore did not only provide theoretical background, but also directly informed the selection of variables, scenario structures, and calculation methods used throughout the study.

This section describes the methodological approach used in the thesis and explains how the research questions are addressed. Rather than aiming to produce precise absolute emission estimates, the methodology is designed to identify dominant factors, relative

differences, and sensitivities related to device choice, user behaviour, and electricity system characteristics.

6.3 Collection of quantitative data

Once the modelling approach had been established, the next stage involved collecting the quantitative data required for the calculations and scenario construction.

The study relies entirely on secondary data collected from scientific literature, technical hardware testing, statistical databases, environmental reports, and energy-related datasets. Since the thesis focuses on operational electricity use, the data collection process primarily focused on obtaining representative measurements of device-level power consumption and usage behaviour.

The collected data can generally be divided into five categories:

1. hardware electricity consumption data
2. user behaviour and gaming duration data
3. demographic and usage statistics
4. electricity emission intensity values
5. electricity consumption related to associated digital activities

Hardware electricity consumption data was collected primarily from technical benchmark testing and scientific studies measuring real-world gaming power usage. These datasets included estimated power consumption values for gaming PCs, gaming laptops, and gaming consoles during active gameplay.

Where several different power consumption values existed for similar hardware categories, representative average values were selected in order to maintain consistency throughout the modelling process. The selected values therefore do not represent the maximum possible power consumption of individual systems, but rather approximate operational averages suitable for comparative scenario analysis.

Behavioural data was collected from gaming surveys, statistical reports, and market analyses. This included information regarding average gaming duration, frequency of gameplay, demographic gaming patterns, and estimated distribution of gaming activity across different user groups.

Previous large-scale studies combining platform-level data from gaming and live streaming services were also used to inform assumptions regarding simultaneous use of digital services during gameplay. This became particularly relevant when constructing behavioural scenarios involving parallel media consumption.

Additional data regarding video streaming and related digital activities was also collected since the literature review showed that gaming is frequently accompanied by simultaneous digital media consumption. These datasets were included in order to broaden the operational perspective beyond the gaming device itself.

Electricity emission intensity values expressed in gCO_2e/kWh were collected from environmental and energy-system datasets. Multiple electricity mixes were included in order to compare how operational emissions change depending on geographical electricity production systems. This became particularly important within the Results section where comparisons are made between low carbon and higher-carbon electricity systems.

6.4 Data organisation and categorisation

After the quantitative data had been collected, the datasets were organised into categories that could be directly implemented within the analytical model.

The first level of categorisation separated gaming systems into hardware groups:

- gaming PCs
- gaming laptops
- gaming consoles

This separation was necessary because the literature review showed substantial differences in electricity consumption between device categories. Gaming PCs generally demonstrated significantly higher operational electricity use than consoles or laptops, particularly when high performance components and higher graphical settings were involved.

The second level of categorisation involved behavioural segmentation. User behaviour was divided into different gameplay scenarios based on gaming duration and digital usage intensity. These scenarios were developed in order to compare how behavioural choices influence total operational energy use.

The behavioural scenarios included variations in:

- weekly gaming hours
- device performance level
- simultaneous streaming activity

The collected data was then structured into tables and calculation matrices that connected each device category to behavioural assumptions and electricity consumption values. This organisational structure became the foundation for the calculations later presented in the Results section.

6.5 Construction of the analytical model

The analytical model was constructed using a bottom-up modelling framework informed by the methods identified during the literature review.

Instead of estimating emissions through aggregated national gaming statistics, the model estimates electricity consumption at device level and scales the results according to behavioural assumptions and scenario configurations.

The model first calculates operational electricity use in kilowatt-hours based on two primary variables:

1. device power consumption,
2. duration of use.

The annual electricity consumption was calculated using:

$$E_{\text{annual}} = \frac{P \times H}{1000} \times 365 \tag{1}$$

where:

- E_{annual} represents annual electricity consumption in kWh
- P represents device power consumption in watts
- H represents average daily usage hours

The operational electricity consumption values were then converted into greenhouse gas emissions using electricity emission intensity values:

$$G_{\text{annual}} = E_{\text{annual}} \times I_{\text{electricity}} \tag{2}$$

where:

- G_{annual} represents annual greenhouse gas emissions in gCO_2e
- E_{annual} represents annual electricity consumption
- $I_{\text{electricity}}$ represents electricity emission intensity in gCO_2e/kWh

The electricity emission intensities used throughout the modelling were based on European Environment Agency datasets and corresponding Swedish electricity statistics:

$$I_{\text{electricity, EU}} = 187 \text{ gCO}_2\text{e/kWh} \tag{3}$$

$$I_{\text{electricity, SE}} = 7 \text{ gCO}_2\text{e/kWh} \tag{4}$$

With these equations added together, a more comprehensive equation can be formed:

$$G_{\text{annual}} = \frac{P \times H \times 365}{1000} \times I_{\text{electricity}} \tag{5}$$

where:

- G_{annual} represents annual operational greenhouse gas emissions in gCO_2e
- P represents device power consumption in watts (W)
- H represents average daily usage in hours per day
- $I_{\text{electricity}}$ represents electricity carbon intensity in gCO_2e/kWh

Where the factor 1000 converts device power from watts to kilowatts, while multiplication by 365 converts daily electricity use to annual electricity use. The electricity carbon intensity is varied depending on the electricity system being modelled.

These calculations form the core methodological connection between the Methodology and Results sections. Every graph, comparison, and scenario presented within the Results section is derived from this modelling structure combined with the behavioural and hardware assumptions established earlier in the methodology.

Separate calculations were performed for each hardware category and behavioural scenario.

6.5.1 Electricity carbon intensity assumptions

Operational greenhouse gas emissions were estimated by combining calculated electricity demand with electricity carbon intensity factors representing different electricity system characteristics. Since identical electricity consumption can result in substantially different greenhouse gas emissions depending on the surrounding electricity system, electricity carbon intensity was treated as an adjustable modelling parameter rather than a fixed assumption.

The European Environment Agency provides harmonised electricity emission intensity data across European countries, highlighting substantial variation between national electricity systems (European Environment Agency, 2025). These differences make electricity carbon intensity an important variable in operational emissions modelling.

Sweden was selected as the primary illustrative electricity system due to its comparatively low carbon electricity mix. Supporting national electricity system data were obtained from the Swedish Energy Agency (Swedish Energy Agency, 2025). To provide broader comparative context beyond the Swedish case, the European average electricity mix was also included as an alternative modelling scenario.

This approach allows identical electricity demand scenarios to be evaluated under different electricity system characteristics, making it possible to assess how infrastructural context influences operational greenhouse gas emissions. In the discussion (specifically section 8.6), we also look at what can be done with variations during the day.

6.5.2 Modelling of associated digital services

In addition to gameplay itself, the analytical model also included electricity consumption related to associated digital services such as video streaming. This was included because the literature review and behavioural datasets suggested that gaming frequently occurs simultaneously with other forms of digital media consumption.

According to the International Energy Agency, one hour of video streaming requires approximately 0.08 kWh of electricity depending on device type, streaming quality, and network conditions. This value was used as a representative baseline assumption within the modelling framework (International Energy Agency, 2020).

The electricity use associated with streaming was calculated as:

$$E_{\text{streaming}} = P_{\text{streaming}} \times t_{\text{streaming}} \tag{6}$$

where:

- $P_{\text{streaming}}$ represents electricity use per hour of streaming,
- and $t_{\text{streaming}}$ represents streaming duration in hours.

This allowed streaming activity to be integrated into the same modelling structure as gaming electricity consumption and enabled analysis of combined digital usage scenarios.

6.5.3 Scenario Development

Scenario analysis was used in order to evaluate how changes in user behaviour, technology, and electricity systems influence operational emissions.

The scenarios were not intended to function as predictions of future gaming behaviour. Instead, they were designed as comparative analytical tools that illustrate how different assumptions produce different environmental outcomes.

The scenario framework was developed directly from patterns identified during the literature review and data collection stages. Variables that appeared most frequently within previous research were prioritised during scenario construction.

User behaviour within the scenarios was represented through variations in gameplay duration, hardware performance assumptions, and simultaneous use of associated digital services. This made it possible to examine how behavioural choices influence total electricity demand under different technological and electricity-system conditions.

The scenarios therefore varied factors such as:

- gameplay duration,
- hardware type,
- hardware performance level,
- electricity mix,
- simultaneous use of streaming services.

This methodological approach made it possible to compare the relative influence of behavioural factors versus technological efficiency improvements. It also made it possible to identify which variables had the greatest impact on operational emissions across different contexts.

6.5.4 Population Scaling

When individual or device-level electricity use was scaled to a larger user group, the total electricity demand was calculated by multiplying the annual electricity use per user by the number of users included in the scenario:

$$E_{\text{population}} = E_{\text{individual}} \times N_{\text{users}} \tag{7}$$

where:

- $E_{\text{population}}$ represents total annual electricity consumption for the user group in kWh,
- $E_{\text{individual}}$ represents annual electricity consumption per user in kWh,
- and N_{users} represents the number of users included in the scenario.

The corresponding greenhouse gas emissions were then calculated as:

$$G_{\text{population}} = E_{\text{population}} \times I_{\text{electricity}} \tag{8}$$

where $G_{\text{population}}$ represents total annual greenhouse gas emissions for the user group.

6.5.5 Demographic scenario scaling

Demographic variation was treated as an exploratory scenario variable rather than as a direct attribution of emissions to specific demographic groups. When differences in reported gaming behaviour between demographic groups were used, electricity demand was estimated by combining the number of users in each group with the assumed annual electricity use per user:

$$E_{\text{group}} = E_{\text{individual, group}} \times N_{\text{group}} \tag{9}$$

where:

- E_{group} represents total annual electricity consumption for the demographic group in kWh,
- $E_{\text{individual, group}}$ represents annual electricity consumption per user in that group in kWh,
- and N_{group} represents the number of users in the demographic group.

The emissions for each demographic scenario were then calculated as:

$$G_{\text{group}} = E_{\text{group}} \times I_{\text{electricity}} \tag{10}$$

This makes it possible to compare how differences in reported usage patterns may influence estimated electricity use and emissions, without treating demographic identity itself as the cause of environmental impact.

6.5.6 Performance adjustment

To represent differences in hardware load caused by graphical settings, game complexity, or performance-related choices, device power consumption can be adjusted using a performance factor:

$$P_{\text{adjusted}} = P_{\text{baseline}} \times f_{\text{performance}} \tag{11}$$

where:

- P_{adjusted} represents adjusted device power consumption in watts,
- P_{baseline} represents baseline device power consumption in watts,
- and $f_{\text{performance}}$ represents the performance adjustment factor.

The adjusted power value was then used in the annual electricity calculation:

$$E_{\text{annual, adjusted}} = \frac{P_{\text{adjusted}} \times H}{1000} \times 365 \tag{12}$$

This allows higher performance scenarios to be represented consistently within the same modelling framework as the baseline calculations. Because electricity demand during gameplay varies depending on software context, performance settings, and hardware workload, representative power values should not be interpreted as fixed constants for all gameplay situations. To account for this uncertainty, sensitivity scenarios are used where relevant to reflect lower- and higher-intensity gameplay conditions.

6.5.7 Sensitivity analysis

Given the scenario based and bottom-up nature of the modelling approach, a sensitivity analysis was conducted to examine how changes in key modelling assumptions influence estimated operational electricity use and greenhouse gas emissions. Sensitivity analysis is commonly used in energy modelling to improve transparency, assess model robustness, and identify which input assumptions most strongly influence model outputs (Usher et al., 2023; Mastrucci et al., 2017).

Sensitivity analysis was used to evaluate the influence of key technical, behavioural, and infrastructural parameters, including device power demand, gameplay duration, electricity system carbon intensity, simultaneous digital activities, and display related electricity demand.

To better reflect realistic gaming PC setups which commonly include one or more external monitors, and in turn contribute additional operational electricity demand, representative monitor power assumptions were derived using the European Product Registry for Energy Labelling (EPREL). EPREL provides publicly available technical specifications for electronic displays sold on the European market (European Commission, 2026). The database was filtered to include monitors between 24 and 32 inches with resolutions ranging from 1920 × 1080 to 3840 × 2160 pixels, representing common contemporary gaming monitor

configurations. Across well-known monitor brands, on-mode power demand ranged from approximately 9 W to 55 W. Based on this range, additional monitor loads of 30 W for a single monitor setup and 60 W for a dual monitor setup were selected for sensitivity analysis.

6.5.7.1 One-at-a-time

A one-at-a-time (OAT) sensitivity analysis was conducted to evaluate the robustness of the model and assess the influence of key input parameters on the estimated annual electricity consumption and greenhouse gas emissions. OAT sensitivity analysis is a commonly used local sensitivity analysis approach in which individual input parameters are varied while all remaining parameters are held constant at their baseline values. This allows the influence of each parameter on the model outputs to be examined independently and facilitates the identification of the assumptions that contribute most strongly to variations in the results (Saltelli et al., 2008, p. 66 – 79); (Azzini and Rosati, 2020, p. 18 – 23).

The sensitivity analysis focused on parameters representing the three dimensions of the analytical framework developed in this study: user behaviour, device characteristics, and electricity system characteristics. User behaviour was represented through variations in gameplay duration and streaming duration. Device characteristics were represented through separate power demand ranges for consoles, gaming laptops, and gaming PCs in order to capture the differing levels of standardisation and variability between gaming platforms. Electricity system characteristics were represented through variations in electricity emission intensity.

6.5.8 Replicability and limitations

An important goal of the methodology was to ensure transparency and replicability. All assumptions, scenario structures, formulas, and data sources were therefore documented throughout the study.

Because the model relies on publicly available secondary data, the methodology can be replicated or updated using alternative datasets, newer hardware measurements, or different behavioural assumptions.

At the same time, several methodological limitations exist. The study relies on estimated behavioural averages rather than direct user measurements, meaning that actual gaming behaviour may differ substantially between individuals. Hardware electricity consumption also varies depending on system configuration, graphical settings, game optimisation, and usage conditions.

Detailed modelling of network architecture, data centre operation, and broader market dynamics was outside the scope of the study. Economic behaviour and rebound effects were also not explicitly modelled within the analytical framework.

The study should therefore be interpreted as a scenario-based operational analysis rather than an exact measurement of real-world emissions. Nevertheless, the methodology provides a transparent framework for understanding how operational electricity use and environmental impact can be analysed within digital gaming environments.

6.6 Ethical considerations

The thesis does not involve human participants, personal data, or experimental testing. All datasets used throughout the analysis were obtained from publicly available sources, published literature, and aggregated statistical databases.

Ethical considerations are therefore primarily related to transparency, correct representation of data, and methodological clarity. Since the study relies on secondary data and scenario-based modelling, uncertainties related to behavioural assumptions and variability in reported electricity consumption values are acknowledged throughout the analysis.

Chapter 7

Results

This section of the thesis presents empirical observations and input data that inform the modelling of these dimensions and support the subsequent analysis. The results are presented in relation to the three core dimensions of the thesis: user behaviour, device related characteristics, and electricity system characteristics. This structure ensures consistency with the analytical framework and supports interpretation in relation to the research questions. To improve readability in the main results chapter, detailed numerical scenario tables, a few sensitivity analysis results, and extended platform power assumptions have been moved to Appendix A, Appendix B, and Appendix C. The results presented here therefore focus on the most analytically relevant comparisons, while complete numerical outputs and supporting assumptions are provided in the appendices for transparency and reproducibility.

7.1 Console energy usage and emissions

This section presents the estimated operational electricity use and greenhouse gas emissions associated with modern gaming consoles under different gameplay scenarios.

7.1.1 Annual electricity usage for consoles

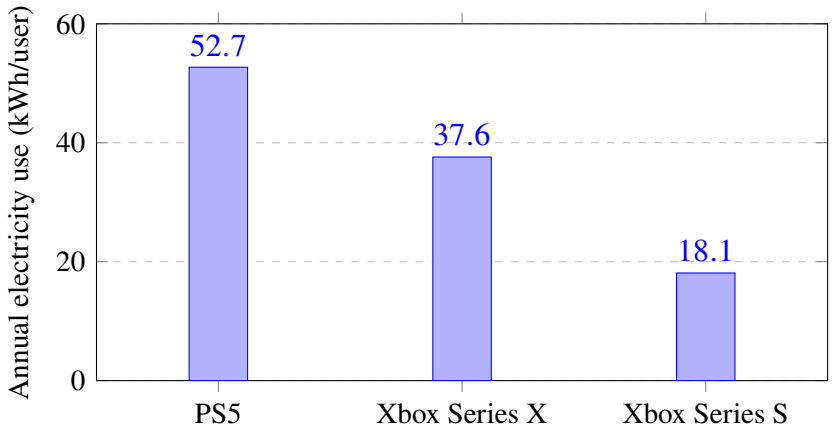


Figure 7.1: *Estimated annual electricity use per average Swedish console user, assuming a weighted gameplay time of approximately 4.7 hours per week*

Figure 7.1 shows that operational electricity demand varies noticeably between modern console platforms, even under identical representative gameplay assumptions. The PlayStation 5 has the highest estimated annual electricity use at 52.7 kWh per user, followed by the Xbox Series X at 37.6 kWh, while the Xbox Series S consumes substantially less at 18.1 kWh.

7.1.2 Annual operation emissions for consoles

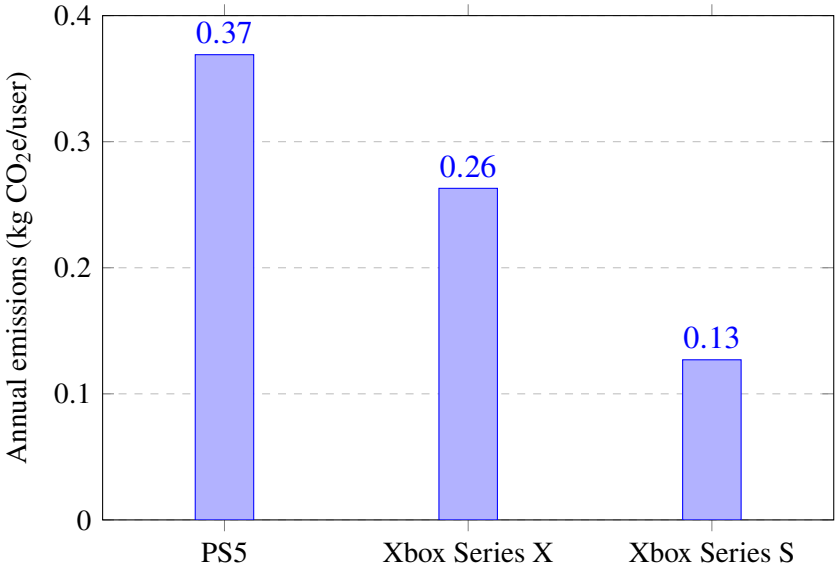


Figure 7.2: *Estimated annual operational emissions under Swedish electricity conditions (7 gCO_2e/kWh) for selected consoles platforms, assuming a weighted gameplay time of approximately 4.7 hours per week. Older hardware generations are excluded*

Figure 7.2 shows the corresponding operational greenhouse gas emissions under Swedish electricity conditions for the same representative gameplay scenario. Although the relative ranking between platforms remains unchanged, the absolute emissions remain comparatively low due to Sweden's low carbon electricity mix. The PlayStation 5 produces the highest estimated annual emissions at 0.369 kg CO_2e per user, followed by the Xbox Series X at 0.263 kg CO_2e, while the Xbox Series S remains the lowest at 0.127 kg CO_2e.

7.1.3 Annual electricity use and emissions for different durations

Table 7.1: *Estimated annual electricity use and operational emissions under Swedish electricity conditions for selected gaming platforms across weekly gameplay categories. Older hardware generations are excluded*

Gameplay category	**h/week**	**PS5 (kWh)**	**PS5 (kg CO_2e)**	**XSX (kWh)**	**XSX (kg CO_2e)**	**XSS (kWh)**	**XSS (kg CO_2e)**
Less than 1 h	0.5	5.6	0.04	4.0	0.03	1.9	0.01
1 – 5 h	3	33.7	0.24	24.0	0.17	11.5	0.08
6 – 10 h	8	89.9	0.63	64.1	0.45	30.8	0.22
11 – 15 h	13	146.0	1.02	104.1	0.73	50.0	0.34
16 – 20 h	18	202.2	1.42	144.1	1.01	69.2	0.48
More than 20 h	25	280.8	1.97	200.2	1.40	96.2	0.67

Table 7.2: *Estimated annual electricity use and operational emissions under European average electricity conditions for selected gaming consoles across weekly gameplay categories. Older hardware generations are excluded*

Gameplay category	**h/week**	**PS5 (kWh)**	**PS5 (kg CO_2e)**	**XSX (kWh)**	**XSX (kg CO_2e)**	**XSS (kWh)**	**XSS (kg CO_2e)**
Less than 1 h	0.5	5.6	1.05	4.0	0.75	1.9	0.36
1 – 5 h	3	33.7	6.30	24.0	4.49	11.5	2.15
6 – 10 h	8	89.9	16.81	64.1	11.99	30.8	5.76
11 – 15 h	13	146.0	27.30	104.1	19.47	50.0	9.35
16 – 20 h	18	202.2	37.81	144.1	26.95	69.3	12.96
More than 20 h	25	280.8	52.53	200.2	37.44	96.2	17.99

Figures 7.1 and 7.2, together with Tables 7.1 and 7.2, show that while gameplay intensity strongly increases console electricity demand, the surrounding electricity system has a far greater influence on operational emissions.

Under Swedish electricity conditions, operational emissions remain comparatively low across all gameplay categories due to the low carbon intensity of the electricity mix. Even in the highest gameplay category of more than 20 hours per week, annual emissions remain below 2 kg CO_2e for the PlayStation 5, 1.40 kg CO_2e for the Xbox Series X, and 0.67 kg CO_2e for the Xbox Series S. This suggests that under low carbon electricity conditions, console gaming contributes relatively limited operational emissions even for higher-intensity users.

At the same time, gameplay duration remains the primary driver of electricity demand within each platform category. Annual electricity use increases by approximately 50 times between the lowest and highest gameplay categories, rising from 5.6 to 280.8 kWh for the PlayStation 5, 4.0 to 200.2 kWh for the Xbox Series X, and 1.9 to 96.2 kWh for the Xbox Series S.

The comparison with the European average electricity mix shows that electricity system characteristics dominate the emissions outcome. For identical gameplay behaviour, the PlayStation 5 increases from 1.97 to 52.53 kg CO_2e annually, the Xbox Series X from 1.40 to 37.44 kg CO_2e, and the Xbox Series S from 0.67 to 17.99 kg CO_2e in the highest gameplay category. This corresponds to approximately 27 times higher emissions under the European average electricity mix, despite unchanged electricity demand.

7.1.4 Video streaming

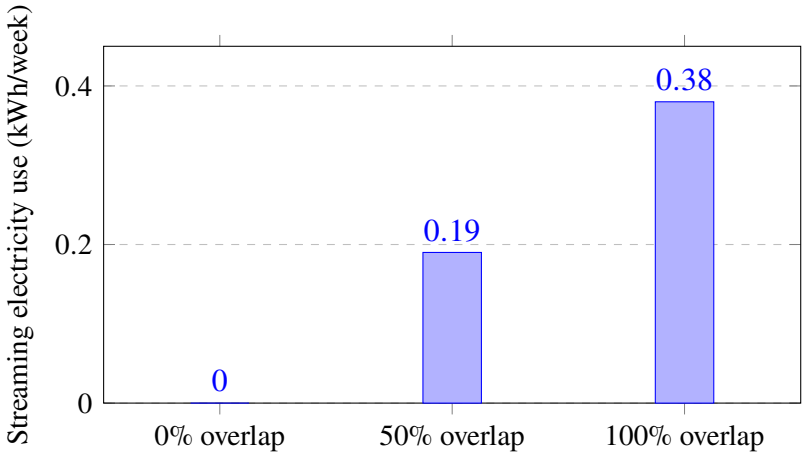


Figure 7.3: *Estimated weekly electricity use from simultaneous video streaming during gameplay under three behavioural overlap scenarios. The calculations are based on an average gaming time of 4.7 hours per week and an assumed streaming electricity intensity of 0.08 kWh*

Figure 7.3 shows how simultaneous video streaming increases total electricity demand during gaming sessions. Under the representative baseline assumption of 4.7 hours of weekly gameplay, full overlap with streaming increases additional electricity demand to approximately 0.38 kWh per week, while 50% overlap adds approximately 0.19 kWh. Since the model assumes constant streaming electricity intensity, the relationship is linear.

Although the absolute increase is modest compared with gaming hardware electricity demand, the figure highlights that operational energy use is not determined solely by the gaming device itself. Simultaneous digital activities can meaningfully increase total electricity demand, reinforcing the importance of user behaviour as a determinant of environmental impact.

7.2 Gaming PCs and gaming laptop energy usage and emissions

This section presents the estimated operational electricity use and greenhouse gas emissions associated with PCs and gaming laptops under different gameplay scenarios.

7.2.1 Annual electricity usage for PCs

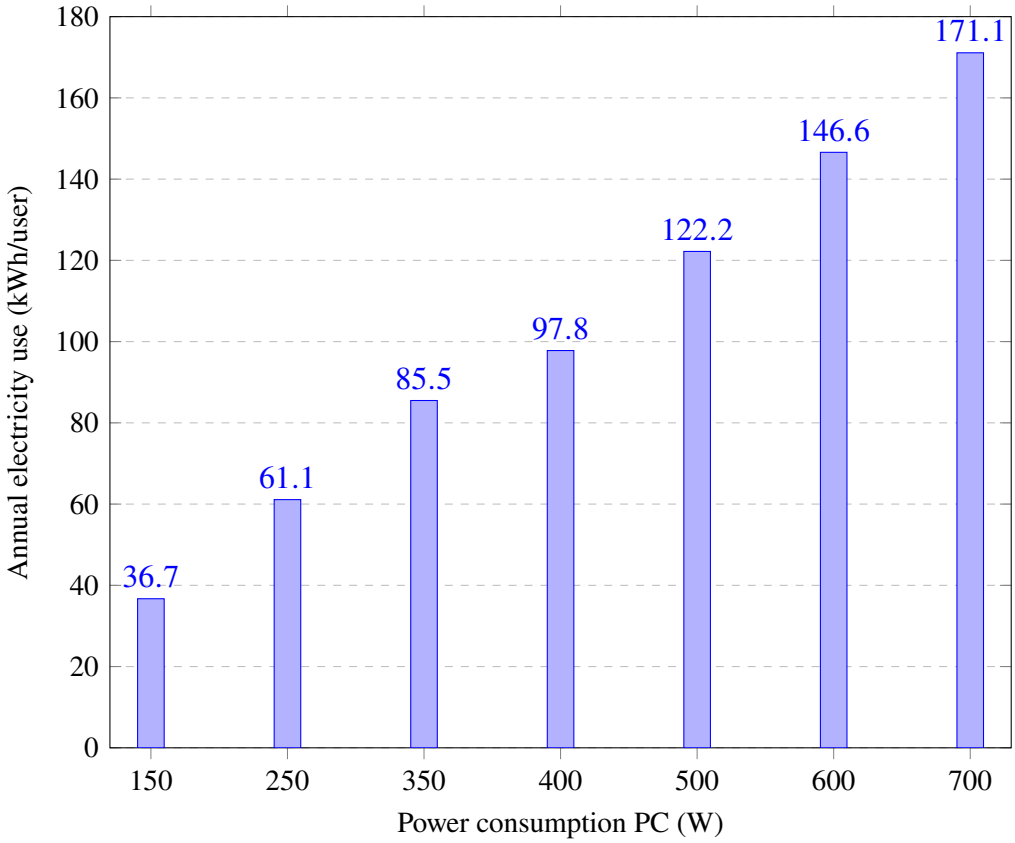


Figure 7.4: *Estimated annual electricity use for gaming PCs under different power assumptions, based on 4.7 hours of gameplay per week. The values include both the typical range and the upper range*

7.2.2 Annual electricity usage for gaming laptops

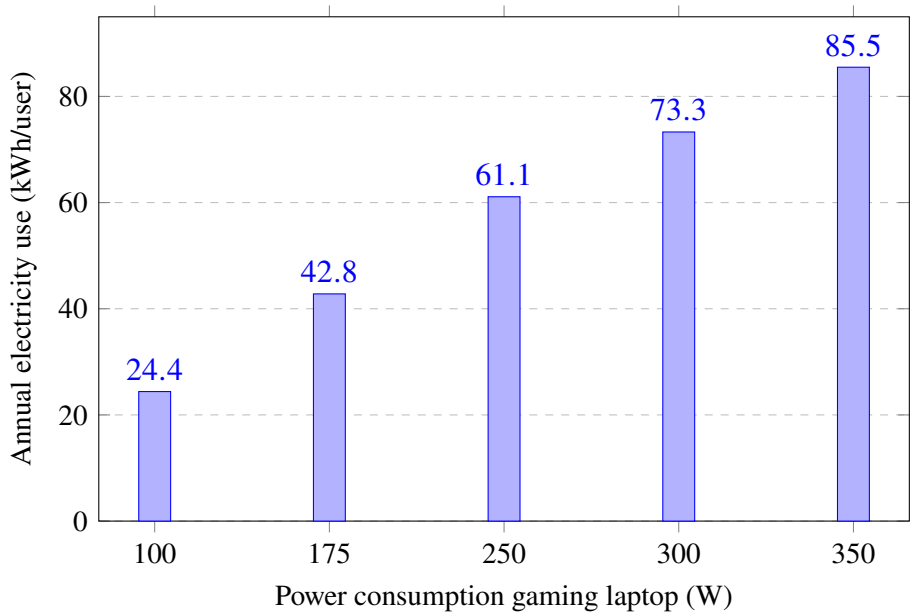


Figure 7.5: *Estimated annual electricity use for gaming laptops in under different power assumptions, based on 4.7 hours of gameplay per week. The values include both the typical range and the upper range*

Gaming PCs show substantially greater variation in annual electricity demand than gaming laptops, highlighting how strongly hardware configuration influences operational energy use. As shown in Figure 7.4, annual electricity use for gaming PCs ranges from 36.7 kWh at 150 W to 171.1 kWh at 700 W, meaning the highest power configuration consumes more than four times as much electricity as the lowest.

By comparison, gaming laptops show a narrower range, as illustrated in Figure 7.5, increasing from 24.4 kWh at 100 W to 85.5 kWh at 350 W. Although electricity demand still increases substantially with higher-performance laptop configurations, the upper range remains well below the highest gaming PC scenarios.

These results suggest that platform choice and hardware performance are major determinants of operational electricity demand. While lower power gaming PCs overlap with higher end gaming laptops, high performance PCs emerge as the most electricity intensive gaming configurations in the results.

7.2.3 Annual operational emissions for PCs

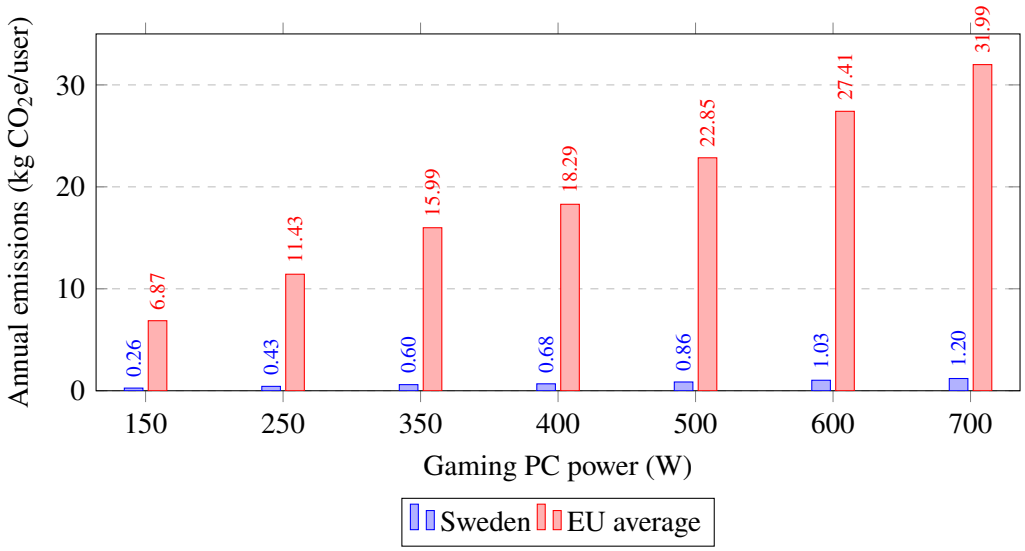


Figure 7.6: *Estimated annual operational emissions for PCs under Swedish and European electricity mixes, based on 4.7 hours of gameplay per week*

7.2.4 Annual operational emissions for gaming laptops

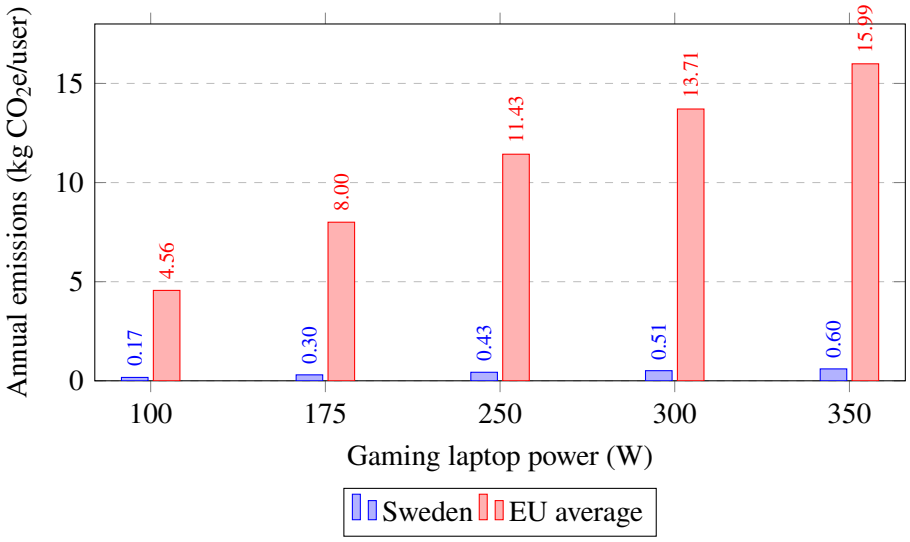


Figure 7.7: *Estimated annual operational emissions for gaming laptops under Swedish and European electricity mixes, based on 4.7 hours of gameplay per week*

Figures 7.4, 7.5, 7.1, and 7.3 show clear differences in annual electricity demand across gaming platforms and associated digital activities. Gaming PCs occupy by far the widest range, increasing from 36.7 kWh annually at 150 W to 171.1 kWh at 700 W, making the highest power configuration more than four times as electricity intensive as the lowest. Gaming laptops show a narrower but still a substantial range, from 24.4 to 85.5 kWh annually, while console electricity demand remains comparatively lower and more tightly together, ranging from 18.1 kWh for the Xbox Series S to 52.7 kWh for the PlayStation 5.

The comparison highlights that hardware configuration can be just as important as platform category in determining electricity demand. Lower-power gaming PCs overlap with higher end gaming laptops, while high performance desktop systems emerge as the most electricity intensive scenarios overall. Simultaneous video streaming also represents a meaningful additional load, reaching 19.6 kWh annually under full overlap assumptions, which is comparable to the annual electricity use of an Xbox Series S.

Figures 7.6 and 7.7 show that these differences translate very differently depending on electricity system characteristics. Under Swedish electricity assumptions, operational emissions remain comparatively low across all scenarios, compressing the environmental differences between platforms. Under the European average electricity mix, however, the same electricity demand produces substantially higher emissions, with the 700 W gaming PC reaching approximately 32 kg CO_2e annually compared with around 1.2 kg under Swedish conditions. The same cross-platform differences persist under both electricity contexts, but their environmental significance changes substantially depending on electricity carbon intensity.

7.3 Representative cross-platform comparison

Table 7.3: *Estimated annual electricity use and operational emissions under representative Swedish gameplay conditions (4.7 hours per week) for digital leisure activities and gaming platforms*

Platform / activity	**Electricity use (kWh/year)**	**SE emissions (kg CO_2e)**	**EU emissions (kg CO_2e)**
Video streaming (80 W)	19.6	0.14	3.67
Xbox Series S (74 W)	18.1	0.13	3.39
Xbox Series X (154 W)	37.6	0.26	7.03
PlayStation 5 (215 W)	52.5	0.37	9.82
Gaming laptop (100 W)	24.4	0.17	4.56
Gaming laptop (250 W)	61.1	0.43	11.39
Gaming laptop (350 W)	85.5	0.60	15.95
Gaming PC (150 W)	36.7	0.26	6.84
Gaming PC (500 W)	122.2	0.86	22.85
Gaming PC (800 W)	195.5	1.37	36.56

Table 7.3 shows substantial differences in annual electricity demand across gaming platforms and associated digital leisure activities under the representative 4.7 hours per week scenario. Higher performance gaming PCs produce the highest electricity demand, while consoles and streaming remain comparatively lower.

The comparison also reinforces the strong influence of electricity system characteristics on environmental impact. While electricity demand remains identical across scenarios, operational greenhouse gas emissions increase substantially under the European average electricity mix compared with Swedish conditions.

7.4 Different gameplay hours

Detailed numerical gameplay duration results are provided in Appendix A. These tables present estimated annual electricity use and operational greenhouse gas emissions for representative gaming PC and gaming laptop scenarios across different weekly gameplay categories under Swedish and European average electricity conditions. Across all scenarios, annual electricity use increases consistently with longer weekly gameplay duration. For example, the 100 W gaming laptop increases from 2.6 kWh annually in the lowest gameplay category to 130 kWh in the highest, while the 800 W gaming PC increases from 20.8 kWh to 1040 kWh annually across the same range. The tables also show substantial variation between hardware configurations within the same platform category, particularly for gaming PCs, where annual electricity demand differs by several hundred kWh depending on assumed power level. While electricity use remains identical between the Swedish and European scenarios, the corresponding greenhouse gas emissions differ substantially. For example, the highest 800 W gaming PC scenario corresponds to 7.28 kg CO_2e annually under Swedish electricity conditions, compared to 194.48 kg CO_2e under the European average electricity mix.

7.5 Demographic and population scenarios

Table 7.4: *Population-scaled annual emissions by age group for selected gaming platforms, using a Swedish population scenario of 10.6 million inhabitants, a 67.35% video game penetration rate, and 4.7 hours of gameplay per week under Swedish electricity conditions*

Age group	Share (%)	Gaming population	PS5 t CO_2e	Xbox X t CO_2e	Xbox S t CO_2e	Laptop 250 W t CO_2e	PC 500 W t CO_2e
18 – 19	4	285,564	105.0	75.3	36.1	122.2	244.4
20 – 29	22	1,570,602	577.8	413.8	198.8	671.8	1,343.6
30 – 39	29	2,070,339	761.7	545.5	262.1	885.5	1,771.0
40 – 49	20	1,427,820	525.2	376.2	180.8	610.8	1,221.6
50 – 59	18	1,285,038	472.7	338.6	162.7	549.7	1,099.4
60 – 64	7	499,737	183.9	131.6	63.2	213.7	427.4
Total	**100**	**7,139,100**	**2,626.3**	**1,881.0**	**904.0**	**3,054.0**	**6,108.0**

Table 7.5: *Population-scaled annual emissions by gender for selected gaming platforms, using a Swedish population scenario of 10.6 million inhabitants, a 67.35% video game penetration rate, and 4.7 hours of gameplay per week under Swedish electricity conditions*

Gender	Share (%)	Gaming population	PS5 t CO_2e	Xbox X t CO_2e	Xbox S t CO_2e	Laptop 250 W t CO_2e	PC 500 W t CO_2e
Male	53	3,783,723	1,392.0	997.0	478.8	1,621.6	3,243.2
Female	47	3,355,377	1,234.3	884.0	425.2	1,432.4	2,864.8
Total	**100**	**7,139,100**	**2,626.3**	**1,881.0**	**904.0**	**3,054.0**	**6,108.0**

Tables 7.4 and 7.5 present exploratory population scaling scenarios for gaming related operational emissions under Swedish electricity conditions, using Sweden's population of approximately 10.6 million inhabitants together with the video game penetration rate of 67.35% resulting in an estimated gaming population of approximately 7.14 million individuals. The representative gameplay assumption of 4.7 hours per week was applied across all scenarios to illustrate how individual operational electricity demand scales when distributed across larger demographic groups.

Across all demographic scenarios, higher power gaming platforms produce substantially larger aggregate emissions than lower power alternatives. Gaming PCs represent the highest total emissions in the scaling scenarios, reaching approximately 6,108 tonnes CO_2e annually under the representative 500 W assumption, followed by gaming laptops at approximately 3,054 tonnes CO_2e. Among consoles, the PlayStation 5 produces the highest scaled emissions at approximately 2,626 tonnes CO_2e, followed by the Xbox Series X and Xbox Series S.

The age based distribution shows that the largest emissions occur in the 30 to 39 age group, reflecting its larger proportional share of the estimated gaming population. This is followed by the 20 to 29 and 40 to 49 age groups, while smaller demographic groups contribute proportionally less under the same behavioural assumptions. The gender based scaling shows a similar proportional pattern, with the male scenario producing somewhat higher total emissions due to the larger population share represented in the available data.

These demographic scaling results should be interpreted as illustrative population scenarios rather than fully accurate, predictive estimates, since the same per user gameplay assumption is applied across all groups.

7.6 Sensitivity analysis

This section presents the sensitivity analysis conducted to examine how changes in key modelling assumptions affect operational electricity use and greenhouse gas emissions.

7.6.1 Gameplay intensity and hardware workload

A sensitivity analysis was conducted to examine how variation in gameplay intensity influences annual operational electricity use and greenhouse gas emissions across the analysed platforms. Representative low, medium, and high intensity scenarios were used

to reflect differences in hardware workload, including variation in software demands, graphical complexity, and performance-related user settings.

For gaming PCs, wider sensitivity ranges were applied to reflect the greater variability in hardware configuration and performance demand compared with more standardised console platforms.

Table 7.6: *Representative power assumptions used in the gameplay intensity sensitivity analysis*

Platform	**Low intensity (W)**	**Medium intensity (W)**	**High intensity (W)**
PlayStation 5	140	215	260
Xbox Series X	100	154	190
Xbox Series S	50	74	95
Gaming PC	250	500	800
Gaming laptop	120	200	300

Using a representative gameplay duration of 10 hours per week under Swedish electricity conditions, the resulting annual operational greenhouse gas emissions were calculated for each scenario.

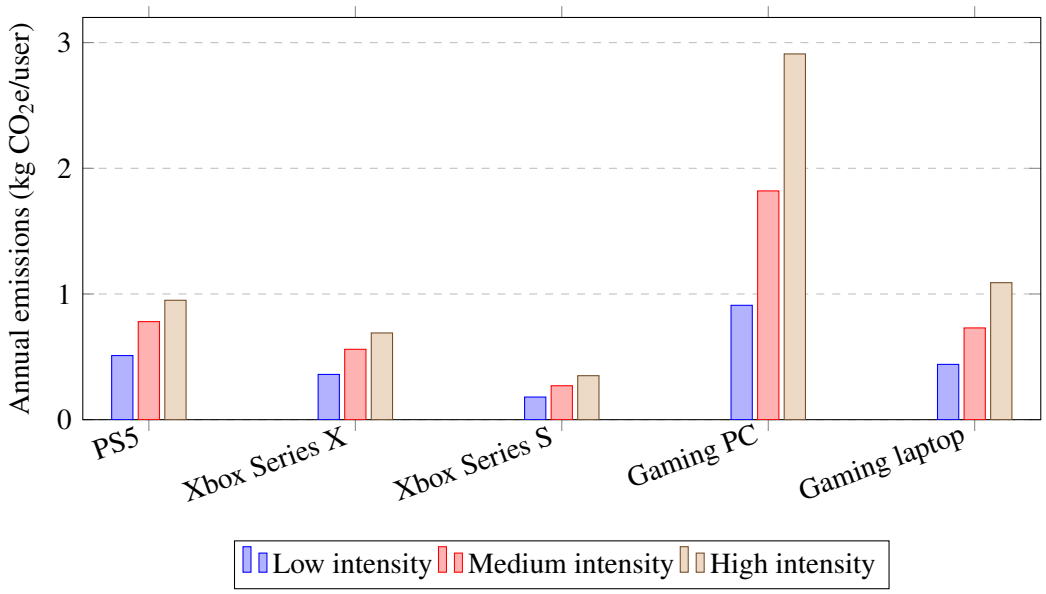


Figure 7.8: *Sensitivity analysis of annual operational greenhouse gas emissions under Swedish electricity conditions for different gameplay intensity assumptions, based on 10 hours of gameplay per week*

The results show that gameplay intensity has a measurable influence on operational emissions, even when the electricity system itself has a comparatively low carbon intensity. For the PlayStation 5, annual emissions increase from approximately 0.51 kg CO_2e under low intensity gameplay assumptions to 0.95 kg CO_2e under high intensity assumptions, representing nearly a doubling of operational impact.

A similar pattern is visible for the Xbox platforms, although absolute values remain lower due to lower baseline power demand. The Xbox Series S remains the least electricity-

intensive console across all scenarios, while the Xbox Series X consistently occupies an intermediate position between the Xbox Series S and PlayStation 5.

The greatest sensitivity is observed for gaming PCs, where annual emissions increase from approximately 0.91 kg CO_2e to 2.91 kg CO_2e depending on gameplay intensity assumptions. This reflects the substantially wider range of hardware configurations and performance oriented usage patterns associated with PC gaming. Gaming laptops show a similar but less pronounced pattern, increasing from approximately 0.44 kg CO_2e to 1.09 kg CO_2e.

These results shows that operational electricity demand is not solely determined by device category, but also by how hardware is used in practice. Even within the same platform category, software context and performance related user choices can significantly influence electricity demand. This shows that user behaviour and technical usage conditions are important determinants of environmental impact alongside hardware efficiency .

Table 7.7: *Sensitivity analysis emissions under Swedish and European average electricity conditions, based on 10 hours of gameplay per week*

Platform	**Low SE kg CO_2e**	**Medium SE kg CO_2e**	**High SE kg CO_2e**	**Low EU kg CO_2e**	**Medium EU kg CO_2e**	**High EU kg CO_2e**
PlayStation 5	0.51	0.78	0.95	13.61	20.89	25.30
Xbox Series X	0.36	0.56	0.69	9.72	14.98	18.49
Xbox Series S	0.18	0.27	0.35	4.86	7.19	9.23
Gaming PC	0.91	1.82	2.91	24.31	48.62	77.79
Gaming laptop	0.44	0.73	1.09	11.67	19.45	29.17

Table 7.7 shows that the same gameplay intensity assumptions produce much larger emissions under the European average electricity mix than under Swedish electricity conditions. This strengthens that gameplay intensity and hardware workload matter in all scenarios, but that their climate significance becomes much more visible when the electricity mix has a higher carbon intensity.

7.6.2 Sensitivity analysis across gameplay durations

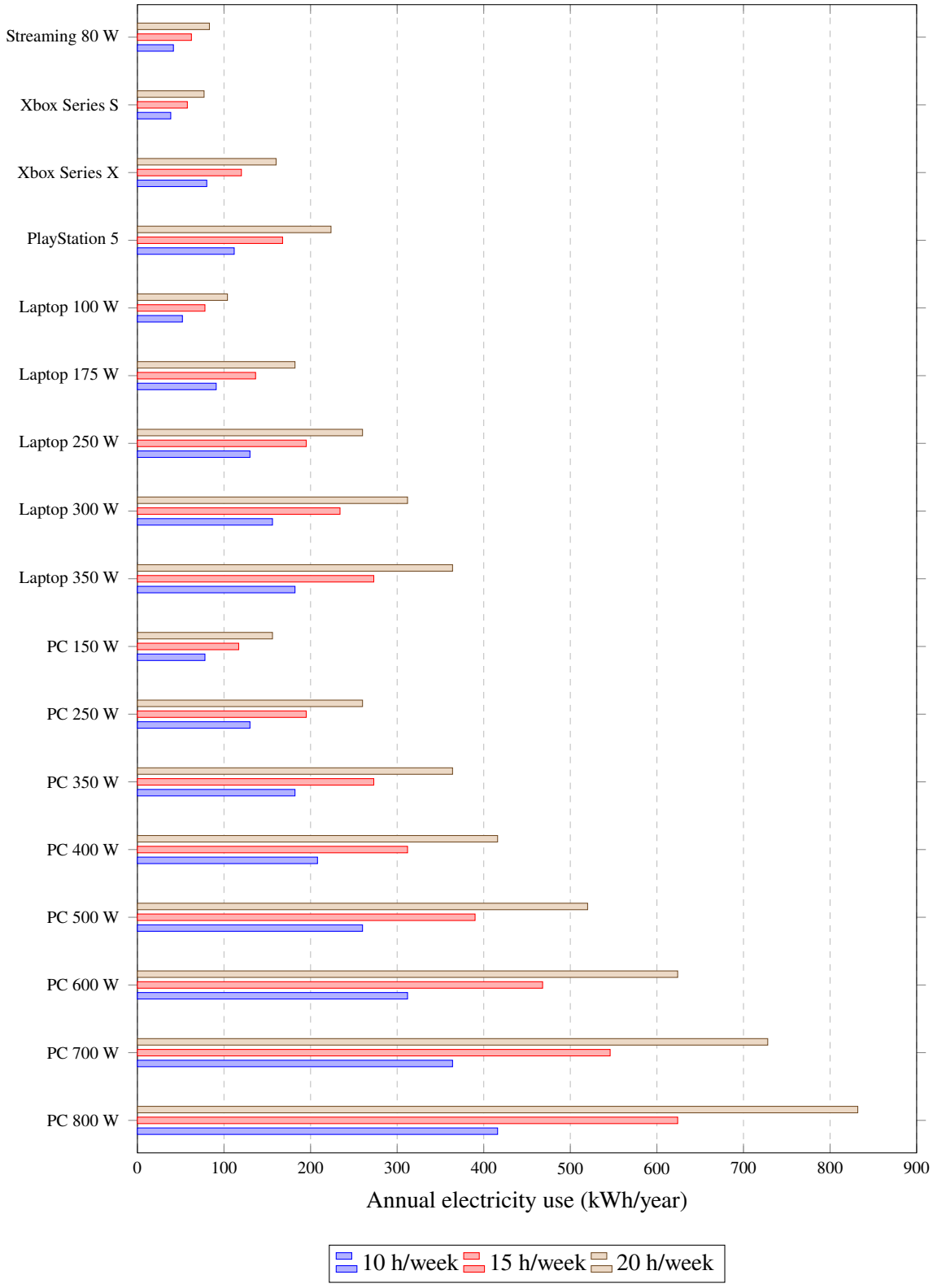


Figure 7.9: *Annual electricity use in Sweden across gaming PCs, gaming laptops, consoles, and video streaming scenarios for 10, 15, and 20 hours of weekly use. Detailed numerical values are provided in Appendix A.*

Figure 7.9 provides a consolidated comparison of annual electricity demand across gaming and streaming scenarios for 10, 15, and 20 hours of weekly use, with detailed numerical values provided in Appendix B (Tables B.1 and B.4). The figure makes the relative scale differences between platforms considerably clearer than the detailed numerical tables alone.

The most prominent result is the dominance of higher power gaming PCs, which occupy by far the widest electricity range and reach the highest overall demand, exceeding 800 kWh annually in the most intensive scenario. Gaming laptops remain substantially lower but still show meaningful variation, with some overlap between higher end laptops and lower power desktop PCs. Consoles remain more tightly clustered due to their standardised hardware configurations, while streaming represents a comparatively modest but still non-negligible additional load, reaching electricity demand levels comparable to lower power gaming devices.

A second clear pattern is the strong influence of gameplay duration across all scenarios. Moving from 10 to 20 hours per week produces substantial increases in annual electricity demand regardless of platform, reinforcing that both technological configuration and user behaviour are central determinants of operational electricity use.

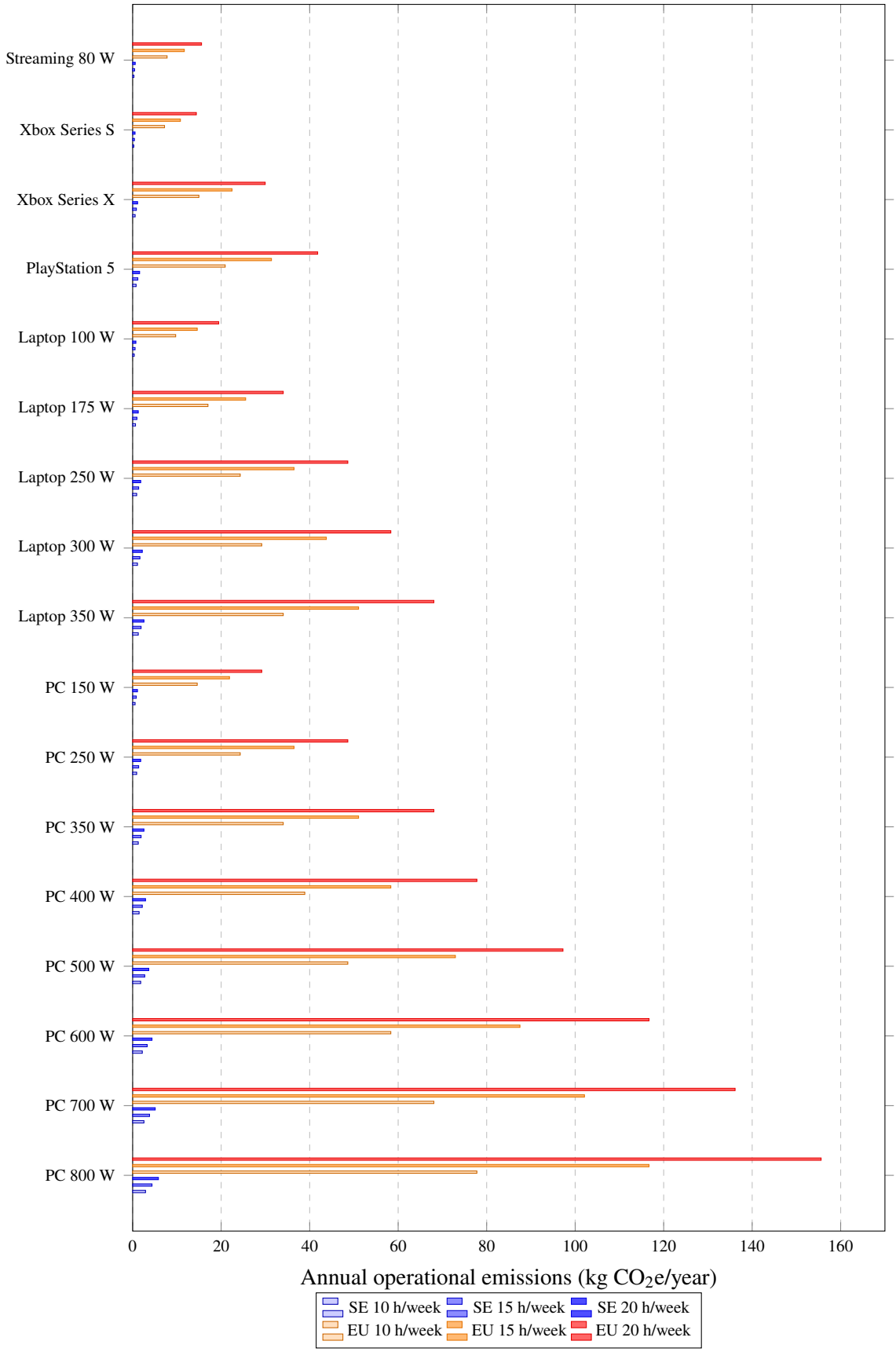


Figure 7.10: *Annual operational greenhouse gas emissions across gaming PCs, gaming laptops, consoles, and video streaming scenarios for 10, 15, and 20 hours of weekly use under Swedish and European average electricity conditions. Swedish scenarios are shown in blue tones and European average scenarios in orange/red tones. Detailed numerical values are provided in Appendix A.*

Figure 7.10 presents the same gameplay scenarios in terms of annual operational greenhouse gas emissions under Swedish and European average electricity conditions, with detailed numerical values provided in Appendix B (Tables B.1 – B.4). Unlike the electricity comparison in Figure 7.9, this figure visualises the scale difference between identical usage scenarios under Swedish and European electricity conditions.

The most prominent result is the substantial separation between Swedish and European scenarios across all platforms. Under Swedish electricity assumptions, operational emissions remain comparatively low even for higher electricity demand scenarios, whereas the same devices and behavioural assumptions produce dramatically higher emissions under the European average electricity mix. In several cases, emissions increase by more than an order of magnitude despite identical electricity demand.

This effect is especially visible for higher power gaming PCs, where European scenarios dominate the figure, but the same pattern remains consistent across laptops, consoles, and streaming. Gameplay duration also continues to influence emissions across both electricity contexts, reinforcing that operational environmental impact is shaped by the interaction between user behaviour, hardware configuration, and electricity system characteristics.

7.6.3 Sensitivity analysis of combined behavioural and technical escalation

Table 7.8 and Figure 7.11 present a sensitivity scenario exploring how combined changes in user behaviour and technical assumptions affect operational emissions under Swedish electricity conditions. Unlike the previous demographic scaling scenarios, this comparison assumes a hypothetical PC only gaming landscape in which all gaming activity takes place on gaming PCs rather than across a mix of consoles, laptops, and desktop systems.

Table 7.8: *PC only sensitivity scenario comparing a normal and extreme use case under Swedish electricity conditions*

Scenario	Power assumption	h/week	kWh/user/year	kg CO_2e/user/year	t CO_2e/year, scaled
Normal PC only case	500 W PC + 30 W monitor	4.7	129.5	0.91	6,473
Extreme PC only case	800 W PC + 60 W monitors + 80 W streaming	20	977.6	6.84	48,832

The normal scenario represents a more moderate gaming setup, consisting of a representative 500 W gaming PC with a single 30 W monitor, operated under the representative gameplay assumption of 4.7 hours per week. Under Swedish electricity conditions, this corresponds to approximately 129.5 kWh of annual electricity use per user and approximately 0.91 kg CO_2e in annual operational emissions. When scaled to the estimated Swedish gaming population of approximately 7.14 million users, this results in approximately 6,473 tonnes CO_2e annually.

The extreme scenario combines several higher impact assumptions. This includes an 800 W gaming PC, a dual monitor setup adding 60 W, continuous simultaneous video streaming adding an additional 80 W, and an intensive gameplay assumption of 20 hours per week. Under the same Swedish electricity conditions, this raises annual electricity demand to approximately 977.6 kWh per user and operational emissions to approximately

6.84 kg CO_2e per user. When scaled to the Swedish gaming population, total annual emissions increase to approximately 48,832 tonnes CO_2e.

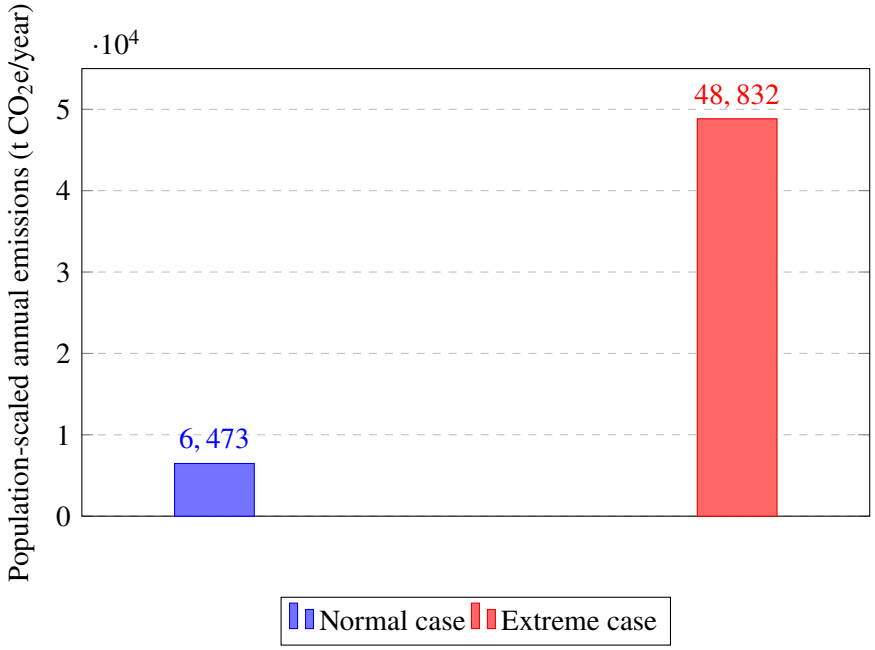


Figure 7.11: *Population-scaled annual operational emissions for a PC-only gaming sensitivity scenario under Swedish electricity conditions.*

The visual comparison clearly shows that the difference is not driven by a single factor alone. Instead, the increase comes from the combined effect of higher hardware power demand, longer gameplay duration, additional display electricity demand, and overlapping digital media use. Compared with the normal scenario, the extreme scenario produces approximately 654% higher operational emissions, despite both scenarios operating under the same Swedish electricity conditions. This scenario illustrates the scale difference between moderate and highly intensive gaming lifestyles under identical electricity conditions.

7.6.4 Sensitivity analysis of cumulative system configuration effects

Table 7.9 and Figure 7.12 present a sensitivity scenario examining how the accumulation of additional energy consuming components and higher hardware power demand affects operational emissions, while holding gameplay duration constant at 20 hours per week under Swedish electricity conditions. To isolate the influence of system configuration rather than gameplay duration, all scenarios assume identical usage time and a 25% reduction in baseline gaming PC power demand relative to the previously defined representative gaming PC scenarios.

Table 7.9: *Sensitivity scenario comparing normal, intermediate, and extreme gaming PC use under Swedish electricity conditions, assuming a 25% reduction in gaming PC power demand*

Scenario	Power assumption	h/week	kWh/user/year	kg CO_2e/user/year	t CO_2e/year, scaled
Normal case	375 W PC + 30 W monitor	20	421.2	2.95	21,060
Intermediate case	375 W PC + 60 W monitors + 80 W streaming	20	535.6	3.75	26,776
Extreme case	600 W PC + 60 W monitors + 80 W streaming	20	769.6	5.39	38,461

The normal case represents a lower intensity gaming setup consisting of a 375 W gaming PC and a single 30 W monitor. Under these assumptions, annual electricity demand reaches 421.2 kWh per user, corresponding to approximately 2.95 kg CO_2e in annual operational emissions. When scaled to the estimated Swedish gaming population, this corresponds to approximately 21,060 tonnes CO_2e annually.

The intermediate case introduces additional display and simultaneous media use while maintaining the same reduced gaming PC power demand. By adding a second monitor and assuming 100% simultaneous video streaming, total annual electricity demand increases to 535.6 kWh per user, with operational emissions rising to approximately 3.75 kg CO_2e annually. This corresponds to approximately 26,776 tonnes CO_2e when scaled to the Swedish gaming population. Compared with the normal case, this represents an increase of approximately 27.1% in total operational emissions, despite no change in gameplay duration or gaming PC power demand.

The extreme case further increases gaming PC power demand to 600 W while maintaining the dual monitor and continuous streaming assumptions. Under these conditions, annual electricity demand rises to 769.6 kWh per user and annual operational emissions increase to approximately 5.39 kg CO_2e. When population scaled, this corresponds to approximately 38,461 tonnes CO_2e annually. Compared with the intermediate case, this represents a further increase of approximately 43.6%, while the difference between the normal and extreme scenarios reaches approximately 82.6%.

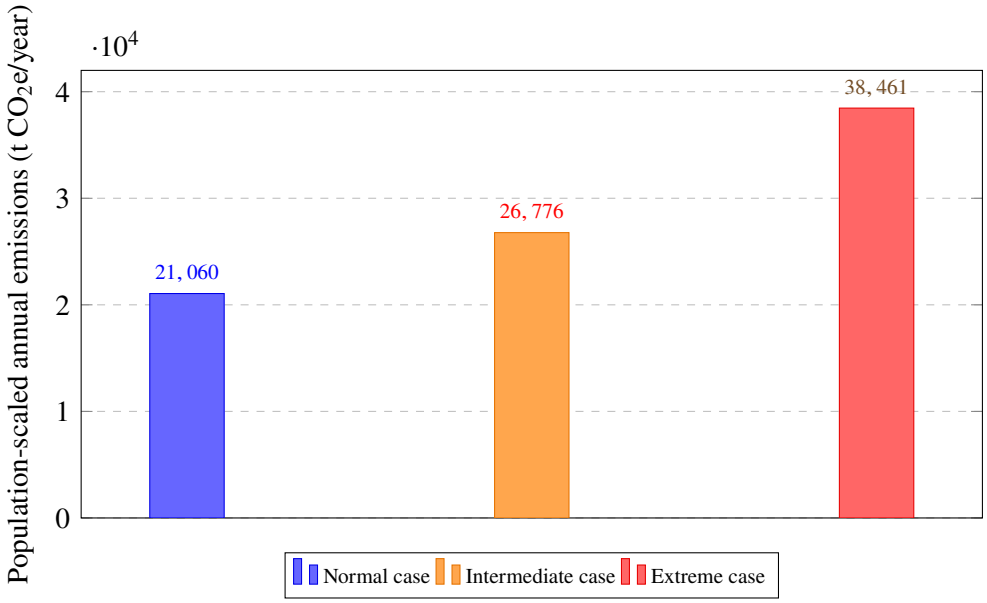


Figure 7.12: *Population-scaled annual operational emissions for illustrative normal, intermediate, and extreme gaming PC scenarios under Swedish electricity conditions, assuming a 25% reduction in gaming PC power demand.*

For visual clarity, Figure 7.12 presents the same results graphically, highlighting how the cumulative addition of higher hardware power demand, multiple monitors, and simultaneous streaming increases total operational emissions under otherwise identical conditions. This controlled comparison isolates how incremental technical additions increase operational emissions even when gameplay duration remains constant.

7.6.5 One-at-a-time sensitivity analysis

Table 7.10: Parameters included in the one-at-a-time (OAT) sensitivity analysis.

Dimension	**Parameter**	**Range**	**Baseline**	**Factor variation**
User behaviour	Gameplay duration	3 – 20 h/day	4.7 h/day	0.64 – 4.26×
	Streaming duration	0 – 8 h/day	2 h/day	0 – 4.00×
Device characteristics	Console power	74 – 215 W	150 W	0.49 – 1.43×
	Gaming laptop power	100 – 300 W	175 W	0.57 – 1.71×
	Gaming PC power	150 – 700 W	250 W	0.60 – 2.80×
Electricity system	Grid intensity	7 – 187 gCO_2e/kWh	7 gCO_2e/kWh	1.00 – 26.71×

Table 7.10 highlights substantial differences in the degree of variation associated with the examined model parameters. The largest variation was observed for electricity emission intensity, which ranged from the Swedish average of 7 gCO_2e/kWh to the European average of 187 gCO_2e/kWh, corresponding to a factor variation of 26.71×.

Among the user behaviour parameters, gameplay duration exhibited a factor variation of 0.64 – 4.26×, demonstrating that differences in player habits can significantly affect annual energy consumption and emissions. Streaming duration showed a similar variation range of up to 4.00×, further emphasizing the importance of considering gaming as part of a broader digital ecosystem rather than as an isolated activity.

The hardware related parameters displayed smaller but still notable variation ranges. Gaming PCs exhibited the largest variation among device categories, with a factor variation of 0.60 – 2.80×, reflecting the substantial diversity in desktop gaming hardware configurations. In comparison, consoles showed the smallest variation range of 0.49 – 1.43×, highlighting the standardisation of consoles.

Chapter 8

Discussion

8.1 Interpretation of the key results

The results show clearly that the operational environmental impact of digital gaming cannot be meaningfully described through a single average estimate. Electricity use and associated greenhouse gas emissions vary substantially depending on device type, gameplay intensity, performance assumptions, user behaviour, and electricity system characteristics. This directly supports the analytical framework established earlier in the thesis, where device characteristics, behavioural patterns, and electricity system characteristics were identified as the three primary determinants of operational environmental impact.

One of the clearest findings is the scale of variation between plausible gaming scenarios. Under representative Swedish assumptions, annual electricity demand ranges from 18.1 kWh for the Xbox Series S to 195.5 kWh for the highest baseline gaming PC scenario, representing more than a tenfold difference between realistic gaming setups. This makes simplified statements such as "gaming uses X amount of electricity" difficult to justify, since the environmental outcome depends heavily on how gaming is defined and what assumptions are applied.

At the same time, operational emissions under Swedish electricity conditions remain comparatively low due to the low carbon intensity of the national electricity mix. On an individual level, even relatively high electricity demand scenarios may therefore appear environmentally modest. However, this interpretation requires caution.

This thesis examines operational electricity use only and excludes embodied emissions associated with hardware production, distribution, and replacement. This distinction becomes particularly important in low carbon electricity systems such as Sweden, where operational emissions may appear small while manufacturing-related emissions remain comparatively significant. A gaming PC used in Sweden may therefore have a lifecycle environmental profile where embodied emissions dominate total impact, whereas in higher carbon electricity systems operational electricity becomes a much larger share of total environmental burden.

Gaming is not a niche activity but a globally widespread form of digital leisure involving millions of users. Even relatively small per-user impacts can therefore become environmentally relevant when scaled across larger populations and repeated over time.

The same electricity demand produces dramatically different environmental outcomes depending on electricity system characteristics. Under European average electricity assumptions, operational emissions increase by more than an order of magnitude compared with Swedish conditions across many scenarios. What appears relatively insignificant under one electricity system may therefore become much more environmentally relevant under another.

Another important finding is the extent to which behavioural assumptions influence environmental outcomes. While platform choice establishes the technical boundaries of electricity demand, gameplay duration, performance expectations, and surrounding digital activities strongly shape actual operational impact. In several scenarios, behavioural differences alone create larger changes than those between entire device categories.

The results suggest that digital gaming should not be understood as a fixed environmental category with stable characteristics. Instead, it is better interpreted as a dynamic digital practice whose environmental impact emerges through the interaction between technology, behaviour, and infrastructure.

8.2 Device characteristics and platform differences

Device characteristics strongly influence operational electricity demand, but the magnitude of this influence varies considerably between platform categories.

The console scenarios provide a useful baseline because consoles are comparatively standardised systems. Even here, however, meaningful variation exists. Under representative gameplay assumptions, the PlayStation 5 consumes nearly three times as much electricity annually as the Xbox Series S. This suggests that even within categories often treated as technically uniform, platform differences remain environmentally relevant.

The most substantial variation appears in the gaming PC scenarios. Lower-power gaming PCs overlap with higher-end consoles and gaming laptops, while the most demanding desktop configurations occupy an entirely different electricity range. This makes gaming PCs particularly difficult to generalise as a single environmental category.

Unlike consoles, gaming PCs are not standardised products. Electricity demand depends not only on platform type, but on component selection, GPU workload, CPU demand, cooling requirements, display configuration, framerate expectations, and software optimisation. Two users both described as “PC gamers” may therefore have dramatically different operational electricity profiles.

This becomes even more relevant when gameplay intensity increases. Under higher-use scenarios, electricity demand rises sharply, with the most intensive gaming PC configurations exceeding 1000 kWh annually. This places high end gaming PCs in a substantially different operational category from lower intensity console gaming.

The sensitivity analysis strengthens this interpretation further. Gaming electricity demand is not fixed simply because a device has a particular nominal wattage. Instead, operational demand depends on workload assumptions, software context, and performance expectations.

This is particularly relevant given recent developments in gaming technology. Higher framerate expectations, increasingly demanding graphical pipelines, ray tracing, AI assisted upscaling, and performance oriented gaming culture all contribute to greater operational workload.

This aligns with Berg (2024), who demonstrates that technologies marketed as efficiency improvements do not necessarily reduce total electricity demand in practice. Pérez et al. (2024) similarly show that software architecture and engine design can significantly influence energy consumption.

A broader implication is that technical efficiency should not automatically be interpreted as environmental improvement. More efficient hardware may reduce electricity demand per unit of performance, but if performance expectations increase simultaneously, total electricity use may remain stable or even rise. Efficiency gains therefore need to be interpreted within behavioural and technological contexts rather than assumed to translate directly into reduced environmental impact.

Platform choice establishes the boundaries of possible electricity demand, but actual outcomes emerge through the interaction between hardware capability, user behaviour, and evolving technological expectations.

8.3 User behaviour as an operational driver

The results shows that user behaviour is one of the most important determinants of operational electricity demand.

Gameplay duration has a direct and substantial effect across nearly all scenarios. While this may seem intuitive, the magnitude of the differences is important. In several cases, variation in gameplay duration alone creates larger differences than those between entire hardware categories.

This shifts the discussion away from purely technical comparisons. A lower-power system used intensively may consume more electricity annually than a higher performance system used only occasionally. Gaming is therefore not simply an environmental issue of device efficiency, but equally one of usage behaviour.

This aligns with previous research. Mills et al. (2019) similarly shows that gaming electricity estimates are highly sensitive to behavioural assumptions, while Hittinger et al. (2012) demonstrate that household gaming electricity demand varies substantially depending on user practices.

The highest individual electricity demand scenarios are associated with intensive users, but behavioural data suggest that most gaming occurs in moderate use categories rather than extreme ones. This means that cumulative environmental significance may emerge not only from small groups of highly intensive users, but from repeated moderate consumption across much larger populations.

This is an important distinction because sustainability discussions often focus on extreme or highly visible use cases, while ordinary repeated consumption receives less attention. The results suggest that both perspectives matter.

Another behavioural dimension concerns performance expectations. Environmental impact is not determined only by how long users play, but also by how they choose to play. Higher framerate targets, ultra graphical settings, demanding rendering features, and performance-focused gaming culture all increase hardware workload and therefore operational electricity demand.

This introduces a behavioural, technological interaction. Improvements in nominal hardware efficiency do not necessarily reduce electricity demand if they simultaneously enable more intensive usage. This aligns with Lange et al. (2020), who describe how digital efficiency gains may coexist with increased total energy demand due to behavioural adaptation and rebound effects.

Concurrent digital activity also deserves discussion. Modern gaming frequently overlaps with streaming, voice communication, music playback, social platforms, or background media consumption. The streaming comparison in this thesis illustrates that such activities contribute additional electricity demand beyond the gaming device itself. However, this should be interpreted proportionally. Compared with high power gaming PCs, the additional electricity demand from simultaneous streaming remains relatively modest. Its significance lies less in dominating gaming electricity demand, and more in illustrating that gaming increasingly exists within broader digital consumption routines rather than as an isolated activity.

Even comparatively small additional loads become environmentally relevant when repeated frequently and scaled across large user populations.

The behavioural findings suggest that user behaviour should not be treated as a secondary modelling assumption. It is one of the central drivers of operational environmental impact.

8.4 Electricity system characteristics and emissions interpretation

One of the most important findings of this thesis is that operational emissions are not determined solely by device electricity demand, but equally by the electricity system in which that demand occurs.

While electricity consumption remains identical regardless of geographical context, associated greenhouse gas emissions change dramatically depending on electricity carbon intensity. This makes electricity system characteristics a decisive analytical variable rather than a minor adjustment factor.

Under Swedish electricity assumptions, operational emissions remain comparatively low across nearly all scenarios due to the low carbon intensity of the electricity mix. Even relatively electricity-intensive gaming systems therefore appear environmentally modest when viewed only through operational emissions. However, this interpretation changes substantially when the same scenarios are evaluated under higher-carbon electricity conditions. Under the European average electricity mix, identical electricity demand produces dramatically higher emissions, often increasing by more than an order of magnitude.

This finding strongly affects how digital environmental impact should be interpreted. The hardware has not changed. User behaviour has not changed. Only the surrounding elec-

tricity infrastructure has changed, yet the environmental outcome becomes fundamentally different.

This reinforces a broader point from digital sustainability research. Aslan et al. (2018) similarly argue that environmental assessments of digital technologies are highly sensitive to analytical boundaries and electricity system assumptions, while Belkhir and Elmeligi (2018) highlight the importance of electricity decarbonisation pathways in ICT-related emissions assessments.

An important implication concerns the relationship between operational and embodied emissions. In low carbon electricity systems such as Sweden, operational electricity may represent only a relatively small share of total lifecycle impact, particularly for energy intensive gaming hardware with potentially substantial manufacturing emissions. In higher carbon electricity systems, operational electricity becomes comparatively more dominant.

This means that conclusions about gaming's environmental significance depend heavily on what is included in the analysis. A Swedish operational-only assessment may suggest relatively modest impacts, while a broader lifecycle perspective could produce a very different interpretation.

This is one reason why operational emissions should not automatically be interpreted as equivalent to total environmental impact.

At the same time, Sweden represents an unusually favourable electricity context. A thesis focused exclusively on Swedish operational conditions would therefore risk presenting conclusions that are overly optimistic and not broadly transferable internationally. The inclusion of European comparison scenarios helps address this limitation. It demonstrates that environmental conclusions about gaming are highly context dependent and that operational sustainability cannot be meaningfully discussed without considering surrounding electricity infrastructure.

8.5 Gaming within broader digital consumption systems

The results support the argument that gaming should be understood as part of a broader digital consumption system rather than as an isolated technical activity.

Modern gaming increasingly overlaps with streaming, communication platforms, social interaction, music playback, and other forms of connected digital media use. While these surrounding activities may not individually dominate electricity demand compared with high performance gaming hardware, they contribute to cumulative environmental impact and challenge narrow device-based interpretations.

This aligns with broader ICT sustainability literature, which emphasises that environmental impacts often emerge through interconnected infrastructures, repeated behavioural practices, and cumulative digital consumption rather than isolated technical events (Freitag et al., 2021; Belkhir and Elmeligi, 2018).

It also supports broader consumption-based interpretations such as those presented by (Akenji et al., 2021), where repeated everyday behaviours become environmentally relevant through scale and frequency rather than through high individual intensity alone.

This broader framing matters because it shifts the discussion away from asking whether a specific gaming device is efficient, and towards wider questions about digital lifestyles, user expectations, and sustainable consumption practices.

Gaming is therefore not simply a technical electricity demand issue, but part of a wider digital behavioural ecosystem.

8.6 What can be done with additional data?

To provide context for gaming related electricity demand, Figure 8.1 shows how Swedish electricity consumption varies throughout the day, while Table 8.1 shows total consumption during the winter months.

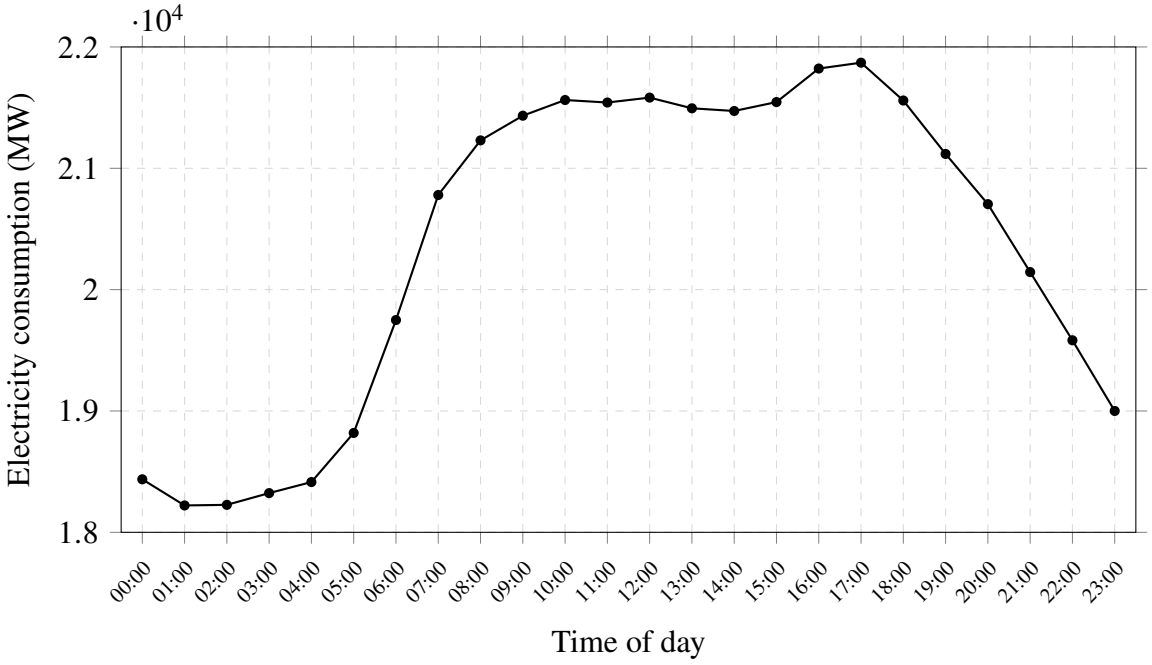


Figure 8.1: Hourly electricity consumption in Sweden on 5 January 2026. Svenska kraftnät, *Förbrukning och tillförsel per timme* Svenska kraftnät (2026).

Table 8.1: Electricity consumption in Sweden by area of use, December 2025 to February 2026.

Area of use	**Dec. 2025**	**Jan. 2026**	**Feb. 2026**
Total electricity consumption	17 271	18 923	16 999
Other (residential, services, etc.)	7 890	9 748	9 032

*V*alues are given in GWh. Statistiska centralbyrån (SCB), *Elanvändning efter användningsområde* Statistics Sweden (SCB) (2026).

The hourly variation is particularly relevant for extending the present bottom-up model. The current analysis estimates electricity consumption from gameplay duration, but does

not identify when during the day this gaming activity occurs. With more detailed behavioural data, the model could therefore distinguish not only how much electricity gaming consumes, but also when this demand occurs relative to total Swedish electricity demand.

With sufficiently disaggregated data, daily gaming electricity demand could be represented as

$$E_{\text{gaming,day}} = \sum_{a=1}^{6} \sum_{p=1}^{3} \sum_{h=1}^{24} N_a D_{a,p} u_{a,p,h} \frac{P_p}{1000} \Delta t, \tag{1}$$

where a represents demographic group, p represents device type ($p = 1$ console, $p = 2$ gaming PC, and $p = 3$ gaming laptop), and h represents hour of the day. N_a is the number of gamers within demographic group a, $D_{a,p}$ represents the prevalence of device p within that group, $u_{a,p,h}$ represents the proportion of these users gaming during hour h, P_p represents device power demand, and Δt represents the duration of the hourly interval.

The three summations therefore represent three successive levels of aggregation: across demographic groups, across the gaming devices used within each group, and across the hours during which gaming occurs. Parts of this equation can already be assigned data available in the thesis. The demographic analysis provides estimates of N_a, while the device scenarios provide representative values of P_p. Detailed data describing device prevalence ($D_{a,p}$) and hourly gaming activity ($u_{a,p,h}$) were not available.

The electricity system side of such a comparison can already be demonstrated. Based on the hourly electricity-consumption data shown in Figure 8.1, total Swedish electricity consumption on 5 January 2026 can be approximated by summing the 24 hourly observations:

$$E_{\text{SE,5Jan}} = \sum_{h=1}^{24} L_h^{\text{SE}} \Delta t \approx 488.6 \text{ GWh}, \tag{2}$$

where L_h^{SE} represents total Swedish electricity demand during hour h. Hourly demand varied from approximately 18.2 GW during the night to 21.9 GW at 17:00. Thus, if the hourly gaming activity term $u_{a,p,h}$ were known, Equation 1 could produce a corresponding hourly gaming load that could be compared directly with the observed national load.

For each hour the relative contribution of gaming to national electricity demand could then be expressed as

$$S_h = \frac{\sum_{a=1}^{6} \sum_{p=1}^{3} N_a D_{a,p} u_{a,p,h} \frac{P_p}{1000}}{L_h^{\text{SE}}} \times 100. \tag{3}$$

Using the example that the national electricity demand at 17:00 on 5 January 2026 was approximately 21.87 GW. The denominator of Equation 3 is therefore known for this specific hour. The numerator cannot currently be evaluated because the available data do not describe how gaming device prevalence varies between demographic groups or how many users of each device are gaming at 17:00.

The same principle can be applied at a larger time scale. Table 8.1 shows the total Swedish electricity consumption of 18 923 GWh in January 2026. If gaming electricity consumption could be estimated for the same period, its relative contribution to national electricity consumption could be expressed as

$$S_{\text{gaming,Jan}} = \frac{E_{\text{gaming,Jan}}}{18\,923\ \text{GWh}} \times 100. \tag{4}$$

The main limitation for applying this extended model is not the availability of electricity system data, but the lack of sufficient gaming behaviour data. Information linking demographic group, device prevalence, platform specific gameplay duration, and time of day would allow the current scenario based model to be developed into an hourly bottom-up estimate that could be compared directly with observed Swedish electricity demand.

8.7 Future research

Several opportunities exist for extending and improving this work.

A major limitation of this thesis is its focus on operational electricity use rather than full lifecycle environmental impact. Future research should therefore incorporate embodied emissions associated with hardware manufacturing, transport, upgrades, and replacement cycles. This would provide a more complete assessment of gaming's total environmental footprint and clarify how the relative importance of operational and embodied emissions changes across different electricity systems.

Further work could improve modelling accuracy through direct empirical measurements of modern gaming hardware under different gameplay conditions. Rapid technological development means that real-world electricity demand can vary substantially depending on software workload, hardware generation, and performance settings.

Future studies could also improve behavioural realism by incorporating more detailed usage datasets, including actual playtime distributions, simultaneous digital activities, platform switching, and dynamic user behaviour over time.

Console modelling could be improved by incorporating duty-cycle based electricity assumptions, where active gameplay, standby operation, streaming media use, pause states, and menu navigation are treated as distinct operating modes rather than represented through a single active benchmark.

Additional international comparisons would also be valuable, particularly involving electricity systems with substantially higher or lower carbon intensities than those included here. This would strengthen understanding of how operational gaming emissions vary geographically.

Future research could also include broader infrastructure effects, such as network electricity demand, cloud services, content delivery systems, and digital distribution platforms, to better capture the wider environmental footprint of connected gaming ecosystems.

Another important direction concerns cloud gaming. As gaming increasingly shifts toward service-based delivery models, future work could compare local gaming hardware with

cloud-based alternatives under different electricity and network assumptions to assess whether such transitions reduce environmental impact or primarily redistribute it.

Behavioural research would also be valuable. This includes examining the social and cultural drivers behind energy-intensive gaming practices, such as competitive gaming culture, graphical expectations, high framerate norms, and platform design incentives that may encourage longer sessions or more demanding hardware choices.

Related to this, future work could investigate whether sustainability interventions meaningfully influence gaming behaviour in practice. Examples include energy visibility tools, platform-level efficiency settings, awareness-focused design interventions, or behavioural nudges intended to reduce unnecessary electricity demand.

Finally, future research could explore the policy implications of digital leisure energy demand more explicitly. As gaming and other digital entertainment activities continue to grow, questions emerge regarding whether digital sustainability should remain framed primarily as an individual consumer responsibility, or whether greater emphasis should be placed on infrastructure design, platform governance, and wider energy system transformation.

Chapter 9

Conclusion

This thesis shows that the operational environmental impact of digital gaming cannot be meaningfully explained through a single average estimate or reduced to one dominant variable. Instead, environmental impact emerges through the interaction between device characteristics, user behaviour, and electricity system characteristics.

Device choice clearly influences operational electricity demand, but the results show that gaming platforms should not be treated as fixed environmental categories. Large differences exist not only between consoles, gaming laptops, and gaming PCs, but also within these categories themselves. Gaming PCs in particular showed substantial variation depending on hardware assumptions, performance expectations, and workload intensity, making broad generalisations difficult.

At the same time, user behaviour proved to be as influential as, and in several scenarios more influential than, differences in device efficiency alone. Gameplay duration created some of the largest differences observed in the analysis, with electricity demand increasing dramatically under higher-intensity use scenarios. Performance-related behaviour also mattered, particularly in gaming PC scenarios where demanding workloads significantly increased operational electricity demand. This shows that environmental impact is shaped not only by what users play on, but also by how they choose to use that hardware.

The inclusion of simultaneous digital activities further strengthened this interpretation. While concurrent video streaming did not dominate total electricity demand compared with high performance gaming hardware, it demonstrated that gaming increasingly takes place as part of broader digital routines rather than as an isolated activity. Even comparatively modest additional loads become environmentally relevant when repeated frequently and scaled across large user populations.

electricity system characteristics was found to be one of the most decisive factors when interpreting greenhouse gas emissions. Identical gaming behaviour produced dramatically different operational emissions depending solely on the surrounding electricity mix. Scenarios that appeared environmentally modest under Swedish electricity conditions became substantially more significant under European average assumptions. This highlights the importance of geographical and infrastructural context when assessing digital sustainability.

The demographic scaling scenarios further suggest that cumulative environmental significance emerges not only through highly intensive users, but also through widespread

moderate consumption across large populations. The exploratory demographic scenarios suggest that differences in reported gaming behaviour between population groups may produce meaningful variation in cumulative operational emissions, particularly when scaled across large user populations. While these estimates are not intended as precise demographic forecasts, they indicate that behavioural variation between groups is relevant when interpreting broader environmental impact.

An important limitation of this thesis is its focus on operational electricity use rather than full lifecycle emissions. Low operational emissions, particularly under low carbon electricity conditions such as Sweden, should not be interpreted as equivalent to low total environmental impact, since embodied emissions associated with gaming hardware may represent a substantial share of the overall environmental footprint.

The findings suggest that digital gaming should be understood not as a fixed technical category, but as a dynamic sociotechnical practice shaped by technology, behaviour, and infrastructure. More efficient hardware alone does not automatically produce lower environmental impact if behavioural intensity increases, and focusing only on individual user choices risks overlooking the importance of platform design, electricity infrastructure, and wider systemic conditions.

As digital leisure continues to expand globally, understanding these interactions becomes increasingly important for evaluating the sustainability of contemporary digital lifestyles.

References

Akenji, L., Bengtsson, M., Toivio, V., Lettenmeier, M., Fawcett, T., Parag, Y., Saheb, Y., Coote, A., Spangenberg, J. H., Capstick, S., Gore, T., Coscieme, L., Wackernagel, M., and Kenner, D. (2021). 1.5-degree lifestyles: Towards a fair consumption space for all. Technical report, Hot or Cool Institute, Berlin.

Aslan, J. (2020). Climate change implications of gaming products and services. Master's thesis, University of Surrey, Faculty of Engineering and Physical Sciences.

Azzini, I. and Rosati, R. (2020). A functioning approach to sensitivity analysis for policy decision making. Technical Report JRC122132, European Commission, Joint Research Centre (JRC).

Belkhir, L. and Elmeligi, A. (2018). Assessing ict global emissions footprint: Trends to 2040 and recommendations. *Journal of Cleaner Production*, 177:448–463.

Berg, M. (2024). Energy implications of upscaling and frame generation in games. Master's thesis, Uppsala University, Department of Information Technology.

Buonocore, C. E. (2016). Comparative life cycle impact assessment of digital and physical streaming of video games in the united states. Master's thesis, Harvard Extension School, Harvard University, Cambridge, MA.

California Energy Commission (2019). A plug-loads game changer: Computer gaming energy efficiency without performance compromise. Technical Report CEC-500-2019-042, California Energy Commission, Energy Research and Development Division, Sacramento, CA.

Cisco (2020). Cisco annual internet report (2018–2023) white paper. White paper.

Dineen, D. (2014). *Bottom-up Modelling of Energy Demand and Technical Energy Savings Potential in the Irish Residential Sector*. Phd thesis, University College Cork.

European Commission (2026). European product registry for energy labelling (eprel): Electronic displays database. Public EU product registry for energy-labelled electronic displays.

European Environment Agency (2025). Greenhouse gas emission intensity of electricity generation in europe. Indicator assessment.

Exploding Topics (2026). Number of gamers worldwide and trends for gaming. https://explodingtopics.com/blog/number-of-gamers. Accessed: 2026-02-04.

Freitag, C., Berners-Lee, M., Widdicks, K., Knowles, B., Blair, G. S., and Friday, A. (2021). The real climate and transformative impact of ict: A critique of estimates, trends, and regulations. *Patterns*, 2(9):100340.

Hittinger, E., Mullins, K. A., and Azevedo, I. L. (2012). Electricity consumption and energy savings potential of video game consoles in the united states. *Energy Efficiency*, 5(4):531–545.

International Energy Agency (2020). The carbon footprint of streaming video: fact-checking the headlines. Accessed: 2026-04-20.

Lange, S., Pohl, J., and Santarius, T. (2020). Digitalization and energy consumption. does ict reduce energy demand? *Ecological Economics*, 176:106760.

Lee, S., Lee, S., and Baek, H. (2025). How does live streaming impact media content consumption? the effect of game live streaming on game players. *Entertainment Computing*, 52:100802.

Lonnqvist, O. (2022). Sustainable game development: Mapping the climate impact and the negative impact reduction actions in the swedish gaming industry. Master's thesis, Uppsala University, STS Programme.

Mahmood, B. H. (2025). Global greenhouse gas emissions of video games based on 2022 market data. Master's thesis, Uppsala University, HCI Programme.

Malmodin, J. and Lundén, D. (2018). The energy and carbon footprint of the global ict and e&m sectors 2010–2015. *Sustainability*, 10(9):3027.

Marsden, M., Hazas, M., and Broadbent, M. (2020). From one edge to the other: Exploring gaming's rising presence on the network. In *Proceedings of the 7th International Conference on ICT for Sustainability (ICT4S 2020)*, pages 247–254. ACM.

Mastrucci, A., Baume, O., Stazi, F., and Leopold, U. (2017). Global sensitivity analysis as a support for the generation of simplified building stock energy models. *Energy and Buildings*, 149:368–383.

Microsoft (2026a). Xbox sustainability global platform baselines. Accessed 2026-03-29.

Microsoft (2026b). Xbox sustainability lab platform baselines. Accessed 2026-03-29.

Mills, E., Bourassa, N., Rainer, L., Mai, J., Shehabi, A., and Mills, N. (2019). Toward greener gaming: Estimating national energy use and energy efficiency potential. *The Computer Games Journal*, 8(3-4):157–178.

Pérez, C., Verón, J., Pérez, F., Moraga, M. Á., Calero, C., and Cetina, C. (2024). A comparative analysis of energy consumption between the widespread unreal and unity video game engines. *arXiv*.

Saltelli, A., Ratto, M., Andres, T., Campolongo, F., Cariboni, J., Gatelli, D., Saisana, M., and Tarantola, S. (2008). *Global Sensitivity Analysis: The Primer*. John Wiley & Sons, Chichester, UK.

Sony Interactive Entertainment (2026). Playstation ecodesign and energy efficiency information. Accessed 2026-03-29.

Statista (2023). Frequency of watching online television services in sweden 2023.

Statista (2025a). Distribution of video game users in sweden by age group 2025.

Statista (2025b). Distribution of video game users in sweden by gender 2025.

Statista (2025c). Hours spent on playing video games per week in sweden 2025. Statista Consumer Insights.

Statista (2025d). Most used media services in sweden 2025.

Statista (2025e). Preferred video game genre in sweden 2025.

Statista (2025f). Video gamer penetration in sweden from 2017 to 2030.

Statistics Sweden (2025). Population statistics.

Statistics Sweden (SCB) (2026). Elanvändning efter användningsområde. månad 1990m01–2026m07.

Svenska kraftnät (2026). Förbrukning och tillförsel per timme.

Swan, L. G. and Ugursal, V. I. (2009). Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. *Renewable and Sustainable Energy Reviews*, 13(8):1819–1835.

Swedish Energy Agency (2025). Energy in sweden 2024. Statistics dataset.

Transportstyrelsen (2025). Statistik över koldioxidutsläpp från personbilar. Accessed: 2026-05-07.

Usher, W., Barnes, T., Moksnes, N., and Niet, T. (2023). Global sensitivity analysis to enhance the transparency and rigour of energy system optimisation modelling. *Open Research Europe*, 3:30.

Williams, E. (2004). Energy intensity of computer manufacturing: Hybrid assessment combining process and economic input-output methods. *Environmental Science & Technology*, 38(22):6166–6174.

Appendix A

Gameplay Duration Scenario Results

Table A.1: *Estimated annual electricity use and operational emissions under Swedish electricity conditions for representative gaming PC and gaming laptop power scenarios across weekly gameplay categories*

Gameplay category	**h/week**	**Laptop 100 W (kWh)**	**Laptop 100 W (kg CO_2e)**	**Laptop 250 W (kWh)**	**Laptop 250 W (kg CO_2e)**	**PC 150 W (kWh)**	**PC 150 W (kg CO_2e)**	**PC 500 W (kWh)**	**PC 500 W (kg CO_2e)**	**PC 800 W (kWh)**	**PC 800 W (kg CO_2e)**
Less than 1 h	0.5	2.6	0.02	6.5	0.05	3.9	0.03	13.0	0.09	20.8	0.15
1 – 5 h	3	15.6	0.11	39.0	0.27	23.4	0.16	78.0	0.55	124.8	0.87
6 – 10 h	8	41.6	0.29	104.0	0.73	62.4	0.44	208.0	1.46	332.8	2.33
11 – 15 h	13	67.6	0.47	169.0	1.18	101.4	0.71	338.0	2.37	540.8	3.79
16 – 20 h	18	93.6	0.66	234.0	1.64	140.4	0.98	468.0	3.28	748.8	5.24
More than 20 h	25	130.0	0.91	325.0	2.28	195.0	1.37	650.0	4.55	1040.0	7.28

Table A.2: *Estimated annual electricity use and operational emissions under European average electricity conditions for representative gaming PC and gaming laptop power scenarios across weekly gameplay categories*

Gameplay category	**h/week**	**Laptop 100 W (kWh)**	**Laptop 100 W (kg CO_2e)**	**Laptop 250 W (kWh)**	**Laptop 250 W (kg CO_2e)**	**PC 150 W (kWh)**	**PC 150 W (kg CO_2e)**	**PC 500 W (kWh)**	**PC 500 W (kg CO_2e)**	**PC 800 W (kWh)**	**PC 800 W (kg CO_2e)**
Less than 1 h	0.5	2.6	0.49	6.5	1.22	3.9	0.73	13.0	2.43	20.8	3.89
1 – 5 h	3	15.6	2.92	39.0	7.29	23.4	4.38	78.0	14.59	124.8	23.34
6 – 10 h	8	41.6	7.78	104.0	19.45	62.4	11.67	208.0	38.90	332.8	62.23
11 – 15 h	13	67.6	12.64	169.0	31.60	101.4	18.96	338.0	63.21	540.8	101.13
16 – 20 h	18	93.6	17.50	234.0	43.76	140.4	26.25	468.0	87.52	748.8	140.03
More than 20 h	25	130.0	24.31	325.0	60.78	195.0	36.47	650.0	121.55	1040.0	194.48

Appendix B

Sensitivity Analysis Results

Table B.1: *Gaming PC scenarios for 10, 15, and 20 hours of gameplay per week*

Power	10 h/week			15 h/week			20 h/week		
(W)	kWh/year	SE kg CO_2e	EU kg CO_2e	kWh/year	SE kg CO_2e	EU kg CO_2e	kWh/year	SE kg CO_2e	EU kg CO_2e
150	78.0	0.55	14.59	117.0	0.82	21.88	156.0	1.09	29.17
250	130.0	0.91	24.31	195.0	1.36	36.47	260.0	1.82	48.62
350	182.0	1.27	34.03	273.0	1.91	51.05	364.0	2.55	68.07
400	208.0	1.46	38.90	312.0	2.18	58.34	416.0	2.91	77.79
500	260.0	1.82	48.62	390.0	2.73	72.93	520.0	3.64	97.24
600	312.0	2.18	58.34	468.0	3.28	87.52	624.0	4.37	116.69
700	364.0	2.55	68.07	546.0	3.82	102.10	728.0	5.10	136.14
800	416.0	2.91	77.79	624.0	4.37	116.69	832.0	5.82	155.58

Table B.1 illustrates how annual electricity demand and operational greenhouse gas emissions increase across a range of gaming PC power assumptions and gameplay durations. The results show a clear proportional relationship between gameplay time, device power demand, and annual electricity consumption, reflecting the structure of the underlying modelling framework.

Even relatively modest gaming PC scenarios produce noticeable annual electricity demand. A lower power 150 W gaming PC used for 10 hours per week consumes approximately 78 kWh annually, increasing to 156 kWh at 20 hours per week. In comparison, higher-performance systems show substantially larger electricity demand. An 800 W gaming PC reaches approximately 416 kWh annually at 10 hours per week, increasing to 832 kWh at 20 hours per week. This demonstrates that hardware configuration alone can create more than a fivefold difference in annual electricity use under identical behavioural assumptions.

The effect of increased gameplay duration is equally significant. For a representative 500 W gaming PC, annual electricity demand rises from 260 kWh at 10 hours per week to 520 kWh at 20 hours per week, effectively doubling as gameplay time doubles. This highlights that longer gameplay durations substantially increase annual electricity demand of operational energy demand, independent of hardware choice.

Under Swedish electricity conditions, the resulting operational emissions remain comparatively low due to Sweden's low electricity carbon intensity. Even the highest scenario of an 800 W gaming PC at 20 hours per week produces approximately 5.82 kg CO_2e annually. However, when the same electricity demand is evaluated under the European

average electricity mix, the environmental impact increases substantially. The equivalent scenario produces approximately 155.58 kg CO_2e annually, demonstrating how strongly electricity system characteristics influence operational emissions.

One particularly important observation is the interaction between hardware performance and electricity system characteristics. Under Swedish conditions, the difference between a lower power 150 W system and a high end 800 W system remains measurable but comparatively modest in total emissions terms. Under the European average electricity mix, however, this difference becomes far more noticeable, increasing from approximately 29.17 kg CO_2e to 155.58 kg CO_2e at 20 hours per week.

The results also suggest that gaming PCs represent one of the most sensitive platform categories in the analysis, due to their wide variation in performance configurations. Unlike consoles, which operate within narrower hardware ranges, gaming PCs can span very low to extremely high electricity demand scenarios depending on component choices and usage conditions. This makes PC gaming particularly relevant when examining the upper bounds of operational gaming related electricity demand.

Table B.2: *Gaming laptop scenarios for 10, 15, and 20 hours of gameplay per week*

Power	**10 h/week**			**15 h/week**			**20 h/week**		
(W)	**kWh/year**	**SE kg CO_2e**	**EU kg CO_2e**	**kWh/year**	**SE kg CO_2e**	**EU kg CO_2e**	**kWh/year**	**SE kg CO_2e**	**EU kg CO_2e**
100	52.0	0.36	9.72	78.0	0.55	14.59	104.0	0.73	19.45
175	91.0	0.64	17.02	136.5	0.96	25.53	182.0	1.27	34.03
250	130.0	0.91	24.31	195.0	1.36	36.47	260.0	1.82	48.62
300	156.0	1.09	29.17	234.0	1.64	43.76	312.0	2.18	58.34
350	182.0	1.27	34.03	273.0	1.91	51.05	364.0	2.55	68.07

Table B.2 presents estimated annual electricity demand and operational greenhouse gas emissions for gaming laptops across different representative power assumptions and gameplay durations. As with the gaming PC scenarios, the results show a clear proportional relationship between gameplay time, hardware power demand, and annual electricity consumption.

Compared with gaming PCs, gaming laptops generally occupy a lower electricity demand range, reflecting their more constrained hardware configurations and lower typical power draw. A lower-power 100 W gaming laptop used for 10 hours per week consumes approximately 52 kWh annually, increasing to 104 kWh at 20 hours per week. At the higher end of the laptop range, a 350 W system reaches approximately 182 kWh annually at 10 hours per week and 364 kWh at 20 hours per week. Although substantial, these values remain consistently below the equivalent high performance gaming PC scenarios.

The effect of increased gameplay duration remains highly visible across all laptop configurations. For a representative 250 W gaming laptop, annual electricity demand increases from 130 kWh at 10 hours per week to 260 kWh at 20 hours per week, reflecting the same near-linear scaling seen in the PC scenarios. This again highlights that gameplay duration is a major behavioural determinant of total electricity demand, regardless of platform type.

Under Swedish electricity conditions, operational emissions remain relatively modest due to the low carbon intensity of the electricity system. Even the highest gaming laptop scenario of 350 W at 20 hours per week produces approximately 2.55 kg CO_2e annually. However, when evaluated under the European average electricity mix, the same scenario

produces approximately 68.07 kg CO_2e annually, demonstrating once again how strongly electricity system characteristics shapes operational environmental impact.

The comparison between gaming laptops and gaming PCs is particularly informative. At similar gameplay durations, gaming laptops generally produce substantially lower electricity demand and emissions than gaming PCs, suggesting that device category remains an important determinant of operational impact. For example, at 20 hours per week, a 250 W gaming laptop produces approximately 260 kWh annually, while a 500 W gaming PC produces 520 kWh under identical behavioural assumptions. This effectively doubles operational electricity demand purely due to hardware differences.

At the same time, the results show that gaming laptops should not be assumed to be negligible contributors to electricity demand. Higher-end gaming laptops with sustained gameplay can still produce meaningful annual electricity use, particularly when scaled across larger user populations or evaluated under higher-carbon electricity conditions. This places gaming laptops in an intermediate position between modern gaming consoles and high performance gaming PCs within the broader modelling framework.

Table B.3: *Console scenarios for 10 hours, 15 hours, and 20 hours of gameplay per week*

Console	**Power**	**10 h/week**			**15 h/week**			**20 h/week**		
	(W)	**kWh/year**	**SE kg CO_2e**	**EU kg CO_2e**	**kWh/year**	**SE kg CO_2e**	**EU kg CO_2e**	**kWh/year**	**SE kg CO_2e**	**EU kg CO_2e**
PlayStation 5	215	111.8	0.78	20.91	167.7	1.17	31.36	223.6	1.57	41.81
Xbox Series X	154	80.1	0.56	14.97	120.1	0.84	22.46	160.2	1.12	29.95
Xbox Series S	74	38.5	0.27	7.20	57.7	0.40	10.79	77.0	0.54	14.39

Table B.3 presents estimated annual electricity demand and operational greenhouse gas emissions for selected modern gaming consoles across different gameplay durations under Swedish and European average electricity conditions. Compared with the gaming PC and gaming laptop scenarios, the console results show a narrower range of electricity demand, reflecting the more standardised hardware configurations of console platforms.

Among the analysed consoles, the PlayStation 5 consistently produces the highest electricity demand due to its representative active gameplay power of approximately 215 W. At 10 hours of gameplay per week, this corresponds to approximately 111.8 kWh annually, increasing to 223.6 kWh at 20 hours per week. The Xbox Series X follows a similar but lower trajectory, rising from 80.1 kWh annually at 10 hours per week to 160.2 kWh at 20 hours per week. The Xbox Series S remains substantially more energy efficient, with annual electricity demand ranging from 38.5 kWh to 77.0 kWh across the same gameplay durations.

These differences highlight the importance of device choice even within the console category. Under identical behavioural assumptions, the PlayStation 5 consumes nearly three times as much electricity as the Xbox Series S at all gameplay durations, while the Xbox Series X occupies an intermediate position. This suggests that hardware efficiency remains a meaningful determinant of operational electricity demand even in the more standardised console market.

The impact of increased gameplay duration is clearly visible across all platforms. For the PlayStation 5, annual electricity demand doubles from approximately 111.8 kWh at 10 hours per week to 223.6 kWh at 20 hours per week. The same proportional pattern

is observed for both Xbox platforms, reinforcing that gameplay duration remains a strong behavioural driver of operational electricity demand regardless of platform choice.

Under Swedish electricity conditions, the resulting greenhouse gas emissions remain relatively low due to the low carbon intensity of the national electricity system. Even the highest console scenario, consisting of a PlayStation 5 used for 20 hours per week, produces only approximately 1.57 kg CO_2e annually. The Xbox Series X produces 1.12 kg CO_2e under the same behavioural assumptions, while the Xbox Series S remains below 1 kg CO_2e.

However, the comparison with the European average electricity mix demonstrates a different environmental outcome. Under the same 20-hour gameplay assumption, the PlayStation 5 produces approximately 41.81 kg CO_2e annually, while the Xbox Series X reaches 29.95 kg CO_2e and the Xbox Series S 14.39 kg CO_2e. This illustrates that while console electricity demand itself remains unchanged, the environmental significance of that demand depends heavily on the surrounding electricity system.

Compared with gaming PCs, modern consoles generally remain less electricity intensive, particularly when compared with high performance desktop configurations.

Table B.4: *Video streaming scenarios for 10, 15, and 20 hours of use per week*

Power	**10 h/week**			**15 h/week**			**20 h/week**		
(W)	**kWh/year**	**SE kg CO_2e**	**EU kg CO_2e**	**kWh/year**	**SE kg CO_2e**	**EU kg CO_2e**	**kWh/year**	**SE kg CO_2e**	**EU kg CO_2e**
80	41.6	0.29	7.78	62.4	0.44	11.67	83.2	0.58	15.56

Table B.4 presents estimated annual electricity demand and operational greenhouse gas emissions for representative video streaming usage across different weekly durations. Using a benchmark electricity demand of approximately 80 W during active streaming, the results show that streaming produces measurable annual electricity demand even though it remains below most gaming hardware scenarios.

At 10 hours of streaming per week, annual electricity demand is estimated at approximately 41.6 kWh, increasing to 83.2 kWh at 20 hours per week. Under Swedish electricity conditions, this corresponds to relatively modest operational emissions ranging from 0.29 kg CO_2e to 0.58 kg CO_2e annually. However, under the European average electricity mix, the same streaming behaviour produces substantially higher emissions, ranging from 7.78 kg CO_2e to 15.56 kg CO_2e.

While streaming remains less electricity intensive than higher performance gaming platforms, sustained streaming activity can still produce annual electricity demand comparable to lower power gaming scenarios such as the Xbox Series S.

Table B.5: *Additional annual electricity use from one and two monitor configurations*

Monitor configuration	**10 h/week**	**15 h/week**	**20 h/week**
One monitor, 30 W	15.6 kWh	23.4 kWh	31.2 kWh
Two monitors, 60 W	31.2 kWh	46.8 kWh	62.4 kWh

Table B.6: *Additional annual operational emissions from one and two monitor configurations under Swedish and European average electricity conditions*

Monitor configuration	**10 h/week**		**15 h/week**		**20 h/week**	
	SE kg CO_2e	**EU kg CO_2e**	**SE kg CO_2e**	**EU kg CO_2e**	**SE kg CO_2e**	**EU kg CO_2e**
One monitor, 30 W	0.11	2.92	0.16	4.38	0.22	5.83
Two monitors, 60 W	0.22	5.83	0.33	8.75	0.44	11.67

Tables B.5 and B.6 shows the additional operational electricity use and associated greenhouse gas emissions introduced by one and two monitor gaming setups across gameplay durations of 10, 15, and 20 hours per week. As expected, the added electricity demand increases linearly with gameplay duration, with a dual monitor configuration contributing twice the electricity use of a single monitor setup. While the additional emissions remain relatively modest under Swedish electricity conditions due to the low carbon intensity of the electricity mix, the same monitor configurations result in noticeably higher emissions under the European average electricity scenario. These tables illustrate that display-related electricity demand, while often overlooked, can represent a meaningful additional operational contribution, particularly under longer gameplay durations and higher-carbon electricity systems.

Appendix C

Detailed Console Power Mode Comparison

The PlayStation ecodesign data is particularly useful because it includes multiple generations, multiple revisions within a generation, separate measurements for digital and disc variants, and several non gaming modes Sony Interactive Entertainment (2026).

PlayStation 5 generation Across the PlayStation 5 generation, active PS5 gaming generally falls in a narrow range around 197 – 219 W depending on revision and model. Early models such as the CFI-1016A and CFI-1016B are just below 200 W in HD mode, while later revisions such as the CFI-2016, CFI-21, CFI-71, and PS5 Pro are mostly in the 214 – 219 W range. UHD values are usually very similar, often only a few watts higher. This indicates that for the PlayStation 5 generation, active power demand is relatively stable across revisions, but has trended upward somewhat from the launch generation to later revisions.

Backward compatibility gaming with PS4 titles uses substantially less power. For example, the values reported for *Marvel's Spider-Man* and *Battlefield 4* are often roughly 88 – 114 W depending on title and console model. This is an important distinction for modelling because it shows that the same device can exhibit very different power demand depending on whether it is running native current-generation software or older software.

Home menu interface power for PlayStation 5 is typically around 43 – 47 W, which is not negligible. Streaming media values, where reported, are around 54 – 56 W for several PS5 revisions. Blu-ray and DVD playback values generally fall around 49 – 56 W, while 4K Blu-ray playback on disc-enabled systems is substantially higher, in some cases above 75 – 80 W for some revisions.

Rest mode values are low in absolute terms, but should still be included in annual modelling because they accumulate over long periods. "Rest" low power values are typically around 0.30 – 0.38 W, but rest mode with USB power and internet connection enabled is often around 3.2 – 4.7 W depending on the model.

Table C.1: *Selected PlayStation 5 family power values*

Model family	PS5 gaming (W)	PS4 game range (W)	Menu (W)	Rest (W)
CFI-1016A / 1016B	196.9 – 199.6	90.3 – 108.0	41.7 – 44.4	3.7
CFI-1116A / 1116B	199.0 – 208.8	90.5 – 111.6	44.0 – 47.3	3.2 – 3.8
CFI-1216A / 1216B	200.8 – 210.9	95.8 – 97.2 / TBC	43.8 – 47.1	3.3 – 4.2
CFI-2016 / 2016 Digital	214.3 – 217.7	91.3 – 107.5	46.4 – 47.3	3.8
CFI-21 / CFI-71	213.3 – 219.2	88.4 – 110.2	43.4 – 47.1	4.7
PS5 Pro CFI-7021	215.2 – 216.1	87.1 – 113.7	43.6 – 44.6	3.6

PlayStation 4 generation The PlayStation 4 data is equally useful because it shows a clear decline in power consumption across model revisions. The earliest PS4 model listed, CFI-1016A, has an active gaming average of 137.3 W, while later revisions such as CUH-22XX are closer to 78.2 W Sony Interactive Entertainment (2026). This is a very substantial reduction within the same console generation.

The same pattern appears in menu and media modes. Early PS4 models show home menu values above 80 W and streaming values above 90 W, while later revisions are substantially lower. This suggests that console revision matters not only for gaming wattage but for the total duty cycle.

The PS4 Pro family sits between the base PS4 and the PS5 generation. Depending on model and output, active gaming averages range from roughly 126 W to 158 W. UHD mode pushes some PS4 Pro configurations close to 150 – 158 W, which places them clearly above the base PS4 and closer to the lower end of modern flagship console consumption.

Table C.2: *Selected PlayStation 4 family power values*

Model family	Gaming average (W)	Battlefield 4 (W)	Menu (W)	Rest all (W)
PS4 CUH-1016A	137.3	134.4	83.7	7.8
PS4 CUH-11XX	115.1	130.4	77.6	7.3
PS4 CUH-12XX	95.1	105.8	65.9	5.2
PS4 CUH-20XX	82.8	84.1	48.5	5.5
PS4 CUH-21XX	75.2	76.7	41.8	5.8
PS4 CUH-22XX	78.2	73.6 – 73.9	40.0	5.4
PS4 Pro 70XX	126.1 (HD), 148.1 (UHD)	95.7	60.4 / 66.7	8.2
PS4 Pro CUH-71XX	139.0 (HD), 149.6 (UHD)	91.1	58.5 / 66.9	7.4
PS4 Pro CUH-72XX	146.4 (HD), 158.2 (UHD)	87.7 / 152.8*	53.9 / 56.9	6.4

*The 152.8 W value refers to *Marvel's Spider-Man* in UHD mode.

PlayStation 3 The PlayStation 3 values provided are much lower than the PS5 generation, but still non-trivial. Active gaming is listed at 76.3 W, while DVD, Blu-ray, streaming media, and home menu use all remain around 64 – 68 W Sony Interactive Entertainment (2026). This is notable because it shows a much flatter distinction between active and non-active modes than is the case for newer consoles.

C.0.1 Xbox Series X and Series S mode-specific power

The Xbox platform baselines are especially useful because they break down power consumption not just by console model, but by *in-game area* and by AV output conditions Microsoft (2026b). This makes them particularly strong for understanding how power demand changes during actual use rather than only under a single averaged "gaming" test.

For the Xbox Series X, global average game power is listed as 122 W and global average app power as 51 W Microsoft (2026a). However, the more detailed mode specific values show that active gameplay commonly reaches around 150 – 154 W, while loading screens, constrained states, pause menus, main menus, and multiplayer lobbies all occupy lower but still substantial ranges.

For the Xbox Series S, global average game power is listed as 61 W and global average app power as 31 W Microsoft (2026a). Active gameplay values commonly fall around 71 – 77 W depending on output and frame rate conditions.

Table C.3: *Xbox Series X mode-specific power values*

Mode	**General / global (W)**	**4K 60 (W)**	**4K 30 (W)**
In-engine cutscene	150 – 151	151	143
Loading screen	105 – 107	107	100
Active gameplay	150 – 154	154	150
Constrained state	133 – 136	136	131
Contextual menu	140 – 144	144	126
Main menu	123 – 126	126	108
Multiplayer active gameplay	150	150	149
Multiplayer lobby	131	131	135

The Xbox Series X values show that constrained and menu related states remain quite power intensive. A constrained state around 131 – 136 W is especially important because it means a user can effectively leave a title suspended while still consuming nearly as much power as in active gameplay. This makes mode transition behaviour highly relevant to annual electricity use.

For the Xbox Series S, the same pattern exists but at a lower overall power level.

Table C.4: *Xbox Series S mode-specific power values*

Mode	1440p (W)	1080p (W)	60 FPS all resolutions (W)
In-engine cutscene	75	66	71
Loading screen	58	57	61
Active gameplay	77	71	74
Constrained state	70	61	65.4
Contextual menu	73	65	71
Main menu	64	60	65
Multiplayer active gameplay	73	68	72
Multiplayer lobby	75	63	71

These Xbox Series S values suggest a console that is substantially more energy efficient than the Series X, but which still maintains the same general mode structure. Menus and constrained states do not collapse to negligible power. They remain meaningful contributors to annual electricity use.

C.0.2 Xbox genre averages

The Xbox global platform baselines also provide genre-based averages, which are very useful because they connect directly to the discussion of Swedish genre preferences Microsoft (2026a). For Xbox Series X, the range across genres runs from 104 W for puzzle and trivia to 133 W for racing and flying. For Xbox Series S, the range is from 55 W for puzzle and trivia or platform titles to 65 W for racing and flying.

Table C.5: *Xbox genrebased average gameplay power*

Genre	Series X (W)	Series S (W)
Action Adventure	121	61
Card and board	110	59
Shooter	127	64
Sports	125	60
Puzzle and Trivia	104	55
Platform	110	55
Role playing	120	62
Racing and flying	133	65
Simulation	126	62
Family and kids	121	60

This is highly relevant because it gives empirical support to the argument that electricity consumption varies not just by console model, but by software type. Although Mills et al.

(2019) showed that genre itself is not always a clean predictor of power demand across all systems, these Xbox telemetry averages still indicate meaningful systematic differences by genre family.

C.0.3 Hourly electricity use implied by updated console wattages

Table C.6:

Hourly electricity use implied by console power values

Console scenario	**Power (W)**	**Energy per hour (kWh)**
PS5 active gaming, typical	200 – 219	0.200 – 0.219
PS5 running PS4 game	88 – 114	0.088 – 0.114
PS5 home menu	43 – 47	0.043 – 0.047
PS5 streaming media	54 – 56	0.054 – 0.056
PS5 rest	3.2 – 4.7	0.0032 – 0.0047
PS4 base, later revisions gaming	75 – 83	0.075 – 0.083
PS4 Pro gaming	126 – 158	0.126 – 0.158
Xbox Series X active gameplay	150 – 154	0.150 – 0.154
Xbox Series X constrained state	131 – 136	0.131 – 0.136
Xbox Series X main menu	108 – 126	0.108 – 0.126
Xbox Series S active gameplay	71 – 77	0.071 – 0.077
Xbox Series S constrained state	61 – 70	0.061 – 0.070
Xbox Series S main menu	57 – 65	0.057 – 0.065

C.0.3.1 Interpretation and modelling implications

The updated console data demonstrates that modern gaming consoles are not low power devices and that electricity demand varies substantially depending on platform, title, and operating state, reinforcing the importance of including consoles within operational gaming energy analysis.

At the same time, the broader console data also show that electricity consumption is mode dependent, with measurable differences between gameplay, media playback, and constrained operating states. While modelling these differences in full detail would require a structured duty cycle framework beyond the scope of the thesis, the findings highlight an important area for future refinement.

For the purposes of the thesis, representative active gameplay wattages were selected to provide transparent and comparable estimates across platforms.

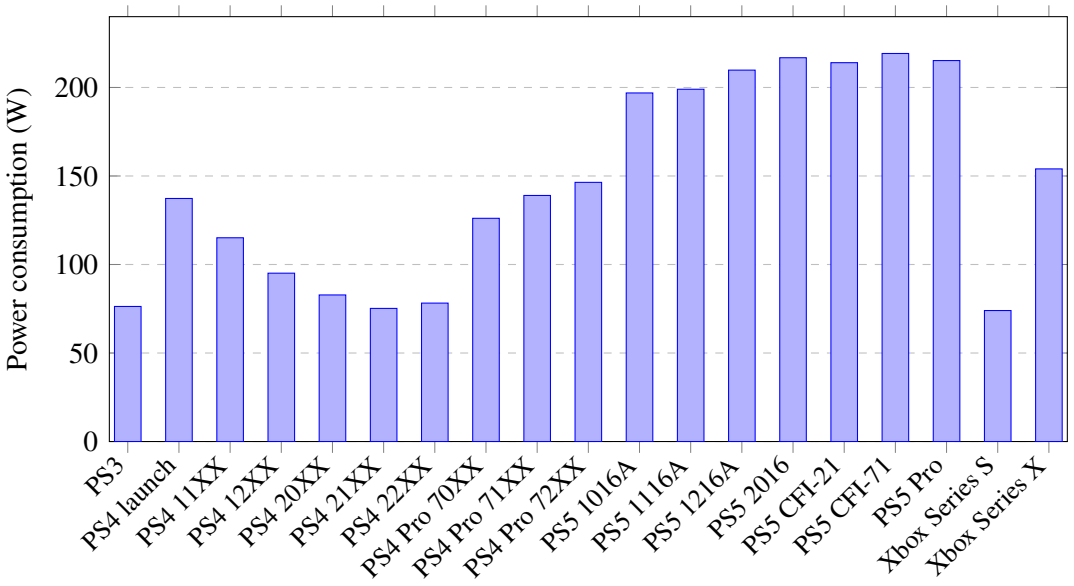


Figure C.1: *Representative active gameplay power consumption across console generations. For PlayStation systems, the values shown are the reported HD active gaming averages. For Xbox Series X and Series S, the values shown are the approximate active gameplay averages from platform baseline measurements*

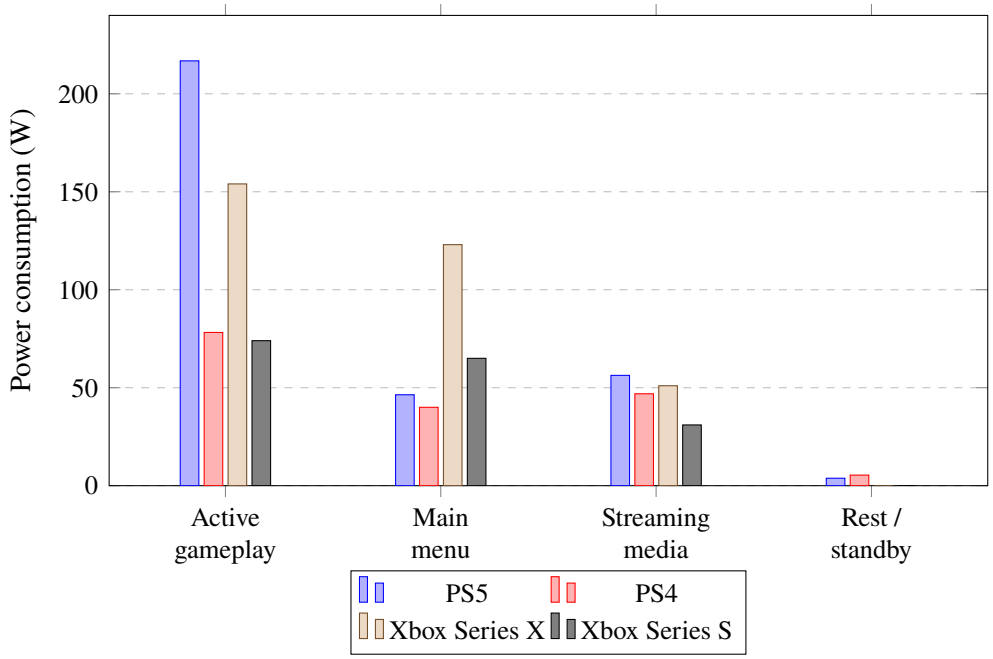


Figure C.2:
Mode-specific power consumption for selected gaming consoles. PlayStation values are based on ecodesign measurements, while Xbox values are based on platform baseline averages. Xbox standby values were not available and are shown as zero only for visual separation