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Review Study of the Ecodesign Voluntary Agreement for the Product Group "Videogames Consoles"

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Final Report

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Ökopol
Institut für Ökologie und Politik GmbH

TU WIEN
ICT
Institute of
Computer Technology

Centre for Strategy & Evaluation Services LLP
Westering House
17 Coombe Road
Otford, Kent TN14 5RJ
United Kingdom
E: enquiries@cses.co.uk
T: +44 (0) 1959 525122

AUTHORS:

Ökopol: Till Zimmermann, Rebecca Bliklen, Lisa Rödig, Laura Spengler, Dirk Jepsen

TU Wien: Stefan Wilker, Thomas Leopold, Andrija Goranović, Mirsad Karat, Alireza Estaji, Marcus Meisel, Thomas Rathfux, Michael Rathmair, Johannes Syböck

CSES: Mike Coyne, Malin Carlberg, Caroline Chandler

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1. Introduction and background

This document constitutes the final draft Report for the Review Study of the Ecodesign Voluntary Agreement (VA) for the Product Group "Videogames Consoles" carried out by CSES, Ökopol and TU Wien.

Video games consoles are one product group covered within a preparatory study in the implementing process of the Ecodesign Directive 2009/125/EC1. The preparatory study is known under the title ENTR Lot 3 "Sound and Imaging Equipment", and was finalised in late 2010. As an alternative to mandatory implementing measures to establish Ecodesign requirements for individual product groups, the Ecodesign Directive provides for the possibility for industry to propose self-regulation measures (art. 15 par. 1).

In August 2012, the manufacturers of game consoles presented a draft proposal for a voluntary measure, which was discussed with stakeholders and subsequently revised by the industry. In 2015, after completing an impact assessment, the European Commission acknowledged the Voluntary Agreement (VA) officially in a report[2]. The VA contains requirements related to energy efficiency, resource efficiency and end-of-life design and user information requirements and also stipulates verification methods. It further contains requirements related to the organisation and processes of the VA. Three companies, Sony, Microsoft and Nintendo, have signed the VA and will hereafter be referred to as the 'signatories' to the VA. The latest version of the Voluntary Agreement, on which this review study is based, is Version 2.6.3 of 11 October 2018[3]. The precise title of the document is "Self-regulatory Initiative to further improve the energy efficiency of Games Consoles". The terms 'self-regulatory initiative (SRI)' and 'voluntary agreement (VA)' will be used in the same sense in this study.

1.1 Study aims and structure

This study for the review of the games consoles VA aims to provide an independent review of the targets contained in the current version of the voluntary agreement on games consoles and possible proposals for change. The study aims to inform the revision of the voluntary agreement planned for 2019. In particular, the study aims to answer a number of research questions:

- Assessment of present and future market size of the sector;
- Assessment of the appropriateness of the energy efficiency requirements;
- Evaluation of the energy savings achieved to date;
- Improvement potential with regard to future energy savings;
- Assessment of the appropriateness and effectiveness of resource efficiency requirements and improvement potential;
- Assessment of the appropriateness and effectiveness of information requirements and improvement potential;
- Assessment of the adequacy of the current policy option and possible proposals for change, if relevant.

[1] Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of eco-design requriements for energy-related products (recast).
[2] Report from the Commission to the European Parliament and the Council on the voluntary ecodesign scheme for games consoles, COM(2015) 178 final, Brussels, 22.4.2015.
[3] See http://efficientgaming.eu/fileadmin/user_upload/2018_SCM/Final_Games_Consoles_SRI_v2.6.3_20181115.pdf

The terms of reference for the project request that the study should follow the Methodology for the Ecodesign of Energy-related Products (MEErP) as far as feasible, but it should at the same time mainly be guided by the given research questions. In order to achieve this balance, the seven Tasks anticipated in MEErP will be followed only as far as needed to answer the research questions, while further chapters dealing more explicitly with the research questions have been added. Table 1 shows the correspondence of the MEErP and the research questions. Tasks 1-5 of MEErP focus on the collection of data and modelling of environmental/economic impacts, for which there is mostly no specific research question in this study. However, the collection of data is needed for this study, too, so this report covers the necessary steps within these tasks.

Table 1 provides an overview of MEErP tasks, research questions and corresponding chapters of this report.

Table 1: Overview of research questions, MEErP and corresponding chapters

MEErP Task	Corresponding research question(s)	Chapter in Report
Task 1 Scope	--	2. Task 1 Scope
Task 2 Markets	Assessment of present and future market size of sector	3. Task 2 Markets
Task 3 Users	--	4. Task 3 Use phase
Task 4 Technologies	--	5. Task 4 Technologies
Task 5 Base Cases	--	6.2 Base Case 2: Mains powered game console with High-Definition gaming capability 6.2 Base Case 2: Mains powered game console with High-Definition gaming capability 6.3 Base Case 3: A high-end game console for handheld use with integrated display plus docking station for stationary use
Task 6 Design Options / Task 7 Scenarios	Assessment of the adequacy of the current policy option and possible proposals for change, if relevant	7 Assessment of the current VA and improvement potential
	Evaluation of energy savings achieved to date	7.3 Energy efficiency and energy savings
	Assessment of the appropriateness of the energy efficiency requirements	
	Improvement potential with regard to future energy savings	6.7 Design options for improved energy efficiency
	Assessment of the appropriateness and effectiveness of resource efficiency requirements and improvement potential	7.4 Material efficiency

MEErP Task	Corresponding research question(s)	Chapter in Report
	Assessment of the appropriateness and effectiveness of information requirements and improvement potential	7.5 Proposed Information Requirements

1.2 The Approach Adopted

1.2.1 Desk research

A significant part of the information presented in this report was collected via desk research. For task 1 (Scope), websites and journals, related Ecodesign and other regulations and standards were reviewed.

For the Market research (T2), the review covered academic literature and supplemented this with market journalism. All sources are quoted in footnotes. VGCharts data predominantly form the basis of the quantitative review, although other sources including Eurostat are also used. For task 3 "Use phase" information was collected via desk research and complemented by an expert consultation (see 1.2.3). For task 4 a major share of the information was collected by desk research and many different scenario measurements. Regarding material efficiency aspects, end-of-life treatment, and use of hazardous materials different studies have been screened.

Regarding aspects of recycling (situation) and material efficiency, additional information from other ongoing research projects at Ökopol has been used.

1.2.2 Laboratory Measurements

Relying on existing data and studies is a good starting point for formulating a solid base for the analysis. In addition, the study team offered and used the possibility of in-depth measurements with highly accurate equipment, mainly for three reasons:

1. Seeing only the final data (as for example average power consumption in various modes) does not give in-depth experience of the study objects. Especially with multi-functional devices with a vast range of different settings, small variations in the wording can have huge impacts and further implications.

   As an example, in various studies about the usage scenarios, the wording "Navigation & Other" as a mode is too vague to conclude the right mode for the usage scenario. With the features offered by games consoles, the power consumption of "Other"- modes can vary a lot.

2. Without measurements, it would not have been possible to discover the potential for some minor improvements in the current generation of games consoles, as these have not been mentioned elsewhere in literature.

3. Without measurements, the study team could not have provided new insights into the estimated usage of games consoles, as the low-power download is a popular feature in use.

Some findings gathered are beyond standardisable procedures, as every games console type is different. The measurements and findings however provide new directions, which are also validated independently.

1.2.3 Expert consultation

Experts were consulted at several stages of the project.

In task 3 several professional repair experts[4] were contacted by the study team to gather information on repair activities, the availability of spare parts, and lifespans of games consoles.

In task 4 (technologies) information on material and weight was provided by the signatories. In addition, recycling experts have been consulted.

1.2.4 Stakeholder involvement

Two stakeholder meetings at DG GROW premises have been part of the study.

The first stakeholder meeting took place on 26th of March in Brussels. An intermediate report was circulated to registered stakeholders before the meeting. Industry (signatories and associated consultants), NGOs and the Commission participated. The meeting allowed stakeholders to express their views on the operation of the Voluntary Agreement and to provide information for the analysis being conducted.

The second stakeholder meeting took place on 9th of July 2019. The draft Final Report was circulated before the meeting. Industry (signatories and associated consultants), NGOs, a Member State representative and the Commission participated. Comments were made both on the revisions to the intermediate report and on the new elements in the draft Final Report.

1.2.5 Consultations with the signatories

Two meetings have been organised and held with representatives of the SRI.

An initial teleconference call was set up between the study team and the SRI on the 24th of January 2019. This was an initial discussion which allowed the study team to present the aims of this study, and the overall work schedule. Questions to the signatories were prepared and data availability and constraints were also discussed.

A face-to-face meeting was held in Hamburg on the 25th of January. This discussed a number of issues in more depth. A work flow for signatories answering the questions of the project team was agreed, using a structured excel sheet. Also, a set of documents and information to be provided by the signatories following the meeting was agreed.

Other questions have been answered by the signatories via email and additional information particularly regarding bills-of-material and energy consumption has been provided by the signatories during the course of the study.

Finally, signatories and NGO participants in the Stakeholder Meetings each provided written comments on the drafts of the report after each meeting and were informed of the response of the study team and, where relevant, how the report has been modified to take the comments into account.

[4] Justcom.de; iFixit.de; konsolenreparatur.de; laser-reballing.de; unitechnix.de; irepair-it.de; konsolenfreax.de; konsolenwelt.eu; gamestop.de; euronics.de; gamedoc.eu; gamecompany.de; phontech.de; meinmacher.de; repaircafe-soldinger.de; repaircafe-stuttgart.de; repaircafe-bremen.de; garage-lab.de; repaircafe-sasel.de; repaircafe-kleve.de; repair-café-meschede.de

2. Task 1 Scope

2.1 Definitions and scope

2.1.1 Definitions in other regulations and standards

Games consoles are computer-like devices whose primary function is to play video games. There exist several detailed definitions in regulations and standards of what games console are. These aim to distinguish games consoles from other products used for gaming, such as computers, thin clients[5] and other streaming devices, commercial arcade machines, tablets, or smartphones[6], and sometimes also to exclude certain products within the class of games consoles.

In particular, the following definitions of 'games console' should be mentioned here:

The Ecodesign ENTR Lot 3 study (2010)[7] for the product group sound and imaging equipment, which also covered games consoles, provides the following definition in Task 7:

'A "Games console" is a mains powered standalone device which is marketed as a product providing video game playing as its primary function through an external screen and which has the following features:

- *Hardware Architecture: CPU, System memory, Video architecture, Network architecture, Optical drives (optional), Hard drives or other internal memory (optional), Mains connected internal or external power supply unit*
- *Input devices: Typically hand-held controllers or other interactive controllers rather than keyboards or mice*
- *Optional Secondary functions: Optical disk playback, Digital picture viewing (via an external screen), Digital music playback, General internet connectivity*
- *Excluded components or functionalities: Integrated screens, Conventional Personal Computing (PC) operating systems, Internal batteries for powering products over extended periods of time'*

The Ecodesign Regulation for computers (2013)[8] excludes games consoles from its scope. Nevertheless, it contains the following definition, which appears to be based in part on the ENTR Lot 3 study:

'"Game console" means a mains-powered standalone device which is designed to provide video game playing as its primary function. A game console is typically designed to provide output to an external display as the main game-play display. Game consoles typically include a CPU, system memory and a graphics processing unit(s) (GPU), and may contain hard drives or other internal storage options, and optical drives. Game consoles typically utilise handheld controllers or other interactive controllers as their primary input device rather than an external keyboard or mouse. Game consoles do not typically include conventional personal computing operating systems but instead utilise console-specific operating systems. Handheld gaming devices, with an integrated display as the primary game-play

[5] Computers and thin clients are covered with binding Ecodesign requirements under Regulation (EC) 617/2013 (see section 2.2).
[6] For smartphones, the Joint Research Center of the European Commission currently is working on a study within the Ecodesign process in particular with regard to material efficiency aspects of these products.
[7] AEA, Intertek: ENTR Lot 3 Sound and Imaging Equipment, Task 1–7 Report, Report to the European Commission DG ENTR, November 2010.
[8] Commission Regulation (EU) No 617/2013 of 26 June 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for computers and computer servers.

display, and which primarily operate on an integrated battery or other portable power source rather than via a direct connection to an AC power source, are considered to be a type of game console.'

Also a definition, dating back to 2013, from the U.S. Environmental Protection Agency (EPA) Recognition Program for Game Consoles[9, 10]:

'Game Console: A standalone computer-like device whose primary use is to play video games. Game Consoles use a hardware architecture based in part on typical computer components (e.g., processors, system memory, video architecture, optical and/or hard drives, etc.). The primary input for Game Consoles are special hand-held controllers rather than the mouse and keyboard used by more conventional computer types. Game Consoles are also equipped with audio visual outputs for use with televisions as the primary display, rather than (or in addition to) an external or integrated display. These devices do not typically use a conventional personal computer (PC) operating system, but often perform a variety of multimedia functions such as: DVD/ Compact Disc (CD) playback, digital picture viewing, and digital music playback. Handheld gaming devices, typically battery-powered and intended for use with an integral display as the primary display, are not included in this test plan.'

The Voluntary Agreement on games consoles in the EU currently covers games consoles that meet the following definition:

'A Games Console is a computing device whose primary function is to play video games. Games Consoles share many of the hardware architecture features and components found in general personal computers (e.g. central processing unit(s), system memory, video architecture, optical drives and/or hard drives or other forms of internal memory). Games Consoles covered by this SRI are those that:

- *Utilise either dedicated handheld or other interactive controllers designed to enable game playing (rather than the mouse and keyboard used by personal computers); and*
- *Are equipped with audio-visual outputs for use with external televisions as the primary display; and*
- *Use dedicated Console operating systems (rather than using a conventional PC operating system); and*
- *May include other secondary features such as optical disc player, digital video and picture viewing, digital music playback, etc.; and*
- *Are mains powered devices that use more than 20 watts in Active Game mode with either internal or dedicated external power supply units.'*

The last point (mains powered devices and 20 W in active gaming mode) is the reason that all products currently placed on the market by one of the three SRI signatories, Nintendo, are out of the scope of the SRI. The main console produced by Nintendo at the moment, the Switch, is a console which is mains powered through a docking station but also usable in handheld mode (with integrated display) and, according to reports and measurements carried out by the study team as well as the internal tests from Nintendo, consumes less than 20 W in gaming mode (around 12 watts). Consequently, there are currently no Nintendo products being sold[11] that fall under the reporting requirements of the SRI.

[9] U.S. Environmental Protection Agency (EPA) Recognition Program for Game Consoles, Performance Requirements Game Consoles V 1.0, effective date: 03/05/2013, https://www.energystar.gov/products/spec (last accessed 11/2/2019).
[10] The specifications for this program do not constitute Energy Star (ES) specifications, even if they are listed on the ES website. Manufacturers that demonstrate that their game consoles meet the proposed performance and testing requirements will be recognized by EPA.
[11] https://store.nintendo.co.uk/ (last accessed 28/02/2019)

These definitions suggest various aspects that are used to distinguish games consoles from other products or to exclude certain product types within the category of games consoles. These include:

- Games consoles are designed to play **video games** (excluding other electric toys, e.g. chess computers with small display)
- **Gaming as the primary function** of games consoles, while it is only a secondary function of other devices such as mobile phones; games consoles optionally have secondary functions such as optical disk playback, digital picture viewing (via an external screen), digital music playback, general internet connectivity
- The use of **console-specific operating systems** instead of conventional PC operating systems
- A number of certain hardware characteristics of games consoles:
  - They typically (but not always) use an **external display** as the main game-play display
  - They use special **handheld controllers** or other interactive controllers as input devices instead of a mouse and keyboard
  - A certain **hardware architecture**, (typically) including the following: CPU, system memory, video architecture, optical drives and/or hard drives or other forms of internal memory, etc.
- Criteria partly used to exclude certain types of consoles:
  - The presence of batteries for powering products over extended periods of time and integrated displays (**handheld** games consoles)
  - A minimum **power limit** for active gaming (only used in games consoles VA)

All the definitions cited above are quite detailed and refer to specific technical characteristics as well as the product function. For the definition of the study scope (see section 2.1.3), other Ecodesign regulations in place which already cover specific products used primarily for gaming are considered, and overlaps are avoided on the basis of technical parameters.

2.1.2 Devices with video gaming capability

As already indicated, there is a variety of devices on the market to be used for playing video games such as Sony's PS4, Microsoft's Xbox, Nintendo's Switch, different arcade consoles, steam machines, smart TVs and others. These devices differ regarding their function and capabilities and/or have significantly different technical properties. The following table provides an overview of different devices with video gaming functionality and compares them using a set of technical and non-technical criteria.

Table 2: Comparison of devices with video gaming capability

Specs	Explanation	PS4	Xbox One	Nintendo Switch	Arcade consoles	Steam Machine	Smart TV, e.g., Apple TV, Samsung Smart TV	NVIDIA Shield TV	Oculus Go
		Games console to be connected with TV or other display	Games console	Games console to be connected with TV or other display using docking station and for handheld use with integrated display	Games console to be connected with TV or other display	"streamlined" PC, optimized to play games on Steam platform, to be connected with TV or other display	TV with multimedia streaming functions	Set-top box for connecting gaming PC and TV	VR device with integrated hardware for gaming and playing multimedia content
Gaming as primary function	The devices is designed to be used primarily for gaming.	YES	YES	YES	YES	YES	NO	YES	NO
Gaming is advertised main function	The advertisement focuses on the gaming function.	YES	YES	YES	YES	YES	NO	YES	NO
Local gaming instance	The gaming function is available without connection to a network (for cloud computing) and/or other devices (except display).	YES	YES	YES	YES	YES	NO (except for simple gaming apps)	Limited (Focus is on game streaming)	YES
Guaranteed game content support	There is a range of games designated for the device which are guaranteed to run w/o problems.	YES	YES	YES	YES	NO (Limited, mainly influenced by used hardware)	Limited (High variety of OS versions and hardware specifications)	Limited	YES
Operating system	Type of operating system: console-specific, PC OS, smartphone OS, Emulator	console-specific	console-specific	console-specific	console emulators	PC OS	smartphone OS	smartphone OS	smartphone OS

Specs	Explanation	PS4	Xbox One	Nintendo Switch	Arcade consoles	Steam Machine	Smart TV, e.g., Apple TV, Samsung Smart TV	NVIDIA Shield TV	Oculus Go
		Games console to be connected with TV or other display	Games console	Games console to be connected with TV or other display using docking station and for handheld use with integrated display	Games console to be connected with TV or other display	"streamlined" PC, optimized to play games on Steam platform, to be connected with TV or other display	TV with multimedia streaming functions	Set-top box for connecting gaming PC and TV	VR device with integrated hardware for gaming and playing multimedia content
Network capabilities	The device has network capability, i.e. can be connected to the internet.	YES	YES	YES	NO	YES	YES	YES	YES
Cloud based gaming	Online gaming where game is run on external servers.	YES	Planned	Planned	NO	NO	NO	YES (GeForce Now)	NO
Mobile use / portability	The device can be used for mobile/ portable gaming running on battery power, using an integrated display.	NO	NO	YES	NO	NO	NO	NO	YES
Multimedia functions	The device provides multimedia functions.	MediaPlayer Blu-Ray Disc	MediaPlayer Blu-Ray Disc	Limited	NO	MediaPlayer	MediaPlayer & TV	MediaPlayer	MediaPlayer
Hard-copy content purchasable and playable with device	Hard-copy content (games) can be purchased and played on the device.	YES Updates requires network connection	YES Updates requires network connection	YES Updates requires network connection	NO	NO	NO	NO	NO
Game content purchasable online and playable on device	Game content can be purchased in online-shops etc. and played on the device after downloading or by streaming	YES	YES	YES	NO	YES	YES	YES	YES

Specs	Explanation	PS4	Xbox One	Nintendo Switch	Arcade consoles	Steam Machine	Smart TV, e.g., Apple TV, Samsung Smart TV	NVIDIA Shield TV	Oculus Go
		Games console to be connected with TV or other display	Games console	Games console to be connected with TV or other display using docking station and for handheld use with integrated display	Games console to be connected with TV or other display	"streamlined" PC, optimized to play games on Steam platform, to be connected with TV or other display	TV with multimedia streaming functions	Set-top box for connecting gaming PC and TV	VR device with integrated hardware for gaming and playing multimedia content
Vendor media content store	Media content provided by the vendor themselves	YES	YES	NO	NO	Limited	YES	NO	YES
Third-party application / content store / services	Content available through application and/or subscription services	YES	YES	Limited,for example with YouTube or Hulu (only available in the U.S.)	NO	YES	YES	YES	YES
System updates	Updates for operating system etc. are provided.	YES	YES	YES	NO	YES	YES	YES	YES
Freedom of hardware choice / different levels (Storage upgrade excluded)	Hardware configurations can be customized and influenced by customer.	Proprietary system	Proprietary system	Proprietary system	Proprietary system, Various number of vendors	Various vendors, Steam OS available, own configurations possible	Proprietary system	Proprietary system	Proprietary system
Connectable with external displays via cable	Connection to external display via cable is possible.	YES	YES	YES	YES	YES	YES	YES	NO
Connectable with external displays via wireless or applications	Connection to external display without cable is possible	Using PlayStation TV	NO	NO	NO	YES, in combination with Steam Link	Not applicable	NO	NO

Specs	Explanation	PS4	Xbox One	Nintendo Switch	Arcade consoles	Steam Machine	Smart TV, e.g., Apple TV, Samsung Smart TV	NVIDIA Shield TV	Oculus Go
		Games console to be connected with TV or other display	Games console	Games console to be connected with TV or other display using docking station and for handheld use with integrated display	Games console to be connected with TV or other display	"streamlined" PC, optimized to play games on Steam platform, to be connected with TV or other display	TV with multimedia streaming functions	Set-top box for connecting gaming PC and TV	VR device with integrated hardware for gaming and playing multimedia content
Can be used without external display	The device can be operated without an external display (i.e. using an integrated display).	NO	NO	YES Built-in	NO	NO	YES Built-in	NO	YES Built-in

Table 2 illustrates the diversity of the different devices available on the market. The key question with regard to the function of the devices is whether gaming is the primary function of the device. In some cases (PS4, Xbox, Switch, arcade consoles, steam machine) this is rather evident. Other devices evidentially have multimedia streaming as the primary function (smart TVs) while other devices like Oculus Go don't have a clear primary function in that product information and advertisement focus on multimedia playing and internet use (surfing) and mention gaming only as an additional possible use.

Another key criterion is whether the gaming function is available without connection to a network (for cloud computing) and/or other devices (except display) (i.e. a local gaming instance). If the device is not capable of the stand-alone running of a video game but relies on an external device (like a gaming PC in the case of the NVIDIA shield TV with "GameStream" together with "GeForce Experience" or a detached server centre for dedicated cloud gaming) a relevant share of the energy consumption (and the resource consumption related to the components) is shifted elsewhere.

For this study, and the scope definition of the next section, the following aspects particularly need be considered with regard to the different devices:

- PS4, Xbox One, and Switch are comparable with regard to most criteria including the key criteria mentioned.
- Arcade consoles (see Figure 1: Atari 2600 Handheld and Figure 2: Super Nintendo Entertainment System Classic Mini for example) also fulfil the key criteria but have some differences with regard to other criteria. Arcade consoles are re-engineered games consoles which were originally sold over 15 years ago (in case of the NES over 25 years ago). They have a very limited energy use (often powered by USB only) and have the ability to play a limited variety of pre-installed games. However, they meet in principle the definition of a games console and given not insignificant sales of some models[12], they are relevant from a material efficiency perspective.

Figure 1: Atari 2600 Handheld

Figure 2: Super Nintendo Entertainment System Classic Mini

- Steam machines are devices for playing PC games using the Steam platform. They basically use gaming PC components and either use SteamOS (an operating system based on Debian 8) or Windows 10 as the operating system[13] with the same hardware configuration (for example Alienware Alpha R2 and Alienware Steam Machine R2[14]). They are usually sold with gaming controllers for input. They are somewhere between a "real" gaming PC and a game console. In

[12] VG Chartz reports 265m global sales cumulatively,
[13] https://www.pcgamer.com/alienware-manager-on-steam-machines-lull-windows-10-changed-everything/ [Accessed: 27 Feb. 2019]
[14] https://www.dell.com/support/home/uk/en/ukbsdt1/product-support/product/alienware-steam-r2-console/diagnose?lwp=rt [Accessed: 27 Feb. 2019]

any case, they are not sold anymore in relevant numbers[15,16].

- Smart TVs have a different primary function and are not relevant in the context of this study. Also, they are subject to the Ecodesign Regulation on electronic displays.
- NVIDIA shield TV is capable of stand-alone gaming, but with a focus of being a device to connect gaming PCs and TV. The NVIDIA shield TV fulfils the criteria of the definition of complex set-top boxes as laid out in the VA on complex set-top boxes[17]. Although NVIDIA is not a signatory of this VA, principally, it falls under the definition of set-top boxes and therefore is subject to the corresponding VA.
- Oculus Go is a VR device which is capable of stand-alone video playing, streaming, internet (using WiFi connection) or game playing. For some features, a connection to a smartphone with an installed Oculus Go app is required. The mobile gaming option is rather limited with a battery life of about 1.5 hours. As described, gaming appears not to be the primary function of the device but is one of many functions. In addition, in contrast to games consoles like PS4, Xbox etc., advertising does not concentrate on the gaming function. Available games are rather simple with regard to gameplay and graphics, when compared to current high-end video games consoles such as PS4 and Xbox One. Also, the gaming function is frequently reported to be immature and further development is required for a gaming experience comparable to dedicated gaming devices. In this regard, the Oculus Go appears not be relevant for this study.

2.1.3 Scope for the review study

Except for the definition of games consoles in Regulation 617/2013, which has the purpose of describing a product category that is *not* covered by the Regulation, all of the definitions mentioned in section 2.1 exclude handheld consoles. The same can be observed with regard to most current studies analysing the gaming market or the energy use of gaming devices (except for the Switch as a console with handheld mode and stationary mode and sometimes the PS Vita and Nintendo 3DS). A reason for this is certainly the low energy use of portable devices (while material efficiency has not been in the focus of eco-design regulation in the past) and probably also the comparably low sales numbers. Also because of low energy use, the scope of the Voluntary Agreement on games consoles excludes consoles with an energy use below 20 W in active gaming mode which emphasizes the focus on energy efficiency.

However, this review study aims to discuss not only energy use, but also the material efficiency aspects of games consoles. There has recently been a trend to rather simple and miniaturised arcade consoles with pre-installed games, which have a rather low power consumption and sometimes are handheld consoles. Some of these arcade consoles have considerable sales numbers and are thus clearly relevant in terms of material efficiency[18,19].

This study should therefore not exclude products from the group of games consoles per se and has aimed to analyse the product category of games consoles comprehensively. This has implied consideration of the variety of devices with video gaming capability that were shown in section 2.1.2 and of products that have been excluded from other Ecodesign measures, particularly those excluded from Regulation 617/2013 on computers. The scope of this study, therefore, is as follows:

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[15] https://www.heise.de/newsticker/meldung/Valve-scheitert-mit-Steam-Machine-Konzept-4010313.html [Accessed: 15 April 2019]

[16] http://www.pcgameshardware.de/Steam-Machine-Hardware-256919/News/darum-sind-sie-nicht-weit-verbreitet-1232632/ [Accessed: 15 April 2019]

[17] Voluntary Industry Agreement to improve the energy consumption of Complex Set Top Boxes within the EU, Version 6.0

[18] Cf. e.g. The Verge, 'The NES Classic is so popular it outsold the PS4, Xbox One, and Switch in June', Aug 2, 2018, https://www.theverge.com/2018/8/2/17642236/nes-classic-npd-sales-data-june-2018

[19] Nintendo Six Month Financial Results Briefing for Fiscal Year Ending March 2019, "Combined global sales of the NES Classic Edition and the Super NES Classic Edition have now surpassed 10 million units."

Games console – Scope Definition for this study
'Games console' means a device which is designed to provide video game playing as its primary function. Games consoles either use an external or an internal display as the game-play display or both. Games consoles typically include a CPU, system memory and a graphics processing unit(s) (GPU), and may contain hard drives or other internal storage options, and optical drives. Games consoles typically utilise handheld controllers or other interactive controllers as their primary input device rather than an external keyboard or mouse. Games consoles do not typically include conventional personal computing operating systems but instead utilise console-specific operating systems. Handheld gaming devices, with an integrated display as the primary game-play display, and which primarily operate on an integrated battery or other portable power source rather than via a direct connection to an AC power source, are considered to be a type of game console.

With regard to the devices with video gaming capability this means:

Table 3: Devices within the scope of this study

Device	Within Scope of this study	Explanation/ Remarks
PS4	Yes	Within Scope. Games consoles from current signatory. Analysed in detail in the report.
Xbox One	Yes	Within Scope. Games consoles from current signatory. Analysed in detail in the report.
Nintendo Switch	Yes	Within Scope. Games consoles from current signatory. Analysed in detail in the report.
Arcade consoles	Yes	Within Scope. But as arcade consoles are re-engineered "old" consoles, no detailed assessment is made.
Steam Machines	No	Not in scope as mostly PC OS are used. In any case, not sold in relevant numbers anymore.
Smart TV, e.g., Apple TV, Samsung Smart TV	No	Not in scope. Subject to electronic display Regulation.
NVIDIA Shield TV	No	Not in scope. Subject to CSTB VA.
Oculus Go	(No)	Not within scope as gaming can currently not be considered the primary function since it is not yet so well-engineered as to be considered a "serious" gaming device. In principal, however, Oculus Go fulfils all the other criteria of the scope definition and after further technical development such devices might become a relevant device for video gaming. Not further assessment in detail in this report but future development needs to be monitored.

2.2 Relevant EU legislation

In the following section, relevant regulations and standards which apply to games consoles or are relevant in terms of context (such as the eco design regulation on computers) are listed and briefly outlined.

2.2.1 Ecodesign Regulation for Computers

Commission Regulation (EU) No 617/2013 of 26 June 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for computers and computer servers

The Regulation establishes Ecodesign requirements for a range of computers including

- desktop computers
- integrated desktop computers
- notebook computers (including tablet computers, slate computers and mobile thin clients)
- desktop thin clients
- workstations
- mobile workstations
- small-scale servers
- computer servers

The Regulation includes requirements on annual typical energy consumption (TEC), various operational modes and power management as well as energy efficiency requirements on internal power supply units. It contains the following definition of computers: 'Computer' means a device which performs logical operations and processes data, is capable of using input devices and outputting information to a display, and normally includes a central processing unit (CPU) to perform operations. If no CPU is present, then the device must function as a client gateway to a computer server which acts as a computational processing unit.

Within the group of desktop computers, the Regulation distinguishes four categories, for which different Ecodesign requirements apply:

- 'Category A' desktop computer means a desktop computer that does not meet the definition of Category B, Category C or Category D desktop computer.
- 'Category B' desktop computer means a desktop computer with: (i) two physical cores within the CPU; and (ii) a minimum of two gigabytes (GB) of system memory.
- 'Category C' desktop computer means a desktop computer with: (i) three or more physical cores within the CPU; and (ii) a configuration of a minimum of one of the following two characteristics: a minimum of two gigabytes (GB) of system memory, and/or a discrete graphics card (dGfx).
- 'Category D' desktop computer means a desktop computer with: (i) a minimum of four physical cores in the CPU; and (ii) a configuration of a minimum of one of the following two characteristics: a minimum of four gigabytes (GB) of system memory, and/or a discrete graphics card (dGfx) meeting the G3 (with FB Data Width > 128-bit), G4, G5, G6 or G7 classification.

For notebooks it defines similar categories. The Regulation thus also covers gaming PCs and notebook computers.

Currently the regulation is being reviewed and a review study is available[20].

2.2.2 Standby Regulation[21]

EU Commission Regulation 1275/2008 (incl. amendment 801/2013)

Commission Regulation (EU) No 801/2013 of 22 August 2013 amending Regulation (EC) No 1275/2008 with regard to ecodesign requirements for standby, off mode electric power consumption of electrical and electronic household and office equipment, and amending Regulation (EC) No 642/2009 with regard to ecodesign requirements for televisions.

Within this Regulation, there are Ecodesign requirements related to standby, networked standby and off mode. Detailed description of power management for networked equipment is given. These requirements apply to the electrical and electronic household and office equipment that are placed on the market.

New requirements are in effect as of 1 January 2019. Intertek provides an overview of the requirements in a more readable form on their website[22].

2.2.3 Ecodesign Regulation for External Power Supplies

Commission Regulation (EC) No 278/2009 of 6 April 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for no-load condition electric power consumption and average active efficiency of external power supplies

This regulation establishes energy efficiency requirements for external power supplies. Recently, there has been a positive vote for a revised regulation. The new regulation is likely to be published officially in the EU Official Journal and enter into force in April 2020.

Detailed no-load conditions are described in the Ecodesign requirements of this regulation for output power specified by the manufacturer either below or equal to 51 Watts and above 51 Watts, with differentiation of AC-AC external power supplies, AC-DC external power supplies and low voltage external power supplies. The low voltage external power supplies are defined with an output voltage of less than 6 volts and a nameplate output current greater than or equal to 550 milliamperes.

The indicative benchmarks state the approximated best available average active efficiency of external power supplies with January 2008 with a factor of 0.890 for the output power specified by the manufacturer above 10.0 Watts.

2.2.4 Further relevant legislation for electric appliances

Other EU directives that are relevant for electric appliances include the Directive on Waste Electrical and Electronic Equipment (WEEE, 2012/19/EU), the Directive on the Restriction of the use of hazardous Substances (RoHS, 2011/65/EU), the Low Voltage Directive (2014/35/EU), the Directive on Electromagnetic Compatibility (EMC Directive, 2014/30/EU) or the Radio Equipment Directive (RED Directive, 2014/53/EU)[23] .

[20] See the study website at https://computerregulationreview.eu/welcome
[21] the latest consolidated version of the regulation is available at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02008R1275-20170109&qid=1551627058218&from=EN
[22] http://www.intertek.com/consumer/news/new-erp-requirements-networked-standby/ [Accessed 04 Feb. 2019]
[23] Devices with radios, i.e. most game consoles, fall under the RED Directive and product under RED directive are excluded from EMC and Low Voltage Directive.

2.3 Relevant standards

The appliance of standards ensures the quality and reproducibility of measurements and the data gathered. The following set of standards was used in the ENTR lot 3 study of 2010 and is therefore relevant and is examined on the basis of the current revisions available to the study team:

2.3.1 Electrical and electronic household and office equipment - Measurement of low power consumption (IEC 62301:2011, modified); German version EN 50564:2011

This standard is in effect from 2011-12-01 and specifies methods for the measurement of electrical power consumption and the reporting of results for a range of household and office electrical and electronic appliances.

An important consideration is that this standard is related to the measurement of electrical power with a focus on low power in the range of a few watts or less, that are absorbed by the mains-powered products. An overview with terms relevant for this standard (stand-by, function, modes, etc.) is listed plus the reference to the terms according to IEC 60050-131 and IEC 60050-300. Also, three-phase modifications for the tests are mentioned. The focus is on the detailed description of testing single-phase products with a range of 100 Volts AC up to 250 AC. The document specifies the general conditions for measurements (room conditions like temperature and maximum air circulation speed, power supply, supply-voltage waveform and power measurement accuracy) as well as the selection and preparation of appliance/equipment for measurement, and test procedure instructions, like checking for internal batteries beforehand.

2.3.2 Audio, video, and related equipment - Determination of power consumption - Part 1: General (IEC 62087-1:2015); German version EN 62087-1:2016

This standard has been in effect from 2015-07-10 and specifies the methods of measurement of the power consumption of audio, video and related equipment. This standard replaces DIN EN 62087:2013, which had a transition period until 2019-02-19. The SRI Version 2.6.3 document states the IEC 62087:2011 specification as approved.

The standard is separated into different parts (1-7) ranging from a general description of the standard to details for the product groups Signals and media, Television Sets, Video recording equipment, Set top boxes (STB), Audio equipment and Computer Monitors.

Additionally to this standard, there are IEC 62301:2011 Household electrical appliances – Measurement of standby power and IEC 62542:2013, Environmental standardization for electrical and electronic products and systems – Standardization of environmental aspects – Glossary of terms are required for carrying out the standard. Due to the availability, the study team refers to IEC 62301:2011 mentioned above, modified; German version EN 50564:2011 - Electrical and electronic household and office equipment - Measurement of low power consumption version, which incorporates IEC 62301:2011.

In the product parts of the standard, various modes are described in detail that have to be measured with the correct settings and measurements outline. Furthermore, it applies only to devices that can be powered by an external power supply. Devices with a non-replaceable main battery are not covered in this standard, but it can contain any number of auxiliary batteries.

2.3.3 Audio/video, information and communication technology equipment - Environmentally conscious design (IEC 62075:2012); German version EN 62075:2012 + AC:2013

This standard has been in effect from 2013-07-01 and specifies environmentally conscious design for audio/video, information and communication technology equipment.

The EN 62075:2012 + AC:2013 standard document specifies requirements and recommendations for the development of environmentally sound products and covers a range of aspects. The following list gives an overview of the contents in regard to the design of:

- lifecycle aspects
- material efficiency
- energy efficiency
- consumables and batteries
- chemical and noise emission
- extension of product life
- end of life
- dangerous substances / preparations
- product packaging

The standard includes an informative 13-page checklist for the responsible developer(s) of the product, which serves as an example for the producer-specific product family, if not already covered. Furthermore, a table for the compatibility of various thermoplastics is included.

2.3.4 Audio, video and similar electronic apparatus - Safety requirements (IEC 60065:2014, modified); German version EN 60065:2014 and Audio/video, information and communication technology equipment - Safety requirements (IEC 62368-1)

This standard has been in effect from 2014-11-17 and specifies the safety requirements for audio, video and similar electronic apparatus. After 20 December 2020 standard 60065:2014 will be replaced by IEC 62368-1.

Standard 60065:2014 applies to electronic equipment intended to be supplied with power from the mains, from a power supply unit, from batteries or for remote power, and intended for the reception, production, recording or reproduction of sound, video and related signals. It also applies to equipment designed to be used exclusively in conjunction with the aforementioned equipment.

Furthermore, the standard applies mainly to appliances intended for home use and similar general applications, but which may also be used in premises where general meetings take place, such as: schools, theatres, divine service and workplaces. Professional application devices are also included unless they are explicitly within the scope of other standards.

This standard only concerns the safety aspects of the devices mentioned above; other properties such as appearance or function are not affected.

The intention is to prevent injury or damage resulting from the following hazards:

- dangerous body currents
- excessive temperatures
- radiation
- implosion
- mechanical hazards
- fire
- chemical burns (i.e., as a result of ingestion of lithium-button cell batteries).

Standard 62368-1 applies to the safety of electrical and electronic equipment within the field of audio, video, information and communication technology, and business and office machines with a rated voltage not exceeding 600 V. It a product safety standard that classifies energy sources, prescribes safeguards against those energy sources, and provides guidance on the application of, and requirements for, those safeguards. The prescribed safeguards are intended to reduce the likelihood of pain, injury and, in the case of fire, property damage.

2.4 Relevant voluntary measures

2.4.1 EPA Recognition Program for Game Consoles

On the Energy Star website, the U.S. Environmental Protection Agency (EPA) lists specifications for games consoles[24], which do not constitute Energy Star (ES) specifications but rather a "recognition program". These specifications have been in effect since May 2013 and contain requirements on auto power down settings, limits on energy use in standby (0.5 W), navigation (40 W), and media streaming modes (50 W), and some product information requirements. Manufacturers who demonstrate that their games consoles meet the proposed performance and testing requirements will be recognized by the EPA.

It has been pointed out by the signatories of the current games consoles VA that it is the Energy Star program's goal to highlight the most efficient products in a category and this only functions if there are many different models in a product category. This is not the case for games consoles which is why the games consoles programme has been dormant and none of the signatories of the games console VA have signed up for the US EPA recognition programme. The signatories further pointed out that the programme was not developed in consultation with producers and was not accepted as a suitable basis during the first EU lot 3 consultation.

[24] Recognition Program for Game Consoles, Performance Requirements Game Consoles V 1.0, effective date: 03/05/2013, https://www.energystar.gov/products/spec (last accessed 11/2/2019).

3. Task 2 Markets

Section 3 constitutes the Market research task (Task 2) of the study.

The first video games console was released in 1972, but the industry has come a long way in the last 40 years, generating billion-dollar sales. In 2016, the video games market in the United States alone was valued at $ 17.68 billion (€15.56 billion), but it can be estimated at twice that amount if one includes gaming content, hardware and accessories.

A highly significant feature of the market is that it is dominated by three major players: Sony, Microsoft, and Nintendo, none of which are primarily based in Europe.[25] These three companies account for more than 80% of the total games console market and are the three signatories to the SRI that is the subject of this study.

Sony was the leading player in the games console hardware, software, and service market in 2016 (the most recent statistics to date) with a 57% share, representing $ 19.7 billion (€ 17.35 bn) of spending by gamers.[26] Today, games consoles form part of a global industry that was valued at $137.9 billion (€ 122.4 bn) in 2018 alongside mobile games, gaming laptops and PC games, and games related merchandise.[27]

The global games console market *alone* reached $ 41 billion (€ 36.1 bn) in 2017. This was largely due to Nintendo's record-breaking sales of the Switch console. Indeed, 2017 was the best games console market performance since 2011. However sales are still short of 2008 when the market was worth $56 billion (€ 49.3 bn).[28]

2017 saw a notable increase in videogames console sales, but taking a longer view over the last six or seven years, mobile game revenue has been steadily increasing while the share of games console sales in the global market has been decreasing. Indeed, a recent study by Quartz estimated the console market in general to have dropped by over 50% since 2009.[29] According to market researchers IHS Markit, the decrease in the games consoles market has been the result of decreased sales volume for console hardware and a reduction in prices for games consoles, including Sony's PS4 and Microsoft's Xbox One. World console hardware spending in 2016 fell to $10.5 billion (€ 9.25 bn) from $12.8 billion (€ 11.2 bn) in 2015.[30]

Although only partial data are available in the public sphere, some key messages can be derived from the research. Firstly, although outperformed by the mobile gaming market, the console gaming market is appears to be in a period of resurgence following a decrease in sales after 2009. Secondly, there have been significant changes in how games consoles are used. This takes two forms: the first is in a divergence between the Nintendo strategy (portable, family-friendly, casual gaming) and the Sony/Microsoft strategy (high-end graphics, exclusive games, and a focus on hardcore gamers). The second, which applies across the video console market, is the necessity of a constant Internet connection for some of the most popular games.

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[25] Video Game Industry - Statistics & Facts (2016). See https://www.statista.com/topics/868/video-games/

[26] Takahashi, D. (2019). *Sony dominates console market with 57% share worldwide*. [online] VentureBeat. Available at: https://venturebeat.com/2017/03/16/sony-dominates-console-market-with-57-share-worldwide/ [Accessed 20 Feb. 2019]

[27] Newzoo. (2019). *Global Games Market Revenues 2018 | Per Region & Segment | Newzoo*. [online] Available at: https://newzoo.com/insights/articles/global-games-market-reaches-137-9-billion-in-2018-mobile-games-take-half/ [Accessed 20 Feb. 2019].

[28] Games console market 2017: Nintendo drives market to 18 per cent growth. See https://technology.ihs.com/600640/games-console-market-2017

[29] Video game consoles are doing just fine https://thenextweb.com/gaming/2018/07/31/sony-nintendo-console-sales/

[30] https://venturebeat.com/2017/03/16/sony-dominates-console-market-with-57-share-worldwide/

The remaining part of this section will present our assessment of the present and expected future size of the video games consoles market.

Section 3 is structured as follows. First we present the data sources used and describe limitations (3.1). This is then followed by a discussion of current and future sales data (3.2) and the shape of the industry and development trends (3.3). The last section (3.4) addresses forecasting.

3.1 Data sources

In terms of quantitative data, our primary source for data on games console sales is VGChartz. These data are considered to be the most comprehensive available. VGChartz uses a methodology that includes polling of end users and retail partners, statistical trend fitting around historic data, consultations with publishers and manufacturers, and verification against data publicly available from tracking firms. These figures are given at global, continental regional, and selected national levels (for Europe, data from the UK, France, and Germany are available). Whilst VGChartz acknowledges that these data represent an estimation, information is not available directly from SRI signatories. According to the SRI signatories this is because they cannot provide market sales figures, information on prices, or possible future technologies in advance. The view of the signatories is that such information is confidential, and it cannot be shared since it risks violating competition law.

In addition to VGChartz, other sources of information (cited as and when relevant) include reports from market researchers such as Newzoo[31], Clairfield International[32], IHS Markit[33], and Digital Trends[34], fact sheets released by industry bodies including UK Interactive Entertainment (Ukie)[35], and academic work studying the history and current trends within the video games market. Games journalism has also been used, particularly in cases where members of the industry have been interviewed.

With regards to the wider literature available, the study team has explored information derived from official EU statistics. Although this has the advantage of being coherent with official data used in EU industry and trade policy, Eurostat data are several years old, which is of less relevance in a fast-moving market. Moreover, although the NACE code 26.40 (Manufacture of consumer electronics), includes data on games consoles, it also covers many other electronic goods, making it only an indicative source.

The primary data limitations stem from the lack of access to direct statistics. This has ramifications beyond sales data: it also means that establishing stock data for each console is difficult (particularly since this information is not held by VGChartz or similar approved statistical sites). Although the ENTR study quoted in this section does make calculations on stock data, including the assumed rate of decay (using VGChartz data), it is unclear how these calculations were made.

Consumer expenditure data also suffer from limitations, as a result of the highly fractured marketplace. Although estimates have been made for product prices of games consoles across EU

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[31] Newzoo. (2019). *Global Games Market Revenues 2018 | Per Region & Segment | Newzoo*. [online] Available at: https://newzoo.com/insights/articles/global-games-market-reaches-137-9-billion-in-2018-mobile-games-take-half/ [Accessed 20 Feb. 2019].

[32] Clairfield.com. (2017). [online] Available at: http://www.clairfield.com/wp-content/uploads/2017/02/Gaming-Industry-and-Market-Report-2018.01-2.pdf [Accessed 20 Feb. 2019].

[33] Technology.ihs.com. (2019). *Games console market 2017 - IHS Technology*. [online] Available at: https://technology.ihs.com/600640/games-console-market-2017 [Accessed 20 Feb. 2019].

[34] Digital Trends. (2019). *The Epic Games Store is Already Luring Indie Studios Away From Steam | Digital Trends*. [online] Available at: https://www.digitaltrends.com/gaming/indie-studios-leave-steam-for-epic-game-store/ [Accessed 20 Feb. 2019].

[35] Ukie.org.uk. (2018). *UK Games Industry factsheet* [online] Available at: https://ukie.org.uk/sites/default/files/UK%20Games%20Industry%20Fact%20Sheet%20October%202018.pdf [Accessed 20 Feb. 2019].

Member States, based on larger retailers or those suggested by SRI signatories, not all Member States have comparable packages: some only sell consoles bundled with games. Moreover, assessing repair and maintenance costs is extremely difficult since repair costs cannot be standardised.

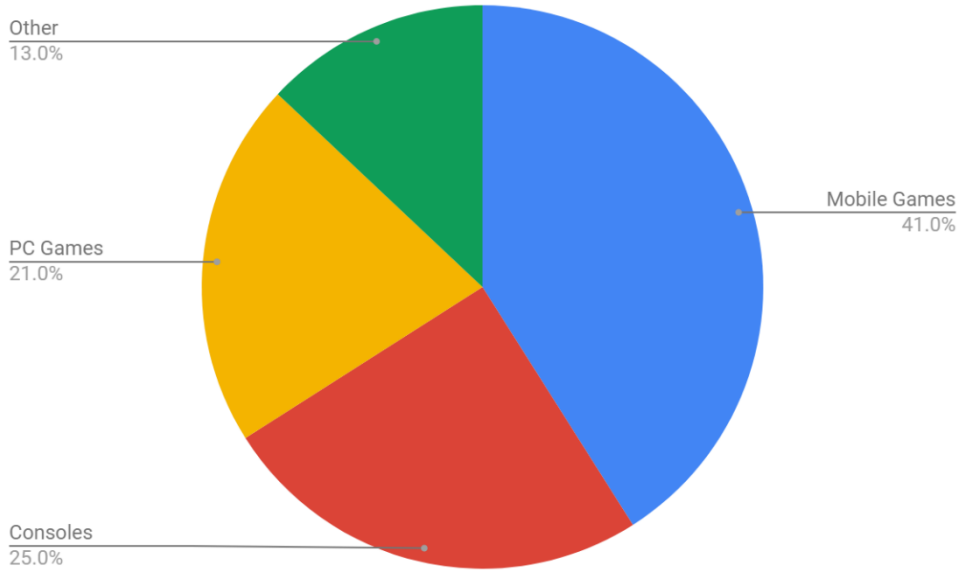
3.2 Sales Data

The sales data discussed in this section pertains to both the international gaming market as a whole, and more specifically the games console market, with a focus on the three signatories and the relative sales of their current generation products. Around the world and across Europe, the PlayStation 4 leads in sales, followed by the Switch. We also provide data on arcade consoles where these are available.

As noted in the ENTR 2010 preparatory study for the Ecodesign Directive, Lot 3, the games market is predicted to continue growing even as other products in the Lot, such as DVD players and video projectors, face a decline[36]. Although the study was carried out during the previous (seventh) generation of products, the growth in market value has continued over the past decade.

As of the end of 2018, the global games market was estimated at a value of € 120.37 billion, divided as shown in the pie chart below.

Figure 3: Share of total gaming market by platform

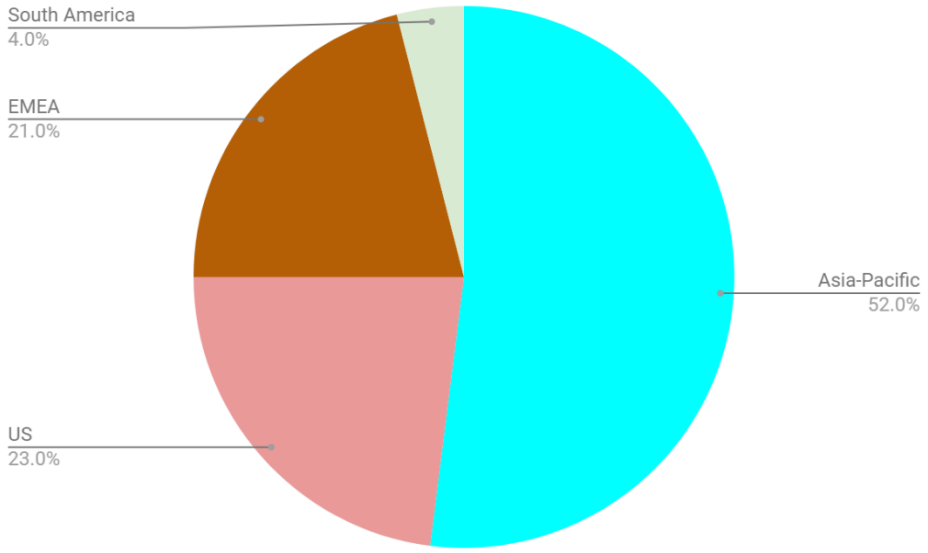


Source: NewZoo[37]

This skew in favour of mobile games is strongly reflective of underlying demographic differences, evident in the following chart.

[36] Eceee.org. (2019). Building on the Eco-design Directive, EuP Group Analysis (I)ENTR Lot 3 Sound and Imaging Equipment Task 1–7 Report [online] Available at: https://www.eceee.org/static/media/uploads/site-2/ecodesign/products/ecomultimedia/final-report-entrlot3.pdf [Accessed 20 Feb. 2019].
[37] Ukie.org.uk. (2019). *UK Games Industry factsheet* [online] Available at: https://ukie.org.uk/sites/default/files/UK%20Games%20Industry%20Fact%20Sheet%20October%202018.pdf [Accessed 20 Feb. 2019].

Figure 4: Share of global gaming market by region.



Source: NewZoo

The growth of the mobile games industry is the result of several factors, the chief amongst them being the size of the mobile phone using population in China. Whilst the penetration rate is less than 60%, this still accounts for the largest target audience in the world[38]. Secondly, from the game developer aspect, designing games for mobile phones is less time and resource intensive than for console games[39]. However, whilst mobile clearly represents the dominant market today, reports suggest that 2018 represented a growth in the games console market around the world [40 41].

Table 4: Console games 7th and 8th generation – Europe (in thousands)

Console	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
PS3	3,418	4,171	4,801	5,317,	6,259	5,009	3,150	1,544	553	215	48	0
Xbox 360	2,026	3,926	3,399	4,089	4,155	2,949	1,607	654	211	81	21	0
Wii	5,111	8,386	6,800	5,656	4,099	1,90	824	223	28	0	0	0
PS4	0	0	0	0	0	0	1,682	6,053	6,859	6,795	8,094	7,468
Xbox One	0	0	0	0	0	0	765	143	2,242	2,302	2,138	1,585
Wii U	0	0	0	0	0	411	628	931	875	346	52	0
Switch	0	0	0	0	0	0	0	0	0	0	3,404	4,504

Source: VGChartz

[38] Wikipedia (2019). *List of countries by smartphone penetration*. [online] Available at: https://en.wikipedia.org/wiki/List_of_countries_by_smartphone_penetration [Accessed 20 Feb. 2019].
[39] Ernkvist, M., & Ström, P. (2018). Differentiation in digital creative industry cluster dynamics: the growth and decline of the Japanese video game software industry. Geografiska Annaler: Series B, Human Geography, 1–24. doi:10.1080/04353684.2017.1423506
[40] Association, E. (2019). *U.S. Video Game Sales Reach Record-Breaking $43.4 Billion in 2018*. [online] Prnewswire.com. Available at: https://www.prnewswire.com/news-releases/us-video-game-sales-reach-record-breaking-43-4-billion-in-2018--300782449.html [Accessed 21 Feb. 2019].
[41] Ukie.org.uk. (2018). *UK Games Industry factsheet* [online] Available at: https://ukie.org.uk/sites/default/files/UK%20Games%20Industry%20Fact%20Sheet%20October%202018.pdf [Accessed 20 Feb. 2019].

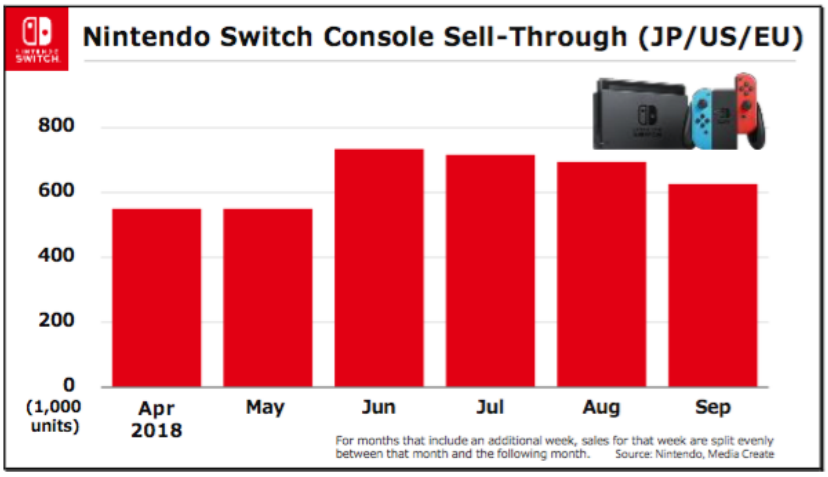
In addition to the above games consoles, the following should be mentioned:

1. **Steam machines.** As noted in section 3 of this report, steam machines are not covered by the scope definition of this study, and they are not sold in relevant numbers. According to market research published in June 2016, fewer than 500,000 steam machines were sold worldwide[42].

2. **Arcade consoles.** Although no comprehensive statistics on sales are available from VGChartz, there are some data published for arcade consoles.

For example, Nintendo Switch sales data has been published through e.g. the 2019 financial results briefing which is available online. This includes an overview of sales of Nintendo Switch in the markets of Japan, the US, and Europe in and after April 2018. Unfortunately, no specific figures are available for Europe only, but total sales can be shown to have topped at over 700,000 units in June 2018.

Figure 5: Nintendo Switch sales in 2018 (Japan, US and Europe)



Source: Nintendo Six Months Financial Results Briefing for Fiscal Year Ending March 2019.

The same report also suggests that the combined global sales of the NES Classic Edition and the Super NES Classic Edition have surpassed 10 million units. The Super NES Classic Edition, released in 2017, and the NES Classic Edition, re-released in June of 2018, both continue to sell as "must-have products".[43]

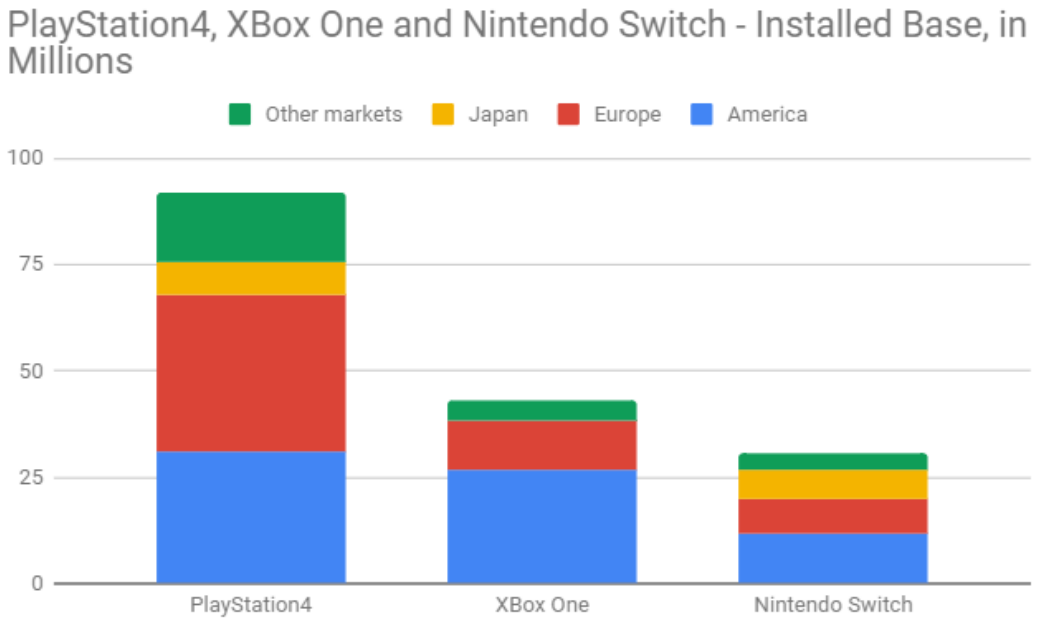
Using historic data from VGChartz, which show sales for both the seventh and eighth generations of games consoles, the market can be put in perspective. Generations of games consoles are not mutually exclusive, although the entrance of a newer model clearly has an impact on older consoles. The Play Station 4 and Switch both showed substantial sales in the first few years after release, whilst the Xbox One has yet to generate this traction. However, trying to apply historical narratives of generations is difficult given the move away from a 5-7 year cycle (discussed in *lifetime of games consoles* below).

[42] See for example *What happened to Steam Machines?* https://www.pcgamer.com/uk/what-happened-to-steam-machines/ and Seven months later, Valve's Steam Machines look dead in the water https://arstechnica.com/gaming/2016/06/its-time-to-declare-valves-steam-machines-doa/

[43] Nintendo Six Months Financial Results Briefing for Fiscal Year Ending March 2019. See https://www.nintendo.co.jp/ir/pdf/2018/181031_2e.pdf

Looking at sales of the most recent games consoles, there is a clear gap between Sony, and Microsoft and Nintendo in terms of the installed base (i.e. sold games consoles which have not fallen out of stock). Despite the PlayStation 4 and Xbox One being launched in September 2013 and competing in the same area of high-end graphics and exclusive third-party titles, the former was by far the stronger performer at both a global and regional level. Internationally, the PlayStation 4 has an estimated installed base of 91,970,000, of which 37,060,000 (40.3%) was in Europe. By contrast, the Xbox One had sales of 43,150,000 globally, and 11,520,000 (26.7%) in Europe. Whilst the Nintendo Switch also lags behind the PlayStation 4, it was released in 2017 and has already reached similar figures to the Xbox One: 30,540,000 in global installed base, and 8,240,000 (27%) in Europe. While these figures are still significantly below the all-time best-selling console the PlayStation 2 (with a global installed base of 157,680,000), the earlier console was produced for 13 years.

Figure 6: PlayStation 4, Xbox One and Nintendo Switch – installed base, in millions

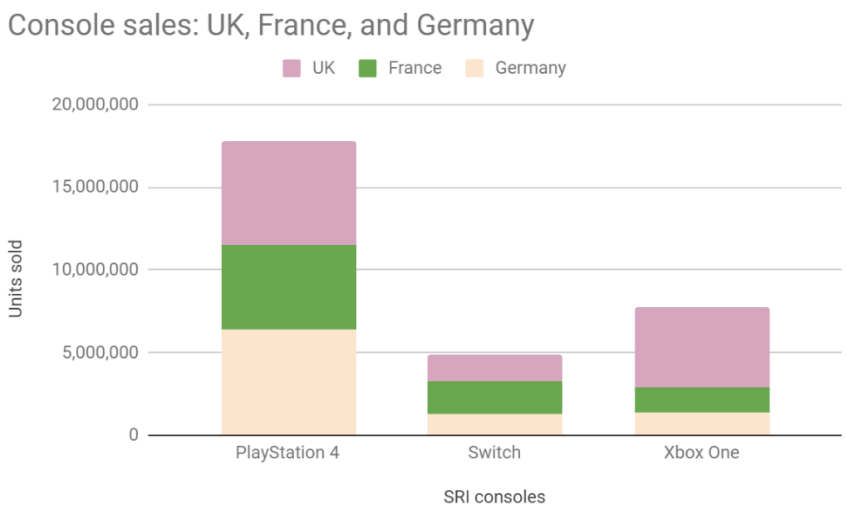


Source: VGChartz The data above does not show differences within console families (e.g. the PlayStation 4 and PlayStation 4 Pro are not differentiated).

As can be seen, whilst Europe does not represent more than 50% of units for any of the games consoles, it is nevertheless more significant than Japan and other markets outside of the US. Within Europe, the market has a clear divide between East and West, with the UK, Germany, and France accounting for most sales[44].

Figure 7: Console Sales in top three European countries

[44] Clairfield.com. (2017). [online] Available at: http://www.clairfield.com/wp-content/uploads/2017/02/Gaming-Industry-and-Market-Report-2018.01-2.pdf [Accessed 20 Feb. 2019].



Data: VGChartz

Although detailed statistics on console sales across Europe are not available, Eurostat data up to 2016 show a substantial variation in imports between member states. (None of the signatories produce games consoles in Europe, instead using countries with lower labour costs, such as China).

Although the category of audiovisual and interactive media is broader than gaming, it nevertheless helpfully shows the great differences between European countries. As shown in the VGChartz data above, the UK, Germany and France import the largest amounts of audiovisual and interactive media, followed by Spain, Italy, and the Netherlands. By contrast, states in eastern and central Europe such as Bulgaria, Slovenia, and Hungary import considerably smaller amounts of audiovisual and interactive equipment. These differences are significant in terms of pricing, leading to considerable national variations.

Figure 8: Intra and extra-EU trade in cultural goods for audiovisual and interactive media including games (values in thousands of Euros)

TIME / GEO	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
European Union (current com	:	:	:	:	:	:	:	:	:	:
Belgium	497,394 (b)	499,498	433,823	425,352	435,668	401,964 (b)	325,721	300,061	310,143	331,871
Bulgaria	12,834 (b)	13,069	8,219	11,834	13,537	7,147 (b)	7,407	16,512	21,018	28,794
Czechia	154,034 (b)	161,443	135,620	173,229	172,442	129,429 (b)	99,379	145,370	216,883	282,355
Denmark	316,595 (b)	401,629	402,876	343,763	318,372	266,972 (b)	245,106	287,233	271,175	280,736
Germany (until 1990 former t	1,413,240 (b)	2,113,580	2,436,523	1,856,590	1,534,335	1,530,363 (b)	1,418,171	1,654,473	1,821,490	1,773,237
Estonia	7,527 (b)	5,624	2,759	5,181	9,106	7,105 (b)	6,298	10,974	10,108	8,412
Ireland	233,783 (b)	239,018	230,891	226,165	225,341	147,593 (b)	114,733	130,055	164,137	162,886
Greece	149,407 (b)	148,344	125,588	109,150	86,746	81,870 (b)	79,321	88,105	89,175	93,887
Spain	843,469 (b)	845,287	561,214	563,262	547,545	371,873 (b)	358,997	456,408	446,107	623,142
France	1,266,766 (b)	1,648,617	1,347,161	1,334,751	1,318,945	1,357,395 (b)	1,208,144	1,202,237	1,219,043	1,108,100
Croatia	17,280 (b)	17,079	12,875	11,446	9,387	11,874 (b)	11,291	23,896	38,660	51,789
Italy	790,535 (b)	812,929	770,563	831,568	794,621	685,599 (b)	513,618	526,342	529,588	521,202
Cyprus	12,318 (b)	13,486	10,573	10,985	7,794	6,119 (b)	4,960	7,104	7,487	7,042
Latvia	9,683 (b)	8,501	3,392	3,656	10,046	9,672 (b)	6,920	7,075	13,079	14,230
Lithuania	7,970 (b)	6,873	3,892	4,497	7,428	9,025 (b)	14,435	27,714	15,300	11,872
Luxembourg	61,766 (b)	62,903	57,707	53,810	55,077	52,477 (b)	43,050	40,536	39,908	37,148
Hungary	61,911 (b)	61,317	55,177	62,343	79,530	89,672 (b)	89,437	93,152	113,272	102,718
Malta	6,302 (b)	6,604	4,601	6,932	6,987	2,024 (b)	1,402	1,383	3,826	3,364
Netherlands	508,699 (b)	708,934	546,759	542,365	538,058	376,431 (b)	324,923	311,364	338,620	247,920
Austria	525,085 (b)	562,838	554,542	558,881	634,976	562,653 (b)	452,839	480,226	494,185	510,804
Poland	144,733 (b)	161,006	137,665	190,373	217,607	238,104 (b)	176,545	556,936	918,812	947,853
Portugal	187,848 (b)	186,369	157,312	144,829	135,821	82,529 (b)	72,440	80,379	80,088	80,307
Romania	58,207 (b)	45,682	38,796	41,818	45,082	35,298 (b)	24,292	38,521	41,762	44,086
Slovenia	16,462 (b)	21,154	26,099	26,278	38,368	23,185 (b)	12,082	22,307	24,780	23,002
Slovakia	54,032 (b)	88,256	106,388	56,754	102,426	91,994 (b)	53,329	100,824	114,936	116,250
Finland	190,091 (b)	190,799	189,210	200,240	183,343	143,539 (b)	118,692	113,885	113,969	109,589
Sweden	399,381 (b)	545,728	491,833	508,060	486,253	420,661 (b)	321,799	390,634	314,809	265,618
United Kingdom	1,515,736 (b)	1,456,919	1,483,417	1,258,833	1,260,839	1,105,438 (b)	1,084,587	930,126	870,376	746,632
Iceland	:	:	:	:	:	:	:	:	:	:
Norway	:	:	:	:	:	:	:	:	:	:
Switzerland	:	:	:	:	:	:	:	:	:	:
Montenegro	711 (b)	620	385	294	102	102 (b)	257	143	409	252
Former Yugoslav Republic of	938 (b)	1,668	1,664	2,048	923	858 (b)	537	780	548	646
Albania	2,112 (b)	1,550	1,300	1,137	464	216 (b)	468	161	751	8,851

Source: Eurostat

3.3 Major players and design trends

This section will focus on the evolution of the video games console industry and current trends in design and development. Although there is a divergence in the marketing strategy adopted by Nintendo on the one hand and Microsoft/Sony on the other, a broader design trend, which encompasses all three signatories, is the emphasis on the Internet as both a medium for playing games and for participating through viewing. This need for an Internet connection means a higher energy usage which had to be considered in Task 3.

3.3.1 Hardware

The console hardware market has largely been streamlined to three major players since 2005-2006, with the Sony PlayStation 3, Nintendo Wii, and Microsoft Xbox 360. By contrast, all previous generations featured at least four competitors – indeed, the 1983 Video Game Crash in part stemmed from the market saturation of poor-quality and largely indistinguishable games consoles[45].

Looking at the capacities of current games consoles, there has been a fundamental bifurcation in the market which stretches back to the sixth generation of games consoles (the PlayStation 2, the Gamecube, and the Xbox). During the sixth generation, PlayStation 2 could process with the "EyeToy" motion-sensing capabilities and include it in gameplay. Both the PlayStation 2 and Xbox boasted DVD reader functionalities, portending their continued transition towards being multimedia devices as well as games consoles. This can be contrasted with the GameCube, which lacked any non-gaming components and which largely targeted a family audience through E rated games[46]. In the seventh generation, the differences became starker as Sony focused further on high-end graphics. By contrast, the Wii further expanded upon its family appeal with the use of motion sensors and games which appealed to all ages[47]. Whilst this motion sense technology has subsequently been integrated into both Nintendo's and Sony's products, it has been far more ancillary than in the case of the Wii.

As such, the current generation of games consoles has two very different product design approaches. Microsoft and Sony are fundamentally focused on high end graphics (with 4K as standard on the Xbox One X and PlayStation 4 Pro), coupled with exclusives, multimedia, and independent games. By contrast, the Switch focuses primarily on family-friendly content, Nintendo exclusives, and the possibility to act as both a handheld and stationary console). These different strategies are also manifest in the design of components such as power supply. As noted in responses from the signatories in February, both Sony and Microsoft use internal power supplies for efficiency and internal cooling, given the higher energy usage. By contrast, Nintendo's Switch uses an external power supply, allowing it to be used with other devices and for easy replacement in case of damage.

These design strategies cover two markets, which were described in the 2010 preparatory report:

> *"For games consoles, competition can be distinguished between those competing for the gaming enthusiast market (demand for enhanced graphics and more advanced game playing) and those competing for lower specification products."*[48]

[45]Dillon, Roberto. The golden age of video games: The birth of a multibillion dollar industry. AK Peters/CRC Press, 2016.
[46] Derdenger, T. (2014). Technological tying and the intensity of price competition: An empirical analysis of the video game industry. Quantitative Marketing and Economics, 12(2), 127–165. doi:10.1007/s11129-014-9143-9
[47] Norman, Donald A., and Roberto Verganti. "Incremental and radical innovation: Design research vs. technology and meaning change." Design issues 30.1 (2014): 78-96.
[48] Eceee.org. (2019). Building on the Eco-design Directive, EuP Group Analysis (I)ENTR Lot 3 Sound and Imaging Equipment Task 1–7 Report [online] Available at: https://www.eceee.org/static/media/uploads/site-2/ecodesign/products/ecomultimedia/final-report-entrlot3.pdf [Accessed 20 Feb. 2019].

However, there are also product design changes which apply across all games consoles. Most noteworthy is that the Internet has become central to how games are acquired (i.e. through downloading or, in some cases, cloud computing) and played. The highly successful 'Battle Royale' genre including Fortnite and Player Unknown's Battlegrounds requires constant Internet connection in order to play[49]. The previous genre to undergo a similar 'boom', the Multiplayer Online Battle Arena (MOBA), also requires an Internet connection to be played. Moreover, the social element of games has also become central to their appeal through streaming, where a game and commentary is uploaded live to dedicated sites like Twitch or general video-hosting services like YouTube. Whilst studies on streaming games have focused on the relatively few streamers who successfully make a living from this new niche, a significantly larger group are broadcasting their gaming for pleasure[50].

One other recent development in the industry is the rerelease of 'classic' games consoles by both Nintendo (the NES Classic Edition, released in 2016, and the Super NES Classic Edition, released in 2017) and Sony (the PlayStation Classic, released in 2018). Unlike the current generation games consoles that are designed to play a range of games which are purchased separately, classic editions are dedicated games consoles with an in-built library, playing on the nostalgia of gaming fans[51]. The Nintendo classic games consoles have fared well, with combined sales of 10 million as of October 2018. Global figures for the PlayStation Classic have yet to be released, although the decision to cut the price by 40% one month after launch suggest sales have been substantially lower than expected[52].

3.3.2 Software

The other vital aspect of the games console market is software (i.e. the games). This can be developed by games console companies or their subsidiaries (first-party development), or by external organisations (third-party development). This relationship has also changed substantially since Activision became the first ever third-party developer, producing games for Atari from 1979 onwards[53]. Poor quality third-party games were one of the causes of the 1983 Video Games Crash, leading to increased levels of quality control from major industry players such as Nintendo[54]. At the same time, a larger library of high-quality third-party games made only for a single platform ('exclusives'[55]) has played a role in the success of some games consoles, most notably the original PlayStation[56]. Third-party developers have also gone through a life-cycle: in the 1970s, when video games were first being produced, they were largely small independent companies but as the cost of video games production increased and console makers grew risk averse, the industry became dominated by larger players[57]. However, with the rise of digital distribution, independent games development has flourished across games consoles as well as the PC market[58]. This can be seen in the

[49] P. Hornshaw, "The History of Battle Royale: From Mod to Worldwide Phenomenon," Digital Trends, 04-Feb-2019. [Online]. Available: https://www.digitaltrends.com/gaming/history-of-battle-royale-games/ [Accessed: 21-Feb-2019]
[50] Mark R. Johnson & Jamie Woodcock (2017): 'It's like the gold rush': the lives and careers of professional video game streamers on Twitch.tv, Information, Communication & Society, DOI: 10.1080/1369118X.2017.1386229
[51] Lizardi, Ryan. *Nostalgic generations and media: Perception of time and available meaning*. Lexington Books, 2017.
[52] Schrier, J. (2018). *PlayStation Classic Gets Huge Price Cut, Which Says A Lot*. [online] Kotaku.com. Available at: https://kotaku.com/playstation-classic-gets-huge-price-cut-which-says-a-l-1831338278 [Accessed 20 Feb. 2019].
[53] Welling, J. (2019). Gamasutra - The History Of Activision. [online] Gamasutra.com. Available at: https://www.gamasutra.com/view/feature/1537/the_history_of_activision.php?print=1 [Accessed 21 Feb. 2019].
[54] Ernkvist, Mirko. "Down many times, but still playing the game: Creative destruction and industry crashes in the early video game industry 1971-1986." (2008): 161-191.
[55] Derdenger, T. (2014). Technological tying and the intensity of price competition: An empirical analysis of the video game industry. Quantitative Marketing and Economics, 12(2), 127–165. doi:10.1007/s11129-014-9143-9
[56] Minotti, M. (2014). Here's who won each console war. [online] VentureBeat. Available at: https://venturebeat.com/2014/08/20/heres-who-won-each-console-war/ [Accessed 21 Feb. 2019].
[57] Walker, J. (2007). RPS Exclusive: Gabe Newell Interview. [online] Rock Paper Shotgun. Available at: https://www.rockpapershotgun.com/2007/11/21/rps-exclusive-gabe-newell-interview/ [Accessed 21 Feb. 2019].
[58] Pereira, L. S., & Bernardes, M. M. S. (2018). Aspects of Independent Game Production. Computers in Entertainment, 16(4), 1–16. doi:10.1145/3276322

UK games industry, with 95% of companies classed as SMEs, and 80% with fewer than four employees.[59]

More recently, third-party developers have also begun to release exclusive Downloadable Content (DLC) and optional additional software. Whilst all players will be able to access the same base game, specific material (for example, different characters or weapons) will only be available to specific games consoles. This can be contrasted with the rise of cross-platform play on online games such as Fortnite: whilst previous console generations had siloed online gaming experiences, users can increasingly play against those who own other consoles, PCs, and mobiles[60].

When looking at the game development market, the three SRI signatories are again major players. According to research by market analysts NewZoo, they all rank within the top 10 for video games sales (excluding hardware). There is only one European contribution to this list (the French company Ubisoft, which ranks 15th). However, European companies have created major games: Rockstar Studios, which originated in Britain but is now owned by American Take Two Interactive, was responsible for Grand Theft Auto V. The majority of Member States (19 of 28) have trade bodies for game developers and publishers, in addition to Europe-wide groups: the Interactive Software Federation of Europe and the European Games Developer Federation.

3.3.3 Lifetime of games consoles

Traditionally, games consoles have been released in 5-7 year cycles (cf. section 5). In earlier generations, new games consoles offered "a leap in terms of the technological performance along key primary performance dimensions such as graphics, sound, processing and storage capacity."[61] However, the demand for increasingly high-end graphics and complex programming means that design teams and attendant costs have similarly risen. As noted by Ernkvist and Strom, the rising overheads have made less resource heavy platforms more appealing, chief amongst them being mobile gaming. Moreover, the actual lifetime of games consoles is likely to be far longer than the development cycle. Although most studies use 5 years as an average (cf. section 4.3.14.3.1), a UK government study suggests that games consoles "never die". Consumers appear to like playing their old games on their old consoles. The question of lifetime, usage time, stock life etc. is looked into in more detail in section 4.3.1.

3.3.4 Consumer expenditure

The cost of games consoles varies across EU Member States (cost data come from local chain dealers or national branches of international retailers). The PS4 500GB (the basic model) has an average cost of €297.71, the 1 TB model of €352.33, and the PS4 Pro of €391.52. By contrast, the Xbox One S (equivalent to the PS4 500GB) has an average cost of €245.21, whilst the higher end Xbox One X costs €443.49. The Switch falls in between the standard and higher end competitor models, with an average cost of €322.384 across Member States. The higher-end models produced by Sony and Microsoft have similar functionality to their standard counterparts, with additional power, memory, and graphical capabilities.

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[59] 2015. Don't clone my indie game, bro": Informal cultures of videogame regulation in the independent sector. Cult. Trends 24, 2 (2015), 143–153. https://doi.org/10.1080/09548963.2015.1031480

[60] Yin-Poole, W. (2018). Ex-Sony dev says PS4 / console cross-platform block is all about the money. [online] Eurogamer. Available at: https://www.eurogamer.net/articles/2018-06-19-ex-sony-dev-says-ps4-console-cross-platform-block-is-all-about-the-money [Accessed 21 Feb. 2019].

[61] Ernkvist, M., & Ström, P. (2018). Differentiation in digital creative industry cluster dynamics: the growth and javascript:void(0);decline of the Japanese video game software industry. Geografiska Annaler: Series B, Human Geography, 1–24. doi:10.1080/04353684.2017.1423506

In addition to purchasing games consoles, there is the additional cost of energy which varies across Member States.

Figure 9: Electricity prices 2016-2018

Electricity prices, First semester of 2016-2018
(EUR per kWh)

	Households (¹)			Non-households (²)		
	2016S1	2017S1	2018S1	2016S1	2017S1	2018S1
EU-28	0,2052	0,2041	0,2049	0,1159	0,1140	0,1142
Euro area	0,2184	0,2196	0,2187	0,1219	0,1208	0,1193
Belgium	0,2544	0,2799	0,2733	0,1115	0,1127	0,1085
Bulgaria	0,0956	0,0955	0,0979	0,1002	0,0763	0,0810
Czechia	0,1420	0,1438	0,1573	0,0730	0,0688	0,0733
Denmark	0,3088	0,3049	0,3126	0,0948	0,0845	0,0807
Germany	0,2969	0,3048	0,2950	0,1505	0,1519	0,1499
Estonia	0,1208	0,1207	0,1348	0,0878	0,0870	0,0865
Ireland	0,2320	0,2305	0,2369	0,1327	0,1237	0,1321
Greece	0,1716	0,1936	0,1866	0,1173	0,1073	0,1028
Spain	0,2185	0,2296	0,2383	0,1105	0,1061	0,1059
France	0,1685	0,1690	0,1754	0,0962	0,0992	0,0982
Croatia	0,1311	0,1196	0,1311	0,0903	0,0874	0,0994
Italy	0,2342	0,2132	0,2067	0,1526	0,1477	0,1423
Cyprus	0,1527	0,1863	0,1893	0,1048	0,1414	0,1405
Latvia	0,1628	0,1586	0,1531	0,1165	0,1179	0,1039
Lithuania	0,1231	0,1116	0,1097	0,0940	0,0837	0,0838
Luxembourg	0,1698	0,1615	0,1671	0,0873	0,0780	0,0833
Hungary	0,1114	0,1125	0,1123	0,0805	0,0740p	0,0840
Malta	0,1257	0,1328	0,1285	0,1422	0,1353	0,1347
Netherlands	0,1620	0,1562	0,1706	0,0857	0,0822	0,0863
Austria	0,2034	0,1950	0,1966	0,1026	0,0930	0,0997
Poland	0,1332	0,1457	0,1410	0,0808	0,0877	0,0876
Portugal	0,2350	0,2284	0,2246	0,1125	0,1145	0,1123
Romania	0,1260	0,1198	0,1333	0,0760	0,0769	0,0831
Slovenia	0,1618	0,1609	0,1613	0,0847	0,0784	0,0860
Slovakia	0,1423	0,1435	0,1566	0,1092	0,1148	0,1166
Finland	0,1541	0,1581	0,1612	0,0685	0,0667	0,0681
Sweden	0,1894	0,1936	0,1917	0,0616	0,0648	0,0684
United Kingdom	0,1951	0,1766	0,1839	0,1377	0,1268	0,1344
Iceland	0,1312	0,1598	0,1540	0,0736	0,0795p	:
Liechtenstein	0,1728	0,1724	:	0,1463	0,1296	:
Norway	0,1515	0,1642	0,1751	0,0744	0,0711	0,0778
Montenegro	0,0956	0,0972	0,1024	0,0794	0,0772	0,0810
Former Yugoslav Republic of Macedonia	0,0822	0,0820	0,0781	0,0819	0,0561	0,0624
Albania	0,0824	0,0844	:	:	:	:
Serbia	0,0641	0,0664	0,0705	0,0670	0,0639	0,0704
Turkey	0,1267	0,1048	0,0904	0,0744	0,0634	0,0589
Bosnia and Herzegovina	0,0831	0,0859	:	0,0612	0,0594	:
Kosovo (³)	0,0590	0,0662	0,0596	0,0750	0,0798	0,0695
Moldova	0,0962	0,0977	0,1020	0,0827	0,0828	0,0880
Ukraine	0,0249	0,0393	0,0410	:	:	0,0595
Georgia	:	:	0,0685	:	:	0,0489

(:) not available
(p) Provisionnal
(¹) Annual consumption: 2 500 kWh < consumption < 5 000 kWh.
(²) Annual consumption: 500 MWh < consumption < 2 000 MWh.
(³) This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo Declaration of Independence.
Source: Eurostat (online data codes: nrg_pc_204 and nrg_pc_205)

eurostat

Source: Eurostat

It is also worth noting that there is a second-hand market across Europe, which is difficult to measure since the figures are divided up amongst a large number of retailers. Ukie estimated the total secondary market (which covers both consoles and games) at £123,000,000 (€107,000,000) in 2017, 9% higher than 2014. This can be compared to the new hardware market of £689,000,000 (€793,000,000) in the same year, showing that it represents a significant proportion of the total games console market. This is significant since older second-hand games consoles are less likely to have the energy efficiency features which appear in updated versions. Finally, as noted in the section on data limitations, data on repairs are very difficult to find. This is because of variations across Member States

and within them, depending on the severity of a games console's malfunction and the route taken to fix it (e.g. whether a larger firm specialising in repairs is chosen or a smaller shop with some technical training).

3.4 Forecasting

Forecasts of the future trends in gaming are fraught with difficulties. As the SRI signatories discussed in a conference call on 24th January 2019, there is a very high element of confidentiality surrounding new games console specifications and release dates. Nevertheless, there is considerable news coverage of the subject, including interviews with signatory staff.

Although reporting on new games consoles from Microsoft[62] and Sony[63] needs independent assessment, it suggests that both developers are continuing down the path of high-quality graphics and increasingly powerful machines (often by maintaining the high energy use but with increasing computing power). Reporting on the Switch has focused on whether it represents a shift in Nintendo's strategy, away from simply selling games consoles to encouraging users to buy larger numbers of games[64]. Similarly to Microsoft and Sony, it is likely that the future direction for Nintendo is attempting to turn strong early hardware sales into long-term games sales from third-party developers. Beyond development trends, the growth of the games console market in 2018 suggests that the appetite for games consoles remains strong (despite constant fears that it has peaked)[65]. Although mobile games are likely to continue to grow faster as smartphone penetration expands further in the Asia-Pacific region, the market for games consoles (and in particular games for consoles) does not seem to have plateaued[66]. According to the SRI signatories, network areas is the major growth area for games consoles.

There are other possible developments. For example, the Oculus Go which is a stand-alone VR device that can be used for playing video games. However at the time of writing, the gaming function appears to be still under development, and the device is not deemed relevant for our study. Having said this, future studies may revisit its relevance since it may become a more prevalent device as it develops and matures.

Extrapolations in the market are inevitably difficult too, but perhaps the most reasonable assumption is of continued growth with the release of the next generation of consoles in the next two to three years. However, competition from PC gaming, mobile games, and other avenues of consumption mean that the focus is likely to shift from simply selling games consoles to encouraging console owners to buy a larger number of games[67]. With such a strategy in mind, the numbers of games consoles sold may fall in further generations, even as the number of games sold for each purchaser will rise. However, an interview with the CEO of Ubisoft, a major French game developer, suggests that the ninth generation would be the last, with the replacement subsequently of dedicated consoles by

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[62] Pino, N., Leger, H. and Hood, V. (2019). *Xbox Two: what we want to see out of a new Xbox*. [online] TechRadar. Available at: https://www.techradar.com/uk/news/gaming/consoles/next-xbox-release-date-news-and-rumors-1266462 [Accessed 25 Feb. 2019].

[63] Boxer, S., Boyle, E. and Hood, V. (2019). *PS5: All the games, specs, news, and rumors for Sony's Playstation 5*. [online] TechRadar. Available at: https://www.techradar.com/uk/news/gaming/consoles/ps5-release-date-news-and-features-1213409 [Accessed 25 Feb. 2019].

[64] Lewis, L. (2019). *Nintendo's share plunge sparks debate on future of console gaming*. [online] Ft.com. Available at: https://www.ft.com/content/383b29d4-27c2-11e9-88a4-c32129756dd8 [Accessed 25 Feb. 2019].

[65] Video game consoles are doing just fine https://thenextweb.com/gaming/2018/07/31/sony-nintendo-console-sales/

[65] https://venturebeat.com/2017/03/16/sony-dominates-console-market-with-57-share-worldwide/

[66] Editorial (2019). *How Southeast Asia ranks on all things digital*. [online] Southeast Asia Globe Magazine. Available at: https://sea-globe.com/how-southeast-asia-ranks-on-all-things-digital/ [Accessed 25 Feb. 2019].

[67] Lewis, L. (2019). *Nintendo's share plunge sparks debate on future of console gaming*. [online] Ft.com. Available at: https://www.ft.com/content/383b29d4-27c2-11e9-88a4-c32129756dd8 [Accessed 25 Feb. 2019].

streaming hardware[68]. As noted by the SRI signatories at the first Stakeholder meeting in March 2019, high-end gaming on streaming would require cloud gaming, with potentially higher energy usage and a commensurate fall in physical video games data carrier sales.[69] Current ongoing research is investigating the relationship of carbon footprint on local gaming with physical data carriers and cloud gaming. First insights of the SRI are that it depends on the duration of the game being played, but more data and studies are needed for a full assessment on the impact. An outlook on cloud gaming is given in Section 5.5.

[68] Gurwin, G. (2018). Ubisoft CEO Thinks Next-Gen Game Consoles Will Be Last | Digital Trends. [online] Digital Trends. Available at: https://www.digitaltrends.com/gaming/ubisoft-ceo-next-game-consoles-will-be-last/ [Accessed 28 Feb. 2019].

[69] More data is needed on the energy use of cloud data centres to fully understand the impacts of a transition to cloud-based gaming.

4. Task 3 Use phase

Task 3 comprises the in-depth assessment of the games consoles' use phase as a basis for the subsequent identification and analysis of environmental impacts (in combination with the findings from Task 4/ Chapter 0).

This comprises an in-depth evaluation of power modes and energy use including measurements of the energy consumption of different games consoles in different operating modes. Based on thermal measurements executed, the thermal behaviour of consoles and power supplies together with corresponding conclusions is described. In addition, a list of updates is presented, providing insight into the frequency and size of updates meant for the operating system of each console investigated in this study. Finally, product lifetime, user behaviour with regard to repair activities and disposal are investigated.

4.1 Power modes and energy use

4.1.1 Power modes

The question of the power modes being investigated and especially in which way they are tested, is fundamental to this study. After close inspection of the documents, slight, but not unimportant differences can also be found in the description of the test procedures.

For example, the U.S. Environmental Protection Agency (EPA) Recognition Program for Game Consoles V1.0 (Revision March 2013)[70] from the Energystar Website makes a distinction within the Mode "Game Functions" and "Streaming Media" with a state of "play" and "pause". Interestingly, the test procedure in the EPA is just defined for networked streaming content, without further mentioning DVDs or Blu-Rays. Additionally, as stated in section 2.4.1, the EPA has been crafted without consultation and without involvement of the manufacturers. For completeness, the modes are listed below.

Table 5 shows a consolidated terminology of the operational modes, since studies and regulations (depending on the origin) have slight variations in their descriptions. In the case of the EPA, the Pause submodus is an interesting idea at first glance, but refers probably to some sort of Game Menu. Depending on the game, the implementations can differ greatly. Some have a dedicated menu for interaction with no or just partial in-game content rendering displayed, interaction for change of settings, a quit, save or load gamestate (for example in Witcher III: The Wild Hunt), or in-game menus where gameplay is also "paused" (for example opening an inventory in a role-play game). Also, developers of games tend to implement some sort of idle-animation after several minutes without receiving controller input and display content, which could otherwise not be seen during 'uninterrupted' active gameplay (for example in Red Dead Redemption 2).

In conclusion, the games console manufacturers have no control over this (ingame) implementation. It would also be difficult to make an attempt at a standardized test procedure, when the game is paused by a console feature (for example Switching to another application, e.g. social interaction with chat), because the necessary resources are still needed by the game, in order to continue being fully functional after resuming to the game. First tests with the games consoles support this observation, with a decrease of the power consumption while being outside of the paused game. During a pause of the video stream, content is most likely buffered to a certain extent.

For the estimation on the TEC calculations, the reported and measured power consumption on standby and networked standby are included in this study. However, these are not within the scope of the SRI, but are covered under lots 6 and 26 legislation.

Rest mode features are provided for all games consoles of the 8th generation as an energy saving mode alternative to leaving the console on and were requested by stakeholders in previous forums. The reasons for the offering this low-power and user-enabled feature as an alternative to users disabling APD and leaving their games consoles on in active modes are various: the game not supporting save-checkpoints anytime, background-updates, waiting time for startup of the console and game. By default, the game console is set to power down to standby mode for European purchasers.

Table 5: Overview Definition of Operational Modes for games consoles

Definition of Operational Modes	SRI 2.6.3	EPA Recognition Program for Game Consoles V1.0 (Revision March 2013)[70]	NRDC[79]
Active Gaming	Mode in which the Games Console is actively performing its primary function of game playing	(1) Game Play: A game is actively being played and the Game Console is receiving user input. (2) Game Play Pause: A game otherwise being played is paused after receiving user input.	Active use of a game program
Media Playback	Mode in which there is decoding and playing of video files and codecs up to UHD content, on the Games Console's own optical discs, and streaming media players	(1) Video Stream Play: The Game Console is playing a video stream through a network connection. (2) Video Stream Pause: The video player is paused during active streaming of the video.	Submode - Video streaming: Viewing of a high-definition (HD) Netflix movie (streamed) Submode - TV Mode: use of the console to control the TV and view programs or the program guide from a cable, satellite, or telco set-top box (currently available only on Xbox One)
Navigation	Mode in which no other mode is engaged and the Games Console is displaying a menu of functions (the "Home Menu") from which the user may select.	Navigation Menu (a.k.a. Home Menu, System Menu, Cross Media Bar, or Dashboard): The Home Menu includes the screen(s) initially displayed for user navigation to selected game features for the selected game.	use of the menu screen to navigate among different functions
Standby	As defined in EU Regulation (EU) No 1275/2008 (Annex II), a mode in which the Games Console is connected to the mains power source, depends on energy input from the mains power source to work as intended and provides only reactivation function, or reactivation function and only an indication of enabled reactivation function, and/or information or status displays. A further description on entering the standby mode is given in the original document.	The mode where the Game Console is plugged into a power source but is not providing any primary or secondary function and has no saved hardware state. The Game Console has no active network link although may be capable of charging devices in this mode.	Lowest power mode, in which the only function available is reactivation from the console's power button or controller
Networked Standby	Networked Standby: As defined in EU Regulation (EU) No 801/2013, means a condition in which the equipment is able to resume a function by way of a remotely initiated trigger from a network connection.	Not defined	"sleep" mode, in which the console remains connected to the internet and can provide limited secondary functions such as charging of usb peripherals and reactivation via voice command (for Xbox One)

[70] https://www.energystar.gov/sites/default/files/Final%20Version%201%200%20EPA%20Voluntary%20Criteria%20for%20Energy%20Efficient%20Game%20Consoles.pdf [Accessed 01. March 2019]

After looking into the definitions of the operational modes of relevant resources, we conclude the following operational modes and submodes should be used, as described in Table 6:

Table 6: Operational modes in study

Definition of Operational Modes in Study	Description	Submodes
Active Gaming	Mode in which the Games Console is actively performing its primary function of game playing	(1) Gameplay in Singleplayer/Local Multiplayer (2) Gameplay in network multiplayer (3) Shared Gameplay (1-3) Investigated with separation of HD/UHD settings, depending on the consoles capabilities
Media Playback	Mode in which there is decoding and playing of video files and codecs up to UHD content, on the Games Console's own optical discs, memory cards and streaming with media players	(1) Networked Media Streaming (2) Optical Drive Media Streaming (3) Memory Card/Storage Media Streaming (1-3) investigated with separation of HD/UHD settings, depending on the consoles capabilities
Navigation	Mode in which no other mode is engaged and the Games Console is displaying a menu of functions (the "Home Menu") from which the user may select applications, settings, social interaction via chat.	Mode in highest available settings of games console.
Low-power standby	As defined in EU Regulation (EU) No 1275/2008 (Annex II), only the following functions should apply:_means a reactivation function, or reactivation function and only an indication of enabled reactivation function, and/or — information or status display	Every setting available to the standby tested. Further submode-specifications will be made if applicable.
Networked Standby	Networked Standby: As defined in EU Regulation (EU) No 801/2013, means a condition in which the equipment is able to resume a function by way of a remotely initiated trigger from a network connection.	Every setting available to the networked standby tested. Further submode-specifications will be made if applicable.
Rest	Game console state in which an active application is on hold, able to resume from a lower power state by awaking on controller or similar input. This mode can incorporate several features like enabling users to put a current game state on hold for a longer time of period or install updates, with considerably reduced power consumption. The different features available for each console in the rest mode are set out in the tables 10, 11 and 12.	This is a popular feature under different names of the 8th games console generation. As probably one of the most prominent reasons for gamers not using a low-power standby. Low-power is set as the default setting, while users in Europe are prompted for the Rest-Option in the first run of the console in the setup. During the first stakeholder meeting, estimations were communicated, that around 25% of the users in Europe use the standby mode, which corresponds to around 75% of the users in Europe using the rest mode.

4.1.2 Power Management – Default settings

4.1.2.1 Xbox - Default settings

The default auto-power down time setting is 60 minutes[71]. The Xbox One features the Instant-On feature, whereby as the games console is downloading updates, it can be woken with voice commands (where available). The power usage is described as 12 watts on the website giving power modes (with European language and country settings). In Europe the Xbox One Instant-On feature is not set as default; the user has to make a choice between an Energy-Saving or Instant-On mode during the first setup. Also, the state of a played game can be held in this mode. The Instant-On has another further subfunction available too, where the storage is turned off. No information can be found on the impact of this feature.

A default value for dimming the screen is set at 10 minutes being idle.

The energy-saving mode is described as 0.5 watts of power usage for the Xbox One,Xbox One S and Xbox One X games consoles.

4.1.2.2 PS4 - Default settings

With the games consoles under consideration, the default automatic shutdown times match the values found on the official website for energy efficiency[72] of Sony. For applications (games) the value is set at 20 minutes. For media playback a time frame of 4 hours is given in the default settings as defined in the SRI.

A screensaver option is set by default to 15 minutes which dims the screen. Beginning after ten minutes without user input, in navigation mode the console enters an idle mode, whereby the wave motion in the navigation mode ceases and the power consumption of the console is reduced.

Additionally, other console-related features are set to “off” by default in the current system version v6.51. These features are:

- Supply Power to USB Ports
- Stay Connected to the Internet
  - Enable Turning On PS4 from Network
- Keep Application Suspended

Besides of these options, the user is notified that each enabled feature will consume more power.

- The energy efficiency website offers values for “standby”, “networked standby” and “rest” (with reported values on the following options: ‘Supply Power to USB Ports’, ‘Stay Connected to the Internet’, ‘Keep Application Suspended’, ‘All’) in detail for the PS4 models.

4.1.2.3 Nintendo Switch - Default Settings

The Nintendo Switch offers an auto-sleep mode with predefined settings according to the official website with the following settings[73]:

Table 7: Nintendo Switch Default Settings Autosleep Mode

[71] https://support.xbox.com/en-GB/xbox-one/console/learn-about-power-modes
[72] https://www.playstation.com/en-gb/legal/energy-efficiency/ accessed 09/02/2019
[73] https://www.nintendo.co.uk/Support/Nintendo-Switch/Troubleshooting/The-Nintendo-Switch-console-is-going-into-sleep-mode-or-turning-off-on-its-own-/The-Nintendo-Switch-console-is-going-into-sleep-mode-or-turning-off-on-its-own--1200921.html access 10/02/2019

Auto-sleep mode for	Auto-sleep mode after(minutes)
TV Mode	60
Handheld Mode	10
Media Playback	240

It is noteworthy here that the TV auto-sleep mode minimum setting is one hour and can be turned off or changed to 2, 3, 6 or 12 hours. Also, auto-sleep for media playback will force the Switch to sleep after 4 hours even it has been suspended with the "Suspend Auto-Sleep While Playing Media Content" function, which prevents auto-sleep from activating while media content is playing.

Furthermore, for the TV-Settings, a "Screen Burn-in Reduction" feature is offered, which reduces the screen brightness after five minutes of inactivity, if turned on (default setting).

Additionally, the Switch is able to be in a hold mode for active applications like games, whereas the users are able to resume the priory console state by waking from the controller or similar input. During this operation mode, measurements show a consumption below than 0.5 watts on average.

4.1.2.4 Summary - Default Settings by SRI

The SRI as of v.2.6.3 defines requirements for Auto-Power Down (APD)[3]. The following gives a direct excerpt from the document:

- "For operational modes other than Media Playback, the period of inactivity required to trigger APD shall be set at 1 hour or less from the time of the last user input when powering down to regulatory standby or networked standby mode;
- In Media Playback mode, APD shall be triggered within 4 hours of starting any audio or video media playback or within 1 hour or less of user inactivity after termination of video media content
- After an automatic wake event, Games Consoles shall power down automatically within 5 minutes after performing required system maintenance and downloads, or other functions that may require an automatic wake-up"[3]

In our desk research, the SRI's requirements for APD are fulfilled at the games consoles' default settings.

4.1.3 Energy use data in different active power modes

Table 8 gives a comprehensive overview of the models in active use from the official numbers of PS4 and Xbox One plus preliminary data for the Nintendo Switch.

Table 8: Overview Consumption of different models in Modes as defined by SRI 2.6.3

	Mode Power Usage in Watt				
Model	Navigation	DVD	Blu-Ray	Streaming	Active Gameplay
Xbox One (1540) [71]	61	68	69	63	106
Xbox One S (1681) [71]	27	33	39	32	70
Xbox One X (1787) [71]	46	51	54	53	108
PS 4 (CUH-11XX) [72]	77.6	97.4	89.1	81.9	115.1
PS 4 (CUH-12XX) [72]	65.9	74.7	66.9	67.5	95.1

	Mode Power Usage in Watt				
Model	Navigation	DVD	Blu-Ray	Streaming	Active Gameplay
PS 4 Slim (CUH-20XX) [72]	48.5	50.0	52.4	52.5	82.8
PS 4 Slim (CUH-21XX) [72]	41.8	42.1	45.8	47.0	75.2
PS 4 Slim (CUH-22XX) [72]	42.2	42.5	45.5	46.9	78.2
PS 4 Pro (CUH-70XX) [72]	60.4 (HD) 66.7 (UHD)	54.1	59.5	59.3	126.1 (HD) 148.1 (UHD)
PS 4 Pro (CUH-71XX) [72]	58.5 (HD) 66.9 (UHD)	51.3	56.0	57.4	139.0 (HD) 149,6 (UHD)
PS 4 Pro (CUH-72XX) [72]	56.1 (HD) 64.3 (UHD)	49.3	54.1	54.7	146.4 (HD) 158.2 (UHD)
Nintendo Switch (TV Mode) (Switch Only) (Nintendo Measurements)	4.97 (reported) 5.35 (measured)	Not available	Not available	7.5 (reported) 6.86 (measured)	12.38 (reported Mario Kart 8 Deluxe) 11.60 (measured Mario Kart 8 Deluxe)

Table 9: Overview Consumption of alternate Nintendo Switch Usage Modes

	Mode Power Usage in Watt (Fully charged Nintendo Switch)				
Model	Navigation	DVD	Blu-Ray	Streaming	Active Gameplay
Nintendo Switch (Table top) (Switch Only) (Lab measurements)	3.99	Not available	Not available	5.31	6.35 (measured Mario Kart 8 Deluxe)
Nintendo Switch (Handheld) (Lab measurements)	5.96	Not available	Not available	6.88	8.06 (measured Mario Kart 8 Deluxe)

Official detailed data have been made available for the Nintendo Switch after the first stakeholder meeting relating to the TV Mode of the Switch in a fully charged state. Additional values are entered based on measurements in the lab. Similar power consumption values have been reported online[74]. As the Switch is a games console with included batteries, the loading state can lead to different power consumptions to charge up the battery state of either the console or the Joy-Con controllers. Hence, there is momentarily lower power consumption, if for example the Joy-Cons are not attached.

4.1.4 Energy use data in different low-power modes

The numbers for power consumption of the low-power modes are delivered differently on the official websites as the features available differ. Table 10, Table 11 and Table 12 give a comprehensive overview of the models in low power modes based on measurements in the lab. As additional information, the average energy consumption values of the charging process are supplied in Table 12 as well. The table contains various possible usage constellations of the Nintendo Switch. It has to be noted that these values can differ for different controller models. Comparing the measurements is not suitable due to different definitions of the modes and also the ability of the Nintendo Switch to be used for handheld gaming.

Table 10: Overview Consumption of Playstation 4 Low Power Modes

	Mode Power Usage in Watt	
Model	PS4 Pro (CUH-7216)	PS4 Slim (CUH-2216)
Off mode	0.25	0.24

[74] https://www.anandtech.com/show/11181/a-look-at-nintendo-switch-power-consumption/2 [Accessed 04 Jan. 2019]

	Mode Power Usage in Watt	
Model	PS4 Pro (CUH-7216)	PS4 Slim (CUH-2216)
Rest mode: Supply power to USB ports.	5.25	4.43
Rest mode: Stay connected to the internet.	0.95	1.00
Rest mode: Keep application suspended.	1.77	1.88
Rest mode: All options enabled.	6.45	5.51
Rest mode: Installing update.	52.69	41.55
Rest mode: Charging one controller.	9.05	8.2
Rest mode: Installing update and charging one controller.	57.07	44.69

Table 11: Overview Consumption of Xbox One Low Power Modes

	Mode Power Usage in Watt	
Model	Xbox One X	Xbox One S
Off mode	0.29	0.33
Energy-saving mode	0.29	0.34
Energy-saving mode: Charging one controller.	3.48	3.25
Instant-on Mode: Turn off memory.	13.48	7.12
Instant-on Mode: On start go to tv.	14.57	6.59
Instant-on Mode: Both options enabled.	15.21	6.68
Instant-on Mode: No option enabled.	15.28	6.91
Instant-on Mode: No option enabled. Installing update.	40.76	16.91
Instant-on Mode: No option enabled. Charging one controller.	17.56	9.37

Table 12: Overview Consumption of Nintendo Switch Low Power Modes

Mode	Mode Power Usage in Watt
Charging console in off mode	12.45
Charging console in off mode and charging one pair of controllers	12.08
Charging console in standby mode	11.04
Charging console in standby mode and charging onepair of controller	13.85
Playing and charging console	12.43
Charging console, charging one pair of controllers and playing with another pair of controllers	16.60
Only docking station	0.26
Charged console in off mode in docking station	0.35

Mode	Mode Power Usage in Watt
Charged console in standby mode in docking station	0.28

4.1.5 Benchmarking active gaming mode

In the Games Consoles Self-Regulatory Initiative 4th Steering Committee Meeting of 13 July 2017[75] and the SRI review report 2017[76], the difficulties in benchmarking the gaming mode were discussed. Many factors, especially for the computation for the graphical output, mean that reproducibility of results is difficult to achieve. In the measurements made, certain patterns can be recognized easily on the measurement line (for details, see graphs in Annex), as for example rendering sequences that occur in certain game situations, such as scoring a goal in a football video game. The number of objects being rendered are different after almost every movement of the players, the object or view screen. Further impacts on regulation or benchmarking gaming mode are discussed in section 7.3.2. TU Wien issued a series of new master thesis topics for carrying out this study to elaborate and gather new insights. Except if a confidentiality restriction is in place, every master thesis has been uploaded to the TU Wien online library[77].

4.1.6 Measurements of energy use

To better visualize and estimate energy consumption in typical modes, a first set of measurements have been conducted at the TU Wien Smart Grids Laboratory with 5 games consoles that are representative for the study. Detailed measurements and results can be found in Annex 2.

With the extensive measurements carried out (currently data for 215+ hours are recorded), the most interesting results are as follows:

- Slightly increased power consumption for the Xbox One X when idle and TV brightness is dimmed (about 2 watts more)
- Side-notification window of Xbox One in Idle leads to increased continuous consumption
- Manufacturer specific as well as 3rd-party USB-Ethernet Adapter can lead to continuous energy consumption (Manufacturer – specific adapter investigations are still proceeding, though this is likely to be a minor drawback. The Nintendo Switch is probably used 95% of the time with WiFi, also within the docking station)
- 1140p – resolution setting leads to significant consumption increase
- Downscaling resolution during DVD playback leads to increased consumption
- Continuous update polling in networked standby with up-to-date console
- Measurement timeframe of 30 minutes showed both lower and higher energy consumption than the reported values

Measurements in Lab conditions included recording of temperature, wind flow and humidity. The currently gathered results and insights will not be greatly affected by further measurements that will be carried out and added to the Annex.

4.1.7 Typical use patterns with regard to product use

In assessing the effectiveness of the energy efficiency measurements undertaken, it has been necessary to determine the use behaviour by gamers. In the following, we present numbers that have

[75] http://efficientgaming.eu/fileadmin/user_upload/Game_Consoles_VA_Signatories__presentation.pdf [Accessed: 15. Jan. 2019]
[76] http://efficientgaming.eu/fileadmin/user_upload/2017_SRI_Review_Report.pdf [Accessed: 15. Jan. 2019]
[77] https://catalogplus.tuwien.ac.at/primo_library/libweb/action/search.do?vid=UTW [Accessed: 15. Jan. 2019]

been accessible to the study team. We present the data in chronological appearance. Definition of modes might differ from the agreed power modes of the SRI or those followed in the study.

In an article by A. Webb et al., "Estimating the energy use of high definition game consoles" of 2013[78], the following data were presented for HD consoles based on studies and reports of 2009. The networked standby has a low percentage compared to the findings of the NRDC, which is issued through the 8th generation of games consoles offering more content to the users. Also, the general availability and speed of Internet bandwidth increased over the last decade.

Table 13: Hours per day spent in console modes based on A.Webb [78]

Mode	Time (hours/day)
Gameplay	1.06
Movie/video playback	0.71
Other functions	0.13
Standby/off	20.89
Networked standby	1.2

In the NRDC issue paper[79] of 2014, the following modes were identified for the games consoles investigated: PS4, Xbox One and Nintendo Wii U (system updates mid-April 2014):

Two different usage assumptions were made in the NRDC issue paper 2014:

Assumptions are made for the products PS4 and Wii U on the one hand and the Xbox One on the other. This separation is argued with the different settings of TV watching in the Xbox One setup. The following data are taken from the NRDC issue paper 2014 based on the modes as stated in Table 5.

Table 14: Usage assumption in hours based on NRDC The Latest-Generation Video Games Consoles 2014 [79]

Mode	Usage assumption (hours, daily average) for PS4 and Wii U	Usage assumption (hours, daily average) for Xbox One
Gameplay	1.45	1.45
Media	1.24	1.45
Navigation/Other	0.23	2.37
Networked Standby	18.89	17.96
Off	2.11	2.00

The average video game console usage differs slightly by the year and location investigated in the studies or report. Data from 2017[80] based on the Nielsen Games 360 Report 2017[81] give a percentage breakdown of the activities for Xbox One and PS4. They are used for this report to predict the general trend of video games console usage. The definitions are different from the ones given by the SRI. In particular, "Other" has a high percentage, without any further definition. The study team assumes that the known mode Navigation is meant here.

[78] Webb, A., Mayers, K., France, C., & Koomey, J. (2013). Estimating the energy use of high definition games consoles. Energy Policy, 61, 1412-1421. doi: 10.1016/j.enpol.2013.05.056

[79] Pierre Delforge, Noah Horowitz; The Latest-Generation Video Game Consoles, iP:14-04-b , NRDC May 2014 https://www.nrdc.org/sites/default/files/video-game-consoles-IP.pdf accessed 23/02/2019

80 Richter, F. 2017, June 12Video Game Consoles Are About More Than Just Gaming [Digital image]. Retrieved February 04, 2019, from https://www.statista.com/chart/9777/video-game-console-usage/

[81] https://www.nielsen.com/us/en/insights/reports/2017/us-games-360-report-2017.html [Accessed 29 Jan. 2019]

Table 15: Active mode usage - percentage distribution based on Nielsen Games 360 U.S. Report 2017[81]

Console Activity (Mode)	Xbox One Mode Usage percentage per week	PS4 / PS4 Pro
Gaming offline and online combined (Active Gaming)	50%	48%
Navigation & Other	15%	19%[80]
Media Playback (Watching Downloaded Content, Streaming, DvDs/Blu-Rays – combined value)	35%	33%[80]

For comparison, the Nielsen Games 360 U.S. Report 2018 [82] provides a percentage of the time spent on the different activities when using games consoles. The Wii U has been left out in this report. Instead the Nintendo Switch is included due to the newer release. The modes of Nielsen were not changed in the Nielsen Games 360 U.S. Report 2018[82], the data for the active mode usage (console is turned on) in percentages are given in Table 16. The report has a rather high percentage for the media playback for the Nintendo Switch, especially since no DVD or Blu-Ray can be played with the Switch. As of May 2019, the streaming services available are YouTube and Hulu. Therefore, the study team concludes the estimate on Media Playback for the switch as well as the "Navigation & Other" mode is too high. The actual mode in use is crucial for an energy consumption prediction. It must be noted, that, as reported by Nintendo, the average power consumption for the Switch ranges between 6.2 (Navigation) & 12.7 Watts (Active Gaming).

Table 16: Active mode usage - percentage distribution based on Nielsen Games 360 U.S. Report 2018

Console Activity (Mode)	XBox One / XBox One X	Switch	PS4 / PS4 Pro
Active Gaming	47%	44%	43%
Navigation & Other	13%	22% to(too high estimate by Nielsen)	12%
Media Playback (Watching Downloaded Content, Streaming, DvDs/Blu-Rays – combined value)	40%	35% (too high estimate Nielsen) (no DVD & Blu-Rays)	45%

The term "Other" is not specified by any example or definition in the freely available report. As before, we assume "Navigation" is meant here. For the Switch, an estimated 22% of Navigation and Other seems to represent a very high usage.

Comparing the data of the reports from 2017 and 2018, a slight decrease in the gameplay mode can be seen in favour of an overall increase in the media usage, especially for the PS4 (20%).%. The increasing popularity of streaming content related to gaming (for example Twitch) and the popularity of eSports in general, favours the media usage mode of the video games consoles in terms of percentages. Uncertainties expressed as variances in the interviewed target group cannot be given, since access is restricted to freely available reports.

[82] https://www.nielsen.com/content/dam/corporate/us/en/reports-downloads/2018-reports/games-360-2018.pdf [Accessed 29 Jan. 2019]

Estimating the usage time for the Nintendo Switch is more difficult than for the games consoles, since the release date is the most recent. Some data can be found in recent studies. According to Nintendo[83], a differentiation needs to be made for the three different Nintendo Switch play modes:

1. TV Mode, where Nintendo Switch is docked and the game play occurs on the connected TV screen,
2. Tabletop Mode (Removed from Dock, Joy-Cons not attached to Switch)
3. Handheld Mode (Removed from Dock, Joy-Cons attached to Switch)

According to the figure of Nintendo Switch Gameplay Trends, about 19% of the Switch users have their gameplay primarily using the TV. About 30% have primarily tabletop or handheld mode, leaving 51% with both modes in even use.

In the work of the Lawrence Berkeley National Laboratory (LBNL) in their latest report of 2018[84], a differentiation of the gamers has been made. These gamer types are different in their overall daily console usage and are designated as follows:

- Light
- Moderate
- Intensive
- Extreme

The estimates of the duty cycle of per user Type based on the gamer type can be seen in Table 17. As a reference point, the following assumptions, based on a correlation between game console and type of users in the work of LBNL[84], are presented and enhanced within the navigation mode, since the LBNL assumption and correlation between the various modes has been understating the amount spent on navigation. Table 17 shows the estimations by LBNL with enhanced Hours per day estimations for Navigation.

Table 17: Estimates of Duty Cycle and User Type (Console & media streaming devices) as defined by LBNL and refined by TU Wien

Users	Gaming	Streaming & Media	Navigation (refined)	Networked Standby	Off
	Hours per day				
Light	0.28	0.18	0.09	23.03	0.47
Moderate	1.02	0.65	0.38	21.82	0.45
Intensive	2.36	1.5	0.65	19.64	0.41
Extreme	6.24	1.91	0.85	15.39	0.32

Table 18: Gaming User Types distributions based on System Type

[83] Nintendo: Six Months Financial Results Briefing for Fiscal Year Ending March 2018 , Tatsumi Kimishima, President of Nintendo, Website: https://www.nintendo.co.jp/ir/pdf/2017/171031_2e.pdf accessed 21/02/2019

[84] Green Gaming: Energy Efficiency without Performance Compromise, 2018, Lawrence Berkeley National Laboratory, Evan Mills, Norm Bourassa, Leo Rainer, Jimmy Mai, Arman Shehabi, Nathaniel Mills, available at https://docs.google.com/a/lbl.gov/viewer?a=v&pid=sites&srcid=bGJsLmdvdnxncmVlbmdhbWluZ3xneDo2YzczNjRhZjE0YmZlNmZk [Last Accessed 28 Feb. 2019]

Console→	7th Generation			8th Generation			
User↓	PS3	Xbox 360	Wii	PS4	Xbox One	Wii U	Switch
Light	30%	30%	65%	15%	15%	45%	55%
Moderate	40%	40%	21%	40%	40%	30%	26%
Intensive	25%	25%	12%	40%	40%	20%	16%
Extreme	5%	5%	2%	5%	5%	5%	4%

In our first assumption, a flat estimate is made depending on the games console units sold in correlation to the user type as defined by LBNL. For comparison, the global units are also displayed in Table 19. The lifetime of the games consoles or a change within the console generation itself have not been investigated.

Table 19: Total number of games consoles sold (million unit) based on System Type in Europe and global (Data from Feb. 2019 based on VGChartz)

Console→	7th Generation			8th Generation			
Sold Unit↓	PS3	Xbox 360	Wii	PS4	Xbox One	Wii U	Switch
Europe	34.55	25.87	33.88	37.06	11.52	3.54	8.24
Global	86.9	85.8	101.64	90.97	43.15	13.97	30.54

The study team assumes based on the NBLN data, that the choice of games console reflects very well the distribution of the type of gamers. Also, the increasing popularity of gaming in general can be seen in the change from light gamers for the 7th generation to the more moderate and intensive or extreme gamers. Data are given in Table 20.

Table 20: Gaming User Types distributions based on Sold Units and System Generation in Europe and Global.

Console→	7th Generation		8th Generation	
Users↓	EU Distribution	Global Distribution	EU Distribution	Global Distribution
Light	42.57%	42.97%	22.22%	24.18%
Moderate	33.17%	32.96%	37.37%	36.65%
Intensive	20.33%	20.18%	35.55%	34.33%
Extreme	3.92%	3.89%	4.86%	4.83%

Table 21: Estimates of Usage Scenario, influenced by LBNL and own measurements

Mode	Active Gaming	Streaming & Media	Navigation and other functions	Standby	Low power download	Rest mode	Off
	Hours per day						
Average User (Stationary Consoles)	1.67	0.98	0.47	5.12	0.15	15.21	0.42

Mode	Active Gaming	Streaming & Media	Navigation and other functions	Standby	Low power download	Rest mode	Off
Nintendo Switch	1.00	0.56	0.28	0	0	21.71	0.45

Table 21Table 21 shows the usage scenario, the study team has worked with for calculations of the typical energy consumption of the games consoles. Over the course of a total of 5 months of networked standby measurements with a set of an average-sized library of five active games, an average of about 0.15 hours of low power download durations has been identified for PlayStation 4 and Xbox One. The low power download allows users to download patches without the graphical unit being active. This can be seen in the power consumption of the console during this mode. For the study team, it was important to reflect usual user type scenarios and consider the energy use in these patterns. In the first stakeholder meeting, stakeholders indicated that about 25% of the users in Europe use the standby mode provided. This is reflected accordingly in the usage scenario. As the Nintendo Switch cannot be put easily into a standby mode without connection to the docking station (the simple airplane mode without subconfiguration shuts off the connection to JoyCons and cannot be used in the Dock), the share has been transferred to the "Rest mode".

4.1.8 Typical Electricity Consumption

As the calculation of the Typical Electricity Consumption (TEC) Methodology is crucial for the impact assessment, the SRI explained the method in their "report on the 2017 review of the game console self-regulatory initiative". This method is used for estimating the energy consumption of devices and formulated by the Energy Star Program[85]. The approach is based on total time spent in each mode and the consumed energy of that mode. It calculates a weighted average energy usage. The formula for the TEC calculation is:

$$TEC = P_1T_1 + P_2T_2 + \cdots + P_nT_n$$

In this equation, n = console use phase mode, P = power consumption in mode n (W) and T = time spent in mode n (s). The estimates of the usage scenario is described in chapter 4.1.7.

4.1.9 Thermal measurements

In order to test the thermal behaviour and identify weak spots in the design, thermal measurements were conducted with the PS4 Slim (CUH-2216) and the Xbox One S. Because of the time limitations in the study, it is not expected that other models will be investigated, as some conclusions can already be made. To identify points that have to be investigated further, thermal images were taken with an infrared camera model PCE-TC 4.

[85] https://www.energystar.gov/ia/partners/manuf_res/Imaging%20Equipment%20TEC_Test_Procedure.pdf

Figure 10: Measurement setup thermal images with infrared camera

The thermal images were taken with the cases open and are therefore only used to localize interesting points. Afterwards the POIs (Points of Interest) were accurately measured with k-type thermal-elements with the cases closed to ensure that the devices were not operated at unusual operating points. Input Power, environmental temperature and wind were logged during the measurements to ensure correct operating conditions.

4.1.9.1 PS4 Slim Thermal Image

First the VRAMs were examined. The thermal image shows that chip number 5 (VRAM named “Messpunkt 1”, marked with a red asterisk in Figure 11 is the hottest one under load (Active Gaming: Star Wars Battlefront 2).

Figure 11: VRAM PS4 Slim

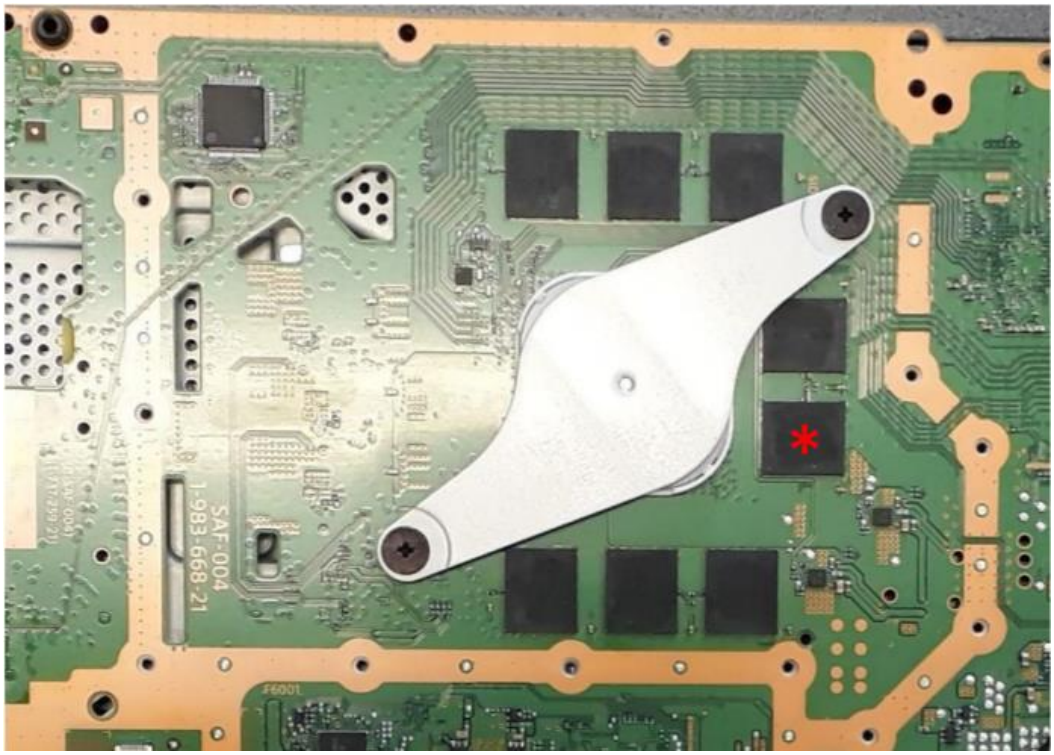
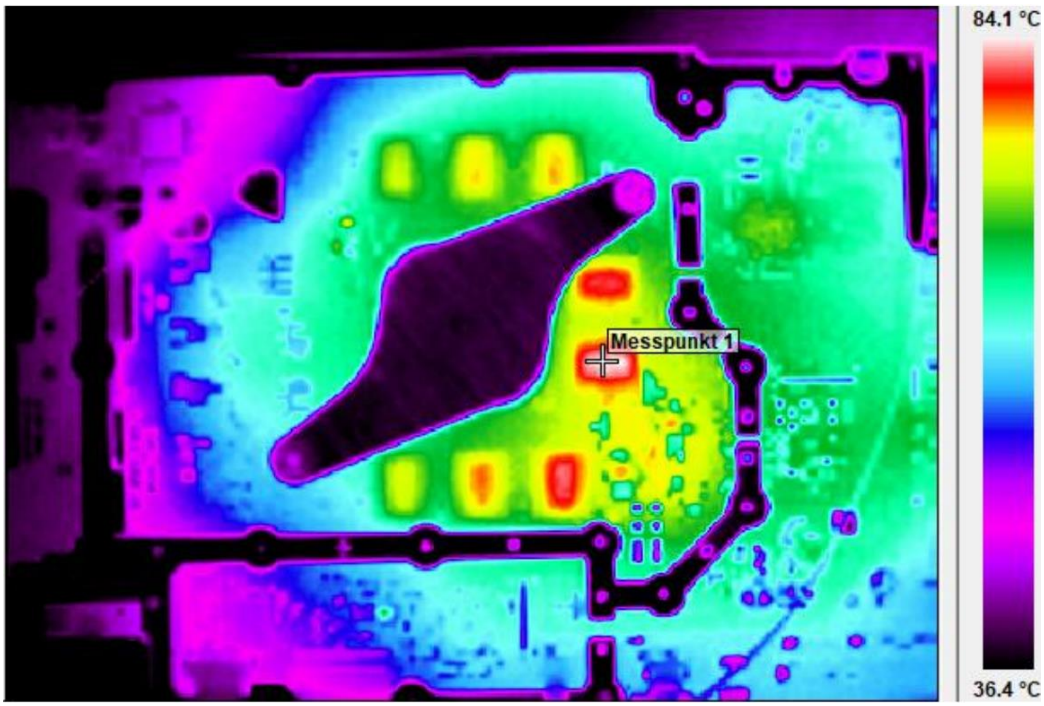


Figure 12: VRAM PS4 Slim false colour thermal image



4.1.9.2 PS4 Slim Temperature Monitoring

The first temperature measurement with the fully assembled console was taken at “Messpunkt 1” (see section 4.1.9.1). The thermal pads and the heatsink were reattached to the VRAM and the console was closed. A peak temperature of 68°C was measured in the case of the chip with the k-type thermal

element. The average power consumption while measuring was 85.5 W (thermal image see Figure 14 and Figure 15 for temperature monitoring).

The second temperature measurement was again taken while the console was fully assembled. The only difference was that instead of gaming a Blu-Ray movie was played (Avatar). The results were that the chip was slightly cooler at 64°C. The average power consumption was 47.9 W. At first, the measurements were taken upside down for easier handling and afterwards verified by turning the console into the intended orientation.

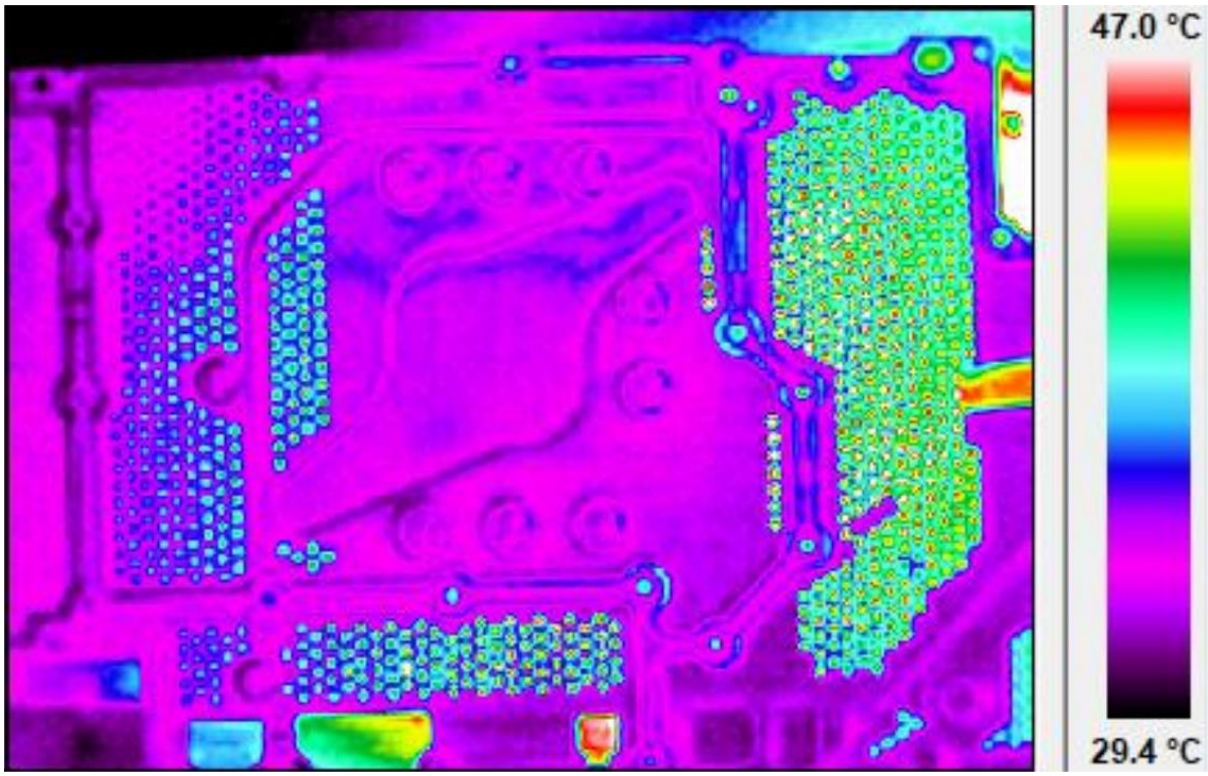
The third temperature measurement was taken to test the effect of the thermal pads. The pads were removed and the case again closed. Due to the missing pads the thermal conduction was degraded and the temperature rose to 71°C.

While the console was in the main menu the chip cooled down to about 56°C.

Table 22: Vram temperature monitoring under different load conditions

Mode	Temperature	Average Power Consumption	Notes
Gaming: Star Wars Battlefront 2	68°C	85.5W	Fully assembled console (upside-down and normal orientation)
Blu-Ray: Avatar	64°C	47.9W	Fully assembled console
Blu-Ray: Avatar	71°C	47.9W	Thermal pads removed
Main Menu	56°C	43.6W	Fully assembled console

Figure 13: Thermal image with attached heatsink and thermal pads of PS4 Slim



4.1.9.3 Xbox One S VRAM and Mainboard thermal image

Initially, interesting points needed to be identified. So, a thermal image was taken. Four points of interest (POIs) were identified and examined thoroughly to analyze the behaviour under different conditions "Messpunkt 1" is the South Bridge, "Messpunkt 2" is the Dual Mode Display Port to HDMI Retimer and "Messpunkt 3" is a VRAM chip. The measurements were made under different load scenarios and with the console open and closed. No extreme measurements were observed.

Table 23: Temperature under different conditions

Mode	South bridge	DP to HDMI	VRAM	Power Consumption	Notes
Main Menu	48.8°C	38.9°C	33.5°C	30.17W	Open console
Blu-Ray: Avatar	45.8°C	45.8°C	40.4°C	38.03W	Fully assembled console
Gaming: Star Wars Battlefront 2	53.6°C	45.9°C	45.8°C	72.48W	Open console
Gaming: Star Wars Battlefront 2	51.3°C	55.2°C	51.0°C	73.36W	Fully assembled console

Figure 14: Xbox One S thermal image setup

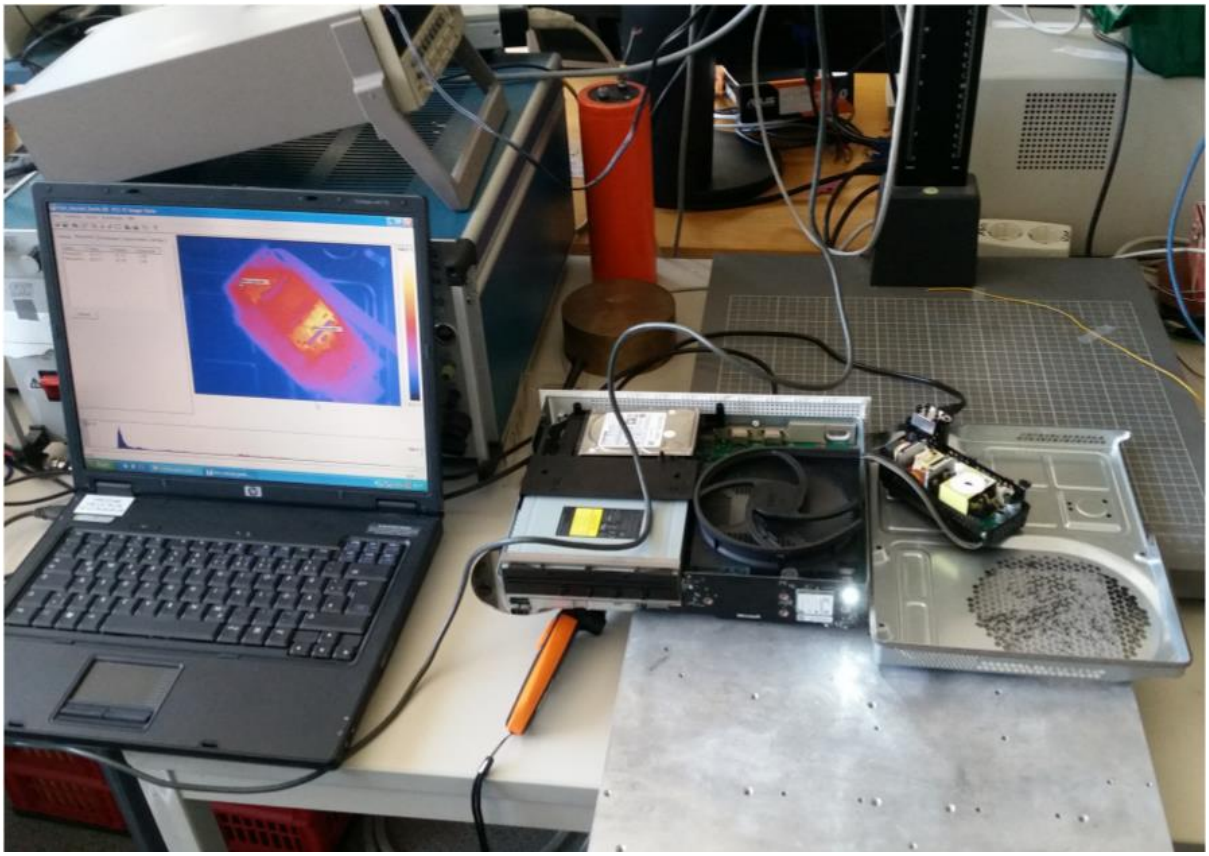
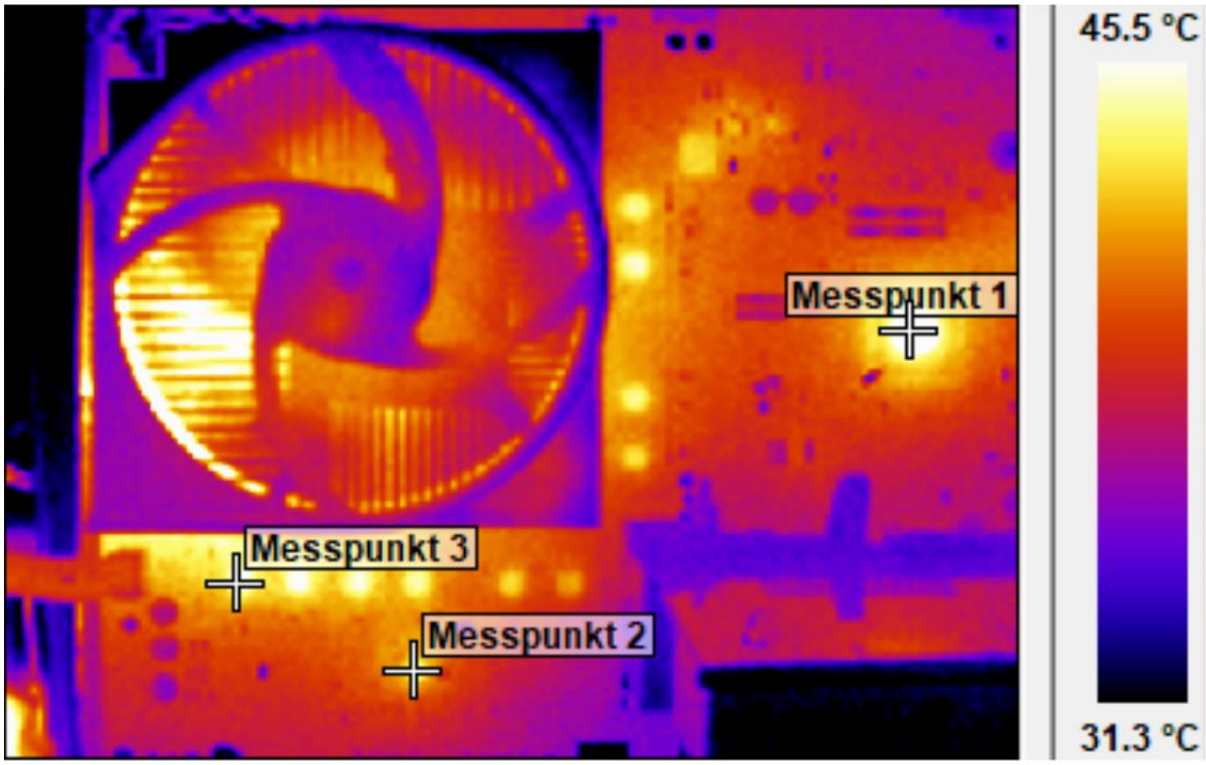


Figure 15: Xbox One S mainboard thermal image



4.1.9.4 Power Supply Measurements

In order to test the thermal properties of the power supplies and identify hot spots, thermal imaging and monitoring with thermal elements have been conducted.

4.1.9.5 PS4 Slim Power Supply

First an overview image was taken to identify hot spots in the device (power supply). The part where the transistor is located turns out to be the hottest part. Close to it are the main capacitors. The capacitors tend to fail sooner if operated at higher temperatures. Therefore, the temperature was monitored at the transistor, the capacitors and in addition at the bridge rectifier. The parts of interest were coated with thermal compound that corrects the emission factor for the thermal imaging to an emission ratio of 0.98. In addition to the thermal imaging, the parts were also monitored with thermal elements. The difference between these two types of measurement was $\Delta T=1K$. The monitoring of the parts showed a rise in temperature at the beginning, with a peak of 81°C at the Transistor, 54°C at the capacitor and 68°C at the rectifier. After some time, the temperature dropped again and settled at values of 65°C at the Transistor, 48°C at the capacitor and 56°C at the rectifier. The proximity of the capacitor to the Transistor would lead to the assumption that it could have an impact on the temperature but a low temperature was maintained nonetheless. The high temperature could be explained by the low RPM of the fan that is providing the power supply with fresh air. It seems that the fan is only controlled by the APU and thus the temperature is higher at first. A second temperature sensor inside the power supply that controls the fan could prevent this.

Figure 16: PS4 Slim power supply top view

Figure 17: PS4 Slim Power supply thermal image top view with coating on the switching MOS-FET to correct emission factor

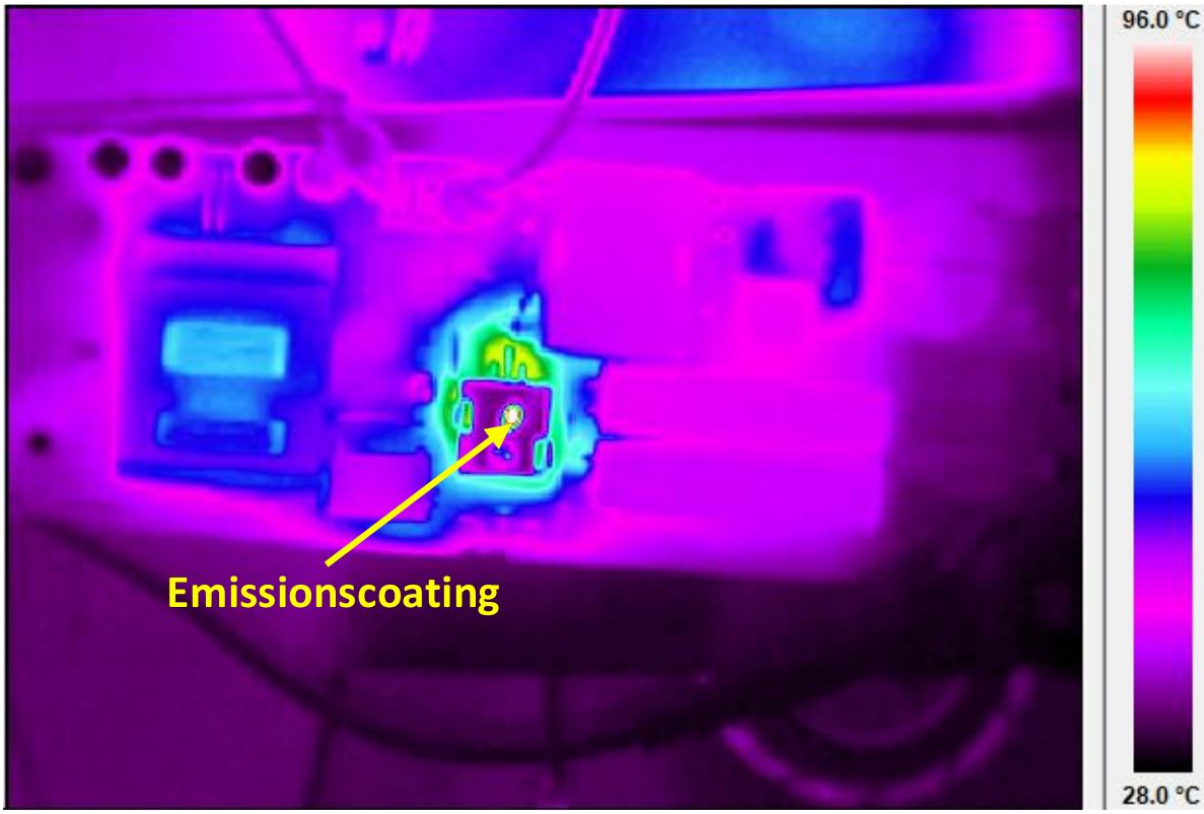


Table 24: Temperature monitoring at different parts

Mode	Part	Peak-Temperature	Settled Temperature
Gaming: Star Wars Battlefront 2	Transistor	81°C	65°C
Gaming: Star Wars Battlefront 2	Rectifier	54°C	48°C
Gaming: Star Wars Battlefront 2	Electrolytic Capacitor	68°C	56°C

4.1.9.6 Xbox One S Power Supply

In the case of the Xbox One S an overview image was again taken. The points of interest are marked in Figure 18. (2) is the heat sink of a Transistor and (3) and (4) are two capacitors. The thermal image of the power supply can be found in Figure 19. The temperatures (see Table 25) measured across the different conditions are fairly low except at the capacitor number 4 when playing. There, the temperature reaches about 80°C. This could be caused by the placement of the capacitor close to the border of the power supply. Better placement or a different airflow design could reduce this.

Figure 18: Xbox One S power supply POI

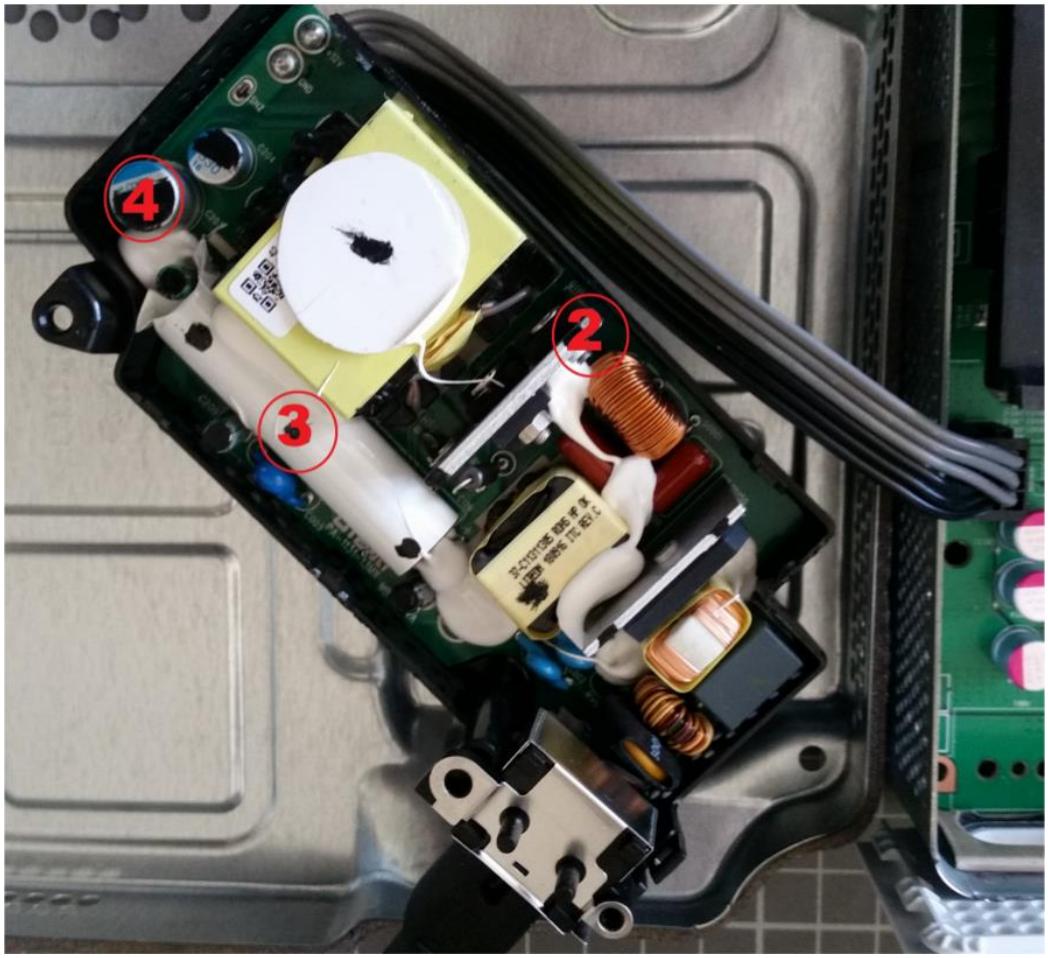


Figure 19: Xbox One S power supply thermal image

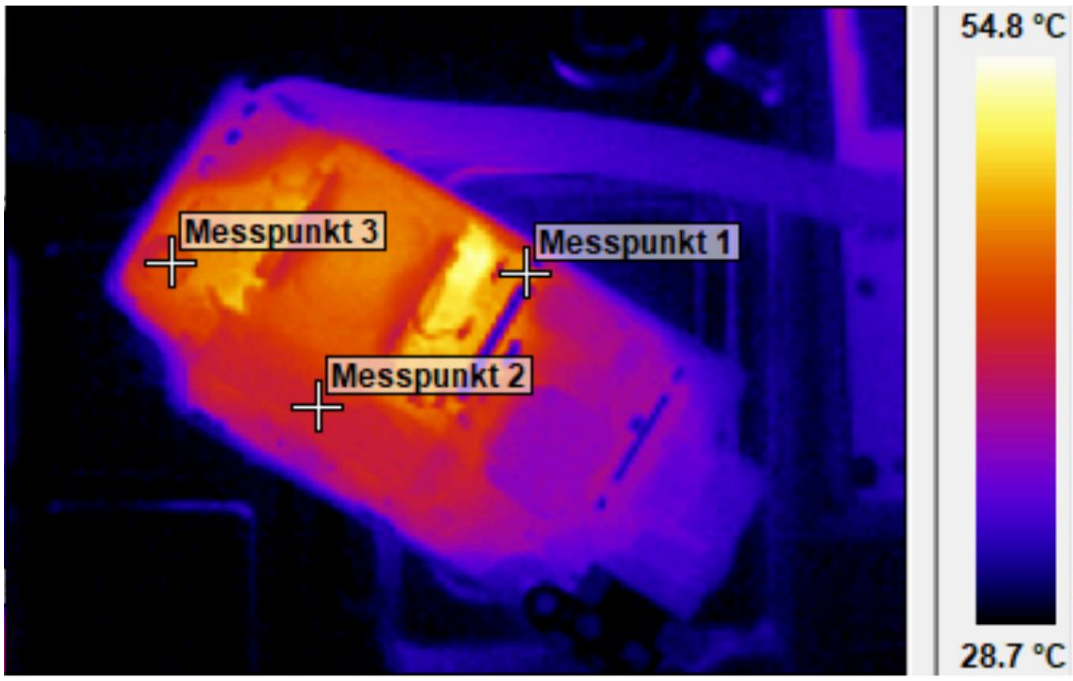


Table 25: Xbox One S power supply temperatures

Mode	Transistor	Capacitor (3)	Capacitor (4)	Power Consumption	Notes
Main Menu	46.7°C	41.9°C	44.7°C	30.17W	Open console
Blu-Ray: Avatar	44.4°C	38.7°C	47.8°C	38.03W	Fully assembled console
Gaming: Star Wars Battlefront 2	89.5°C	62.8°C	64.8°C	72.33W	Open console
Gaming: Star Wars Battlefront 2	59.9°C	49.0°C	80.8°C	73.51W	Fully assembled console

4.1.9.7 Conclusion

The thermal measurements show no fatal weak points in the designs.

The VRAM measurements showed no extreme hot spots and as long as the games consoles are operated at idle mode most of the chips cool down since it seems they are not used any more. Additionally, the thermal measurements showed the low activity of the VRAMs during Blu-Ray playback, undermining the efforts taken to reduce the power consumption in this mode. The thermal pads used in the PS4 Slim help to keep the VRAM at even lower temperatures.

The electrolytic capacitors in the power supplies stay relatively cool and are therefore not in danger of premature breakdown. When operating the power supplies open without any forced cooling from the fan, the components get very hot. Therefore, the constant airflow of the fan is necessary to keep the device operating. The capacitor (4) (see Table 25) **Error! Reference source not found.** in the Xbox One S power supply got hotter than expected in closed operation. This could be due to the placement close to the border of the power supply.

Due to time constraints a full analysis could not be made but the analysis conducted is promising in that the consoles are designed to be operating for a long period as well as limiting any unnecessary use of VRAM processing power for modes any other than active gaming.

4.2 Product operating systems and updates

Games consoles come with a console-specific operating system (OS). A list of updates provides insights into the frequency and size of updates meant for the operating system of each console investigated in this study.

4.2.1 List of updates

4.2.1.1 Microsoft Xbox One

The operating system of Xbox One was launched with a version of Windows 8 and replaced in the "New Xbox One Experience" update with "Windows 10 on Xbox One".

The official website offers a list[86] of updates released in regard to the OS. In total, with the latest version 10.0.17763.4085 (as of March 2019),), there have been 58 updates to the Xbox One system, the OS installed at the factory not included. The size of updates is not publicly available on the website. Offline update packages are available for Xbox One (two updates needed to update to current version: "OSU3" - 1,9 GB in size, "OSU1" - 4,9 GB in size), Xbox One S or Xbox One X just need "OSU1" - 4,9 GB in size.

4.2.1.2 Sony PlayStation 4

The operating system of the PlayStation 4 is based on a version of the FreeBSD 9.0 platform, an open source Unix-like operating system[87].

The official website offers a list[88] with the 21 most recent updates dating back to March 2017, from the System Software Update Version 4.50 up to the current System Software Update Version 6.51 (as of April 2019). The size of updates is not publicly available on the website. Offline updates are available, for the 6.5151 Version. The size is 442 MB. Another download for a new installation of the system software is available and is 995 MB in download size.

The study team received information from Sony on the following system updates, since the availability of official patch notes in the online system reaches back only to March 2017. The summary of these modes was reported as follows:

- System software version 2.00 from 10/28/2014 introduced an automatic power-down for the peripheral battery-charging feature when the console is in rest mode. This feature prevents people leaving their console on to charge peripherals, and the power management introduced avoids charging power being unnecessarily and constantly supplied to the PlayStation 4 USB ports.
- System software version 2.50 from 03/26/2015 introduced a 'suspend' mode option when the console is in rest mode, allowing users to very quickly resume their activity without needing to save their place in the game (preventing people for disabling power management)

4.2.1.3 Nintendo Switch

The operating system of the Nintendo Switch is currently at version v8.1.0 with no further officially specified name. The lab measurements were carried out with version v7.0.1.

[86] https://support.xbox.com/en-US/xbox-one/console/system-update-operating-system accessed 23/02/2019
[87] https://doc.dl.playstation.net/doc/ps4-oss/freebsd_kernel.html accessed 20/02/2019
[88] https://asia.playstation.com/en-ph/ps4/system-update/ps4-system-update-change-log/ accessed 20/03/2019

The official website offers a list[89] of 20 updates on top of the release version. Offline updates for the system are not available for download.

4.2.2 Impact of System Updates

4.2.2.1 Impact - Microsoft Xbox One

The following updates have been identified, that could be related to energy use (general information about the performance update is not included) with the original description from the operating system website[90]:

Table 26: List of Xbox One Updates

Update Name (OS Version)	Release	Feature Updated	Description as provided by Microsoft
10.0.17134.4071 (rs4_release_Xbox_dev_1806.180802-1822)	13/08/2018	Networking	Resolved an issue with wireless and wired networks failing to be detected when the console wakes from instant-on power.
10.0.16299.5101 (RS3_RELEASE_XBOX_DEV_1802.180131-1450)	07/02/2018	More options for inactivity	Previously, you could set your Xbox to turn off after one or six hours of inactivity. We thought we'd give some other numbers a shot. Now you can also choose options for two, three, four, and five hours of inactivity.
6.2.12825.0 (xb_rel_1505.150507-2219)	11/05/2015	Power on/off from Xbox One SmartGlass	The versions of the Xbox One SmartGlass apps for Windows, Windows Phone, iOS, and Android are being updated to let you power your Xbox One on and off when your devices are on the same home network as your console.
		User-selectable power mode	The initial setup experience on Xbox One worldwide has been updated to enable users to select their preferred power mode. Instant-On mode uses slightly more energy but has faster startup, enables use of the "Xbox on" voice command, and receives background system, games, and app updates. Energy-saving mode uses less energy by shutting down the console completely, requiring you to press the Xbox button on your console to start up your Xbox One. This will create a slower startup time, and your experience will be interrupted for system, games, and app updates.
6.2.10812.0 (xb_rel_1404.140411-1830)	14/04/2014	System update improvements	The ability for the console to reboot and complete system update while in Instant-On power mode. Take future updates on demand when one is available without waiting for the console to do it from Instant-On mode. Feature available under System Settings.

[89] https://www.nintendo.co.uk/Support/Nintendo-Switch/System-Updates/Nintendo-Switch-System-Updates-and-Change-History-1445507.html accessed 20/03/2019
[90] https://support.xbox.com/en-GB/xbox-one/console/system-update-operating-system

Conclusion on Impact from Xbox One Updates:

The changes in the update OS version: 10.0.16299.5101 have been introduced as a further energy saving effort, since the prior setting options for automatic turn off of one hour or 6 hours of inactivity have been the only setting options. The users are allowed to set more specific APD time windows than before with only three options. The update does not change default settings.

4.2.2.2 Impact - Sony PlayStation 4

No special information on system updates that could be relevant to energy use could be found. A general information notice about improved system performance is found in each update version. Current default settings are described in section 4.1.2.2.

The impact of system updates 2.00 and 2.50 are notably the most impactful in terms of energy savings. Update 2.00 dealt with unnecessary charging power to USB ports. System update 2.50 featured, according to the discussion in the first stakeholder meeting, numerous community requests, leading to the availability of a 'suspend' mode, in a function comparable to XBox "Instant-On" mode.

4.2.2.3 Impact - Nintendo Switch

Direct impact information in the patch notes of the Nintendo Switch that are relevant to energy use could not be found. General information notices about improved system performance are not included in this list.

With v4.0.0, a feature has been introduced to enable the matching of game versions with local users. This system update does not have a direct impact on the energy consumption of the console itself, but the feature can reduce the internet traffic for the updates of games and this is a noteworthy feature, especially with the market moving more and more towards digital purchased content. Given that the Switch is also designed as a handheld device, this feature could be used more often than for the PS4 or Xbox One, where a similar feature is available, too.

4.2.2.4 Impact System Updates - Summary

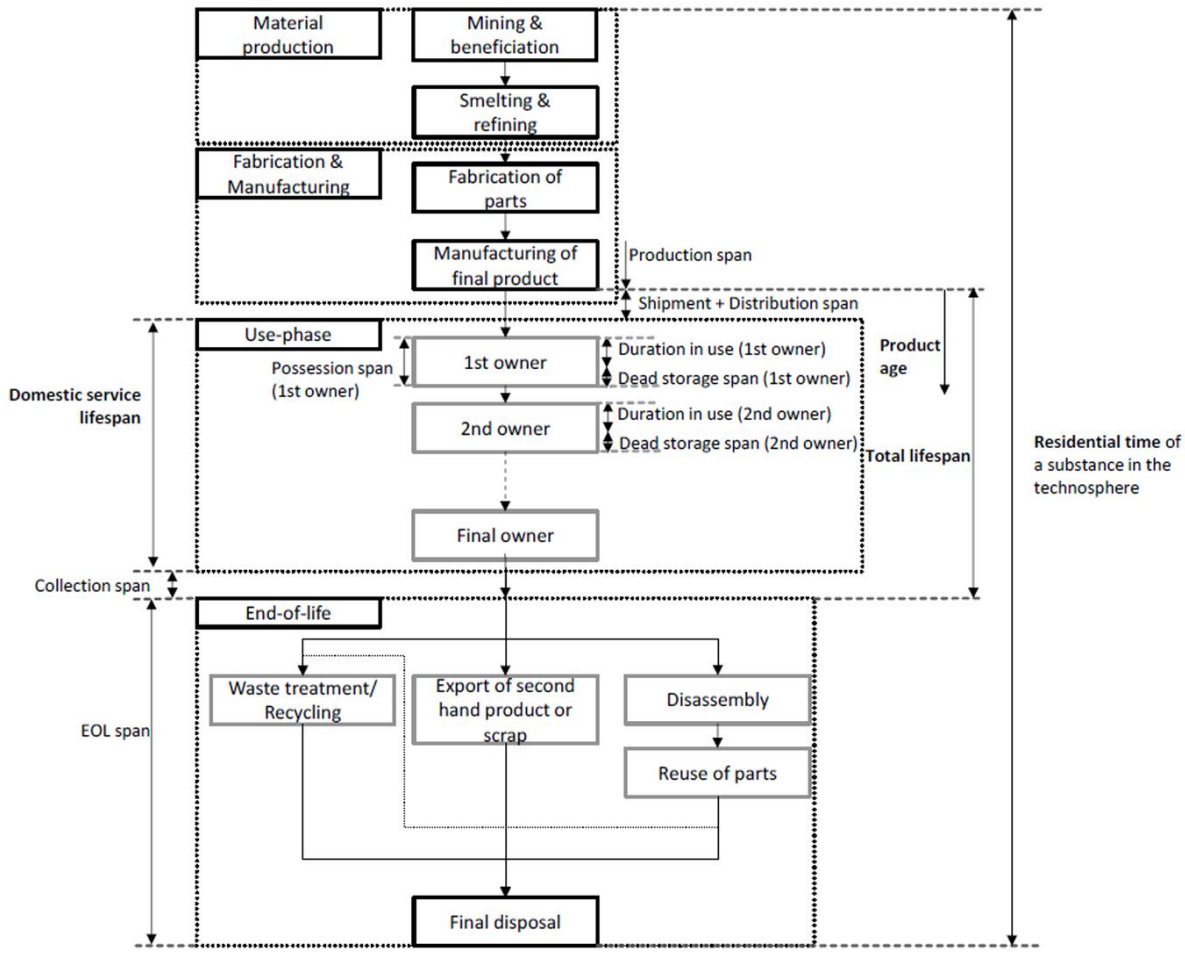
As data are limited on the detailed changes of the operating systems, verifiable testing is also limited within the scope of this study. Some data on the impact of usage profiles can be found for the game console modes after introducing the auto-power-down features or updating them in their functionality (PS4 suspend-to-RAM feature) or in the time window[76]. The general trend in operating system updates can be seen as positive, especially with more auto-power-down time settings introduced and reduced default time settings.

4.3 Product lifetime, repair and disposal

4.3.1 Typical product lifetime

Little is known about the actual technical life time and the usage time of games consoles. There are no comprehensive empirical studies on this. At the same time, the different spans defining a product's lifetime need to be differentiated. Figure 20 provides an overview of different spans which define a products' residential time in the technosphere. In most cases, lifetime is used synonymously with the domestic service lifespan, i.e. the time between placing the product on the market and its disposal by the final owner/user. With regard to games consoles and their environmental impacts an additional differentiation needs to be made. For games consoles there typically is a span at the beginning of the games consoles use phase in which the console is used intensively. After this, there typically is a span in which the use intensity is significantly lower.

Figure 20: Different "spans" defining a products' life[91]



In studies that need to define a time span in order to calculate the environmental impacts of the use phase, a typical usage time of 5 to 5.5 years is assumed[92]. This is based on the observation that the time that passes between the launch of one console generation and the launch of the next one has in the past often been close to 5 years, although the periods have been getting longer more recently (see Table 16).

Table 27: Console generations

Console generation	Market launch in the U.S.	Years since launch of previous generation
3rd gen. (e.g. Famicom, Master System, Atari 7800)	1985-1986 (1986)	7
4th gen. (e.g. Super NES, Mega Drive, Game Boy)	1989-1991 (1990)	4
5th gen. (e.g. PlayStation, Nintendo 64, Sega Saturn)	1993-1996 (1995)	5
6th gen. (PS 2, GameCube, Xbox, Dreamcast, Game Boy Advance)	1999-2001 (2000)	5

[91] Zimmermann, Till (2015): Cycles of Critical Metals: Dissipative Losses and Potential Optimizations: Bremen, Universität Bremen, Diss., 2015.; amended from Murakami, Shinsuke; Oguchi, Masahiro; Tasaki, Tomohiro; Daigo, Ichiro; Hashimoto, Seiji (2010): Lifespan of Commodities, Part I. In Journal of Industrial Ecology 14 (4), pp. 598–612. DOI: 10.1111/j.1530-9290.2010.00250.x.

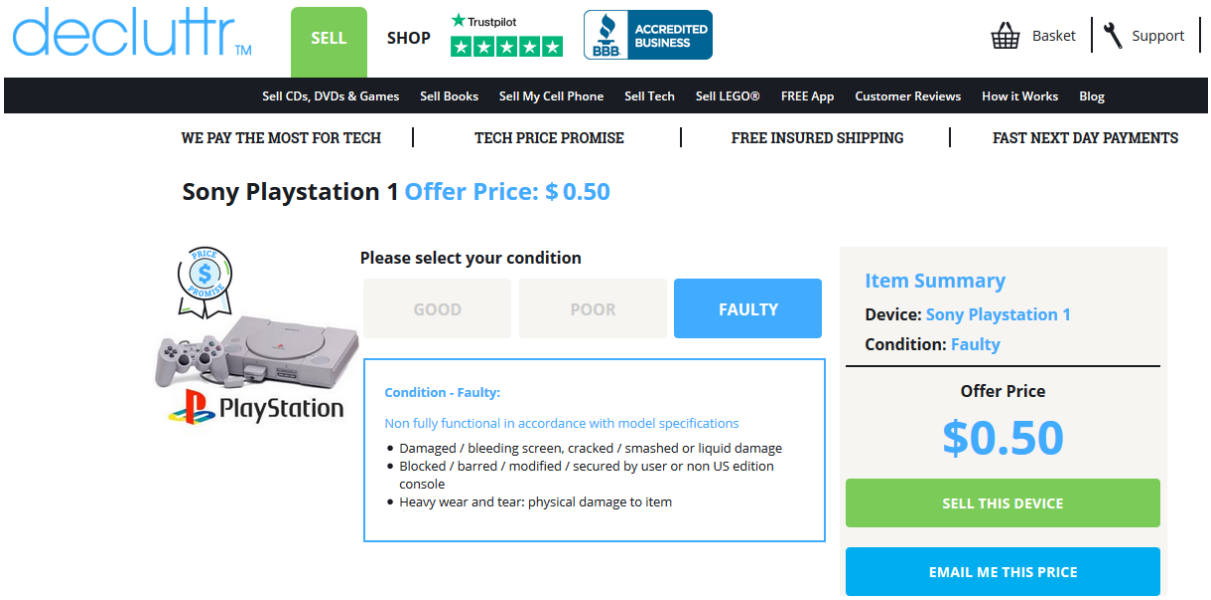
[92] Cf. NRDC (2008, 2014), AEA/Intertek (2010, p. 69), LBNL (2018, p. 111). Game consoles manufacturers also use 5 years for calculations within the framework of the SRI.

Console generation	Market launch in the U.S.	Years since launch of previous generation
7th gen. (PS 3, Wiii, Xbox 360, NDS)	2005-2006 (2006)	6
8th gen. (e.g. PS 4, Xbox One, Wiii U, Switch, 3DS, PS Vita)	2012-2013/2017 (2013)	7
9th gen.	?	≥ 6

The estimated console lifetime of 5 to 5.5 years appears to rely on the assumption that users will buy a new games console once a new generation is released and use the old games console only occasionally or cease to use it at all.

However, there is information indicating that games consoles are much longer in use, albeit with a reduced use intensity. Information from an analysis of games consoles traded on eBay indicates that even up to 14 years after the production of a games console had been discontinued, these are still traded on eBay in relevant numbers[93]. On websites such as Decluttr where old games consoles can be sold and purchased, even non-functional PlayStation 1 consoles still have a low market value, if just as a source of spare parts (see Figure 10). It is also reported that the emotional attachment of users to their games consoles is higher than for other electronic devices and that they tend to keep them for a rather long time. However, the continued usage of older games consoles might also be the result of a lack of total backwards compatibility, as games from older consoles usually cannot be used with their newer counterparts.

Figure 21: Offer by the webstore Decluttr for the purchase of a faulty PlayStation 1



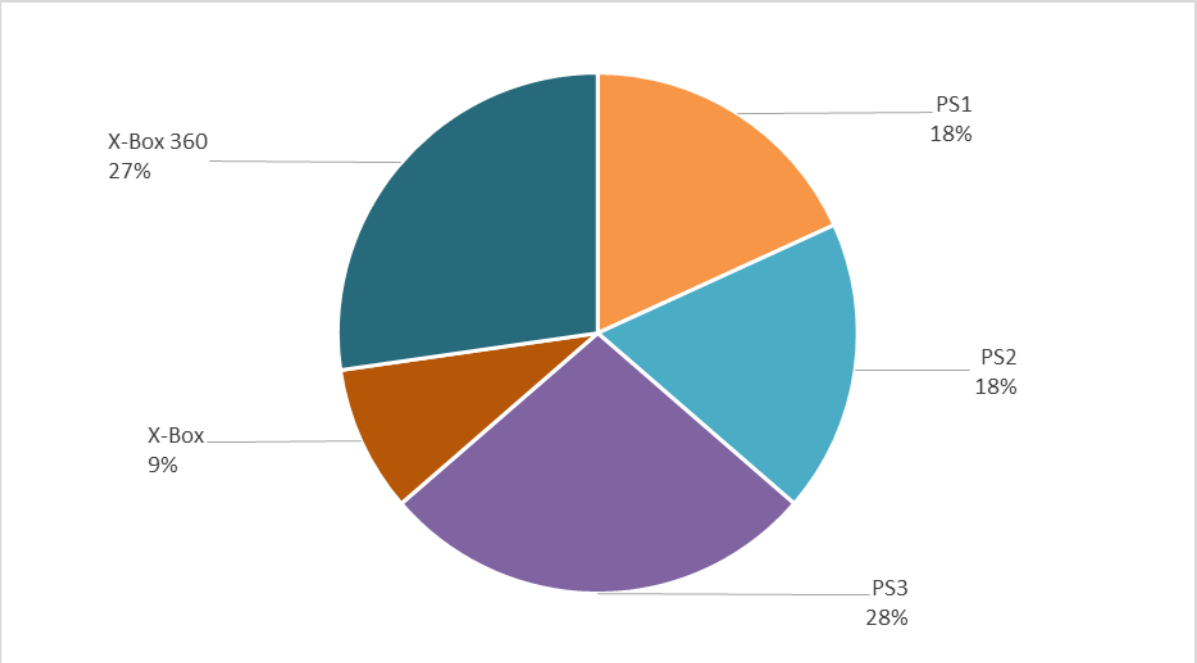
Source: www.decluttr.com

Findings from on ongoing EU project in which Ökopol is involved also indicate rather long life spans for games consoles. In the project, 10 tonnes of small WEEE sampled in September 2018 have been manually dismantled. In the sample, a number of games consoles from different generations could be found. The newest game console found in this sample was the X-Box 360 which was sold (in significant amounts) until 2016[94]. The oldest console found here was the PS1 which was sold until 1999. The distribution of the games consoles found in this sample is shown in Figure 22. The distribution also

[93] Richard Peagam, 2017 http://efficientgaming.eu/fileadmin/user_upload/Richard_Peagam__Anthesis_presentation.pdf
[94] According to VGCHARTZ.

indicates a potential life span of games consoles (or span until disposable) of significantly more than 5 years and at the same time a significant spread of life spans.

Figure 22: Games consoles found in 10 tonnes of WEEE, sampled in Sept. 2018



It can therefore be concluded that some games consoles have a life time much longer than 5 years and that there is still a market demand for old consoles. There are of course also non-functional current games consoles that have been on the EU market for a limited time, e.g. non-functional Switch consoles[95], but the fact that these are traded on eBay in most cases for a rather high value of 50-200 Euros indicates that they are likely to be repaired and that their technical life time will be extended.

Based on this information, an estimated service lifetime of around 7 years is assumed as a basis to calculate the environmental impacts resulting from the use phase. This is based on an assumed 5-7 year period during which a games console is used intensely and frequently until a new generation of games consoles is released and an additional two years during which they might end up on a shelf and be used only from time to time. They might, however, also be sold after intense usage on the second hand market, which would result in a more intense use compared to a console being stored at home. As there is no reliable information about the second-hand use of games consoles at the moment, this is not taken into account for the estimate regarding console lifetime. Based on the findings of the trading of games consoles and the age of consoles entering waste treatment, the total stock life ("domestic service lifespan" in Figure 20) of games consoles appears to be significantly longer than 7 years, and is estimated by the study team to be 14 years.

4.3.2 User behaviour with regard to repair and maintenance, refurbishment and reuse, disposal

As for console lifetime, there is also very little information about user behaviour with regard to repair and maintenance, refurbishment, reuse and disposal of these products. Games consoles have a free 1-year manufacturer warranty as standard. After this, if there are defects, in most EU countries for a period of 2 years after purchase, consumers must prove that they have not caused the defect if they want to claim the legal guarantee for a product. If they are not able to provide this proof, and after the end of the two-year period, they have to pay for any repairs themselves.

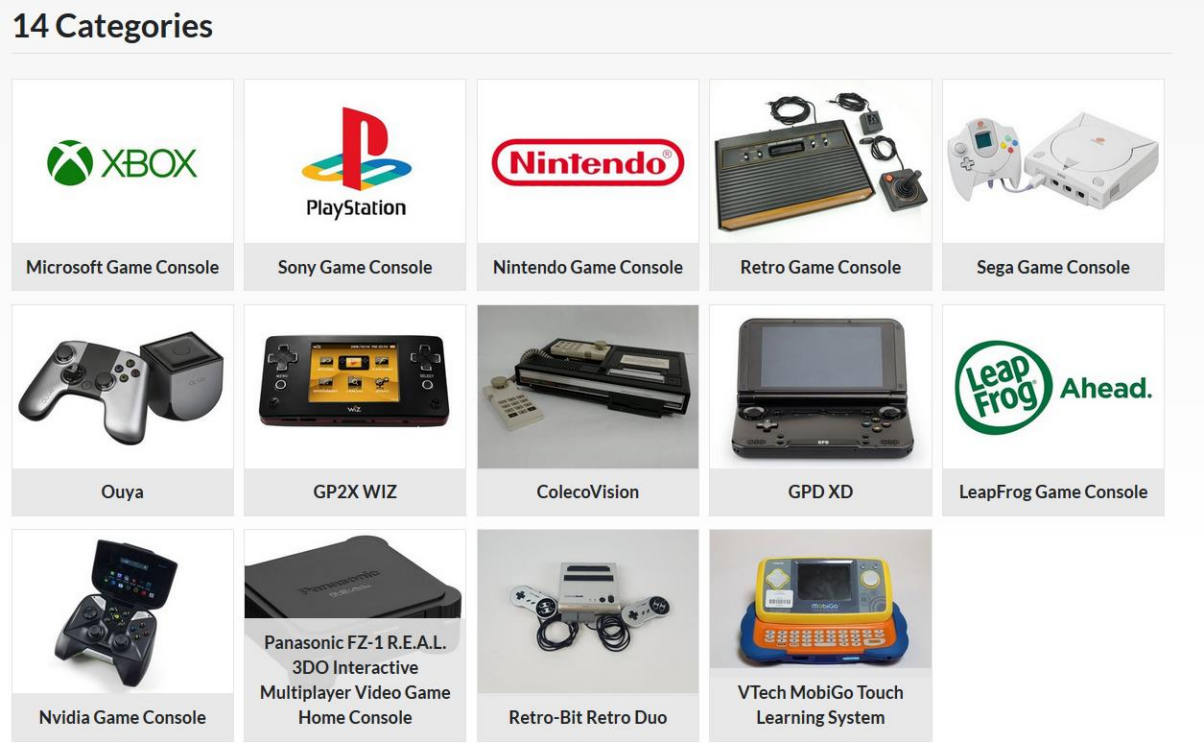
[95] The Switch has been on the EU market for 2 years and by February 2019, 443 non-functional Switch consoles had been sold via eBay in Germany – presumably only those that developed defects after the warranty phase.

The SRI commits each manufacturer to provide out of warranty repair services for their games consoles, and also commits SRI signatories to provide spare parts to authorised repair centres. According to games consoles manufacturers, consumers are often provided with a refurbished console and spare parts are also recovered from consoles that are broken beyond repair. The SRI does, however, not specify for how long repair services and spare parts have to be offered after the discontinuation of a games console. Microsoft reports that it continues to offer repairs for the Xbox 360 last sold in 2016 and according to Sony, the company continues to offer exchange of broken PS3 units out of warranty with refurbished models. Nintendo sells spare parts only for the consoles which they currently sell and not for discontinued models. Out of warranty service is assured at least as long as the product is still on sale.

With regard to user behaviour, in terms of their demand for repair and spare parts, the study team chose to take a look at a hybrid community-based approach that aims to tackle issues in the repair and maintenance of games consoles (and also other electric or electronic appliances). Ifixit[96] provides free game console repair manuals for end-users as well as for independent professional repair facilities and offers spare parts and tools for sale for Sony, Microsoft and Nintendo games consoles based on the ID of each console. Ifixit is a user- and wiki-based site, aiming to empower individuals and independent repair facilities by providing repair information, tools and spare parts. Although ifixit does not represent all users of games consoles or even "typical" user behaviour with regard to repair and maintenance , it is worth looking at closer, since this international community involves more than one million individuals worldwide.

According to ifixit, complete disassembly and installation guides for most games consoles manufactured since 1986 have been developed and published by the community:

Figure 23: Types of game consoles covered by ifixit



[96] see online: https://www.ifixit.com/Info/index

An overview of the number of spare parts provided for different Sony PlayStation models is given in Figure 24. The number of spare parts available varies among the models, with a minimum of nine parts for PlayStation 4 Slim and a maximum of 54 parts for PlayStation Vita. With regard to Nintendo and Microsoft, the minimum number of spare parts offered for Nintendo DS Lite and Nintendo DS is zero, the maximum is 39 parts for the Wii Console. For Microsoft, the minimum number of spare parts for Xbox Original and Xbox360 E is two each and 26 parts for Xbox 360.

Most spare parts offered are virgin, although a share is assumed to be from used or waste consoles. According to ifixit Europe, it is not possible to source spare parts from the original manufacturers. The organisation sources the spare parts offered from an Asian trader of spare parts. Although ifixit is able to provide a relatively big number of spare parts, there are also parts that are requested by customers (professional repair centres and end-users) which the organisation cannot access. In addition, there is no publicly available information on the spare part inventories and which spare parts are maintained for what time. According to ifixit, considerable effort and time is required to find providers or traders of a variety of spare part types.

Figure 24: Spare parts offered for Sony PlayStation offered by ifixit

(Source: https://www.ifixit.com/Store/Game-Console/Sony-Games-Consoles)

According to ifixit, there is considerable interest in repairing games consoles by end-users and by independent repair facilities. However, ifixit does only represent those users that are able to repair and are interested in repairing their games consoles. Since the prices of the consoles themselves are rather low compared to the games, substituting a defective console for a new one may be likely, if the costs and effort associated with the repair of the games consoles are too high.

With regard to the typical weaknesses of specific parts, which are likely to break-down over time, no general statement can be made that applies to all models. An interview with ifixit, however, indicated that for high performance games consoles heat stress in association with insufficient heat management may lead to a variety of defects in those parts that are heat-sensitive. This might affect for example the power supply, parts of the PCBs, the fans or the motherboard[97].

As far as disposal is concerned, games consoles that are disposed of correctly in the EU are collected separately from other household waste as a mixed fraction together with other small WEEE. However there are indications that small electronic devices are often not disposed of correctly by end-users but are disposed of in the residual waste. In the latter case, the devices do not enter the proper WEEE recycling route. SRI signatories all report that they provide information to games consoles users on appropriate WEEE take-back at end-of-life and participate in various WEEE recycling schemes that operate in EU countries. There are no data on the amounts of waste games consoles collected separately from other household waste.

In Europe, there are no specific take-back programmes for waste games consoles organised by the manufacturers. Microsoft reports having an own take-back scheme, but for Europe, this refers to the general WEEE collection schemes[98]. For Nintendo products, there is a specific take-back programme for video games consoles for the USA and Canada[99]. To participate in the programme, consumers need to send an e-mail to Nintendo to receive a shipping label so that they can send in their products for recycling.

[97] As described in section 4.1.9 thermal measurement on new PS 4 Slim and Xbox one S carried out by the study team did not indicate any heat issues. If this discrepancy between thermal measurements and Ifixit observations results from a difference in the age of the consoles could not be resolved by the study team.
[98] See https://support.xbox.com/en-IE/my-account/warranty-and-service/recycle-your-xbox
[99] See https://www.nintendo.com/consumer/recycle.jsp.

5. Task 4 Technologies

Task 4 includes a technical product description of existing games consoles, Best Available Technology (BAT), and Best Not Yet Available Technology (BNAT) as well as a description comprising the reporting of product weight, bills-of-materials and end-of-life treatment of games consoles.

5.1 Technical description existing products

5.1.1 Main components

A videogames console is typically composed of the following components:

- Power Supply
- APU
- System Memory
- Mainboard
- Case
- Connectors
- Storage
- Removable Data Media
- Controller
- Display (optional)
- Battery (optional)

5.1.1.1 Power Supply

The Power Supply transforms the Input Voltage and Current to the needs of the System. It provides the power necessary to operate the game consoles. In the case of game consoles, it converts AC input to low Voltage DC output. It can be an external device or an internal module.

5.1.1.2 APU

The APU is the heart of the game console and is built like an SOC. The main parts are the CPU (Central Processing Unit) and a GPU (Graphics Processing Unit). The CPU does the main calculations for the operating system and the games. The GPU serves as an accelerator for the processing of data for the video output. Additionally, it can contain blocks to support certain functions like an audio processing unit (PS4), memory controller, SRAM (Xbox One) and video decoders.

5.1.1.3 System Memory

The System Memory is the location for all the data that are needed at runtime. The data for the operating system as well as data for the games are divided, depending on the system.

5.1.1.4 Dock

In case of portable consoles, there is an additional dock, so that it can be used as a stationary device that is attached to a display and to gain some processing power because the internal display can be shut off and a fan can be added to support cooling.

5.1.1.5 Mainboard

The mainboard is the PCB (Printed Circuit Board) where all the components like APU and Memory are connected to each other.

5.1.1.6 Case

The case is the base for the console and serves as protection and housing.

5.1.1.7 Connectors

There are several connectors inside a console that serve as Power Input, Display output, Controller output/charge port, internet connection, Audio Output, peripherals and more.

5.1.1.8 Storage

In order to save or install games a storage device is needed. In the case of consoles this is normally a hard disk drive (PS4 and XBOX One) or a flash memory (Nintendo Switch).

5.1.1.9 Removable Storage Device

For the purpose of playing games or watching movies the necessary files have to be provided. These files are either downloaded from the supplier or inserted into the removable storage bay. The removable media can be a DVD, Blu-Ray, proprietary card and others.

5.1.1.10 Controller

Another important component of every console is the input device or controller. It is connected to the Console via cable or some sort of wireless interface like Bluetooth. In most cases these are battery powered, offer analogue and digital inputs and have feedback via vibration and sound. Furthermore, some controllers offer the possibility to connect a headset to the console via the controller.

5.1.1.11 Display

In order to view the content of the consoles, a display is needed. This can be part of the console (Nintendo Switch) or be an external display which is connected via suitable connectors (HDMI for PS4 and XBOX One).

5.1.1.12 Battery

For handheld consoles, a rechargeable battery is needed as a power supply.

5.1.2 Joining techniques used, reparability and dismantling

Current generation games consoles can be opened without permanent damage and components can be exchanged with the use of specific instructions for each console[100]. For most connections, screws are used (for some of which, such as for Nintendo's Tri-point screws, specific – commercially available – specialised screwdrivers are needed) as well as a limited number of snap fits. Glueing and adhesive tape are used as a joining technique only for fixing a few components to the Switch console (touchscreen, loudspeakers), and a USB port is soldered to the console. The battery of the Switch is not designed to be replaced by the users, but can be exchanged by professional repair services.

Ifixit rates all current generation games consoles with a reparability score of 8 points (out of 10, with 10 being the best score)[101]. Most games consoles of the previous generation did not receive such a score, and there appear to have been many more difficulties in opening the casing and exchanging components. In particular with regard to the Xbox 360 there was not only a lot of media coverage with

[100] The following description is based on Ifixit's teardown documentations, see https://ifixit.com/Device/Game_Console.
[101] See https://ifixit.com/Device/Game_Console.

regard to frequent defects back in 2007[102], but it was also very difficult to repair the product due, among other things, to seven tiny snap fits in the casing that made it very hard to open it without damage.

5.1.3 Product categories

There are some basic technical differences between current products on the games consoles market and these constitute the features for defining different product categories.

- HD vs UHD capabilities
- Handheld vs non-handheld consoles (and consoles, which can do both)

5.1.3.1 HD vs UHD capabilities

The different consoles on the market composing the 8th generation have different capabilities when it comes to playback and gaming in high resolution. The first consoles of the actual generation were able to render games with Full HD but not with 4k. Only the 2nd revision of the consoles (PS4 Pro and XBOX One X) are able to deliver a performance sufficient for 4k gaming. Nevertheless, it is possible with some devices to do 4k playback for streams and movie files. An overview is provided in the following Table 28[103], excluding any upscaling from HD to UHD.

Table 28: Playback and gaming capabilities

Model	HD Gaming	HD Playback (Stream & Blu-Ray)	UHD Gaming	UHD Playback (Stream)	UHD Playback (Blu-ray)
Xbox One	yes	yes	no	no	no
Xbox One S	yes	yes	no	yes	yes
Xbox One X	yes	yes	yes	yes	yes
Nintendo Switch	yes	yes (only stream with apps like YouTube or Hulu)	no	no	no
PS4	yes	yes	no	no	no
PS4 Slim	yes	yes	no	no	no
PS4 Pro	yes	yes	yes	yes	no

The SRI distinguishes between HD consoles, UHD media capable, and UHD gaming capable consoles in its power caps for consoles, as high resolution has an impact on energy use. Because the UHD playback for Blu-Rays is limited to the build-in component, a separation was made in Table 28.

5.1.3.2 Handheld vs non-handheld

Another differentiation can be made when it comes to portability. Most of the devices dominating the market are stationary except for the Nintendo Switch currently, which can be used either in portable (handheld, with or without Joy-Cons attached) or in stationary mode (in the docking station).. There are or have been until recently also pure handheld games consoles such as PS Vita and simpler handheld consoles. Since portable devices are optimised with regard to a low energy use and optimized performance/energy ratio, due to the limited energy storage and weight, they cannot directly be compared to stationary devices and should be discussed separately (like stationary PCs vs notebooks).

[102] See, e.g., https://web.archive.org/web/20071022181418/http://www.bbc.co.uk/consumer/tv_and_radio/watchdog/reports/consumer_goods/consumer_20070213.shtml; https://www.gamesindustry.biz/articles/rings-of-red; https://wayback.archive-it.org/all/20160429125635/http://www.1up.com/news/tale-11-broken-360s; https://web.archive.org/web/20090906005326/http://www.gamespot.com/news/6216691.html

[103] https://www.techradar.com/news/ps4-pro-vs-xbox-one-x-how-are-the-mid-generation-consoles-shaping-up [Accessed 02 Feb. 2019]

5.1.4 Technical Specifications – Overview

There is a correlation between computing power and energy needed for its computation. For a better understanding of the hardware components in use, a breakdown of the models and their revisions is given in Table 29. The data is based on following references ([104],[105],[106],[107],[108],[109],[110],[111],[112]).

[104] https://de.wikipedia.org/wiki/PlayStation_4 & subreferences [accessed 07 Feb.2019]
[105] http//www.gamespot.com/articles/console-specs-compared-xbox-one-x-ps4-pro-switch-a/1100-6443665/ [accessed 07 Feb.2019]
[106] https://www.playstation.com/de-at/get-help/help-library/system---hardware/storage---data/ps4--new-model-comparison/ accessed 07/02/2019
[107] https://news.xbox.com/wp-content/uploads/Xbox_One_Spec_Sheet.pdf accessed 08/02/2019
[108] https://en.wikipedia.org/wiki/Xbox_One & subreferences accessed 08/02/2019
[109] https://www.ign.com/articles/2019/01/23/nintendo-switch-was-the-best-selling-console-of-2018-in-the-us accessed 09/02/2019
[110] https://www.nintendo.at/Nintendo-Switch/Spezifikationen/Spezifikationen-1176277.html#1 accessed 09/02/2019
[111] https://en.wikipedia.org/wiki/Nintendo_Switch & subreferences accessed 09/02/2019
[112] https://en.wikipedia.org/wiki/Joy-Con & subreferences accessed 07/02/2019

Specs	PS4	PS4 Slim	PS4 Pro	Xbox One	Xbox One S	Xbox One X	Nintendo Switch
Models	CUH-10xx CUH-11xx CUH-12xx	CUH-20xx CUH-21xx CUH-22xx	CUH-70xx CUH-71xx CUH-72xx	1540	1681	1787	HAC-001 (Handheld) HAC-007 (Dock)
Processor	Semi-custom AMD "Jaguar" 8 Core, up to 1.6 Ghz, 2 MiB L2 Cache, 28nm process	Semi-custom AMD "Jaguar" 8 Core, up to 1.6 Ghz, 2 MiB L2 Cache, 16nm process	Semi-custom AMD "Jaguar" 8 Core, up to 1.6 Ghz, 2 MiB L2 Cache, 16nm process	Semi-custom AMD "Jaguar" 8 Core, up to 1.75 Ghz, 2 MiB L2 Cache, 28nm process	Semi-custom AMD "Jaguar" 8 Core, up to 1.75 Ghz, 2 MiB L2 Cache, 16nm process	Semi-custom AMD "Jaguar" 8 Core, up to 2.3 Ghz, 2 MiB L2 Cache, 16nm process	Custom NVIDIA Tegra Processor X1 Octa Core 1.02GHz
GPU	1.8 Teraflops 18 Comp.-Units 800Mhz AMD Radeon™ based	1.8 Teraflops 18 Comp.-Units 800Mhz AMD Radeon™ based	4.2 Teraflops 36 Comp.-Units 911Mhz AMD Radeon™ based	1.3 Teraflops 12 Comp.-Units 853Mhz AMD Radeon™ based	1.4 Teraflops 12 Comp.-Units 914Mhz AMD Radeon™ based	6 Teraflops 40 Comp. Units, 1172Mhz AMD FreeSync	256 Maxwell based Cuda Cores with 307.2-921Mhz, depending: docked, portable
Rated power	230(250)W	165W	310W	220W	120W	245W	39W
Input	AC100-240V 50/60Hz	AC100-240V 50/60Hz	AC100-240V 50/60Hz	AC100-240V 50/60Hz	AC100-240V 50/60Hz	AC100-240V 50/60Hz	AC100-240V 50/60Hz
System Memory	8 GB GDDR5 (5 Available), 176 GByte/s	8 GB GDDR5 (5 Available), 176 GByte/s	8 GB GDDR5 (5.5 Available), 218 GByte/s 1GB DDR3-RAM	8 GB DDR3 (68 GByte/s), 32MB ESRAM (204 GByte/s)	8 GB DDR3 (68 GByte/s), 32MB ESRAM (218 GByte/s)	12 GB GDDR5 (9 available) (326 GByte/s)	4GB LPDDR4
HDD	500GB/1TB	500GB/1TB	1TB	500MB/1TB	500MB/1TB/2TB Elite Version with SSHD	500MB / 1TB	FlashMem 32GB, microSD(H)(X)C up to 2TB
Media-Type	Blu-ray, Download	Blu-ray, Download	Blu-ray, Download	Blu-ray, Download	4K Blu-ray, Download	4K Blu-Ray, Download	Proprietary Game-Cards, Download
HDMI	1.4 (HDR)	1.4 (HDR)	1.4 (HDR)	1.4b (no HDR)	2.0 (out) 1.4b (in)	2.0b HDR (out), 1.4b (in)	1.4b
Ethernet	Yes	10/100/1000	10/100/1000	10/100/1000	10/100/1000	10/100/1000	

Specs	PS4	PS4 Slim	PS4 Pro	Xbox One	Xbox One S	Xbox One X	Nintendo Switch
WLAN	IEEE 802.11 b/g/n	IEEE 802.11 b/g/n/ac	IEEE 802.11 b/g/n/ac	IEEE 802.11 b/g/n dualband	IEEE 802.11 a/b/g/n/ac	IEEE 802.11 a/b/g/n/ac	IEEE 802.11 b/g/n dualband
Bluetooth	2.1 + EDR	4.0	4.0	2.1 + EDR	2.1 + EDR	4.0	4.1
Additional Connectivity	S/PDIF	--	S/PDIF	IR, S/PDIF	IR, S/PDIF	IR, S/PDIF	IR
USB	USB 3.1 Gen. 1	USB 3.1 Gen. 1	USB 3.1 Gen. 1	USB 3.1 Gen. 1	USB 3.1 Gen. 1	USB 3.1 Gen. 1	USB 3.1 Gen. 1
Video Modes	Games up to 1080p, Video up to 4k	Games up to 1080p, Video up to 4k, No 4k video Blue-rays	Games up to 4k, Videos up to 4k	Games up to 1080p, Videos up to 1080p, 60Hz	Games up to 1080p (upscaling to 4k), Videos up to 4K, 60Hz	Games up to 4k, Videos up to 4k, 120 Hz	Games up to 1080p, Videos up to 1080p, 60Hz (when using as handheld 720p due to display limitations)
Online-Features	Browsing Streaming Gaming	Browsing Streaming Gaming	Browsing Streaming Gaming	Browsing Streaming Gaming	Browsing Streaming Gaming	Browsing Streaming Gaming	Streaming Gaming
Battery	--	--	--	--	--	--	Li-Ion battery 15.95Wh
Display	--	--	--	--	--	--	LCD 6.2 inch 720p
Weight	2.8kg	2.1kg	3.3kg	3.5kg	2.9kg	3.8kg	Console: 297g Joy-Con: 98g
Size in mm W × H × L	305×53×275	265×39×288	305×53×275	343×80×263	295x65x230	300x60x240	203.1x102x13.9 (console only), 239x102x13.9 (with Joy-con)

Table 29: Technical Comparison between Consoles and their revisions

Specs	PS4	PS4 Slim	PS4 Pro	Xbox One	Xbox One S	Xbox One X	Nintendo Switch
Models	CUH-10xx CUH-11xx CUH-12xx	CUH-20xx CUH-21xx CUH-22xx	CUH-70xx CUH-71xx CUH-72xx	1540	1681	1787	HAC-001 (Handheld) HAC-007 (Dock)
Processor	Semi-custom AMD "Jaguar" 8 Core, up to 1.6 Ghz, 2 MiB L2 Cache, 28nm process	Semi-custom AMD "Jaguar" 8 Core, up to 1.6 Ghz, 2 MiB L2 Cache, 16nm process	Semi-custom AMD "Jaguar" 8 Core, up to 1.6 Ghz, 2 MiB L2 Cache, 16nm process	Semi-custom AMD "Jaguar" 8 Core, up to 1.75 Ghz, 2 MiB L2 Cache, 28nm process	Semi-custom AMD "Jaguar" 8 Core, up to 1.75 Ghz, 2 MiB L2 Cache, 16nm process	Semi-custom AMD "Jaguar" 8 Core, up to 2.3 Ghz, 2 MiB L2 Cache, 16nm process	Custom NVIDIA Tegra Processor X1 Octa Core 1.02GHz
GPU	1.8 Teraflops 18 Comp.-Units 800Mhz AMD Radeon™ based	1.8 Teraflops 18 Comp.-Units 800Mhz AMD Radeon™ based	4.2 Teraflops 36 Comp.-Units 911Mhz AMD Radeon™ based	1.3 Teraflops 12 Comp.-Units 853Mhz AMD Radeon™ based	1.4 Teraflops 12 Comp.-Units 914Mhz AMD Radeon™ based	6 Teraflops 40 Comp. Units, 1172Mhz AMD FreeSync	256 Maxwell based Cuda Cores with 307.2-921Mhz, depending: docked, portable
Rated power	230(250)W	165W	310W	220W	120W	245W	39W
Input	AC100-240V 50/60Hz	AC100-240V 50/60Hz	AC100-240V 50/60Hz	AC100-240V 50/60Hz	AC100-240V 50/60Hz	AC100-240V 50/60Hz	AC100-240V 50/60Hz
System Memory	8 GB GDDR5 (5 Available), 176 GByte/s	8 GB GDDR5 (5 Available), 176 GByte/s	8 GB GDDR5 (5.5 Available), 218 GByte/s 1GB DDR3-RAM	8 GB DDR3 (68 GByte/s), 32MB ESRAM (204 GByte/s)	8 GB DDR3 (68 GByte/s), 32MB ESRAM (218 GByte/s)	12 GB GDDR5 (9 available) (326 GByte/s)	4GB LPDDR4
HDD	500GB/1TB	500GB/1TB	1TB	500MB/1TB	500MB/1TB/2TB Elite Version with SSHD	500MB / 1TB	FlashMem 32GB, microSD(H)(X)C up to 2TB
Media-Type	Blu-ray, Download	Blu-ray, Download	Blu-ray, Download	Blu-ray, Download	4K Blu-ray, Download	4K Blu-Ray, Download	Proprietary Game-Cards, Download
HDMI	1.4 (HDR)	1.4 (HDR)	1.4 (HDR)	1.4b (no HDR)	2.0 (out) 1.4b (in)	2.0b HDR (out), 1.4b (in)	1.4b

Specs	PS4	PS4 Slim	PS4 Pro	Xbox One	Xbox One S	Xbox One X	Nintendo Switch
Ethernet	Yes	10/100/1000	10/100/1000	10/100/1000	10/100/1000	10/100/1000	
WLAN	IEEE 802.11 b/g/n	IEEE 802.11 b/g/n/ac	IEEE 802.11 b/g/n/ac	IEEE 802.11 b/g/n dualband	IEEE 802.11 a/b/g/n/ac	IEEE 802.11 a/b/g/n/ac	IEEE 802.11 b/g/n dualband
Bluetooth	2.1 + EDR	4.0	4.0	2.1 + EDR	2.1 + EDR	4.0	4.1
Additional Connectivity	S/PDIF	--	S/PDIF	IR, S/PDIF	IR, S/PDIF	IR, S/PDIF	IR
USB	USB 3.1 Gen. 1	USB 3.1 Gen. 1	USB 3.1 Gen. 1	USB 3.1 Gen. 1	USB 3.1 Gen. 1	USB 3.1 Gen. 1	USB 3.1 Gen. 1
Video Modes	Games up to 1080p, Video up to 4k	Games up to 1080p, Video up to 4k, No 4k video Blue-rays	Games up to 4k, Videos up to 4k	Games up to 1080p, Videos up to 1080p, 60Hz	Games up to 1080p (upscaling to 4k), Videos up to 4K, 60Hz	Games up to 4k, Videos up to 4k, 120 Hz	Games up to 1080p, Videos up to 1080p, 60Hz (when using as handheld 720p due to display limitations)
Online-Features	Browsing Streaming Gaming	Browsing Streaming Gaming	Browsing Streaming Gaming	Browsing Streaming Gaming	Browsing Streaming Gaming	Browsing Streaming Gaming	Streaming Gaming
Battery	--	--	--	--	--	--	Li-Ion battery 15.95Wh
Display	--	--	--	--	--	--	LCD 6.2 inch 720p
Weight	2.8kg	2.1kg	3.3kg	3.5kg	2.9kg	3.8kg	Console: 297g Joy-Con: 98g
Size in mm W × H × L	305×53×275	265×39×288	305×53×275	343×80×263	295x65x230	300x60x240	203.1x102x13.9 (console only), 239x102x13.9 (with Joy-con)

Figure 25: PS 4 Slim in Lab

Figure 26: PS4 Pro in Lab

Figure 27: Xbox One S in Lab

Figure 28: Nintendo Switch (Docked) with Joy-Con Comfort Grip

Figure 29: Xbox One X in Lab

5.1.5 Improvements in games consoles over lifespan

At release, games consoles are put on the market under time pressure so that they are not necessarily optimised with regard to all environmentally relevant design features. During the lifetime of a games console, several improvements are made to enhance certain properties of the device. This means that, for example, the processes of the main processing unit are improved/altered and therefore the power consumption is reduced. Often there are improvements in one model that are not visible from the outside, but the model numbers are different.

For instance, Sony reports a reduction in the weight of PS4 since its introduction in 2013 by 23 %, the weight of PS3 since its introduction in 2007 by 58%, and even the weight of the handheld PS Vita has been reduced by 17% since 2012. At the same time, the energy use in gaming mode has been reduced since the PS3 release by more than 60% for gaming and by more than 80% for the standby mode[113]. As for the PS4, the energy reduction for gaming is estimated to be about 43%, and the overall energy consumption reduction for PS Vita is 27%[113].

5.2 Weight and materials

5.2.1 Product weight

The weight of products currently on the market ranges from 2.1 kg (PS 4 Slim) to 3.8 kg (Xbox One X) for stationary high-end consoles. For portable consoles, the product weight ranges from 219 g (PS Vita) to 398 g (Switch, with controller attached, without docking station). The stationary arcade console Super Nintendo Classic Mini weighs 299 g without the two controllers.

5.2.2 Bills of materials (BOMs)

Limited data are available with regard to product BOMs. All three SRI signatories have provided data on the BOM of one of their recent products. Where the information on material composition supplied by the signatories was not detailed enough for the purpose of an impact assessment in the Ecoreport tool, assumptions had to be made. These assumptions were based on teardown information and visual appearance of components from in-house dismantling and have been approved by the signatories.

Table 30: BOM of games console 1 (PlayStation 4 model CUH-2216A)

Console component	Console part	Material/s	Mass (g)
Casing	Top casing	Plastic (ABS)	147,6
	Bottom casing	Plastic (ABS)	197,7
	Inner casing	Steel	18,8
	Inner casing	Steel	152,9
	Inner casing	Steel	27
	Heat sink unit	Steel, Aluminium, Copper	244,3
	Frame casing	Plastic (ABS)/steel	244,3
PCB	Motherboard PCB	PCB	153,1
Power supply	Power supply unit	Various	310,4
Optical drive	Blu-ray disc drive	Various	292,4

[113] https://www.playstation.com/de-de/footer/about-us/playstation-and-the-environment/

Console component	Console part	Material/s	Mass (g)
Storage	HDD drive	Various	127,3
Fan	Cooling fan	Various	108,1
Screws	Various screws	Various	10,4
Cables	AC power cord	Various	123,2
	USB DS4 charging cable	Various	39,1
	HDMI cable	Various	75,6
Peripherals	Controller	Various	217,7
	Headphone/microphone	Various	9,6
Total mass			**2272,2**

Table 31: BOM of games console 2 (Switch model HAC-001)

Console component	Console part	Material/s	Mass (g)
Casing	Top casing	Plastic (PC+ABS)	12,0
	Bottom casing	Plastic (PC+ABS)	24,0
	Inner casing	Magnesium	23,5
	Inner casing	Aluminium	15,0
	Joint Rail connector	Steel, Plastic, etc.	19,0
	Button, Lens, Cover, Stand	Various	5,9
	Heat sink unit	Steel, Aluminium, Copper	8,0
PCB	Motherboard PCB	PCB	20,5
	Sub PCB/FPC/Antenna	PCB, FPC, etc.	8,7
Display	Touch Panel + LCD	Component	80,4
Speaker	Speaker	Component	3,0
Battery	Battery	Component	75,0
Fan	Cooling fan	Component	10,0
Screws	Various screws	Various	2,4
Peripherals	JOY-CONN L	Various	49,2
	JOY-CONN R	Various	53,3
Total mass			**409,8**

Table 32: BOM of games console 3 (Xbox One X)

Console component	Console part	Material/s	Mass (g)
Casing	Top casing	Plastic (ABS)	909,5
	Inner casing	Steel	1580,5
PCB	Motherboard PCB	PCB	434,4
Optical drive	Blu-ray disc drive	Component	473,0
Storage	HDD drive	Component	84,0
Ventilation	Motor	Component	123,7
Cables	AC power cord	Various	309,0
	Cable	Various	174,4
	Others	Various	37,1
	Batteries	Various	46,0
Peripherals	Controller	Various	280,49
Total mass			**4171,8**

To be used in the MEErP Ecoreport Tool (cf. section 6), the material types had to be refined based on before-mentioned assumptions.

According to the SRI signatories, current games consoles do not contain any post-consumer recycled plastics and no brominated flame retardants are used in any of the games console casings of products placed on the market by SRI signatories at present.

5.2.3 Expected end-of-life treatment of consoles/materials

Games consoles according to Annex III of the Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE) fall under category 5 “small equipment”. WEEE enter the designated treatment route via collection at public waste disposal sites, commercial collection sites or collection systems provided by the producers. Before being treated for further recycling - where technically and economically feasible - a check must be made as to whether the waste equipment or individual components thereof can be reused (prepared for reuse). Subsequently, the devices are pre-treated with the aim to separate the different materials contained in the devices and sort them into distinct material fractions for recovery.

In some pre-treatment facilities the first treatment step consists of semi-manual removal of components with a high resource potential such as large PCBs or hard drives and cables. Which components are removed strongly dependents on the market conditions with regard to the recycling revenues. Further treatment steps include several shredding and automated sorting technologies to derive at the main output fractions, which are:

(i) mixed plastics

(ii) ferrous (Fe-) metals

(iii) aluminium

(iv) copper and precious metals (PM)

(v) non-ferrous (NE-) metals excluding PM

(vi) fine shredding material which can be further separated in plastics and metals via density separation.

These output fractions then enter secondary treatment such as metal smelters for recovery of the materials or thermal treatment.

If the material outputs enter secondary treatment for material recovery, the material fractions are further treated to produce pure material outputs such as pure copper, steel, precious metals (gold, silver, etc.) and plastic granulates. Due to the inefficiencies of recycling, - with the exception of copper and precious metals - it is in many cases not possible to produce output materials in primary material quality e.g. the heterogeneous mixture of plastics with different filling materials, flame retardants and colours poses challenges to the recycling and plastic is therefore often not further recovered but treated thermally; some alloying elements and contaminants in aluminium are unfeasible to recover due to metallurgical reasons.

Some examples of secondary treatment facilities that do recover plastic from WEEE however exist: One of the biggest is MGG Recycling[114] situated Austria who separate, extrude and compound polymers from WEEE. They produce secondary PP, ABS, HIPS and PC/ABS. Other polymer types in the mixed plastic stream as well as plastics with flame retardants and other materials hindering the recycling process make up about 50 % of the waste stream and are separated by multiple density separation steps from the recyclable polymers to then enter thermal treatment. Other plastic recyclers are Bage plastics[115], also situated in Austria, who also apply density separation with similar outputs and Hamos recycling[116] who use electrostatic separation to further separate mixtures of polymers that cannot be separated by density separation due to similar physical properties.

However there are indications that small electronic devices are often not disposed of correctly by end-users but are disposed of in the residual waste. In the latter case, the devices do not enter the proper WEEE recycling route.

The actual end of life treatment of game consoles can be characterized by:

- A lack of information about which share of waste game consoles enter the designated treatment route (including proper pre-treatment and preparation for reuse)
- No significant preparation for reuse (after the devices have obtained waste status)

Shredding of the whole device is common practice, typically resulting in the following output fractions: mixed plastics, Fe-metals, aluminium, copper and precious metals, non-ferrous metals excluding precious metals and fine shredding material.

[114] https://www.mgg-recycling.com/
[115] https://bage-plastics.com/
[116] https://www.hamos.com/front_content.php

5.3 Best available technologies (BAT)

BAT (Best Available Technology) is assessed as such according to either technical requirements or functional performance requirements. Considering technical requirements, the BAT should not only fulfil the technical requirement to the extent of being the best in its category, but also fulfil additional requirements, such as availability, quality, or durability, so that the BAT can be a viable replacement for the technology.

There are a variety of technologies that could be discussed in this section. Some technologies, such as chip architecture, die shrink or separate video architecture have been discussed and are already known to manufacturers (see doctoral thesis by Amanda Webb[117] and SRI review report 2017[76]). Therefore, this section focuses on a number of technologies that have not yet been presented, to highlight new opportunities and perspectives.

The MEErP manual[118] provides a good description with examples. The manual also lists an example for functional performance requirements being considered as the main selection criteria for a BAT, which this study will use.

5.3.1 Storage Technologies

When it comes to storing data, the most used technology is the hard disk drive (HDD). Due to the need for a rotating platter inside the device it consumes a non-negligible amount of energy. There exist a couple of technologies to improve on this. First of all Solid State Drives (SSDs) are more and more common in today's computer world. Another approach would be a hybrid solution where a small SSD is paired with a larger HDD.

5.3.1.1 Solid State Drive

Solid State Drives are flash based memories that use standard interfaces of HDDs to be compatible or newer interfaces[119], such as NVMe or PCI Express, to have even faster connections. Their main advantage over HDDs is that they are less sensitive to mechanical shock, their form factor[120] can be significantly smaller and their much higher data transfer rates. An important disadvantage over HDDs is that they are more expensive. When the SSD breaks, it is difficult to recover data which is another disadvantage. A lifetime estimation of the SSD is stated by the manufacturers, for example as the terabytes written (TBW) value. As a calculation example[121], a TBW of 70 would need a user (or in this case the games console) to write 190 GB daily over a period of one year, which could be achieved only by extensive installing and de-installing video games on the console.

Typical form factors:

- msata - approx 30mm x 50mm (uses the SATA interface)
- m.2 - approx. 22mm x (40,60 or 80)mm (width x length) (uses the SATA or PCI Express interface)
- 2.5 inch - same as HDD notebook drives (uses the SATA interface)

Typical Interface:

[117] http://epubs.surrey.ac.uk/809999/
[118] MEErP Methodology, p. 84 https://www.eup-network.de/fileadmin/user_upload/Produktgruppen/Lots/Working_Documents/MEErP_Methodology_Part_1_Final_01.pdf [Accessed 17 Feb. 2019]
[119] https://www.storagereview.com/ssd_interfaces accessed 22/02/2019
[120] https://eu.crucial.com/eur/en/store-ssd-form-factors-overview accessed 22/02/2019
[121] https://www.ontrack.com/blog/2018/02/07/how-long-do-ssds-really-last/ accessed 23/02/2019

- NVM Express - (Interface for connecting the SSD over PCI-E without the need of a special driver[122]) → fast
- SATA - typical Interface for Hard Disk Drives → slower

Improvements in games consoles

When using SSDs in games consoles a couple of advantages can be observed:

- Reduced time for installing updates → reduced time in active mode
- reduced loading time → shorter time from starting to playing
- reduced power consumption → Due to less waiting time, lower power draw from the SSDs and faster updates
- less weight
- smaller form factor → smaller consoles
- higher resource efficiency

5.3.1.2 Hybrid Approach

In order to combine the advantages of SSDs and HDDs, a hybrid approach could be used. That could mean storing frequently accessed data like the operating system on the SSD and less frequently accessed data like games (as only one game is used at a time) on the HDD. An important application apart from playing is streaming, where only the operating system (doing some background task like updating) is active. A connection to the streaming provider and a small buffer are needed.

Already existing solution are:

- SSHDs - SSD and HDD combined in one drive
- Dual drives - Two separate drives visible to the host and managed manually or automatically

A hybrid solution can be a way to improve the system performance while keeping the price at a low level[123]. This would also be the case with consoles as the operating system (OS) is accessed regularly and a perfect candidate for data that is stored on the SSD. Unfortunately, as the SSD part of hybrid drives are rather small (~16GB) games usually cannot be stored there since the game data are in most cases of a larger size than that. Therefore, loading time cannot be reduced for the games in a hybrid approach.

5.3.2 Power Supplies

Power supplies are a key component in nearly every electronic device. Their energy efficiency is fundamentally import because all of the power drawn from the device is provided by the power supply. Therefore, the energy efficiency of the power supply is critical if systems are to have a low power consumption.

[122] https://de.wikipedia.org/wiki/M.2 accessed 22/02/2019
[123] https://www.pcworld.com/article/2025402/storage-drives/ssds-vs-hard-drives-vs-hybrids-which-storage-tech-is-right-for-you.html accessed 22/02/2019

In the Personal Computer area, there are several certifications for power supplies, depending on their efficiency, like Cybenetics[124] and 80 Plus[125]. These test Advanced Technology Extended (ATX) power supplies for parameters like efficiency, loudness, voltage ripple, power factor and other characteristics. According to their data there are power supplies available, that are able to deliver an average energy efficiency of up to approximately 94%[126]. These Power Supplies are usually designed for a higher Power class than games consoles. Nevertheless, the power supplies used in games consoles are specially designed for their specific mode of operation and thus optimized for specific scenarios. Power supplies in that range have an efficiency of about 89-92%[127, 128, 129]. Another important fact that cannot be ignored is that highly efficient power supplies are expensive and often cost nearly as much as a games console itself.

5.3.2.1 Power Supplies Efficiencies

After measuring the efficiency of the power supplies it is apparent that they have a very good efficiency in the important consumption ranges. The efficiencies measured are listed in Table 24 and the corresponding Power Factors in Table 25. The Power factor describes the ratio between Real Power and Apparent Power. If the factor is close to 1, there is little Reactive Power which cannot be used. It is a by-product of AC Systems that causes phase displacement of current and voltage and in the case of switching power supplies it is the non-linear behaviour of the internal components (especially the rectifiers that load the DC Circuit Capacitor). A high Power Factor reduces loss and load on the conductors and the grid. Therefore a Power Factor Correction Unit is used in these devices.

Table 33: Power Supply Efficiency

Specs		PS4 Slim		PS4 Pro		Xbox One S	Xbox One X	Nintendo Switch	
Model in Lab		CUH-2216B		CUH-7216B		1681	1787	HAC-001 (Handheld) HAC-007 (Dock)	
Rated Power		165W		310W		120W	245W	39W	
Output Voltage/Current		12V/13A 5VSB/1.5A		12V/23.5A 5VSB/1.5A		12V/10A	12V/22.42A	5V/1.5A 15V/2.6A	
Voltage		12V	5VSB	12V	5VSB	12V	12V	15V	5V
No Load Power (5 min average)		1,41W	58mW	1,41W	53mW	167mW	93mW	235mW	116mW
Efficiency in % at	**10% Load**	86.02	67.75	90.29	78.70	88.24	87.11	81.50	70.95
	20% Load	91.89	74.65	92.37	79.24	89.55	91.08	86.59	75.79
	25% Load	91.29	74.51	92.6	81.04	89.29	91.72	87.28	77.05
	30% Load	91.80	77.55	90.4	80.77	89.55	92.04	87.94	78.35
	40% Load	90.20	80.72	92.07	82.00	90.15	93.25	88.46	80.18
	50% Load	90.97	80.44	91.97	82.09	90.29	93.31	88.66	82.23

[124] https://cybenetics.com/ accessed 22/02/2019
[125] https://www.plugloadsolutions.com/80PlusPowerSupplies.aspx accessed 22/02/2019
[126] https://cybenetics.com/index.php?option=database&volts=2&cert=1&bdg=2&volts=2 accessed 22/02/2019
[127] https://deltapsu.com/products/download/Datasheet/MDS-300APB12-AA accessed 29/07/2019
[128] https://de.tdk-lambda.com/KB/CUS200LD-Datasheet-.pdf accessed 29/07/2019
[129] https://www.xppower.com/portals/0/pdfs/LF_ECP180 accessed 29/07/2019

Specs	PS4 Slim		PS4 Pro		Xbox One S	Xbox One X	Nintendo Switch	
60% Load	91.27	80.75	92.37	82.91	88.27	93.47	88.99	81.77
70% Load	91.54	82.49	92.58	84.03	88.72	93.40	89.33	82.02
75% Load	91.65	82.31	93.14	83.07	88.78	93.45	89.52	83.21
80% Load	91.13	81.06	93.1	83.38	88.91	93.45	89.64	82.83
90% Load	91.24	82.27	92.6	84.15	89.11	93.13	89.37	82.20
100% Load	91.27	81.36	92.87	83.51	88.93	92.87	88.80	81.95
Average Efficiency	**91.24**	**78.82**	**91.91**	**82.07**	**89.15**	**92.36**	**88.01**	**79.88**
Average Efficiency (25%, 50%, 75%, 100%)	**91.29**	**79.66**	**92.21**	**82.43**	**89.32**	**92.84**	**88.56**	**81.11**

Figure 30: Power supply efficiency of Lab Consoles

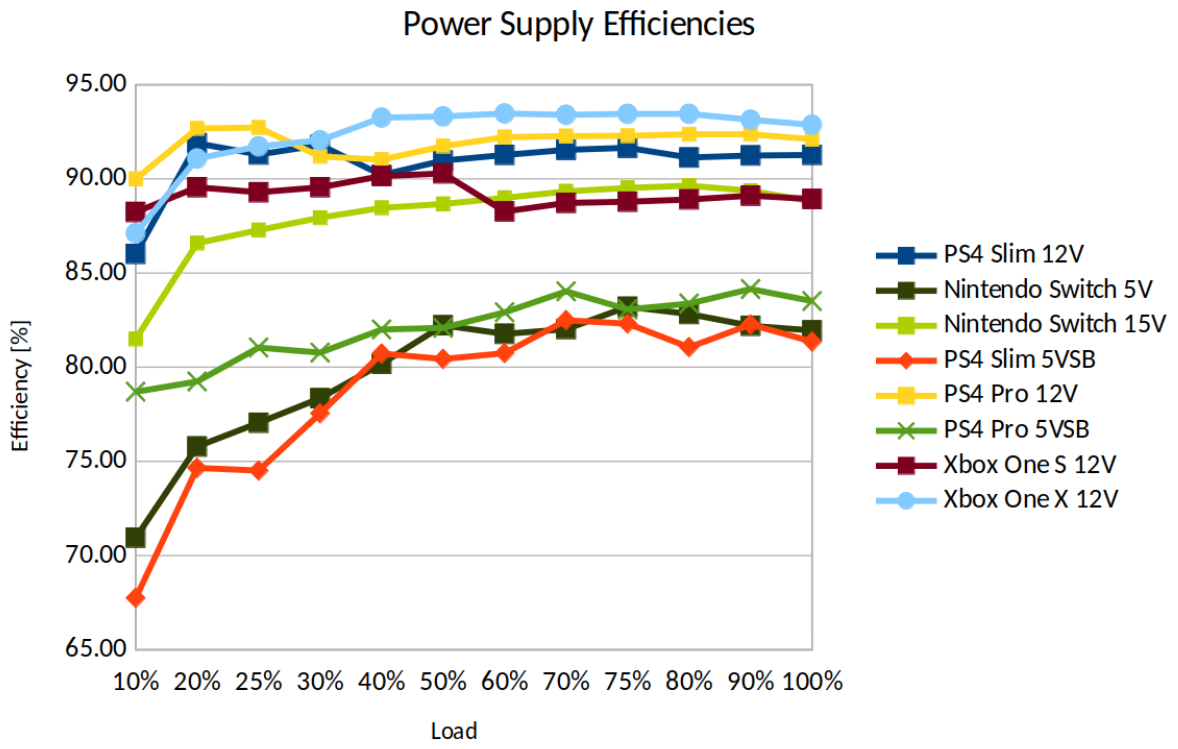


Table 34: Power Factor at Different Load Levels

Specs	PS4 Slim	PS4 Pro	Xbox One S	Xbox One X	Nintendo Switch
Model in Lab	CUH-2216B	CUH-7216B	1681	1787	HAC-001 (Handheld) HAC-007 (Dock)
Rated Power	165W	310W	120W	245W	39W
Output Voltage/Current	12V/13A 5VSB/1.5A	12V/23.5A 5VSB/1.5A	12V/10A	12V/22.42A	5V/1.5A 15V/2.6A

Specs		PS4 Slim		PS4 Pro		Xbox One S	Xbox One X	Nintendo Switch	
Voltage		12V	5VSB	12V	5VSB	12V	12V	15V	5V
Power Factor at	10% Load	0.48	0,04	0.53	0,03	0.5	0.77	0.43	0.26
	20% Load	0.62	0,08	0.66	0,05	0.56	0.86	0.49	0.34
	25% Load	0.66	0,10	0.70	0,06	0.57	0.89	0.51	0.36
	30% Load	0.70	0,11	0.73	0,08	0.57	0.90	0.53	0.34
	40% Load	0.76	0,14	0.77	0,10	0.56	0.92	0.54	0.40
	50% Load	0.8	0,17	0.81	0,12	0.92	0.93	0.53	0.42
	60% Load	0.83	0,19	0.84	0,14	0.93	0.94	0.53	0.44
	70% Load	0.85	0,22	0.86	0,16	0.93	0.94	0.51	0.45
	75% Load	0.86	0,24	0.88	0,17	0.92	0.94	0.50	0.46
	80% Load	0.87	0,25	0.88	0,18	0.93	0.94	0.50	0.47
	90% Load	0.89	0,27	0.90	0,20	0.93	0.95	0.51	0.50
	100% Load	0.90	0,30	0.91	0,23	0.94	0.95	0.51	0.51

5.3.2.2 Measurement Setup

The setup for the efficiency measurements consists of a power meter for measuring the input power, a power supply from one of the consoles, a voltmeter for measuring the output voltage directly at the output, an ampere meter for measuring the output current and an adjustable current load. Figure 31 provides a schema for the lab setup, while Figure 33 provides the picture in the Lab of TU Wien. For the Nintendo Switch a slightly different setup was used which can be found in Figure 32. In order to adjust the voltage of the power supply a USB Power Delivery controller was used.

Figure 31: Measurement setup: Efficiency tests

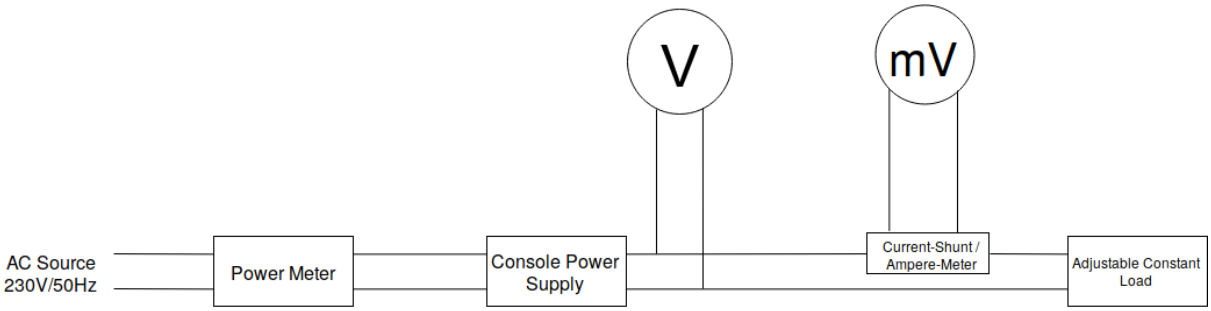


Figure 32: Measurement setup : Efficiency tests Nintendo Switch

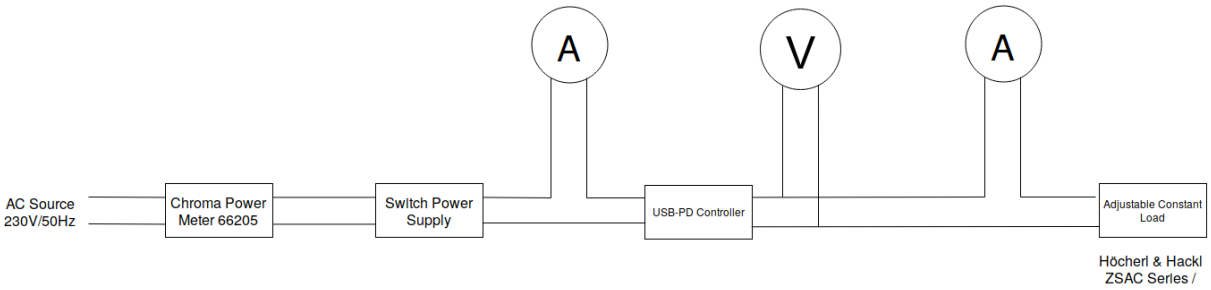


Figure 33: Lab setup for efficiency measurements

The instruments in use for carrying out these measurements are listed in Table 35, along with the manufacturer and model type.

Table 35: Measurement instruments

Measurement Instruments	Manufacturer	Model Type	Uncertainty
Power Meter	Chroma	66205	Power: max 0,22% (No load 0,48%-1,52%) Power Factor: 0.001+(15ppm/PF) x Hz
Measurement Test Fixture	Chroma	A662022	-
Voltmeter	Voltcraft	VC650BT	Max 0,26%
Ampere Meter	Agilent	U1251B	Max 0,52 % (with shunt)
Electronic Load	Höcherl & Hackl	ZSAC 4244	-
Current Shunt DC	Murata	DC Power Shunt 50mV 50A	Max 0,25%

5.3.3 Field Programmable Gate Arrays

Field Programmable Gate Arrays (FPGAs) are a well-established technology. They are used as customizable digital integrated circuits. Their main advantage is their reconfigurability, which can be used to optimize system performance after the product is sold on the hardware side. For example, a new decoder for video streams could be included, a faulty hardware-part could be replaced by the FPGA or a security critical hardware bug could be corrected. This technology should not be used as a replacement for the present SOCs, since FPGAs are not as energy efficient. Nevertheless, for a specific scenario they could help improve performance in areas that the SOC was not designed for (e.g the new AV1 Video Codec[130]). According to XIlinx [131] it is possible to use an embedded Microcontroller and program the device in-System for example from a RAM or EPROM. Therefore, it is feasible to reconfigure the device after sales. Energy Savings could be achieved by implementing new Codecs not available at the launch of the games console and resource savings could be achieved by fault tolerances introduced due to the FPGA. For example, the Xilinx Zynq SoC or MPSoC[132] Series which includes an ARM Processor which can be used as a separate Video architecture and a separate Programmable Logic Area (FGPA) could be used as such.

5.3.4 Self-learning auto-power-down feature for individual users

Programs and algorithms that are able to analyse and learn the behavior of users are not anything particularly new. Thanks to fuzzy logic, heuristic methods, neural networks, and evolutionary algorithms, it is easy and practical to use these techniques to extract and interpret user behavior patterns. This works by observing and sensing the activities of the system under study. Especially in the energy management system, this approach can deliver potential energy efficiency and user comfort.

Clearly, there are some factors which affect the logic of the system and will define the methods for the optimisation process. The first considerable factor is energy consumption, in addition, the time of consumption may be affected by price and type of energy e.g. green energy. It means that some activities may reduce the energy consumption and some of them may create flexibility for shifting the load to a suitable time. As an example, smart dishwashers will operate in a predefined time span to minimize the electricity price (cost reduction is an objective). Windows 10 indicates the inactive times and schedules the system update and restart at that time (User convenience is an objective). In a similar way, smart thermostatic controls can learn the temperature preferences of users and, based on this, automatically schedule the temperature. Likewise, adaptive mechanisms for analysing an optimizing auto-power-down timeframe could be offered as an additional option in the settings, additionally to the predefined timeframes. Different users have different patterns of behaviour, and these patterns, for instance, can be used for indicating the optimum value for APD, which optimize the energy consumptions and user comfort.

Updating software and games is another task, shifting this task won't change the energy consumption, but if there is a chance to use green or cheaper energy then postponing the update process is a great choice. A considerable portion of non-gaming activity is in networked standby mode, in which the games console remains connected to the internet and can provide limited secondary functions. If updates are provided in the predefined or prescheduled timeslot of the day/week then there is a chance to reduce the internet connection (turn off networking). To realise this, various challenges, e.g. information retrieval on renewable energy production, must be resolved. These challenges cannot be mastered solely by video game manufacturers, cooperation between e.g. video game manufacturers and energy system operators is necessary. However, goodwill in this direction would

[130] http://socionextus.com/pressreleases/socionext-implements-av1-encoder-over-cloud-service/ accessed 07.08.2019
[131] https://www.xilinx.com/support/documentation/application_notes/xapp058.pdf
[132] https://www.xilinx.com/products/silicon-devices/soc.html

be welcomed. In another approach, the system can check for the new updates every few hours and there is no need for continuous connections. In the case of unscheduled necessary security patches, the users can be informed about the need for these security patches after turning on the console and then proceed with the installation.

The main purpose of these activities is achieving energy efficiency improvements in this field. The amount of total energy consumption for games consoles is high enough to make it worth investigating any potential way of energy efficiency improvement, even for a fraction of one percent. Investigating methods and approaches for achieving possible energy efficiency improvement is an important goal. Although these methods can impact on the user experience, e.g. disabling remote wake-up of the games console, involving the users in smarter energy consumption and promoting it is another issue of considerable importance. A study shows that using green energy produced by PV is a motivator for users to shift dishwashing and laundering to when the sun is shining[133].

5.3.5 Material efficiency

Better dismantling/ optimized EOL treatment

In current recycling practices for small WEEE, impurities and/or contaminations of the output fraction with other materials can be observed. One example for the limits of (automatic) separation is shown in Figure 34 where aluminium heat sinks are attached to a PCB. If the PCB entered the Cu-route for recovery of the Copper and PMs, aluminium parts on its surface (if not removed manually) would be lost for recovery. If the PCB on the other hand were fed into the Al-route through automatic sorting with an eddy-current separator, the PMs would be lost for recovery. Such losses are inevitable in the current recycling practices due to the complexity of WEEE and the many materials used in components such as PCB. PCB which haven't been separated are distributed in almost all other fractions through shredding and the concentration of these metals is diluted in other material streams, making it economically unfeasible to recover them. This way, up to 40-50 % of gold, silver, platinum, and copper are lost via the plastics route alone, next to losses due to distribution of the metals into the ferrous and aluminium route[134]. Plastics can be found in all other fractions, while in the plastic fraction – after shredding and sorting – housing plastics are mixed with plastics from PCB and other contaminants which significantly reduces the achievable quality in recycling[135].

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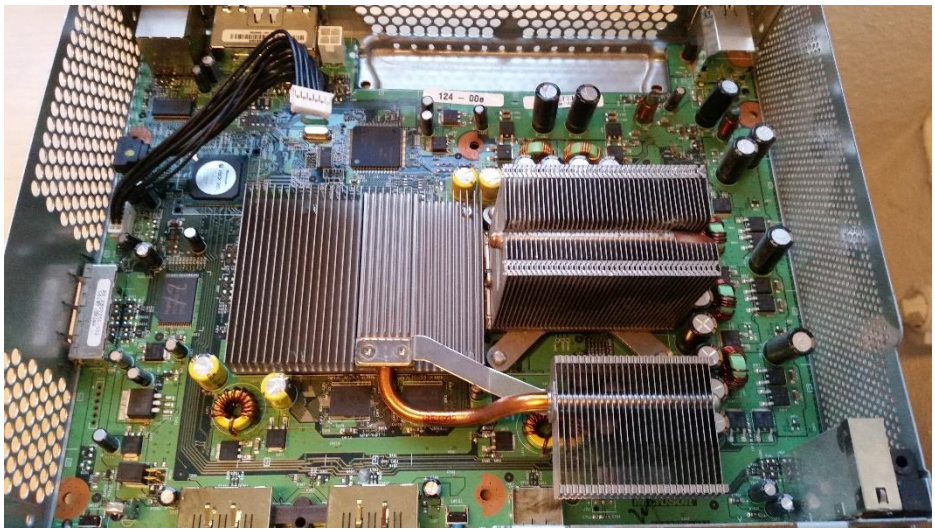
[133] Toke Haunstrup Christensen, Freja Friis,Tomas Moe Skjølsvold, Changing practices of energy consumption: The influence of smart grid solutions in households https://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2017/9-consumption-and-behaviour/changing-practices-of-energy-consumption-the-influence-of-smart-grid-solutions-in-households/2017/9-162-17_Christensen.pdf/

[134] Rotter, Vera Susanne; Ueberschaar, Maximilian; Geiping, Julia; Chancerel, Perrine; Flamme, Sabine (2012): Potenziale zum Recycling wirtschaftsstrategischer Metalle aus Elektroaltgeräten. Ergebnisse aus dem UPgrade Projekt. In ReSource (4).
Reuter, Markus A.; van Schaik, Antoinette; Ballester, Miquel (2018): Limits of the Circular Economy: Fairphone Modular Design Pushing the Limits. In World Metall. Erzmetall. 71 (2), pp. 68–79.
Sander, Knut; Otto, Sarah Julie; Wagner, Lukas; Rödig, Lisa (2018): Behandlung von Elektroaltgeräten unter Ressourcen- und Schadstoffaspekten. Ökopo, Hamburg. Edited by Umweltbundesamt, Dessau-Roßlau, Germany.

[135] Stråt, Martin; Nilsson, Camilla (2018): Decabromodiphenyl ether and other flame retardants in plastic waste destined for recycling. Edited by Swerea IVF.
Köhnlechner, Ralf (2014): Erzeugung sauberer PS- und ABS-Fraktionen aus gemischtem Elektronikschrott. In Karl Thomé-Kozmiensky, Daniel Goldmann (Eds.): Recycling und Rohstoffe. Neuruppin: TK.
Oguchi, Masahiro; Sakanakura, Hirofumi; Terazono, Atsushi (2013): Toxic metals in WEEE: characterization and substance flow analysis in waste treatment processes. In The Science of the total environment 463-464, pp. 1124–1132. DOI: 10.1016/j.scitotenv.2012.07.078.

Figure 34: Printed circuit board with aluminium heat sinks (picture: Ökopol)



Through additional pre-treatment (such as manual dismantling or customised automated mechanical treatment) the ferrous and non-ferrous metal fractions can be separated with lower impurities and fed into the designated routes for recovery resulting in a higher material recovery especially for precious metals[136].

Recycled material content

Concerning material efficiency, several frontrunners from the electronics sector can be identified by the study team that use (postconsumer) recycled input material.

In 2018 Dell became the first PC manufacturer to use recycled gold from e-waste instead of virgin mined gold in its products. The first laptops containing gold from recycled PC motherboards will be launched in 2019. Furthermore Dell uses post-consumer recycled (PCR) plastics from recycled computers (from Dell's own take-back channel) for parts of over 90 products with currently recycled content of 35 % of the plastic. Apple recently committed to "closing the loop" for its materials, starting with tin and aluminum[137].

The PC manufacturer Lenovo also started to use PCR plastics from water bottles in its products, starting with 30 % recycled HB-ABS/PET content in 2007. In 2009, Lenovo developed a new HB-ABS recycled material with 65% PCR plus 20% post-industrial recycled plastic for use in producing decorative monitor parts. This material contains no virgin resin. The post-consumer source is plastics recovered from end-of-life electronic products. Lenovo is the first company whose displays are certified with the "TCO Certified Edge Displays" certificate. This certificate requires a minimum of 85 % of PCR plastic by weight in the total weight of all product parts made out of plastic. (Except panels, electronic components, cables, connectors, PWBs, insulating mylar sheets and labels).

Depending on the final application requirements, the plastic resins used for Lenovo products contain between 10 % and 85 % PCR plastics. Some plastic resins also contain between 20 % and 99 % post-industrial recycled plastics. New targets were established for 2018/19:

- All newly released desktops, all-in-one computers, workstations, notebooks, tablets and visual products shall contain a minimum of 2 % PCR.
- All newly released server products shall contain a minimum of 10 % PCR in the external enclosure.

[136] Ibid.
[137] Greenpeace. (2017). Guide to greener electronics.

Material efficient components

Material efficiency can also be improved by using components that require lower material input for the same or even better performance. Using SSD storage technology instead of HDD not only increases the energy efficiency of the devices (cf. section 6.7) amongst other advantages, but also increases material efficiency, since SSDs are lighter in weight than HDD.

Furthermore HDD have moving parts that make them susceptible to physical damage. The modern drives incorporate shock-proofing technology - "drop" sensors that protect the head and media. The hard drives have an endurance level of 5-6 years, depending upon the usage and wear and tear. The SSD lifespan or reliability depends on factors like age and the total terabytes of data written over the time. SSD lifespan is limited to its read-write cycle which is defined by it the capacity and TBW (TeraBytes Written) which estimate the lifespan of an SDD. In a typical environment, the SSD's are expected to have a longer lifespan as compared to hard drives.

Use of easy-to-replace batteries

There are legal requirements concerning the use of batteries (Battery Directive/ WEEE Directive)[138]. The Battery Directive requires that batteries should be easily replaceable except where needed for data integrity and safety reasons. However, significant differences in real life products can be observed: E.g., the Xbox One X and Xbox One S contain regular AA batteries in the controllers, which can be replaced by the users. The PS4 Pro and PS4 Slim however come with controllers whose batteries are not of conventional types and are difficult to access and replace. The same observations can be made for products other than games consoles, e.g. for smartphones: While the battery can easily be exchanged by the user in some Samsung models, this is generally not possible for iPhones.

5.3.6 Use of hazardous materials

Substances are hazardous if they meet at least one of the criteria specified in Article 3 of the CLP Regulation (EC) 1272/2008 on the classification, labelling and packaging of substances and mixtures. Even more extensive requirements apply to hazardous substances identified under Article 57, REACH as “substances of very high concern”, and to substances, mixtures[139] and articles that contain them as (impurity) constituents.

Concerns regarding the use of hazardous materials in electronic goods exist both for materials used in the production of electronics and substances released during the waste treatment. Hazardous substances used in electronic devices are typically halogenated substances such as brominated flame retardants (BFR) in housings and printed circuit boards used to prevent products from catching fire, and plasticizers (e.g., phthalates), that make polymers such as polyvinylchloride (PVC) less brittle, especially in cables[140].

There are some manufacturers with comparably ambitious policies with regard to the use of hazardous substances. Example here are Apple[141,142], Google and HP[143].

Some manufacturers (Acer, Apple, Samsung, LG, Lenovo, Dell and HP) committed to phasing out PVC and BFRs from their products, to stem the tide of toxic e-waste. Now in 2017, only Apple and Google products are free of BFR and PVC across their product lines.

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[138] Batteries in EEE are collected according to WEEE Directive which requires the separation of batteries (Annex 7). Batteries are then treated according to the requirements of the battery directive.
[139] With the introduction of the CLP Regulation, the term “mixture” replaces the former term “preparation”
[140] Greenpeace. (2017). Guide to greener electronics.
[141] https://www.apple.com/environment/pdf/Apple_Prioritizing_Chemicals_2018.pdf
[142] https://www.apple.com/environment/pdf/Apple_Environmental_Responsibility_Report_2019.pdf
[143] Greenpeace. (2017). Guide to greener electronics.

5.4 Best not yet available technologies (BNAT)

In the BNAT (Best Not Available Technology) section, cutting edge technology developments, innovations, or technology replacements currently in research, provide a glimpse into possible product futures. The MEErP manual[118] provides descriptive advice, especially with respect to time-to-market for BNATs. With BNAT sometimes being made from software as a novel method, it is hard to foresee a situation with only 3 years to market. Therefore, this study considers it necessary to envisage at least 5-10 years of R&D work in a BNAT and up to 10 years before these products are on the market.

5.4.1 Energy-efficient compilers

Nowadays compilers offer compilation with standard optimization levels that are tailored to specific ISAs (Instruction Set Architectures) in order to produce good outputs on average with respect to execution performance and code size. These compilers have usually following characteristics:

a) They have no optimization level for energy consumption.

b) They do optimization without much regard for the hardware platform the code will run on.

c) They do not optimize based on the specific profile of a given input software program.

Specific compilers for games consoles that overcome these shortcomings could be used to optimize applications and games and could be offered for example to 3rd party companies as development kits in order to reduce overall energy consumption.

The COGUTS (Code Generation for Ultra-Thin Systems) project is a subproject of the ITEA3 COMPACT[144] (Cost Efficient Smart System Software Synthesis) project initiated and driven by Infineon Technologies AG, Germany, which is aiming to create and provide an encompassing ecosystem for the (energy) efficient development of smart, Ultra-Thin IoT nodes. COGUTS is a cooperation between ABIX and TU Wien, with a focus on the introduction of novel compile time modules that support balanced analyses and optimizations (i.e. multi-objective analyses and optimizations) of the key performance parameters code size, energy consumption, and execution performance. To date, compiler optimizations in compilers from major commercial manufacturers and open source groups feature optimizations targeted at execution performance and/or code size reduction. None of these compilers provides a compiler option involving energy consumption and code size reduction optimization while maintaining execution performance.

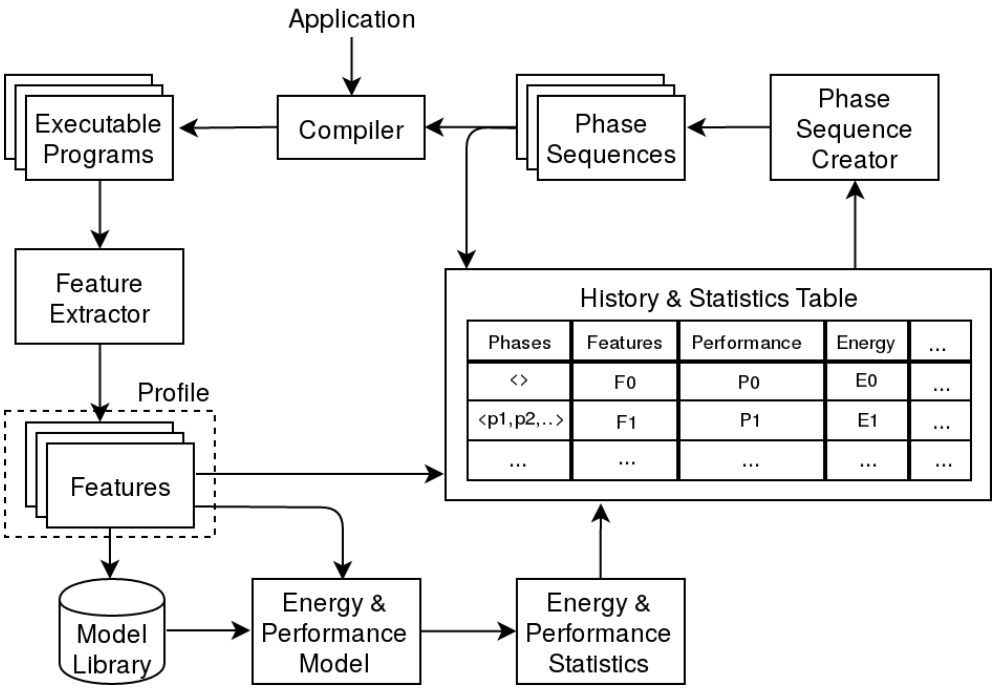
The envisaged compiler modules are to be understood as different sets of analyses and optimizations that optimize the application code with regard to the specific key objectives. Leveraging the existing LLVM compiler framework the compilation modules aim is to find suitable optimizations tailored to the profile of the target application and the power model of the respective target system's instruction set. Although the project is focused on Ultra-Thin IoT devices, the knowledge gained can be applicable to other (embedded) systems, where performance, code size and energy are key factors. This approach and its fruits integrated into future compiler options, will be relevant for the future development of the non-gaming parts of the video games console software.

For clarification of the background and competence of the project COGUTS, Austrian Bit Experts is a technology, services and consultancy company that provides software tool solutions for the embedded system and IoT markets, in particular with competences in the design and development of code generation tools (i.e. compilation, assembling and linking tools), integrated development environments, simulators, debuggers and of sophisticated tracing tools which are becoming more and more popular today.

[144] https://itea3.org/project/compact.html Accessed: 02.04.2019

The architecture of the finished system (see Figure 35) is envisaged as follows. An application is initially compiled and its profile built using a feature extractor. Based on the feature profile, an appropriate energy and performance model can be selected from an existing model library created in a model training phase, which is tailored to the specific ISA and hardware platform. The resulting statistics are recorded in a history and statistics table and used by a phase sequence creator, which is also tailored to the specific ISA and hardware platform. Using the history & statistics, the phase sequence generator then proposes new phase sequences with which the application should be compiled. The whole procedure is repeated until desired thresholds concerning, for example, power consumption, are met.

Figure 35: Schematic overview of COGUTS



5.4.2 Future battery technologies

With the recent success of the Nintendo Switch as a console with the capability of handheld and stationary use, further advancement in battery technologies can have impacts on resource efficiency and use and charging durations. Wireless game controllers can benefit from the developments as well. Lithium-ion batteries are used widely for consumer electronics to electric vehicles. While lithium-ion batteries have a good energy efficiency from 90-250Wh/kg and a good cycle lifetime with around 2000 cycles, corresponding recovery and recycling schemes are rather ineffective[145]. In this chapter, five different battery technologies, which are currently in a research and development phase, are presented briefly. Among other considerations, these technologies have the potential to improve or replace existing lithium-ion batteries.

In Favors, Zachary et al (2014)[146], a method to improve lithium-ion batteries is proposed, which uses sand to create carbon coated nano-silicon electrodes. By using this process, the batteries are cheaper

[145] Zubi, Ghassan & Dufo-López, Rodolfo & Carvalho, Monica & Pasaoglu, Guzay. (2018). The lithium-ion battery: State of the art and future perspectives. Renewable and Sustainable Energy Reviews. 89. 292-308. 10.1016/j.rser.2018.03.002.
[146] Favors, Zachary & Wang, Wei & Hosseini Bay, Hamed & Mutlu, Zafer & Ahmed, Kazi & Liu, Chueh & Ozkan, Mihrimah & Ozkan, Cengiz. (2014). Scalable Synthesis of Nano-Silicon from Beach Sand for Long Cycle Life Li-ion Batteries. Scientific reports. 4. 5623. 10.1038/srep05623.

and more environmentally friendly than standard lithium-ion batteries. Currently, these batteries have a current capacity of 1024 Ah/kg and a cycle lifetime over 1000 cycles.

Another way to improve the cycle lifetime and charging capability of lithium-ion batteries is presented by researchers from the Samsung Advanced Institute of Technology[147]. A graphene-ball coating is used, which increases the volumetric energy density by 27.6% and reduces the charging time to around 20%. The battery has a cycle lifetime of around 500 cycles.

Another environmentally friendly type of battery is Lithium-Sulphur (Li-S) batteries, which are seen as possible candidates to replace Lithium-Ion batteries. In Cha, E. Patel, M. et al (2018) [148] the authors propose a Lithium-Sulphur battery with a Li-MoS2 anode and a CNT-S cathode. The battery has a specific energy density of 589 Wh/kg with a capacity retention of 84% for 1200 cycles.

The company PJP Eye from Japan manufactures carbon batteries in cooperation with Kyushu University in Fukuoka, Japan. Their Cambria Eye battery, previously known as Ryden battery, is a dual carbon battery. One battery cell operates at 3.2V and has a capacity of 20Ah. Its energy density is around 116Wh/kg and it has a cycle lifetime of 8000 charging/discharging cycles. Rare metals are not used and it can be recycled [149,150,151].

The company Zap&Go manufactures Carbon-ion batteries, which are non-inflammable, when compared to Lithium-ion batteries, can operate at higher temperatures and have a cycle life of 100,000 cycles. The current generation of these batteries, called Generation 3 batteries, operate at 3.4V and have an energy density of 32-56 Wh/kg. The next battery generations, which are in development, should operate at higher voltages, e.g. Generation 6 at 6V, and have an energy density above 100 Wh/kg. The Carbon-ion batteries are manufactured by using many of the technologies that are used for manufacturing Lithium-ion batteries. Thus Carbon-ion batteries could be produced in the same factories as Lithium-ion batteries, only requiring minor changes. Furthermore, Carbon-ion batteries do not contain any rare earth materials and can be recycled[152,153,154].

5.5 Future Trends & Developments

Cloud gaming

Cloud gaming or gaming on demand, is a type of online gaming. The idea is directly providing the ability to play games across different devices. A gaming server executes a gaming engine and streams the processed data to the client device. Cloud Gaming operates based on video streaming or file streaming. In Murugesan & Bojanova (2016)[155], cloud gaming is categorized into:

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[147] Hyuk Son, In & Park, Jong & Park, Seongyong & Park, Kwangjin & Han, Sangil & Shin, Jaeho & Doo, Seok-Gwang & Hwang, Yunil & Chang, Hyuk & Choi, Jang. (2017). Graphene balls for lithium rechargeable batteries with fast charging and high volumetric energy densities. Nature Communications. 8. 10.1038/s41467-017-01823-7.

[148] Cha, Eunho & Patel, Mumukshu & Park, Juhong & Hwang, Jeongwoon & Prasad, Vish & Cho, Kyeongjae & Choi, Won. (2018). 2D MoS2 as an efficient protective layer for lithium metal anodes in high-performance Li–S batteries. Nature Nanotechnology. 13. 10.1038/s41565-018-0061-y.

[149] http://www.pjpeye.tokyo/Product Accessed: 06.06.2019

[150] http://powerjapanplus.com/about/research.html Accessed: 06.06.2019

[151] http://powerjapanplus.com/ryden/index.html Accessed: 06.06.2019

[152] https://zapgo.com/wp-content/uploads/2016/09/Carbon-Ion-a-new-category-of-energy-storage-devices-Technical-White-Paper.pdf Accessed: 06.06.2019

[153] https://zapgo.com/technology/, https://zapgo.com/about-us/ Accessed: 06.06.2019

[154] https://chargedevs.com/features/charge-like-a-supercap-store-like-a-battery-zapgos-carbon-ion-technology/ Accessed: 06.06.2019

[155] *Murugesan, San; Bojanova, Irena (2016). Encyclopedia of Cloud Computing. Hoboken, NJ: John Wiley & Sons. p. 525. ISBN 9781118821978*

- Video-Based Cloud Gaming
- Instruction-Based Cloud Gaming
- File-Based Cloud Gaming
- Component-Based Cloud Gaming

The basic idea of Video-Based Cloud Gaming is to offload all parts of a game into the cloud, including the game engine, artificial intelligence (AI) processing, and rendering modules.

In Cloud-based gaming, the local client uses the remote server for graphics processing and consequently the associated workload is shifted to a data center. Cloud gaming not only eliminates the need for a powerful gaming device (Console, PC, Laptop…) but also removes the downloading, installing and updating processes. "Just choose the game you want, press 'Play', and get your very own gaming machine in seconds!" [156]

As for now, there are several actors in cloud gaming sector:

- GeForce Now cloud service from Nvidia allows users to stream games *"on nearly any device anywhere"*.
- Google Stadia has been announced in 2019
- Apple Arcade Gaming Services has been announced as arriving in Autumn 2019.
- Vortex
- Parsec
- Shadow
- PlayStation Now
- Microsoft Azure for Gaming[157]

Sony and Microsoft formed a new Gaming Partnership in which cloud gaming is a mentioned objective. "Under the memorandum of understanding signed by the parties, the two companies will explore joint development of future cloud solutions in Microsoft Azure to support their respective game and content-streaming services. In addition, the two companies will explore the use of current Microsoft Azure datacenter-based solutions for Sony's game and content-streaming services." [158,159]

Based on the LBNL report, available information suggests that cloud-based gaming is by far the most energy-intensive form of gaming via the Internet. Data available for the server-side are considerable. LBNL states that: *"For cloud-based gaming on PCs, about 180 watts is associated with network energy and about 340 watts with energy in the data center, which is a more energy-intensive configuration than purely local gaming. The corresponding values for console cloud gaming are 180 and 120 watts. When cloud-based gaming is performed by PCs, 50% of total energy use (averaged over systems and user types) is in networks and data centers. The value for laptops and media-streaming devices is 75% and for consoles is 40%."*

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[156] https://vortex.gg Accessed: 27.05.2019
[157] https://azure.microsoft.com/en-gb/free/gaming/ Accessed 06.06.2019
[158] https://www.patentlyapple.com/patently-apple/2019/05/with-google-stadia-and-apple-arcade-gaming-services-coming-this-fall-sony-microsoft-announce-a-new-gaming-partnership.html Accessed: 27.05.2019
[159] https://news.microsoft.com/2019/05/16/sony-and-microsoft-to-explore-strategic-partnership/ Accessed: 27.05.2019

Research on the energy use associated with data transfer across the Internet (from the data centre to the user) estimates this energy use at 0.027 kWh/GB [160]. The corresponding value for 2011 was 0.145 kWh/GB, and it is predicted for 2021 to be 0.005 kWh/GB.

For example, a device in cloud gaming mode receives 1 GB of data per hour (equal to the Netflix HD streaming services). When the data are transferred with the factor of 0.027 kWh/GB then the consumed energy for the data transfer is 27 Watts. However, as is predicted for 2021, a consumption rate as low as 0.005 kWh/GB can be considered, where the energy consumption for the data transfer is 5 Watts. So, any advancement in communication technology decreasing the consumed energy for transferring data has a positive impact on consumed energy in cloud gaming. It is to be noted that this value compared to the total consumed energy in the gaming device and cloud gaming server-side, is relatively small and the share of energy consumed for data transfer in total energy consumed for cloud gaming is shrinking.

Clearly, the cloud gaming strategy (video-based, instruction-based, file-based, and component-based), the type of game, target resolution and fps, data compression method and other factors have an impact on the average hourly transmitted data.

Some popular online games titles use between 40MB to 300MB per hour in online gaming (Note: this is for online gaming, not for cloud gaming). To compare these numbers with TV/movie streaming services, consider that Netflix SD, Netflix HD, and Netflix 4K respectively use 1000, 3000 and 7000 MB per hour[161]. According to data usage in PlayStation Now, it is stated that *"You will use about the same amount of data as you would for streaming video."* so it can be assumed that for cloud gaming, the required transmission rate is the same as for video streaming. Depending on video quality, encoding approach, and game properties, the data rate required can vary considerably. Netflix data usage is reported as being 300MB per hour at the lowest video quality, 700MB per hour for SD video quality, 3GB per hour for HD video quality and 7GB per hour for UHD (4K) video quality.

As another example is the Nvidia Shield, which streams at 15 Mbps (average rate), meaning 6.75 GB per hour data transmission. Cisco notes that "if cloud gaming takes hold, gaming could quickly become one of the largest Internet traffic categories" [162].

Although Cloud gaming is an energy-intensive type of gaming, there are also some remarkable signs.

- Since 2018, Microsoft has been supplying half of its data centre's energy usage from renewable sources and Microsoft is on track to power 60 percent with renewable energy by the end of 2019. Reaching 70% of renewable energy by 2023 [163] is a further plan.
- Apple Arcade is a new cloud gaming service. Apple claimed to be operating on 100 percent renewable sources in 2018 and is trying to clean up its entire supply chain, too[164].

As Newzoo reported[165], 5G is the most important factor for the quality of service of cloud gaming and a significant number of consumers need to have access to 5G in order to reach the greatest potential of cloud gaming. Reducing the data latency and increasing bandwidth are considerable results of 5G

[160] Aslan, J., Mayers, K., Koomey, J. G., & France, C. (2018). Electricity intensity of internet data transmission untangling the estimates. Journal of Industrial Ecology, 22(4), 785–798. https://doi.org/10.1111/jiec.12630
[161] https://www.abc.net.au/news/2018-06-06/online-gamers-nbn-bandwidth/9836186 Accessed: 27.05.2019
[162] Cisco. (2015). Whitepaper - The Zettabyte Era: Trends and Analysis.
[163] https://www.datacenterdynamics.com/news/microsoft-promises-data-centers-will-use-60-renewable-energy-2020/ Accessed: 28.05.2019
[164] https://www.zdnet.com/article/microsofts-green-plan-our-data-centers-will-run-on-60-renewable-energy-by-2020/ Accessed: 28.05.2019
[165] https://resources.newzoo.com/hubfs/Newzoo_Cloud_Gaming_Report.pdf Accessed: 28.05.2019

technology. 5G networks will support cloud gaming and provide users access to a high-end gaming experience.

One study based on recent progress [166] shows that cloud gaming could represent 25% to 50% of 5G data traffic by 2022. John Giere, President, and CEO of Openwave Mobility stated that *"the recent emergence of cloud gaming platforms […] has not escaped the attention of the operator community"* [166].

Maybe there is still some doubt about the performance claimed and the quality of service of cloud gaming, but it is clear that cloud gaming is developing very quickly in concept and implementation. However, it is not realistic to think that cloud gaming is a console gaming killer or a full replacement for them.

"With new technologies, consumers tend to find new application rather than substitute what is already there. The iPad didn't replace laptops, laptops didn't replace PCs, Airbnb hasn't replaced hotels, and cloud gaming won't fully replace local gaming." [165]

In the coming years, the coexistence of cloud gaming alongside PC/console gaming can be expected. Cloud gaming will bring new gamers, new content, new experience, and new pricing strategies and models.

Gaming at 8K resolution

The current definition of Ultra-High-definition is commonly known for the 4K resolution of content. As of the announcements made by Sony at IR Day 2019 [167] on 21.05.2019 and Microsoft [168] at E3 2019 on 09.06.2019, gaming at 8K UHD (7680 pixels and 4320 lines, resulting into 33.18 megapixels) will be one of the key advertisement features. Higher resolutions go hand in hand with higher computational resources needed for displaying the content. The current definition of a "Ultra-High-Definition gaming capable Console from in the SRI as of Version 2.6.3, is that "Game Consoles having potential of rendering video output with resolutions *greater* or equal to 4K (3840 pixels x 2160 lines)". This definition would include the gaming at 8K UHD resolution. If manufacturers are able to keep the current power cap limitations for the higher resolution at 8K, the definition would still fit. As of the knowledge in mid 2019, probably a new definition category for 8K-UHD games console seems likely and advisable.

Ray Tracing

Also new rendering techniques have emerged and will come to the games consoles industry according to the latest announcement [167,168]. As for the technology, the following statement wraps the important key points as "Ray tracing is a rendering technique that creates more realistic light effects. By using ray tracing tech to simulate the physical behaviour of light, you'll see it bounce off objects in the virtual world just as it would in reality" [169]. The physical simulation will take extra computational power to be rendered for the games. The advertisement is already made similar to what can be seen with HDR.

[166] https://www.cxotoday.com/story/cloud-gaming-to-drive-50-of-5g-data-traffic-by-2022-openwave-mobility/ Accessed: 28.05.2019
[167] https://www.sony.net/SonyInfo/IR/library/presen/irday/pdf/2019/presen_E.pdf Accessed: 10.06.2019
[168] https://www.xbox.com/en-US/project-scarlett Accessed: 10.06.2019
[169] https://www.trustedreviews.com/news/nvidia-ray-tracing-3638206 Accessed: 10.06.2019

6. Task 5/6 Base cases and design options

In this section, three base cases are selected using data from previous chapters. In these cases, environmental impacts are calculated using the MEErP EcoReport tool. Each base case represents typical product categories within the range of games consoles. Since in the case of games consoles, the number of products on the market is limited and the nature of the product changes significantly from one generation to the next in terms of performance and functions, it is not easy to define "typical" product categories. Based on current games consoles, the following three product categories have been defined as base cases:

- BC 1 – A high-end mains-powered games console with Ultra-High-Definition (4k) gaming capability
- BC 2 – A high-end mains-powered games console with High-Definition gaming capability
- BC 3 – A high-end games console with a capability for both handheld gaming with integrated display and stationary gaming with docking station.

This selection reflects most games consoles available at the time of the study and categorises them according to their capability for 4K gaming and their functionality (handheld or docking station gaming). The base cases each represent at least one real product and are described further in the following sections.

6.1 Base Case 1: Mains powered game console with Ultra-High-Definition gaming capability

6.1.1 Description

Games consoles in the Base Case 1 are capable of active gaming with Ultra-High-Definition resolutions up to a resolution of 4K (3840 pixels x 2160 lines) and usually with stationary use. Media content with 4K content can either be displayed through medium carriages like Ultra HD Blu-rays or video streaming services. In order to fulfil the requirements for belonging to Base Case 1, 4K for both video gaming and for media content must apply. The games console is typically used through a games console-specific controller that is capable of being used wirelessly.

The operating system offers various applications, settings and features for the users. The users can access vendor-specific stores to acquire new applications or games, when connected to the internet. Social features and messenger possibilities enable interaction between two or more users through the games console.

Typical usage scenarios are: Active Gaming (Single or Network Multiplayer); Media Playback; Navigation; Rest; Networked Standby; Low-Power Standby. Less popular usage scenarios like shared gameplay (i.e. giving control of the game to a user in the friend list) are not listed separately.

The main decision driver for the choice of a game console belonging to Base Case 1 are the AAA games, which are usually console/vendor specific and therefore not available on devices from other manufacturers. The combination of a device from Base Case 1 and AAA games offer the users the best visual experiences for active gaming and media playback, provided that an external device such as a TV with 4K or higher resolution capabilities is available.

Typical user patterns are provided and described in chapter 4.1.7.

Typical game modes are gaming in single-player or local multiplayer mode, plus online in network multiplayer.

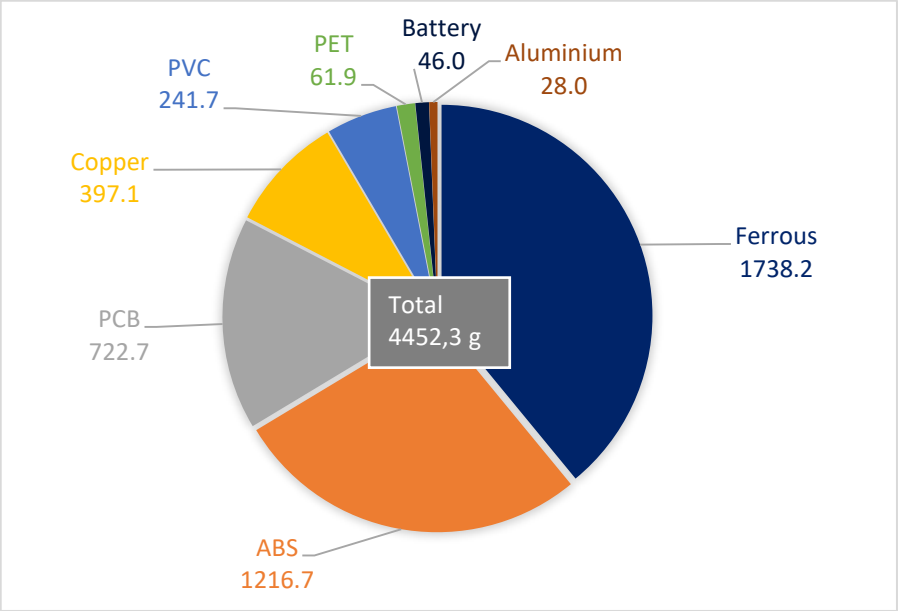
The product service life[170] of base case 1 is 7 years in which the device is intensively used (see 4.3.1), which is approximately the time until a new generation of device is released. The stock life[171] is considerably longer and is approximated at 14 years.

6.1.2 Materials and weight

For base case 1 the Xbox One X was taken as the basis for the material composition. The composition can be found in section 5.2.2. For the impact assessment using the Ecoreport, however, additional assumptions on the material composition of the components had to be made, which do not necessarily accurately represent the real material composition of the components. Information on the material composition in the required level of detail was not available to the authors.

Based on the data presented in section 5.2.2, for the impact assessment, it was assumed, that the outer casing consists of ABS plastic, while the inner casing is made entirely out of steel. The printed circuit boards (PCB) contained in the console have a density of approximately 4.5 kg/m^2. It was assumed that the optical drive is made out of equal shares of ABS plastic, stainless steel and PCB. For the hard drive disk (HDD) a material composition of one part aluminium for the platters and two parts ABS plastic for the casing was assumed. The ventilation unit was assumed to consist of half aluminium parts and half ABS plastic. The power supply and all cables were assumed to consist of half copper wire and half PVC plastic as insulation around the wire. Included in the "others" section are batteries used in the controllers and more PCB parts.

Figure 36: Material composition (in g) of a base case 1 mains powered console



Components such as the optical drive or the hard disk drive are not likely to be recycled as there is currently no manual dismantling process established for small electronic devices, which are instead mostly shredded followed by automatic sorting into material fractions as described in the EOL in section 5.2.3.

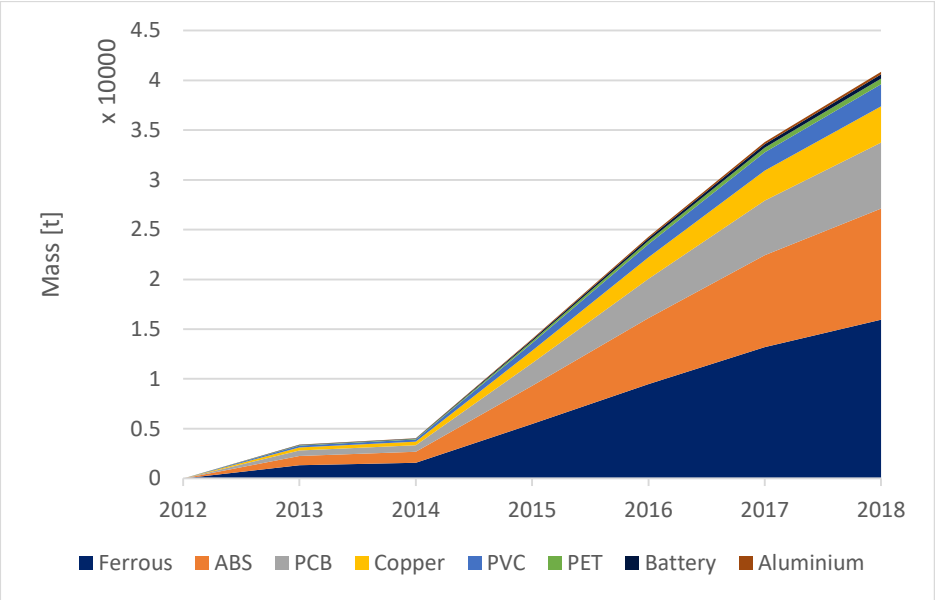
The outer casing of the console is theoretically recyclable if it is sorted into the shredder light fraction and further treated in a plastic recycling facility. PCBs contained in the device can be recycled, however as they distributed over various fractions during the shredding. Losses of metals into material fractions from which they cannot be recovered, are to be expected. The inner casing can be recovered after the shredding together with other ferrous components. Copper from cables and the power supply might

[170] The product service life represents the period the product is in use and not yet discarded
[171] The stock life represents the period the product is out of use but not yet discarded

end up in the copper fraction after the automatic shredding and separation steps during treatment of the games console.

Cumulated over the sales time of the Xbox One X, as described in section 3.2, from 2013 until 2018, the consumption of materials used in the production of the games console amounts to roughly 40,000 tonnes. The distribution of material fractions is in accordance with the BOM depicted in Figure 36. The largest fraction of the materials is ferrous metals, which accumulated over the sales time amounts to around 16,000 tonnes, followed by ABS plastic with about 11,000 tonnes and PCB plastic with roughly 7,000 tonnes.

Figure 37: Cumulated material consumption over sales time for Xbox One X



6.1.3 Typical Energy Consumption

As a reference, lab measurements have been carried out with five video games. The average consumption for PS4 Pro and Xbox One X are listed in Table 36.

Table 36: Measured average energy consumption of Base Case 1 Game Consoles

Game played	PS4 Pro (CUH-7216B)	Xbox One X (Model 1787)
Red Dead Redemption 2	161.13 W	166.17 W
FIFA 19	136.95 W	125.37 W
Need for Speed Payback	136.98 W	143.24 W
World of Tanks	115.90 W	130.65 W
Fortnite	148.83 W	160.19 W
Average across Games	139.96 W	145.13 W

By considering the Usage Scenario for an average user, power consumption and corresponding TEC for each mode is summarized in Table 37.

Table 37: Base Case 1, Energy Consumption and TEC in different Modes

		PS4 Pro (CUH-7216B)		Xbox One X (Model 1787)	
Mode	Usage Scenario (hours per day)	Power Consumption (W)	TEC	Power Consumption (W)	TEC
Active gaming	1.67	135.93	82.80	148.69	90.56
Media	0.96	78.58	27.59	51.61	18.12
Other functions	0.47	63.74	10.89	49.32	8.42
Standby	5.12	1.77	3.31	0.29	0.54
Charging enabled	0.00	5.25	0.00	0.29	0.00
Peripheral charging	0.00	9.05	0.00	3.48	0.00
Low power download	0.15	52.69	2.88	40.76	2.23
Rest mode[172]	15.21	0.95	5.25	13.48	74.82
Off	0.42	0.25	0.04	0.29	0.04
SUM	24.00	-	132.76	-	194.75

6.1.4 Environmental impact results from Ecoreport

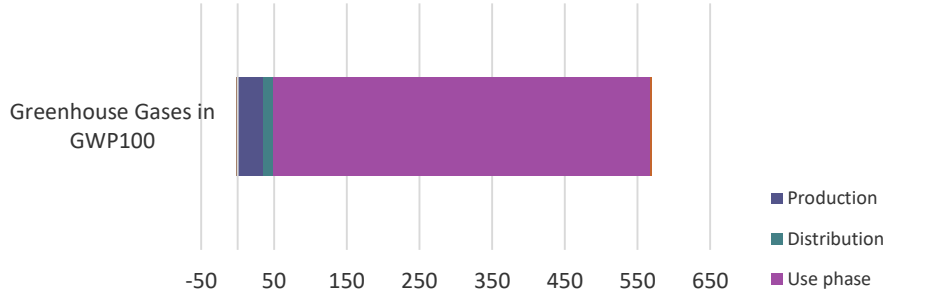
The environmental impacts in Ecoreport are calculated based on the product service and product stock life, on the material input as described above and on the TEC of the games consoles. Included in the Ecoreport tool is background data on the resources, energy consumption and emissions connected to the production of different materials. This information together with the material composition is used to calculate the environmental impacts during the production phase of one console. The impacts resulting from the distribution of the console from production to the end user is based solely on the size of the packaging which was assumed to be 0.018 m^3 based on information from online sales platforms. The tool does not, however, offer the possibility to insert data on the distance travelled for distribution or the transport mode.

For calculation of the impacts during the use phase, the TEC was used. Because the Ecoreport tool does not allow for different usage scenarios which change the TEC of the console a usage scenario was chosen for the calculation that is influenced by LBNL together with our own measurements for an average user. This is described in more detail in section 4.1.7. With this usage scenario, the monthly TEC of a single console of Base case 1 amounts to 16.22 kWh. Combined with the assumed service life of 7 years, over the lifetime of one console a total of 1.36 MWh of energy is consumed.

Compared to the impacts from production and distribution, the energy usage during the use phase has the highest environmental impacts according to the Ecoreport results as is depicted in Figure 38. The treatment during end of life has negligible environmental impacts. For recycling, negative impacts or credits are rewarded, assuming that recycling products substitute virgin materials and therefore resources and emissions during production of virgin materials is avoided.

[172] In this table, for the Rest mode TEC calculations, the lowest consumption for the available features, e.g. suspend application / instant-on, was taken.

Figure 38: Global warming potential in kg CO_2-eq. distributed over life cycle phases



	Greenhouse Gases in GWP100
Production	35
Distribution	13
Use phase	519
End of Life	2
Recycling credits	-2

In the following tables further results from the Ecoreport tool are depicted. Table 38 shows the amount of energy and water consumed and waste generated over the lifetime of one games console of the Xbox One X type. Table 39 lists further environmental impacts, including the global warming potential and acidification potential that are distributed over the life cycle phases for one games console of the Xbox One X type.

Table 38: Resources consumed and waste generated distributed over life cycle phases

	Unit	Production	Distribution	Use	End of Life	Recycling credits	Total
Total Energy (GER)	MJ	682	175	12.274	29	-47	13.113
of which, electricity	MJ	178	0	12.270	0	-29	12.419
Water (process)	ltr	386	0	4	0	-103	286
Water (cooling)	ltr	323	0	548	0	40	911
Waste, non-haz./ landfill	g	6.384	137	6.382	76	-864	12.115
Waste, hazardous/ incinerated	g	1.384	3	207	0	-413	1.180

Table 39: Emissions to air and water distributed over life cycle phases

	Unit	Production	Distribution	Use	End of Life	Recycling credits	Total
Greenhouse Gases in GWP100	kg CO2 eq.	35	13	524	2	-2	572
Acidification, emissions	g SO2 eq.	488	42	2.322	4	-81	2.775
Volatile Organic Compounds (VOC)	g	2	1	274	0	0	277

	Unit	Production	Distribution	Use	End of Life	Recycling credits	Total
Persistent Organic Pollutants (POP)	ng i-Teq	53	1	29	3	-1	84
Heavy Metals	mg Ni eq.	110	7	125	8	-15	235
PAHs	mg Ni eq.	12	4	29	0	-1	43
Particulate Matter (PM, dust)	g	52	21	49	38	-7	153
Heavy Metals	mg Hg/20	145	0	54	2	-27	175
Eutrophication	g PO4	4	0	2	0	0	6

6.2 Base Case 2: Mains powered game console with High-Definition gaming capability

6.2.1 Description

Games consoles in the Base Case 2 are capable of active gaming with High-Definition resolutions up to a High-Definition resolution (1920 pixels x 1080 lines) and usually have stationary use. Media content with High-Definition content can be displayed either through medium carriages like Blu-rays or video streaming services. High-Definition for both video gaming and media content must apply to fulfil the requirements of belonging to Base Case 2. The games console is typically used through a games console specific controller that is capable of being used wirelessly. PlayStation 4 Slim is an example of a base case 2 games console.

The operating system offers various applications, settings and features for the users. The users can access vendor-specific stores to acquire new applications or games, when connected to the internet. Social features and messenger possibilities enable interaction between two or more users through the games console.

Typical usage scenarios are: Active Gaming (Single or Network Multiplayer); Media Playback; Navigation; Rest; Networked Standby; Low-Power Standby. Less popular usage scenarios like shared gameplay (i.e. giving control of the game to a user in the friend list) are not listed separately.

The main decision driver for the choice of a games console belonging to Base Case 2 is less-frequent users who choose the console/vendor-specific game offering or for the combination of a Blu-Ray-Player with advanced entertainment features like gaming. Users with games consoles from Base Case 2 are often aware, that consoles of this design tend to be more energy efficient as opposed to providing a huge increase in computational power.

Typical user patterns are provided and described in section 4.1.7.

Typical game modes are gaming in single-player or local multiplayer mode, plus online in network multiplayer.

The product service life[173] of base case 2 is 7 years in which the device is intensively used (see 4.3.1), which is approximately the time until a new generation of device is released. The stock life[174] is considerably longer and is approximated at 14 years.

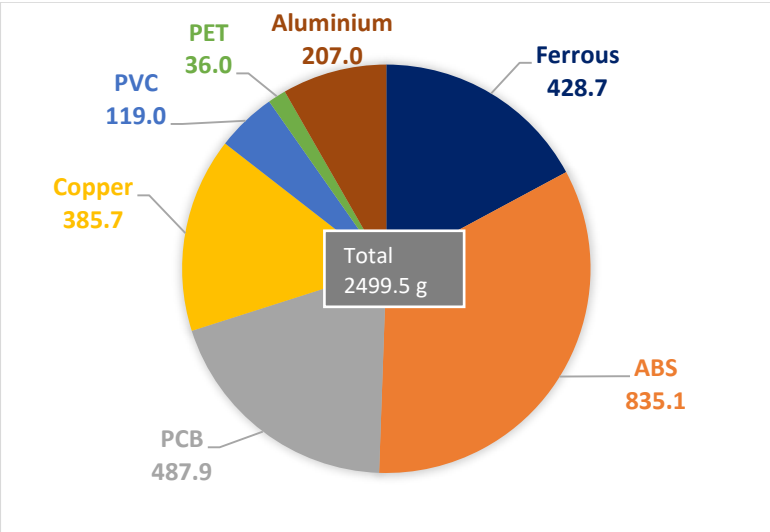
6.2.2 Materials and weight

For base case 2, the PlayStation 4 Slim was taken as the basis for the material composition. The material composition can be found in section 5.2.2. Analogously to base case 1, additional assumptions regarding the material composition of different components had to be made.

For the impact assessment it was assumed, that the outer casing consists of ABS plastic, while the inner casing is made entirely out of steel. The heat sink unit is assumed to consist of equal parts aluminium, steel and copper. The frame casing is assumed to consist of half steel and half ABS plastic.

The printed circuit boards (PCB) contained in the console have a density of approximately 4.5 kg/m^2. It was assumed that the optical drive is made out of equal parts ABS plastic, stainless steel and PCB. For the hard drive disk (HDD) a material composition of one part aluminium for the platters and two parts ABS plastic for the casing was assumed. The ventilation unit was assumed to consist of half aluminium parts and half PET plastic. The power supply was assumed to consist of 50% ABS plastic and 50% PCB. The Power cord and all cables were assumed to consist of 50% copper wire and 50% PVC plastic as insulation around the wire. The dual shock controllers furthermore contain a battery pack which is not depicted in the material composition figure due to unknown mass and material composition.

Figure 39 Material composition (in g) of a base case 2 mains powered console



Entire components such as the optical drive or the hard disk drive are not likely to be recycled as there is currently no manual dismantling process established for small electronic devices, which are instead mostly shredded followed by automatic sorting into material fractions as described in the EOL in section 5.2.3.

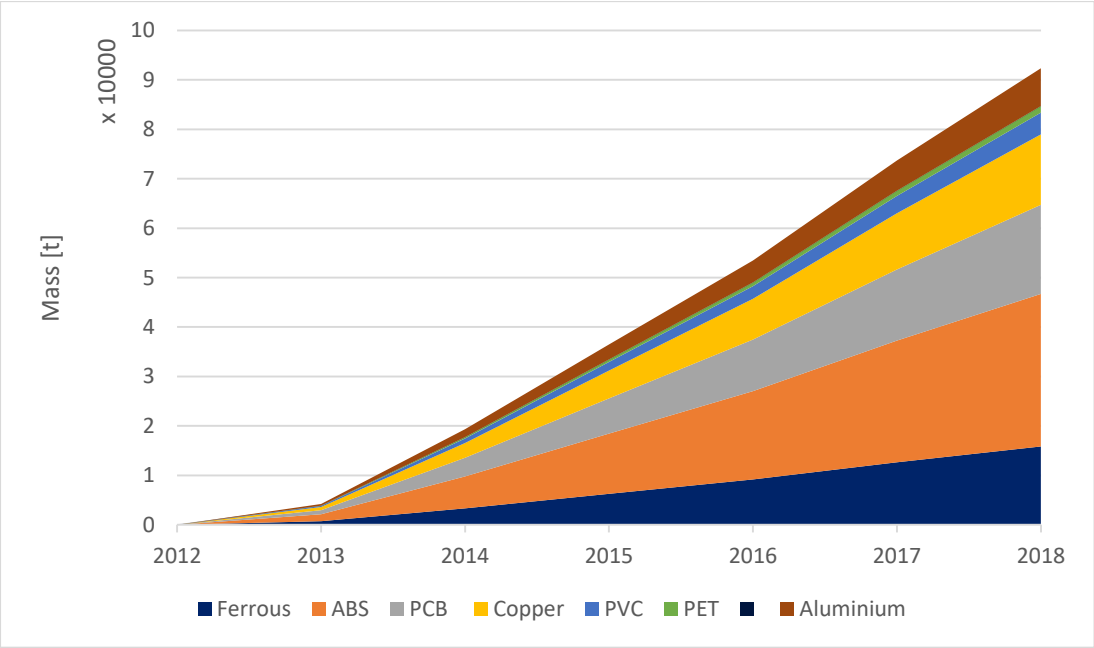
The outer casing of the console is theoretically recyclable if it is sorted into the shredder light fraction and further treated in a plastic recycling facility. PCBs contained in the device can be recycled, however, as they are distributed over various fractions during the shredding, losses of metals into material fractions from which they cannot be recovered, are to be expected. The inner casing can be recovered after the shredding together with other ferrous components. Copper from cables and the

[173] The product service life represents the period the product is in use and not yet discarded
[174] The stock life represents the period the product is out of use but not yet discarded

power supply might end up in the copper fraction after the automatic shredding and separation during treatment of the console.

Cumulated over the sales time of the PlayStation 4, as described in section 3.2, from 2013 until 2018, the consumption of materials used in the production of the games console amounts to roughly 92,000 tonnes. The distribution of material fractions is in accordance with the BOM depicted in Figure 41. The largest fraction of the materials, ABS plastic, accumulated over the sales time, amounts to around 31,000 tonnes followed by PCB - about 18,000 tonnes - and ferrous metals - roughly 16,000 tonnes. Copper and aluminium amount to roughly 14,000 and 8,000 tonnes respectively cumulated until 2018.

Figure 40 Cumulated material consumption over sales time for PlayStation 4 Slim



6.2.3 Typical Energy Consumption

As a reference, lab measurements have been made with five video games. The average consumption is shown in Table 38.

Table 40: Measured average energy consumption of Base Case 2 Game Consoles

Game played	PS4 Slim (CUH-2216A)	Xbox One S (Model 1681)
Red Dead Redemption 2	82.75 W	73.54 W
FIFA 19	64.38 W	61.38 W
Need for Speed Payback	74.50 W	64.35 W
World of Tanks	64.81 W	58.58 W
Fortnite	79.24 W	69.13 W
Average across Games	73.14 W	65.40 W

By considering the Usage Scenario for an average user, power consumptions and corresponding TEC for each mode is summarized in Table 41.

Table 41: Base Case 2, Energy Consumption and TEC in different Modes

		PS4 Slim (CUH-2216A)		Xbox One S (Model 1681)	
Mode	Usage Scenario (hours per day)	Power Consumption (W)	TEC	Power Consumption (W)	TEC
Active gaming	1.67	73.14	44.55	66.59	40.56
Media	0.96	47.18	16.56	35.30	12.39
Other functions	0.47	44.07	7.53	28.30	4.83
Standby	5.12	1.88	3.51	0.34	0.63
Charging enabled	0.00	4.43	0.00	0.34	0.00
Peripheral charging	0.00	8.20	0.00	3.25	0.00
Low power download	0.15	41.55	2.27	16.91	0.93
Rest mode[172]	15.21	1.00	5.55	7.12	39.51
Off	0.42	0.24	0.04	0.33	0.05
SUM	24.00	-	80.01	-	98.91

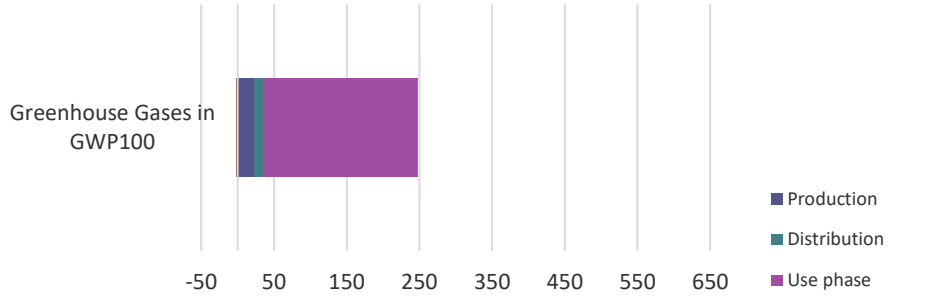
6.2.4 Environmental impact results from Ecoreport

The environmental impacts in Ecoreport are calculated based on the product service and product stock life, on the material input as described above and on the TEC of the games consoles. Included in the Ecoreport tool is background data on the resources, energy consumption and emissions connected to the production of different materials. This information together with the material composition is used to calculate the environmental impacts during the production phase of one console. The impacts resulting from the distribution of the console from production to the end user is based solely on the size of the packaging which was assumed to be 0,016 m^3 based on information from online sales platforms. The tool does not, however, offer the possibility to insert data on the distance travelled for distribution or the transport mode.

For calculation of the impacts during the use phase, the TEC was used. Because the Ecoreport tool does not allow for different usage scenarios which change the TEC of the console, a usage scenario influenced by LBNL together with our own measurements for an average user was chosen for the calculations, described in more detail in section 4.1.7. The typical energy consumption differs considerably between the different PS4 Slim models with a range from 6.5 kWh to 12.4 kWh. The data on PS4 Slim (CUH-2216) was chosen for the calculation of the use phase impacts because for this model the BOM has been provided by the signatories. The TEC for a single on PS4 Slim (CUH-2216) console amounts to 6.67 kWh. Combined with the assumed service life of 7 years, over the lifetime of one console a total of 0.56 MWh of energy is consumed.

Compared to the impacts from production and distribution, the energy usage during the use phase has the highest environmental impacts according to the Ecoreport results as is depicted Figure 38. The treatment during end of life has negligible environmental impacts. For recycling, negative impacts or credits are rewarded, assuming that recycling products substitute virgin materials and therefore resources and emissions during production of virgin materials is avoided.

Figure 41: Global warming potential in kg CO_2-eq. distributed over life cycle phases



	Greenhouse Gases in GWP100
Production	23
Distribution	13
Use phase	210
End of Life	1
Recycling credits	-2

In the following tables further results from the Ecoreport tool are depicted. Table 42 shows the amount of energy and water consumed and waste generated over the lifetime of one games console of the PS4 Slim type. Table 43 lists further environmental impacts including the global warming potential and acidification potential, distributed over the life cycle phases for one games console of the PS4 Slim type.

Table 42: Resources consumed and waste generated distributed over life cycle phases

	Unit	Production	Distribution	Use	End of Life	Recycling credits	Total
Total Energy (GER)	MJ	469	168	5.044	15	-32	**5.665**
of which, electricity	MJ	116	0	5.041	0	-20	**5.136**
Water (process)	ltr	260	0	3	0	-69	**193**
Water (cooling)	ltr	217	0	226	0	27	**470**
Waste, non-haz./ landfill	g	3.026	133	2.625	45	-578	**5.251**
Waste, hazardous/ incinerated	g	957	3	89	0	-286	**762**

Table 43: Emissions to air and water distributed over life cycle phases

	Unit	Production	Distribution	Use	End of Life	Recycling credits	Total
Greenhouse Gases in GWP100	kg CO2 eq.	23	13	215	1	-2	**251**
Acidification, emissions	g SO2 eq.	350	40	955	2	-54	**1.293**
Volatile Organic Compounds (VOC)	g	2	1	113	0	0	**115**

	Unit	Production	Distribution	Use	End of Life	Recycling credits	Total
Persistent Organic Pollutants (POP)	ng i-Teq	19	1	12	2	-1	**33**
Heavy Metals	mg Ni eq.	75	7	52	4	-10	**127**
PAHs	mg Ni eq.	22	4	12	0	-1	**37**
Particulate Matter (PM, dust)	g	35	19	20	20	-5	**90**
Heavy Metals	mg Hg/20	104	0	23	1	-19	**109**
Eutrophication	g PO4	2	0	1	0	0	**3**

6.3 Base Case 3: A high-end games console with capability for both handheld gaming with integrated display and stationary gaming with docking station

6.3.1 Description

Game consoles in the Base Case 3 are capable of active gaming with High-Definition resolutions up to a High-Definition resolution (1920 pixels x 1080 lines) and usually have stationary use. Media content with High-Definition content can be displayed through video streaming services and applications. The game console of Base Case 3 has the feature of being able to be connected to a TV via a dedicated docking station in order to play games or watch videos, or in a portable mode where the game console is detached from the docking station and the content is displayed on an integrated display. The input controllers are also detachable. Nintendo Switch is an example for a base case 3 games console.

Three features must apply for a games console to fulfil the requirements of belonging to Base Case 3: High-Definition for video gaming and media; the main component of the game console is able to execute and view content on its own; the games console is able to duplicate the display via a docking station to an external TV.

The games console is typically used through a games console-specific controller and is capable of being used wirelessly. The main component of the games console has internal batteries so that it can be used without a permanent power supply connection.

The operating system offers various applications, settings and features for the users. The users can access vendor-specific stores to acquire new applications or games, when connected to the internet. Social features and messenger possibilities enable interaction between two or more users through the games console.

Typical usage scenarios are: Active Gaming (Single or Network Multiplayer); Media Playback; Navigation; Rest; Networked Standby; Low-Power Standby. Differentiations could be made in the use mode, with either a TV mode, Handheld or Tabletop mode.

The main decision driver for the choice of a games console belonging to Base Case 3 are users who choose the console/vendor-specific game offering and the ability to have an advanced mobile usable entertainment system with features like gaming. Users with consoles from the Base Case 3 are often aware, that consoles of this design tend to be highly energy efficient for an improved battery lifetime and mobile user experience.

The product service life[175] of base case 3 is 7 years in which the device is intensively used (see 4.3.1), which is approximately the time until a new generation of device is released. The stock life[176] is considerably longer and is approximated at 14 years.

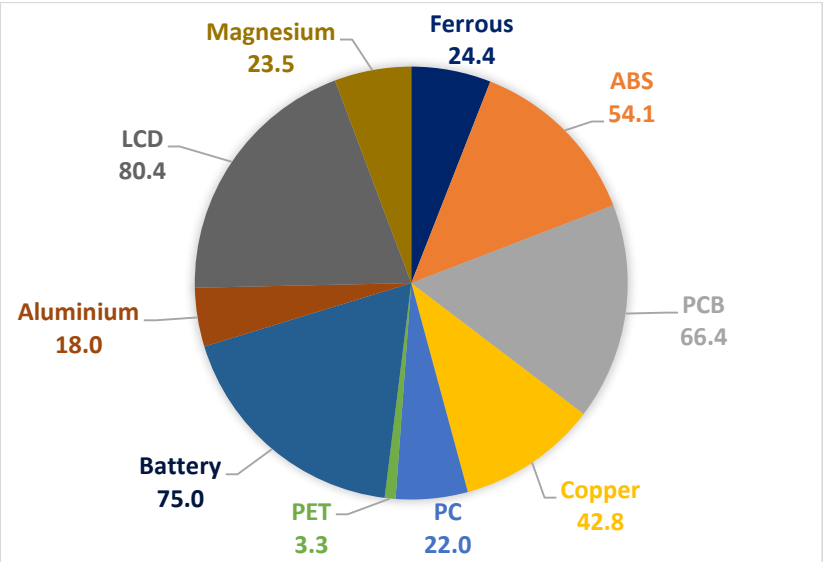
6.3.2 Materials and weight

The component composition of a base case 3 device can be found in section 5.2.2. For base case 3 the Nintendo Switch was taken as the basis for the material composition. As for the other base cases, additional assumptions on the material composition had to be made for the assessment, using the Ecoreport. All assumptions were cross checked with the signatories and approved where possible.

It was assumed, that the outer casing is made out of an alloy material with approximately one third ABS plastic and two thirds PC plastic, while the inner casing is made out of injection moulded magnesium and aluminium. The heat sink unit is assumed to consist of one quarter part copper and three quarter parts aluminium and steel with a joint rail connector attached to it that is made mostly out of stainless steel. A battery pack is included in the console for power supply when used as a handheld console.

The printed circuit boards (PCB) contained in the console have a density of 3 kg/m^2, which was approximated in the Ecoreport with 4.5 kg/m^2 because no corresponding choice was available in the Ecoreport tool. PCB parts are found in the controllers, the speakers and the motherboard. The display is made out of approximately 0,01 m^2 of LCD and a touch panel. Cover, stand, buttons and lens are made out of various materials but due to missing information were approximated to be mostly made out of ABS plastic. Similarly the ventilation unit consists of various materials and its composition was approximated with one part PET plastic and two parts copper. The power supply of the handheld device is a lithium ion battery pack. The controllers were assumed to consist of one part copper, one part ABS plastics and one part PCB.

Figure 42: Material composition (in g) of a base case 3 handheld games console



Entire components such as display are not likely to be recycled as there is currently no manual dismantling process established for small electronic devices, which are instead mostly shredded followed by automatic sorting into material fractions, as described in the EOL in section 5.2.3.

The Outer casing of the console is theoretically recyclable if it is sorted into the shredder light fraction and further treated in a plastic recycling facility. PCBs contained in the device can be recycled, however

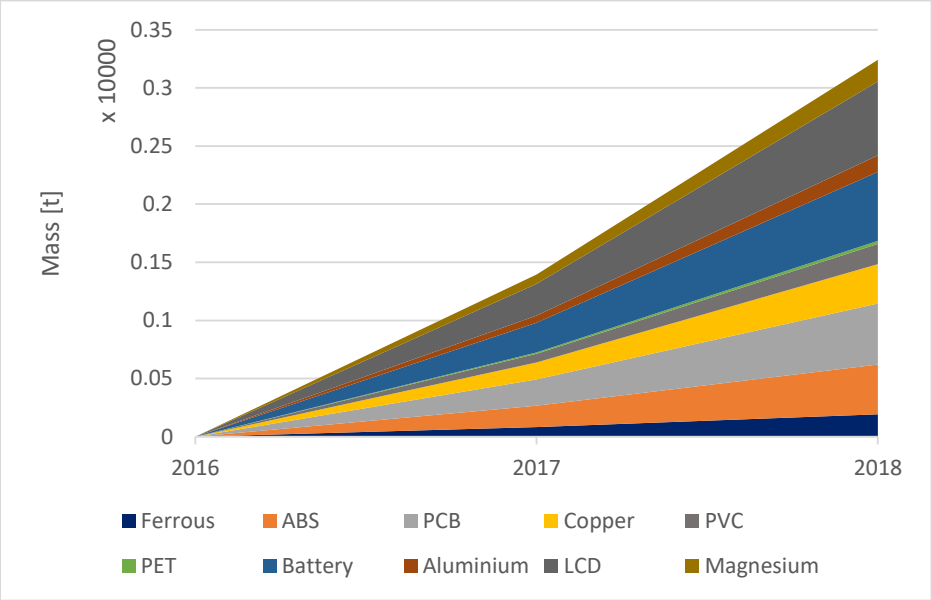
175 The product service life represents the period the product is in use and not yet discarded

176 The stock life represents the period the product is out of use but not yet discarded

as they distributed over various fractions during the shredding. Losses of metals into material fractions from which they cannot be recovered, are to be expected. The inner casing can be recovered after the shredding together with other ferrous components. It is most likely that the battery is not recycled as it difficult to access for separation and separate treatment.

Cumulated over the sales time of the Nintendo Switch, as described in section 3.2, in 2017 and 2018, the consumption of materials used in the production of the games console amounts to roughly 3,200 tonnes. The distribution of material fractions is in accordance with the BOM depicted in Figure 42. The largest fractions of the materials are the LCD screen and the battery pack, which accumulated over the sales time amount to around 600 tonnes each. The ABS and the PCB cumulate to roughly 430 tonnes and 520 tonnes respectively. Copper amounts to roughly 340 tonnes and magnesium from the casing and aluminium to about 190 tonnes respectively cumulated over the two sales years. Ferrous metals make up about 200 tonnes and PVC about 170 tonnes.

Figure 43: Cumulated material consumption over sales time for Nintendo Switch



6.3.3 Typical Energy Consumption

As a reference, lab measurements have been carried out with five video games. The average consumption are as listed in Table 44.

Table 44: Measured average energy consumption of Base Case 3 Game Consoles

Game played	Nintendo Switch
MarioKart 8 Deluxe	11.60 W
FIFA 19	11.05 W
Super Smash Bros.Ultimate	12.04 W
Carnival Games	9.10 W
NBA2K Playground 2	13.29 W
Average across Games	11.42 W

By considering the Usage Scenario for an average user, power consumptions and corresponding TEC for each mode is summarized in Table 45. For future versions of the Nintendo Switch or similar game consoles from other manufacturers, the lab measurements from the report can be used as a baseline.

Table 45: Base Case 3, Energy Consumption and TEC in different Modes

Nintendo Switch			
Mode	Usage Scenario (hours per day)	Power Consumption (W)	TEC
Active gaming	1.00	11.42	4.18
Media	0.56	8.10	1.67
Other functions	0.28	5.02	0.52
Standby[177]	0.00	-	0.00
Charging[178]	(2.46)	(11.04-13.85)	(6.93)
Low power download	0.00	0.00	0.00
Rest mode[177]	21.71	0.28	2.25
Off	0.45	0.35	0.06
SUM	24.00	-	8.67 (9.23)

6.3.4 Environmental impact results from Ecoreport

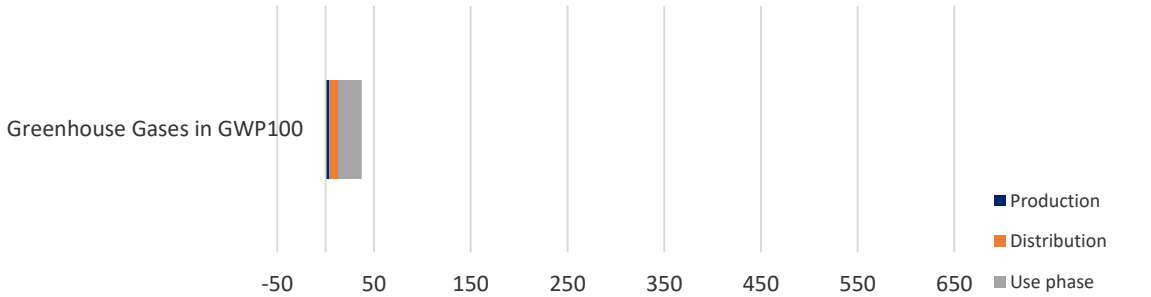
The environmental impacts in Ecoreport are calculated based on the product service and product stock life, on the material input as described above and on the TEC of the games consoles. Included in the Ecoreport tool is background data on the resources, energy consumption and emissions connected to the production of different materials. This information together with the material composition is used to calculate the environmental impacts during the production phase of one console. The impacts resulting from the distribution of the console from production to the end user is based solely on the size of the packaging which was assumed to be 0.006 m^3 based on information from online sales platforms. The tool does not, however, not offer the possibility to insert data on the distance travelled for distribution or the transport mode.

For calculation of the impacts during the use phase, the TEC was used. Because the Ecoreport tool does not allow for different usage scenarios that change the TEC of the console a usage scenario influenced by LBNL together with our own measurements for an average user was chosen for the calculations. These are described in more detail in section 4.1.7. With this usage scenario, the annual TEC of a single Switch console amounts to 8.67 kWh. Combined with the assumed service life of 7 years, over the lifetime of one console a total of 0.06 MWh of energy is consumed.

[177] The Nintendo Switch does not allow the airplane mode to be turned on while being connected to the docking station. Therefore, only the rest mode is available, and the standby mode is set to zero hours.
[178] For power consumption of charging, a range is given because charging the Nintendo Switch and its peripherals cannot be differentiated for homogeneous use. Fully charging the Nintendo Switch requires 2.46h after using the Nintendo Switch in handheld mode according to the usage scenario in Table 45, which involves playing Mario Kart for 1h, watch videos on Youtube for 0.56h and navigate through the shop for 0.28h. For handheld mode the power consumption in the modes active gaming, media and other functions, does not apply because power is only consumed from the grid in docking mode.

Compared to the impacts from production and distribution, the energy usage during the use phase has the highest environmental impacts according to the Ecoreport results as is depicted in Figure 44. The treatment during end of life has negligible environmental impacts. For recycling negative impacts or credits are rewarded, assuming that recycling products substitute virgin materials and therefore resources and emissions during production of virgin materials is avoided.

Figure 44: Global warming potential in kg CO_2-eq. distributed over life cycle phases



	Greenhouse Gases in GWP100
Production	3
Distribution	10
Use phase	23
End of Life	0
Recycling credits	0

In the following tables further results from the Ecoreport tool are depicted. Table 46 shows the amount of energy and water consumed and waste generated over the lifetime of Switch. Table 47 lists further environmental impacts including the global warming potential and acidification potential, distributed over the life cycle phases for one Switch games console.

Table 46: Resources consumed and waste generated distributed over life cycle phases

	Unit	Production	Distribution	Use	End of Life	Recycling credits	Total
Total Energy (GER)	MJ	58	133	547	3	-7	**734**
of which, electricity	MJ	15	0	546	0	-3	**558**
Water (process)	ltr	36	0	0	0	-9	**27**
Water (cooling)	ltr	21	0	24	0	0	**45**
Waste, non-haz./ landfill	g	349	117	285	9	-81	**679**
Waste, hazardous/ incinerated	g	126	2	10	0	-38	**100**

Table 47: Emissions to air and water distributed over life cycle phases

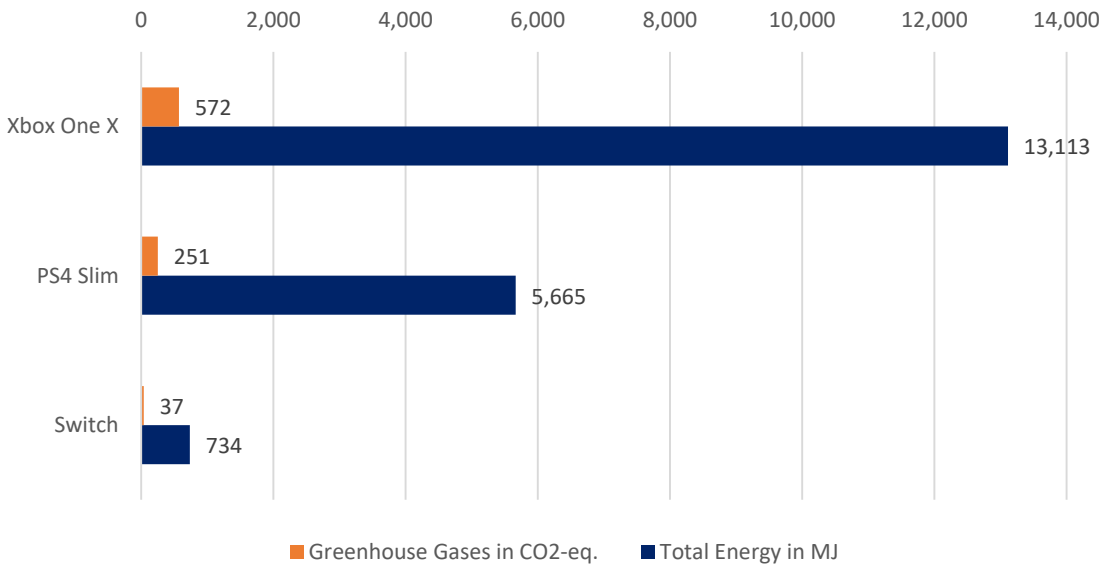
	Unit	Production	Distribution	Use	End of Life	Recycling credits	Total
Greenhouse Gases in GWP100	kg CO2 eq.	3	10	23	0	0	**37**
Acidification, emissions	g SO2 eq.	46	31	104	0	-8	**173**

	Unit	Production	Distribution	Use	End of Life	Recycling credits	Total
Volatile Organic Compounds (VOC)	g	0	0	12	0	0	**13**
Persistent Organic Pollutants (POP)	ng i-Teq	2	1	1	0	0	**4**
Heavy Metals	mg Ni eq.	8	6	6	1	-1	**19**
PAHs	mg Ni eq.	4	3	1	0	0	**8**
Particulate Matter (PM, dust)	g	5	8	2	4	-1	**18**
Heavy Metals	mg Hg/20	13	0	2	0	-2	**14**
Eutrophication	g PO4	0	0	0	0	0	**0**

6.4 Overview of environmental impacts of base cases

When comparing the total greenhouse gas emissions and the total energy consumption of all three base cases over the entire life cycle, the Nintendo Switch appears to have the lowest overall impact while the Xbox One X, being the heaviest of the consoles and the only mains powered console with ultra-high definition gaming capacity, has the highest overall energy consumption and global warming potential. The PlayStation 4 Slim, as a mains powered games console without ultra-high definition capacity lies in between the other two base cases with regard to both global warming potential and total energy consumption as can be seen from Figure 45 below.

Figure 45: Greenhouse gases and total energy consumption over life time for all three base cases



The results of the environmental impact assessment have to be put into perspective with the main characteristics of the different base cases. The following Table 48 gives an overview of the base cases main characteristics relating to materials and energy consumption plus their overall function.

Table 48: Overview of base cases and differentiation

Parameter	Base case 1	Base case 2	Base case 3
Console(s) represented by base case	PS4 Pro, Xbox One X (weight and material composition of Xbox One X has been used as default)	PS4 Slim, Xbox One S (weight and material composition of PS4 Slim has been used as default)	Nintendo Switch
Weight (g)	4452.3 (Xbox One X)	2499.5 (PS 4 Slim)	408.90 (Nintendo Switch)
Active gaming average (W)	145.91 (PS 4 Pro) 148.80 (Xbox One X)	75.20 (PS 4 Slim) 66.78 (Xbox One S)	11.42 (Nintendo Switch)
Media (W)	56.50 (PS 4 Pro) 51.83 (Xbox One X)	44.9 (PS 4 Slim) 34.31 (Xbox One S)	8.10 (Nintendo Switch)
Other functions (W)	65.22 (PS 4 Pro) 49.60 (Xbox One X)	41.8 (PS 4 Slim) 29.30 (Xbox One S)	5.02 (Nintendo Switch)
Connected standby (W)	1.30 (PS 4 Pro) 13.48 (Xbox One X)	1.20 (PS 4 Slim) 7.12 (Xbox One S)	0.285 (Nintendo Switch)
Low power download (W)	55.28 (PS 4 Pro) 40.76 (Xbox One X)	42.00 (PS 4 Slim) 16.91 (Xbox One S)	N/A (Nintendo Switch)
Peripheral charging (W)	11.40 (PS4 Pro) 3.48 (Xbox One X)	11.40 (PS 4 Slim) 3.25 (Xbox One S)	13.85(Nintendo Switch)

6.5 End of life for all three base cases

The end of life treatment is assumed to be indifferent among the three selected base cases. As elaborated in section 5.2.3 expected end of life treatment can be characterized by:

- A lack of information about the share of waste games consoles that enter the designated treatment route (including proper pre-treatment and preparation for reuse)
- Probably nearly no preparation for reuse (after the devices have obtained waste status)
- Shredding of the whole device is common practice, typically resulting in the following output fractions: mixed plastics, Fe-metals, aluminium, copper and precious metals, non-ferrous metals excluding precious metals and fine shredding material

The end of life mass fractions were based on expert judgements and reflect the shortcomings mentioned earlier of the collection and treatment scheme by assuming a ratio of 50 percent of the waste devices entering the proper separate collection and treatment route for WEEE[179]. Due to lack of information on end of life treatment the level of material fractions across Europe, the estimations

[179] Based on collection data of small electronic devices across Europe, aggregated in the urban mine platform [Accessed on 22.05.2019]

for EcoReport were based on total recovery, recycling and reuse rates of small electronics from Eurostat[180] supplemented by literature data on energy and material recovery rates for small WEEE.

Table 49: Data on average end of life of small electronic devices collected in the EU (Eurostat,2019)

Treatment	2014		2015		2016	
	Mass in t	% of collected	Mass in t	% of collected	Mass in t	% of collected
Collected	332.829	100%	377.072	100%	408.050	100%
Recovered total	299.937	90%	329.333	87%	361.497	89%
Recycled and reused	269.706	81%	297.064	79%	339.329	83%
Thermally recovered	30.231	9%	32.269	9%	22.168	5%
Reuse	0	0%	0	0%	0	0%

The Eurostat data summarized in Table 49 indicates that over the time period from 2014 to 2016 approximately 80 % by mass of all collected WEEE was recycled and 10 % by mass was thermally recovered. No data are available on the preparation for reuse of small electronic devices, but it is assumed to be close to zero. Chancerel et al. (2009) estimate the material specific recovery rates for small WEEE in a basic treatment scenario to be about 70 % for electronics such as PCB, 90% for ferrous and non-ferrous metals and close to 0 % for plastics[181].

Based on these data on recycling and recovery rates of small WEEE, collection rates for selective treatment of small WEEE in Europe and further expert estimations, the assumptions summarized in Table 50 were made for the impact calculations in the Ecoreport tool. It was furthermore assumed that none of the material fractions arose from treatment of small WEEE treated thermally without heat recovery. Based on the Eurostat data on recovery a loss of 10 % by mass of all collected small WEEE is assumed which is either landfilled, exported or else goes missing.

Table 50: End of life of game consoles material fractions

Per fraction	Bulk Plastics	Technology Plastics	Ferrous metals	Non-ferrous metals	Electronics
EoL mass fraction to re-use, in %	0%				
EoL mass fraction to (materials) recycling, in %	1%	1%	95%	95%	35%
EoL mass fraction to (heat) recovery, in %	89%	89%	0%	0%	55%
EoL mass fraction to non-recov. incineration, in %	0%				
EoL mass fraction to landfill/missing/fugitive, in %	10%	10%	5%	5%	10%

6.6 Mains powered arcade console with external display

6.6.1 Description

Additionally, to the three base cases, arcade consoles exist on the market and are not represented by the base cases. Therefore, the typical energy consumption and material composition of a mains powered arcade console with external display will be described separately. However this is not the

[180] Eurostat database [Accessed on 22.05.2019]

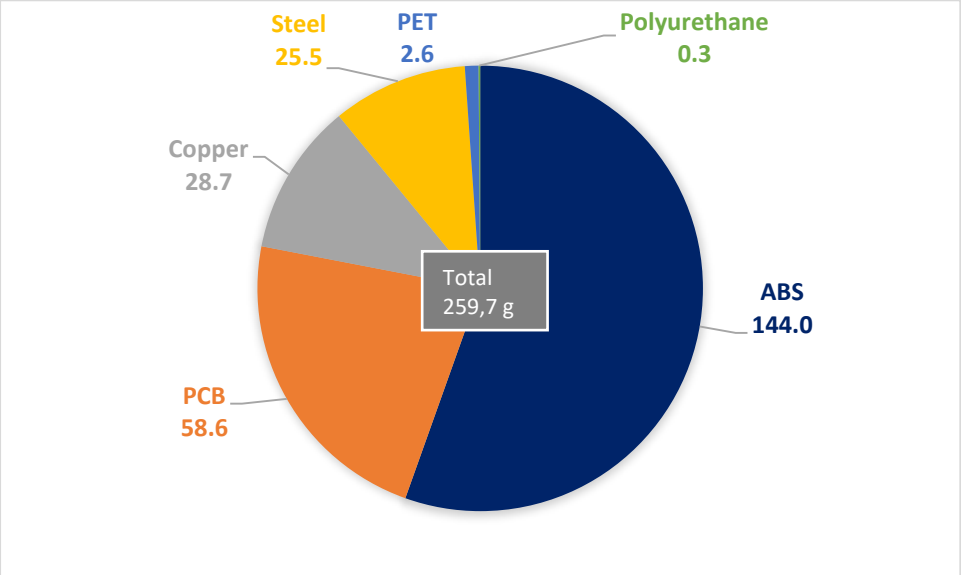
[181] Chancerel, P., & Rotter, S. (2009). Recycling-oriented characterization of small waste electrical and electronic equipment. *Waste management*, *29*(8), 2336-2352.

subject of Ecoreport calculations or design improvement options. Arcade consoles are re-engineered games consoles which were originally sold over 15 years ago. They have a very limited energy use (often powered by USB only) and have the ability to play a limited variety of pre-installed games. Due to added functionalities in the navigation menu, gamers are able to save the game state.

6.6.2 Materials and weight

For the material composition, the information on the materials of a "Nintendo Classic Mini: Nintendo Entertainment System sample" (model CLV-001) was used and is depicted in Figure 46: Material composition (in g) of a mains powered arcade console with external display. The top and bottom casing are made of ABS plastic, the inner casing is assumed to consist of ABS plastic and steel. The controller connector is assumed to be made of equal parts PCB, PET and steel. The motherboard as well as the Sub PCB/FPC are made out of (flexible) PCB. The screws are assumed to consist of steel and the bottom rubber of polyurethane. Peripheral controllers are assumed to consist of equal parts ABS plastic, PCB and copper for the connecting cables.

Figure 46: Material composition (in g) of a mains powered arcade console with external display



6.6.3 Typical Energy Consumption

There are no measurement data available on the power consumption of arcade consoles. However several sources[182] state a power consumption of around 2.5 W for the SNES Classic. Therefore for gaming and navigation 2.5 W power consumption can be estimated and these values can be assumed to be valid for the NES, SNES and PS Classic.

Assuming a navigation to gaming ratio of 20%, and a moderate gaming usage scenario of 2h gaming per day and 0.4 h of navigation per day, the annual TEC amounts to 2.19 kWh. Taking into consideration the point that an arcade console is used for 3 months a year or 25 % of the year and is afterwards not used any more than this, the annual TEC at moderate gaming intensity decreases to 0.55 kWh according to the research team's calculations.

[182] https://arstechnica.com/gaming/2017/09/everything-you-need-to-know-about-the-super-nes-classic-edition/ and http://energyusecalculator.com/electricity_gameconsole.htm

6.7 Quantifiable design options for improved energy efficiency

This section presents the design options that that could be employed to increase the energy efficiency of the devices as compared to the three base-cases. The design options have been based on the following criteria:

- They have a significant potential for device energy savings
- They are applicable without excessive costs for redesign and product development
- They do not hinder the functionality and performance of the devices compared to the base cases

6.7.1 Design option 1: SSD for base case 1 games consoles

The use of an SSD in the Xbox One X instead of a HDD storage would have had several implications if it had been applied to the games consoles from the release onward.

On the one hand, it would have reduced the energy consumption of modes “Media” and “Connected Standby”. An energy saving of 97.97 GWh would have been achieved cumulated over all Xbox One X games consoles in Europe from their release in 2017 up to the year 2031. This would reduce the energy consumption by 2.6 % in these modes.

On the other hand, it would have increased the energy consumption of the mode “Active Gaming” but would have reduced gaming load times by 42 seconds per game load (based on measurements with the game Red Dead Redemption 2). Assuming one game start per day, this would have led to an annual reduction of 4h 15min of time spent in the mode “Active Gaming”.

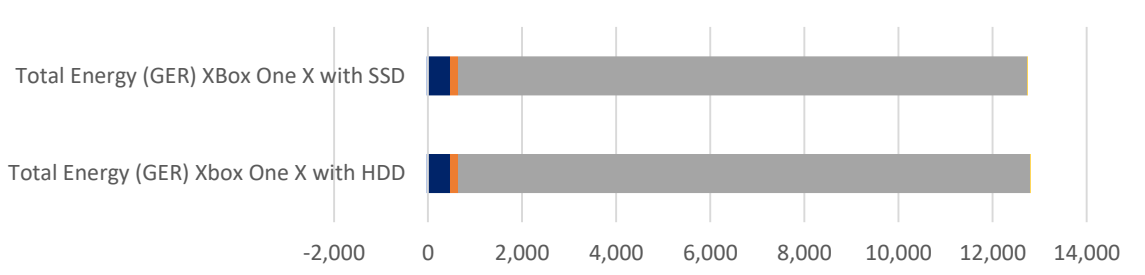
Although the energy consumption would be higher in the mode “Active Gaming”, an energy saving of 35.21 GWh over all Xbox One X consoles over their lifetime would have been achieved, which corresponds to a reduction of 0.51 %.

Table 51: Change in TEC of Xbox One X using SSD compared to HDD storage

Xbox One X	SSD	HDD	Difference
TEC annual (kWh)	191.97	192.95	0.98
TEC cumulative (GWh)	6 932.08	6 967.30	35.21
TEC cumulative w/o Active Gaming (GWh)	3 668.62	3 766.59	97.97

Evaluation of this design option in the Ecoreport tool for the Xbox One X results in a reduced energy consumption during the use phase and different material composition of the games console. The former can be depicted in the tool. However, for the latter, no material information is available. It is therefore left out in the further calculations of the environmental impacts of the design options. In Figure 47 the impact of SSD technology on the total energy consumption is depicted. The change occurs only during the use phase and is equal to a relative reduction of 0.51 %. Figure 48 depicts the change in total global warming potential over the life cycle if SSD was used instead of HDD storage technology. The savings amount to approximately 3 kg CO_2-eq. over the lifetime without taking into consideration the change in the material composition of the games console.

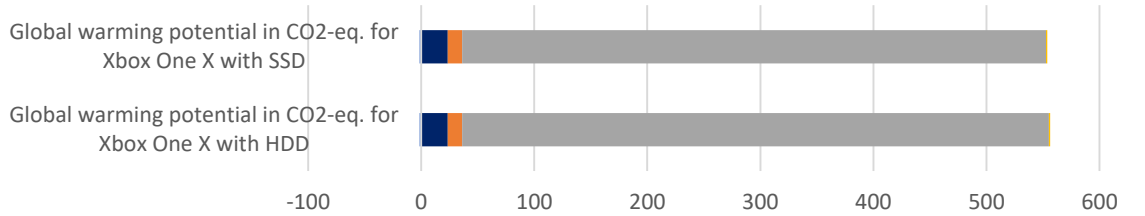
Figure 47: Comparison of total energy consumption over the lifetime of one Xbox One X with HDD and SDD storage technology respectively



	Total Energy (GER) Xbox One X with HDD	Total Energy (GER) XBox One X with SSD
Production	469	469
Distribution	168	168
Use	12,159	12,098
End of life	15	15
Recycling credits	-32	-32

Production Distribution Use End of life Recycling credits

Figure 48: Comparison of global warming potential over the lifetime of one Xbox One X with HDD and SSD storage technology



	Global warming potential in CO2-eq. for Xbox One X with HDD	Global warming potential in CO2-eq. for Xbox One X with SSD
Production	23	23
Distribution	13	13
Use	519	516
End of life	1	1
Recycling credits	-2	-2

Production Distribution Use End of life Recycling credits

The use of a SSD in the PS4 Pro (CUH-7216) would have had the following implications.

On the one hand, it would have reduced the energy consumption of modes “Media” and “Connected Standby”. An energy saving of 34.69 GWh would have been achieved, which would have reduced the energy consumption by 1.61 % in these modes.

On the other hand, it would have increased the energy consumption of the mode “Active Gaming” but would have reduced gaming load times by 63 seconds per game load (based on measurements with the game Red Dead Redemption 2). Assuming one game start per day, this would have led to an annual reduction of 6h 23min of time spent in the mode “Active Gaming”.

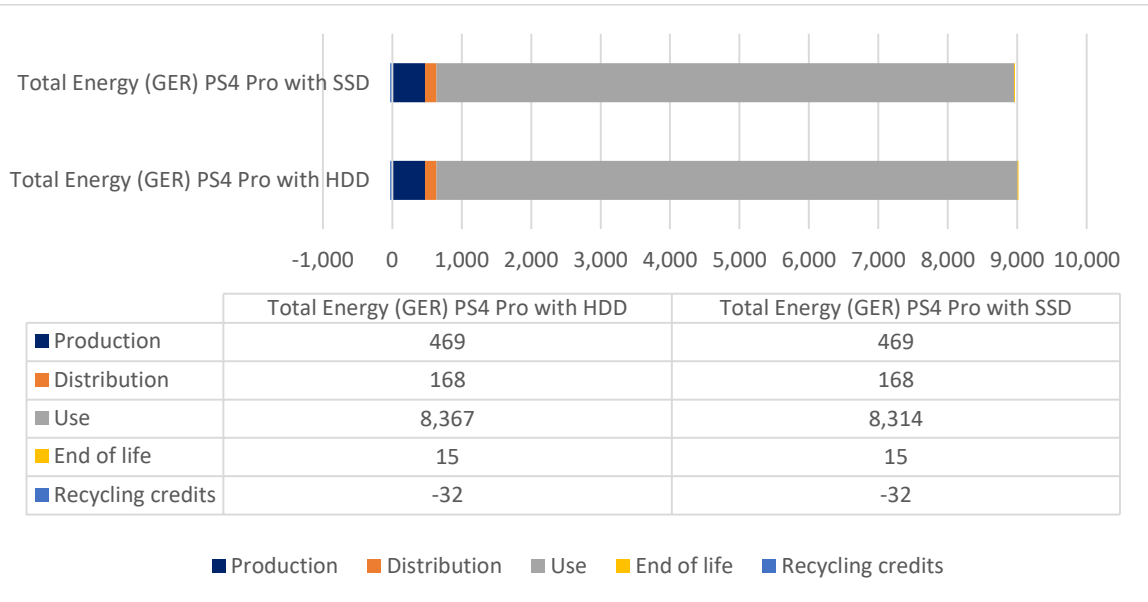
Although the energy consumption would be higher in the mode "Active Gaming", an energy saving of 36.57 GWh over all Xbox One X consoles over their lifetime would have been achieved. This corresponds to a reduction of 0.64 %.

Table 52: Change in TEC of PS4 Pro (CUH-7216) using SSD compared to HDD storage

PS4 CUH-7216	SSD	HDD	Difference
TEC annual (kWh)	131.92	132.76	0.84
TEC cumulative (GWh)	5 703.89	5 740.45	36.56
TEC cumulative w/o Active Gaming (GWh)	2 125.75	2 160.44	34.68

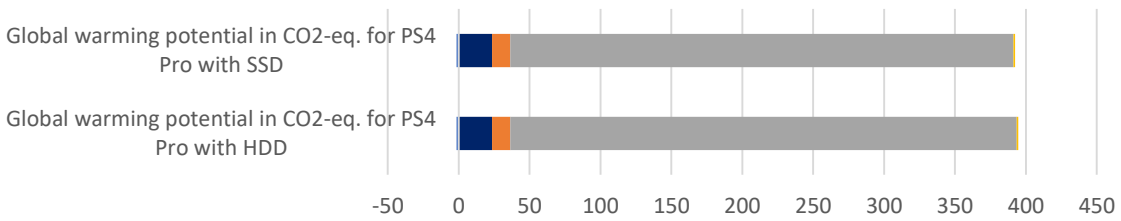
Evaluation of this design option in the Ecoreport tool for the PS4 Pro results in a reduced energy consumption during the use phase and different material composition of the games console. The former can be depicted in the tool. However, for the latter no material information is available. It is therefore left out in the further calculations of the environmental impacts of the design options. In Figure 49 the impact of SSD technology on the total energy consumption is depicted. The change occurs only during the use phase and is equal to a relative reduction of 0.63 %. Figure 50 depicts the change in total global warming potential over the life cycle if SSD was used instead of HDD storage technology. The savings amount to approximately 2 kg CO_2-eq. over the lifetime without taking into consideration the change in the material composition of the games console.

Figure 49: Comparison of total energy consumption over the lifetime of one PS4 Pro with HDD and SDD storage technology respectively



	Total Energy (GER) PS4 Pro with HDD	Total Energy (GER) PS4 Pro with SSD
Production	469	469
Distribution	168	168
Use	8,367	8,314
End of life	15	15
Recycling credits	-32	-32

Figure 50: Comparison of global warming potential over the lifetime of one PS4 Pro with HDD and SSD storage technology



	Global warming potential in CO2-eq. for PS4 Pro with HDD	Global warming potential in CO2-eq. for PS4 Pro with SSD
Production	23	23
Distribution	13	13
Use	357	355
End of life	1	1
Recycling credits	-2	-2

Production Distribution Use End of life Recycling credits

6.7.2 Design option 2: Turn-off

This section presents the current possibilities to turn off the PlayStation 4, the Xbox One and the Nintendo Switch. It concludes with a design option on the process to turn a console off.

6.7.2.1 PlayStation 4

The PlayStation 4 can be turned off by using one of the following options:

- The user must open the function screen by pressing the UP button on the d-pad of the controller from the home screen. In the function screen the option “Power” has to be selected. To turn off the console the option “Turn Off PS4” needs to be chosen.
- The user must open the quick menu by holding the PS button on the controller for a min. 1 second. In the quick menu the option “Power” must be selected. To turn off the console the option “Turn Off PS4” needs to be chosen.

The PS4 can be turned off physically by holding the power button for min. 7 seconds[183].

6.7.2.2 Xbox One

Only if the console is not set for instant on mode, can the console be turned off by using one of the following options:

- The user must open a power menu by holding the Xbox button on the controller. To turn off the console the option “Turn off console” needs to be chosen.
- The user can turn off the console by pressing the power button of the console.
- The user must open the guide by pressing the Xbox button. In the guide the option “System” must be selected. To turn off the console the option “Turn off console” needs to be chosen.

[183] https://manuals.playstation.net/document/en/ps4/basic/power.html

If the console is set for instant on mode, the user must complete following steps:

1. Open the guide by pressing the Xbox button on the controller.
2. Select option “System”
3. Select option “Settings”
4. Select option “Power & startup”
5. Select option “Turn off or restart”
6. Select option “Full shutdown”

The Xbox One can be physically turned off by holding the Xbox button on the front of the console for min. 10 seconds.[184]

6.7.2.3 Nintendo Switch

To turn off the Nintendo Switch, the user needs to open the Power Menu by holding the POWER button on the controller for min. 3 seconds. The Power Menu displays the options “Standby Mode” and “Power Options”. By selecting “Power Options”, the following options are displayed: “Standby Mode”, “Restart” and “Power Off”. To turn off the console the option “Power Off” needs to be chosen.

The Nintendo Switch can be turned off physically by pressing the power button for 12 seconds[185]. However this method is intended to be used only if turn off is not possible via the menu.

6.7.2.4 Design option

As described in the previous sections, the possibilities to turn off the games consoles presented could be improved. Turning off a console should be easily accessible to the user. It should be possible to turn off the console by using the graphical user interface and physically without use of the graphical user interface.

Turning off the console should have a higher priority than putting the console into standby. This could be implemented by displaying the option “Turn off” before the option “Standby” in the graphical user interface. By setting the “Turn off” option as default, the percentage of users, who turn off the console, could be increased. The impact of setting the turn off option as default from July 2019 onwards was calculated on the basis of a survey for games consoles of the seventh generation carried out in a doctoral thesis by Amanda Webb[186]. According to this survey, 65 % of the users would turn off their consoles. For games consoles of the eight generation this value is assumed to be lower, around 40%, because various features that have been introduced, e.g. low power download or suspend application would not be available for these consoles.

Setting the turn off option in the Xbox One models in July 2019 would lead to an energy saving of 2.20 TWh, thereby reducing the energy consumption of all Xbox One consoles by 11.07% over their lifetime. The TEC numbers for the Xbox One models are given in the following Table 53.

[184] https://support.xbox.com/en-GB/xbox-one/console/turn-console-on-off
[185] https://www.nintendo.co.uk/Support/Nintendo-Switch/Unable-to-Power-Off-the-Console-or-the-POWER-Button-Does-Not-Respond-1518558.htmlhttps://www.nintendo.co.uk/Support/Nintendo-Switch/FAQ/How-do-I-turn-the-Nintendo-Switch-console-off-/How-do-I-turn-the-Nintendo-Switch-console-off--1200811.html
[186] http://epubs.surrey.ac.uk/809999/

Table 53: Xbox One Standby / Turn Off Comparison on TEC

Xbox One Model	TEC cumulative with default standby (GWh)	TEC cumulative with default turn off (GWh)	Difference (GWh)
Xbox One	7 762.54	7 216.57	545.96
Xbox One S	5 204.26	4 532.11	672.14
Xbox One X	6 967.30	5 979.14	988.15

A default turn off option in the PS4 models from July 2019 onwards would achieve an energy saving of 0.65 TWh, which corresponds to an energy consumption reduction by 1.78% of all PS4 consoles over their lifetime. The TEC numbers for the PS4 models are given in the following Table 54.

Table 54: PS4 Standby / Turn Off Comparison on TEC

PS4 Model	TEC cumulative with default standby (GWh)	TEC cumulative with default turn off (GWh)	Difference (GWh)
CUH-1016	4 127.63	4 093.95	33.68
CUH-1116	4 870.83	4 801.20	69.62
CUH-1216	6 853.09	6 703.29	149.80
CUH-2016	2 079.39	2 046.13	33.25
CUH-2116	2 589.93	2 536.36	53.56
CUH-2216	3 306.44	3 193.06	113.37
CUH-7016	3 685.74	3 643.37	42.36
CUH-7116	3 258.35	3 213.51	44.84
CUH-7216	5 740.45	5 630.58	109.87

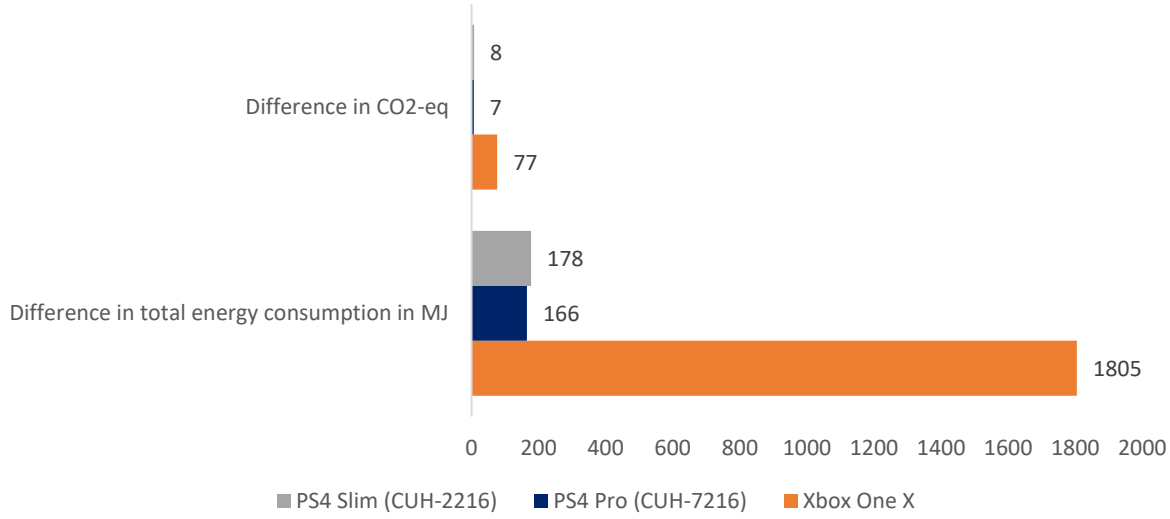
Even if the turn-off option is not set as default, turning off the console in the graphical user interface should not require more than one additional step, e.g. button press, compared to putting the console into standby mode. This should be regardless of whether the console is set to instant on mode or not.

To physically turn off the console, currently a button must be held for up to 12 seconds. A shorter period could improve the user experience and increase the use of this option. Therefore, it should be limited to max. 5 seconds. This same option should be available for holding a button on a controller.

6.7.2.5 Environmental impacts of turn off design option

Evaluation of this design option in the Ecoreport tool for Xbox One X, PS4 Slim and PS4 Pro results in a reduced energy consumption during the use phase of the games consoles. No changes occur during the distribution, production or end of life phases. The change of energy consumption and the difference in CO_2-equivalents emitted during the lifetime of one games console respectively is depicted in Figure 51. The highest energy savings can be realised for the Xbox One X with a total of 1,805 MJ potential savings during the use phase which equals a relative reduction of 15 % over the lifetime. For the PS4 Pro and Slim the energy savings over one games console lifetime are 166 MJ and 1748 MJ respectively (2 % and 4 % reduction relative to baseline).

Figure 51: Difference in energy consumption and GWP with improved turn off design as compared to current turn off design for one games console over its lifetime



6.7.3 Design option 3: Adaptive APD

As described in section 5.3.4, by using programs and algorithms to analyse user behaviour patterns, adaptive mechanisms for optimizing auto-power-down timeframe could be implemented. By using adaptive APD the on-time, which includes the modes "Active Gaming", "Media" and "Other functions", could be reduced. In addition, this would increase the standby and off time.

The impact of adaptive APD from July 2019 onwards on the energy consumption was calculated under the assumption that it would reduce the on-time by the same percentage as the standard APD. In the SRI 2.6.3 a reduction of the on-time by 7% due to standard APD was assumed. Based on this number, the impact of adaptive APD was calculated.

Adaptive APD in Xbox One models from July 2019 onwards would lead to an energy saving of 499.93 GWh, thereby reducing the energy consumption of all Xbox One consoles by 2.51% over their lifetime. The TEC numbers for the Xbox One models are given in Table 55.

Table 55: Xbox One Standby / Adaptive APD Comparison on TEC

Xbox One Model	TEC cumulative with default standby (GWh)	TEC cumulative with default turn off (GWh)	Difference (GWh)
Xbox One	7 762.54	7 675.75	86.78
Xbox One S	5 204.26	5 042.18	162.07
Xbox One X	6 967.30	6 716.23	251.07

For the PS4 models adaptive APD would achieve from July 2019 onwards an energy saving of 1.42 TWh, which corresponds to an energy consumption reduction by 3.89% of all PS4 consoles over their lifetime. The TEC numbers for the PS4 models are given in Table 56.

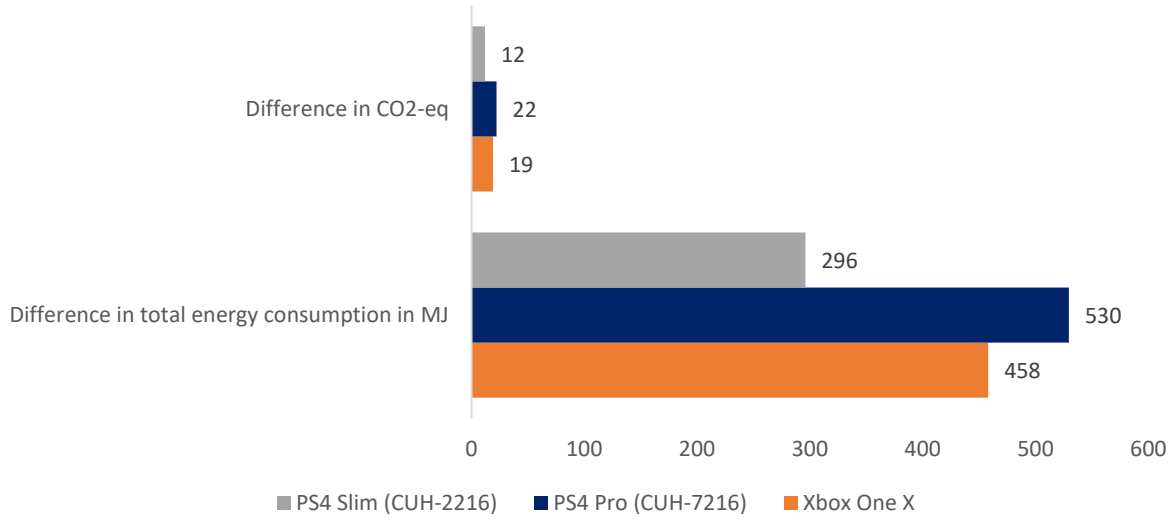
Table 56: PS4 Standby / Adaptive APD Comparison on TEC

PS4 Model	TEC cumulative with default standby (GWh)	TEC cumulative with default turn off (GWh)	Difference (GWh)
CUH-1016	4 127.63	4 069.34	58.29
CUH-1116	4 870.83	4 773.79	97.03
CUH-1216	6 853.09	6 658.65	194.44
CUH-2016	2 079.39	1 997.88	81.50
CUH-2116	2 589.93	2 464.82	125.11
CUH-2216	3 306.44	3 117.50	188.93
CUH-7016	3 685.74	3 529.05	156.68
CUH-7116	3 258.35	3 091.02	167.32
CUH-7216	5 740.45	5 389.18	351.27

6.7.3.1 Environmental impacts of APD design option

Evaluation of this design option in the Ecoreport tool for Xbox One X, PS4 Slim and PS4 Pro results in a reduced energy consumption during the use phase of the games consoles. No changes occur during the distribution, production or end of life phases. The change of energy consumption and the difference in CO_2-equivalents emitted during the lifetime of one games console respectively is depicted in Figure 51. The highest energy savings can be realised for the PS4 Pro with a total of 529 MJ potential savings during the use phase which equals a relative reduction of 6 % over the lifetime. For the PS4 Slim and Xbox One X the energy savings over one games consoles lifetime are 458 MJ and 296 MJ respectively (4 % and 6 % relative reduction to baseline).

Figure 52 Difference in energy consumption and GWP with improved APD design as compared to current turn off design for one games console over its lifetime



6.7.4 Overview on Options for Improved Energy Efficiency

This subsection presents an overview on options for improved energy efficiency derived from sections 4.1, 5.1, 0, 6.7. It contains a list of the status quo, improvement potential, current VA requirements and proposed new requirements.

First, an assessment based on measurements and default settings for each of the console types is given. Table 55 gives an overview of the positive impacts or features that have been implemented for the console generation of each manufacturer.

Table 57: Energy related good implementations

Mode	PS4	Xbox One	Nintendo Switch
Connected Standby	• Low Energy consumption when in Rest Mode: Stay Connected to the Internet" (~0.9W) • Updating in connected Standby saves Energy	• The option to charge controllers does not add any extra power consumption and is always available • Updating in connected Standby saves Energy	Very low energy consumption (< 0.3W)
Active Mode	Energy Consumption scales with resolution	Xbox One S has the lowest energy consumption in video playback (stationary consoles)	Generally <20W when in Active Gaming Mode
Auto Power Down	Powers down the console completely	Download progress is maintained	
First Start Setup	Most pre-selected settings are to save energy	Most pre-selected settings are to save energy	No energy-related options required
General	High Efficiency Power Supply	High Efficiency Power Supply (highest among the games consoles)	• Overall energy consumption very low • Articles bought in the shop can be automatically downloaded • High Efficiency Power Supply

After having a look at the good solutions and features of each console, some aspects were identified by either desk research or the intensive measurements undertaken. Table 58 describes settings, features or console behaviour that could be improved.

Table 58: Energy efficiency improvement potential

Mode	PS4	Xbox One	Nintendo Switch
Connected Standby	When the option to charge controllers is selected power consumption is very high even if no controller is connected (this has already been addressed by a power down feature. Nevertheless, this should be improved in the next generation by a different design)	High Energy consumption when in Instant-On mode (~14W)	• When a USB to Ethernet adapter is connected while in connected standby, energy consumption is relatively high(~4W) • Software cannot be updated in Connected Standby

Mode	PS4	Xbox One	Nintendo Switch
Active Mode	• Very high Energy Consumption at Video Playback (up to 86W HD streaming PS-store PS4 Pro) • High energy consumption in navigation mode (up to 65W @4k)	• No big difference in Energy consumption when playing in different resolutions • High energy consumption in navigation mode (64W in Navigation mode @1440p Xbox One X)	
Power Down	It takes 7 seconds to power down the console with the power button	• First power down option puts the consoles in Instant-On mode or Energy Saving (Icon and description is misleading) Full shutdown hidden in the settings • It takes 10 seconds to power down the console with the power button	• Power Down Menu is hard to find • Power off consumes more than Connected Standby • Not possible to turn off the console with the controller
Auto Power Down		• The time until the screen dims is added to the APD time • Auto Power Down goes into Energy Saving or Instant-On mode and does not shut down completely	
First Start Setup	Recommendations to save energy while setting up rest mode	Decision to use Energy Saving instead of "Instant-On should be pre-selected	
General	Automatic resolution adjustment when media with low resolution is played	• Energy Consumption stays the same after altering the resolution. Only after restarting the console it is lower/higher • Energy Consumption in 1440p is higher than in 4k • Automatic resolution adjustment when media with low resolution is played	

Auto-Power Down (APD) Requirements

In the SRI as of version 2.6.3, the activation of the APD function, which powers down the console to a low power state, is defined as the default setting for consoles on the EU market. Specific inactivity time periods are described for the activation of the APD function in different modes and also the corresponding behaviour. It is assumed that the introduction of APD led to a reduction of the on-time by 7%, as mentioned in the section 6.7.3. As our desk research confirms, these requirements are fulfilled by the consoles' default settings. Furthermore, released operating system updates show a positive trend regarding APD settings in that they reduce the default time settings for APD and increase the available options for APD time settings.

Power Cap for Low Power Modes (Rest)

The rest mode is offered by the game consoles of the 8th generation under several names, such as instant-on mode and hold mode. According to estimations from the first stakeholder meeting, 75% of the users in Europe use such a low power mode. These low power modes enable users to put active applications, such as the current game state, on hold for a longer time period and then allow the user to resume from this low power state by awaking on controller or similar input. The energy consumption in these low power modes varies depending on enabled options and additional actions such as update installations and can reach a significant energy consumption level. The VA does not contain any power cap on low power modes with a Rest feature yet. Therefore, a power cap of <5W is recommended for the rest mode for next generation consoles.

Reduced energy consumption while inactive

Several features provided by the consoles aim to reduce energy consumption. One of these is the transition to an idle mode after a specific time period without user input. In this mode, e.g. an idle-animation can be shown or the brightness can be dimmed. These features aim to decrease the energy consumption but as described in chapter 4.1.6, in some cases the opposite is achieved. An example mentioned is the increase of the energy consumption due to the presence of a side-notification window in the idle mode. It is recommended that these features should be checked for increased energy consumption and if necessary, these features fixed. The behaviour of these features should again be reviewed as part of the next SRI review.

Limit power consumption in networked standby mode to 2W according to EU 801/2013

As described in chapter 2.2.2, the EU Commission Regulation 1275/2008 (incl. amendment 801/2013) contains Ecodesign requirements related to standby, networked standby and off mode. Since 1 January 2019 new requirements for this Regulation apply. These new requirements limit the maximum power consumption of networked standby to 2W for not high network availability network equipment, such as game consoles. Currently the PS4 is the only games console offering a networked standby mode and complies with this Regulation according to lab measurements.

Guaranteed battery lifetime of at least 3 years

Non-conventional battery types, which are difficult to access and replace, can be used in controllers, as described in chapter 6.9.1. Furthermore, these batteries are utilized as power supply for high-end games consoles with a capability for handheld gaming with integrated display plus stationary gaming with a docking station, which are described in chapter 7.2. Such batteries are not designed to be replaced by the user and must have a guaranteed minimum lifetime. Since, as a result of differences in consumer behaviour and use patterns it is difficult to define a minimum lifetime in years, the number of full charge cycles is used here. Therefore, following the requirements of the Blue Angel for mobile phones[187], it is recommended that after 500 full charge cycles these batteries should still have a capacity of a minimum of 90% of the nominal capacity. In addition, analogous to EC/617/2013, the minimum number of loading cycles that the batteries can withstand should be provided in the technical documentation.

The VA does not yet include any requirements on console battery lifetime.

[187] https://produktinfo.blauer-engel.de/uploads/criteriafile/en/DE-UZ%20106-201707-en%20Criteria.pdf

6.8 Quantifiable design options for improved material efficiency

This section presents design options that could be employed to increase the material efficiency of the devices as compared to the three base cases. The design options have been chosen based on the following criteria:

- They have a significant potential to improve the durability, disassemble ability, reparability or recyclability of the device, resulting in higher material efficiency
- They are applicable without excessive costs for redesign and product development
- They do not hinder the functionality and performance of the devices compared to the base cases

6.8.1 Design option 1: Improved material efficiency due to use of post-consumer recycled plastic

According to the SRI signatories, currently no post-consumer recycled plastic is used for the production of the game consoles (see 5.2.2). Post-consumer recycled (PCR) plastic refers to the recycled product of waste created by consumers as opposed to "pre-consumer" or "post-industrial" waste, which is generated from industrial or manufacturing processes. Using PCR plastics can significantly reduce environmental impacts when compared to using virgin material by avoiding exploration, mining and transportation of natural gas and oil and by reducing energy consumption as compared to the energy required to produce virgin material.

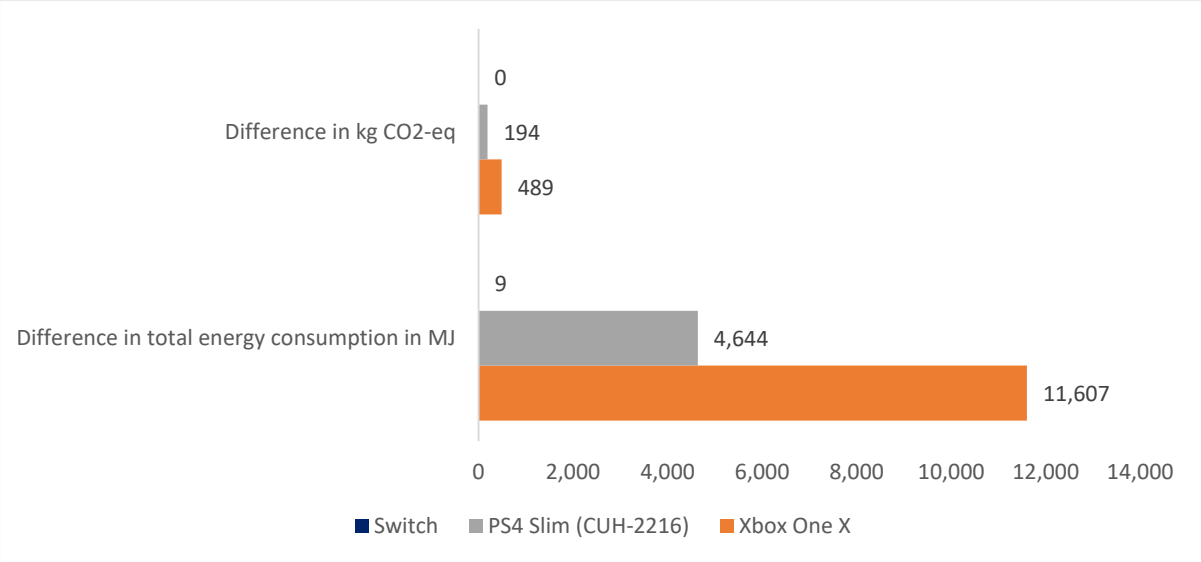
Assuming the signatories were to apply the best practice of using 85 % PCR plastic as described in section 5.3.5, energy use as well as CO_2-emissions could be avoided in the production phase of the games consoles. According to Hischier and Wäger (2015)[188] the environmental impacts connected to PCR plastics are 80-90 % lower compared to those of virgin plastics. Assuming a reduction in the impacts of all plastics by 80 % compared to the virgin plastics impacts data in the Ecoreport[189] and a PCR plastic content of 85 % in the casings and controllers of the games consoles, the energy and emissions savings depicted in Figure 53 could be achieved.

For the Xbox One X, energy savings amount to 11,607 MJ and CO_2-eq. savings to 489. For the PS4 Slim the savings are about 4,644 MJ of energy and 194 kg of CO_2-eq. The savings that could be achieved for the Nintendo Switch are lowest at about 9 MJ of energy and with zero reduction in the emission of CO_2-eq. due to the low mass of the Nintendo Switch and few parts that could be substituted by PCR plastics.

[188] Wäger, P. A., & Hischier, R. (2015). Life cycle assessment of post-consumer plastics production from waste electrical and electronic equipment (WEEE) treatment residues in a Central European plastics recycling plant. *Science of the Total Environment*, *529*, 158-167.

[189] Consultants and the EU Commission have agreed on this approach of assessing the environmental impacts of PCR plastics based on literature research.

Figure 53: Energy and CO_2-eq. savings in the production phase if 85 % post –consumer plastics in the housings and controllers were applied compared to no recycled plastic content of the games consoles



6.8.2 Design option 2: Improved durability due to better resistance against heat stress

The thermal measurements as described in 4.1.9 indicated no fatal weak points in the architecture of the devices that might lead to premature heat damage to components. Nonetheless, the information on repair and durability provided by iFixit in 4.3.2 indicates, that one reason for damage to devices can be found in the overheating of components, especially the motherboard and the battery pack. Overheating of components may lead to an increased risk of their early failure. To prevent overheating while running at high power, the consoles are equipped with a ventilation system. However, due to the compact design of the consoles overheating appears to remain an issue under some circumstances. The discrepancy between the thermal measurements carried out in this study and the information from ifixit might result from the fact that “new” games consoles have been used in the measurements while ifixt naturally deals with “older” consoles that have probably been exposed to a higher amount of dust than has accumulated in the lab environment for the study duration.

By using a stronger fan in the consoles, the technical lifetime of the devices might be prolonged, and materials used in the production of replacement components can be saved. This measure however might correlate with higher energy demand and a trade-off should be avoided if possible.

Another measure to improve the heat stress resistance of the devices is to adjust the architecture of the components in such a way, that heat sensitive parts are further away from heat generating parts where possible without causing trade-offs.

These design options for improved heat resistance cannot be modelled in the Ecoreport tool because data on the BOM of additional components such as the improved fan are not available nor are data on the changed power consumption of the consoles.

6.9 Further design options for improved material efficiency

In this section additional measures to further improve the material efficiency of game consoles are elaborated based on the analysis in the previous chapters. The measures can be categorized as:

- Further measures with regard to product design

- Non-design related measures and
- Information-based measures.

Additionally to the measures derived from the analysis of the current product design, user behaviour and best practice (section 4 and 5 of this report), some of the following measures proposed have been derived from the JRC study "Guidance for the Assessment of Material Efficiency: Application to smartphones"[190], the JRC study "Analysis of material efficiency aspects of personal computers product group"[191]and from the "Resolution on a longer lifetime for products: benefits for consumers and companies" by the European Parliament[192]. In addition, it is stated whether or not the measures are already considered in the current VA and to what extent. It will be shown that there are a number of measures the signatories have committed to that are congruent with the study team's findings, while another part of the proposed measures are not yet adopted by the VA.

6.9.1 Further measures with regard to product design

Non-destructive disassemblability of the device for key components

It has been established in section 4.3.1 that games consoles are used and traded for up to 14 years after their market launch and enter waste treatment only after up to 20 years of technical lifetime. Due to the fact that consoles of any generation appear to have a market value, defective and intact games consoles might be repaired and/or given a second life on the second hand market after first intensive use. Access to the main components for repair supports this prolongation of lifetime by enabling repair, refurbishment and maintenance. To further support product life extension, it should therefore be possible to disassemble the devices without causing any damage or leaving any other residue which precludes reassembly or reuse[193]. This includes accessing and removing the motherboard, any hard disk drive, optical drive, and internal power supply. This measure is already partly part of the VA.

Improved durability due to use of easy-to-replace batteries

Games consoles differ in their energy supply technology. The Xbox One X and Xbox One S contain regular AA batteries in the controllers, which can be replaced by the users. The PS4 Pro and PS4 Slim however come with controllers whose batteries are of not conventional types and are difficult to access and replace (see section 5.3.5). The same holds true for the Nintendo Switch described in 6.3 for base case 3, which relies on battery power when used as a handheld console. However, it is not designed so that there can be replacement of the battery pack by the user.

The use of batteries or power supply parts inside the device, that are difficult to access, hinders the user from replacing these parts. This is the case for both the controllers of games consoles with both handheld and stationary gaming capability and for game controllers of mains powered stationary consoles. To improve the durability of both the handheld games consoles and the controllers it is recommended to make batteries easily accessible[194]. This measure is not yet part of the VA.

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[190] Cordella, Mauro; Alfieri, Felice & Sanfélix, Javier (6 May 2019) Guidance for the Assessment of Material Efficiency: Application to smartphones – v2. European Commission, Joint Research Center Directorate B, Unit 5 (Sevilla).
[191] Tecchio, P., Ardente, F., Marwede, M., Christian, C., Dimitrova, G. and Mathieux, F., Analysis of material efficiency aspects of personal computers product group, EUR 28394 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-64943-1, doi:10.2788/89220, JRC105156
[192] European Parliament (July 4th 2017): Resolution on a longer lifetime for products: benefits for consumers and companies. Online: http://www.europarl.europa.eu/doceo/document/A-8-2017-0214_EN.html, last access May 23rd 2019.
[193] Ibid.
[194] Ibid.

Improved disassembleability due to use of non-proprietary screws or other fasteners which can be removed with common tools

Proprietary or security screws or other fasteners that cannot be removed hinder the owner from disassembling and repairing and should therefore be avoided[195]. The use of common screws is essential to guarantee maintenance and repair accessibility e.g. for the cleaning of the fan or replacement of broken parts. This can prolong the product's life time. The VA already commits to using only commercially available screws in order to allow access to key components. However the need to purchase specific tools might still hinder repair and maintenance activity for some customers and should therefore be avoided by making such tools available by supplying them with the consoles (or providing the necessary information to obtain such tools such as direct links to websites where the required tools can be purchased). Furthermore, all screws should be visible and not hidden by "Warranty Void If Removed" stickers, which are intended to keep consumers from repairing their devices. This measure is not yet part of the VA.

If the devices have reached their end of life and enter waste treatment, enhanced disassemblability can lead to improved recyclability. This is however only the case if the devices are treated separately during recycling and undergo (semi-)manual dismantling to remove valuable components or hazardous parts such as batteries.

Standardized interfaces for external power supply

The power supply in games consoles of base case 1 and base case 2 are built-in components, whereas for base case 3 devices a battery pack is used for the power supply. Use of an external power supply instead of a built-in power supply can increase material efficiency due to the possibility of replacing the power supply with similar power supplies from other devices as in the case of laptops. Integrating the power supply into the games console might on the other hand reduce material usage for cables and increase energy efficiency due to the compact design of the components. For this reason, standardised interfaces should be considered and weighed up against the potential advantages of an integrated design[196]. This measure is not yet part of the VA.

Phasing out hazardous substances

Electronic devices contain several halogenated substance such as brominated flame retardants in plastic parts, printed circuit boards and plasticizers (making polymers less brittle) and otherwise halogenated polymers such as PVC. These are all detrimental to the quality of recycled products and might release hazardous substances during use and waste treatment (see section 5.3.5). These substances are widely used in electronic devices and a few manufacturers are committed to phasing out hazardous substances from their products. Including binding phase out goals in the VA does not have a direct link to material efficiency. However, it should be considered as a measure since it has links to recyclability and the quality of secondary raw material stemming from the end of life treatment of electronic devices. The signatories state that there are currently no brominated flame retardants contained in the casings of games consoles (see 5.2.2). Binding phase out goals for all kinds of halogenated flame retardants and other hazardous substances are seen as the next significant step for higher material efficiency. This measure is not yet part of the VA.

[195] Ibid.

[196] Cordella, Mauro; Alfieri, Felice & Sanfélix, Javier (6 May 2019): Guidance for the Assessment of Material Efficiency: Application to smartphones – v2. European Commission, Joint Research Center Directorate B, Unit 5 (Sevilla).

6.9.2 Non-design-related measures for improved material efficiency

Binding guarantee for free of cost update support at all times

End-users should be provided with free of charge updates on the operating system, software and firmware, in order to enhance the product's technical lifetime. The software updates should be available to all consoles at all times. System updates are provided by the signatories free of charge and at all times, however this is not yet a binding part of the VA.

Availability of spare parts for professional repair centres

Given a service lifetime of at least seven years for a major portion of the devices (see section 4.3.1) with, in many cases, an occasional use even after seven years, the availability of spare parts[197, 198], for at least seven years after placing the last unit on the market, is crucial for the product's longevity and reparability. The spare parts should be available to all professional repair centres[199].

The commitment to availability of spare parts as currently stated in the VA should therefore at least be specified with regard to the information requirements on available spare parts and the timespan of availability.

Commitment to repair

Currently a one year free statutory warranty is standard for all games consoles, followed by a period of two years after purchase during which free manufacturer warranty can be claimed if the defects are not caused by the consumers as has been described in section 4.3.2. Furthermore, the SRI commits to out of warranty repair services being offered by authorised repair centres. However, there is little information about how defective game consoles are treated when sent for repair, both within the guarantee time and out of the guarantee time. There are indications that at least in some cases, consoles are substituted instead of being repaired by the manufacturer or its authorised repair centres. This reduces the material efficiency of the console. Therefore a commitment to free repair as the first remedy within the guarantee time[200] should be defined in the VA, along with appropriate consideration of consumer and product safety aspects[201]. Hence, a "free repair first" clause should be part of the guarantee contract.[202] This measure is not yet part of the VA.

Take-back schemes for game consoles

There is currently no separate take-back scheme established in the EU by the manufacturers of games consoles[203]. If disposed of correctly, games consoles are collected as part of a mixed fraction of small household electronic devices as laid out in the WEEE Directive and are mostly treated, according to current recycling standards, by automatic shredding and separation as described in 5.2.3. Valuable components and recyclable and reusable parts are consequently not separated before the automatic shredding and are lost for refurbishment of defective consoles or for recycling. This can be improved either by broadly changing recycling standards to include more in-depth dismantling and separation

[197] Ibid.

[198] European Parliament (July 4th 2017): Resolution on a longer lifetime for products: benefits for consumers and companies. Online: http://www.europarl.europa.eu/doceo/document/A-8-2017-0214_EN.html, last access May 23rd 2019

[199] According to information from the signatories, as some parts are proprietary these cannot be made available to all repair centers.

[200] Cordella, Mauro; Alfieri, Felice & Sanfélix, Javier (6 May 2019): Guidance for the Assessment of Material Efficiency: Application to smartphones – v2. European Commission, Joint Research Center Directorate B, Unit 5 (Sevilla).

[201] E.g. there might be cases such as water damage for which repair or partial replacement of components is not compatible with product and or customer safety requirements.

[202] Ibid.

[203] Manufacturers of sWEEE currently fulfil their extended producer responsibility (EPR) by taking part in the collective WEEE systems of the Member States.

of components before the shredding or by separating valuable devices already at the collection point and treating them separately and specifically.

By setting up take-back schemes for the separate and non-destructive collection of the devices, preparation for re-use and high-quality recycling of games consoles can be facilitated because of the more homogeneous nature of the waste stream collected. An individual take-back scheme might furthermore increase collection rates of games consoles, whereas collection as part of the small electronic devices waste fraction is associated with a lack of information about how much of the games consoles enter the designated collection and treatment route. This measure is not yet part of the VA.

6.9.3 Information-based measures

Durability, upgradeability and reparability

Informing customers about the technical durability, upgradeability and reparability [204] of a device might lead to more informed customer decisions and an increased market competition with regard to some of the core parameters of material efficiency**.** There is currently no manufacturer information available to the users on spare part availability, the timespan of spare part availability and the technical durability of components as previously described in section 6.9.2. Information on spare part availability is currently only provided to authorised repair centres. Information on upgradeability options (where applicable) is currently made available to customers as stated in the VA. Further provisions concerning information on spare part availability, timespan of spare part availability and durability of components is not yet part of the VA.

Boosting collection rates

Collection rates on small WEEE remain relatively low, while collection is vital for proper end-of-life treatment and recycling. By informing customers about how to discard the devices according to the WEEE Directive, a proper discard can be promoted. This measure can be combined with efforts to establish separate take-back schemes for games consoles as described in 6.9.2. This measure is already addressed by the VA.

Use and maintenance

The provision of information to end-users about the correct use and maintenance of the device[205] supports the right handling of the device and thus its technical lifetime. This measure is already addressed by the VA.

Data deletion

Personal data on devices often hinder the willingness of the owner to sell the device for reuse. The provision of information to end-users about how to delete personal data is therefore crucial to make the device ready for reuse[206]. This measure is already addressed by the VA.

[204] European Parliament (July 4th 2017): Resolution on a longer lifetime for products: benefits for consumers and companies. Online**:** http://www.europarl.europa.eu/doceo/document/A-8-2017-0214_EN.html, last access May 23rd 2019.
[205] Cordella, Mauro; Alfieri, Felice & Sanfélix, Javier (6 May 2019): Guidance for the Assessment of Material Efficiency: Application to smartphones – v2. European Commission, Joint Research Center Directorate B, Unit 5 (Sevilla).
[206] Ibid.

Repair options

Provision of information to end-users about refurbishment and out-of-warranty repair options available within the operating instructions supports refurbishing and repair This measure is already addressed by the VA.

Technical information

The provision of technical information (about disassembly steps etc.) to professional repair centres[207] makes repair more (cost-)efficient and thus more attractive for end-users. The signatories state that provision to non-authorised professional repair centres is not feasible. In the VA, technical information only needs to be provided to authorised professional repair facilities.

Marking plastic parts

The correct identification of a plastic part's material type is crucial for its subsequent treatment and recycling. Marking plastic parts > 25g and > 100mm^2 in accordance with ISO 11469[208] should therefore be a requirement for game consoles. The requirement to mark plastic parts > 25g specifying their material composition is already part of the SRI. Furthermore the VA states that the removability and recyclability of plastic parts > 100g should be considered during their next review. The research team support this as it would significantly support the recycling of plastic parts from games consoles.

Flame retardants

The correct identification of parts containing flame retardants offers the possibility for their separation in order to facilitate the production of flame-retardant free recycled plastic granulate. This is provided that the games consoles are treated separately during end of life treatment and plastic parts containing flame retardants are identified and removed from the residual plastic fraction, which currently is not common practice, as described in 5.2.3. Flame retardants contained in PCBs might also enter the plastic recycling route during shredding. The VA should therefore include reference not only to providing information on the content of flame retardants in plastic parts but also on flame retardants in other components such as PCBs in order to improve the quality of recycling and recycling secondary raw materials. The form in which the information is provided to the recyclers, in order to be beneficial in the recycling process, should be developed together with stakeholders from recycling plants. Knowledge about the constituents of substances entering their processes is especially valuable to recyclers who aim to produce secondary plastic granulate. They have to classify and label their recycled product as laid down in Directives 67/548/EEC and 1999/45/EC, and in the new CLP Regulation.

Furthermore, information on flame retardants in components help customers make informed decisions and market competition can be increased with regard to phasing out flame retardants from electronic devices as described in 6.9.1. As of January 1st 2020 marking of plastic parts containing flame retardants is part of the SRI, but only addressing plastic parts with brominated flame retardants.

Critical raw materials (CRM)

Closely related to the benefits described of information relating to a manual dismantling in the recovery of precious metals (see section 5.3.5), the provision of information on critical raw materials[209] content can also be vital in enabling their identification and hence improving their separation and recycling. Once the devices have reached their end of life and enter waste treatment, this information enables the identification of relevant components so that they can be separated from

[207] Ibid.
[208] Ibid.
[209] Cordella, Mauro; Alfieri, Felice & Sanfélix, Javier (6 May 2019): Guidance for the Assessment of Material Efficiency: Application to smartphones – v2. European Commission, Joint Research Center Directorate B, Unit 5 (Sevilla).

the rest of a device during (semi-) manual dismantling and thus enter specific recycling routes. This is provided that the games consoles are treated separately during end of life treatment and (semi-) manual dismantling steps are part of the treatment process, which is currently not common practice, as described in 5.2.3. This measure is not yet part of the VA.

Spare part inventory and timespan of spare parts availability

Provision of information about availability and the duration of availability of spare parts to (all) professional repair centres is not seen as feasible by the signatories because of some spare parts being proprietary. However, easy access to information on which spare parts can be provided at what cost makes repair activities more time and cost-efficient for professional repair centres. Ultimately lower costs for repair and better information on possibilities to repair can foster repair activities and increase the lifetime of games consoles. The provision of such a spare part inventory to professional repair centres[210] is therefore recommended by the study team.

Additionally, informing not only repair centres but also customers about the timespan of the spare parts availability of a device might lead to more informed customer purchase decisions and an increased market competition with regard to spare parts. This measure is not yet part of the VA.

Recycled material content

As stated in section 5.2.2, currently no recycled plastic is used in games consoles. Introducing binding targets for recycled material content into the VA (see 6.8.1) and informing interested parties about the percentage of recycled material content in a device – similar to the VA for imaging equipment[211] – might lead to more informed customer decisions and an increased market competition with regard to the share of recycled material content used in games consoles. It also lays the ground for future material efficiency requirements and can help establish the market availability of recycled materials of the required standard by creating a stable demand. This measure is not yet part of the VA.

Information on energy consumption

Informing the users of the games consoles on the energy consumption in different operating modes can contribute to incentivising the use of energy saving modes etc., consequently contributing to a reduced energy consumption. Also, in the Report on the 2017 Review of the Game Console Self Regulatory Initiative, it is stated that "Gamers should also benefit by receiving additional information on the energy consumption of their consoles and instructions on how to minimise energy consumption."

The current SRI obliges each signatory to "provide energy efficiency information for consumers within console operating instructions (with instructions either provided with the console itself, onscreen or hard copy, or online). Instructions for use provided to consumers with their consoles will be neutrally worded so as not encourage users to disable power-saving features".

However, this information is so far not easily accessible in games consoles manuals/ operating instructions. E.g., for the PS4 the respective information could not be found by the study team in the

[210] Cordella, Mauro; Alfieri, Felice & Sanfélix, Javier (6 May 2019): Guidance for the Assessment of Material Efficiency: Application to smartphones – v2. European Commission, Joint Research Center Directorate B, Unit 5 (Sevilla).

[211] "For all products Signatories shall make information available to customers on the minimum percentage of postconsumer recycled plastic content, calculated as a percentage of total plastic (by weight) in each product." Industry Voluntary Agreement to improve the environmental performance of imaging equipment placed on the European market (March 2019), p. 12. Online: http://www.eurovaprint.eu/fileadmin/eurovaprint_files/pdfs/2019/VA_on_Imaging_Equipment_25March19.pdf, last access May 23rd 2019.

user guide[212]; for the Xbox One the information is only available on English-speaking EU Member State versions of the website (and not on the German, French, Belgium, Spanish versions etc.)[213].

Here, the provision of the information can be significantly improved.

Further future measures

The spare parts currently offered by the games consoles manufacturers are mostly virgin parts with some unknown share being sourced from used or waste consoles (see 4.3.2). The manufacturers could offer to use intact spare parts from otherwise defective games consoles for repair services, which would save resources and increase material efficiency. Informing interested parties about the availability of reusable components for repair of devices might lead to more informed customer decisions and an increased market competition with regard to offering such reused components as spare parts. It also lays the ground for future material efficiency requirements. However, the sourcing of used components requires either a scheme for collection of components from repair centres or separate collection at end of life and (semi-)manual dismantling to identify and separate reusable components. This measure is not yet part of the VA.

[212] The information can be found on the Playstation website under „Legal".
[213] See, e.g., https://support.xbox.com/en-GB/xbox-one/console/learn-about-power-modes (checked: 14/08/2019) v https://support.xbox.com/fr-BE/xbox-one/console/learn-about-power-modes (checked: 14/08/2019)

7. Assessment of the current VA and improvement potential

This chapter aims to provide an assessment of the adequacy of the currently adopted SRI policy option and, if relevant, to provide possible proposals for improvement. This assessment uses the results from previous tasks of this review study, in particular scenarios with regard to energy efficiency. Special attention will be given to

- Representativeness: scope and market coverage
- Energy efficiency and energy savings, and
- Material efficiency

7.1 Assessment of the current SRI based on Annex VIII Ecodesign Directive and the Commission's SRI guidelines

To provide guidance and minimum criteria for the development, implementation and monitoring of self-regulation measures, the Commission has published specific "Guidelines for self regulation measures concluded by industry under Directive 2009/125/EC". The recommendation clarifies and thus facilitates the process for recognition of self-regulation measures within the Ecodesign framework and provides details on how the Annex VIII criteria are to be interpreted. The criteria set comprises

- Openness to participation
- Added value
- Representativeness
- Quantified and staged objectives
- Involvement of civil society
- Monitoring and reporting
- Cost-effectiveness of administering a self-regulatory initiative
- Incentive compatibility

The Commission has already concluded that all Annex VIII criteria are met, based on an assessment in its "Report from the Commission to the European Parliament and the Council on the voluntary eco-design scheme for games consoles of 2015"[214]. The assessment concluded for games consoles

> *"that the proposed voluntary scheme would achieve the policy objectives more quickly and at lesser expense than mandatory requirements. It also concluded that, as required by Annex VIII to the Ecodesign Directive, the proposed scheme complied with all provisions of the Treaty (in particular internal market and competition rules), international engagements of the EU (including multilateral trade rules), the objectives of the Ecodesign Directive, and the specific assessment criteria, i.e. (i) openness of participation, (ii) added value, (iii) representativeness, (iv) quantified and staged objectives, (v) involvement of civil society, (vi) monitoring and reporting, (vii) cost effectiveness of administering a self-regulatory initiative, (viii) sustainability, and (ix) incentive compatibility."*[215]

[214] COM (2015) 178 final: Commission staff working document: Report from the Commission to the European Parliament and the Council on the voluntary ecodesign scheme for game consoles

[215] COM (2015) 178 final: Commission staff working document: Report from the Commission to the European Parliament and the Council on the voluntary ecodesign scheme for game consoles

However, it was also stated that "the consoles manufacturers, aware of the fact that the draft proposal is not fully compliant with the Directive, expressed their commitment to amend the proposal in order to fulfil the Annex VIII criteria, i.e. its No. 6 on Monitoring and Reporting". The latter has meanwhile been implemented by the signatories, which is also mirrored in the "Report on the 2017 review of the game console self-regulatory initiative"[216]. The report of 2017 also explains, that at the initial drafting of the Voluntary Agreement, the guidelines for self-regulation measures had not yet been finalized. This is why most but not all aspects had been aligned accordingly.

To date, all of the procedural criteria mentioned by Annex VIII of the Directive are well established procedures: To the consultants' knowledge there are no discrepancies regarding the criteria openness to participation, added value, involvement of civil society, monitoring and reporting, cost-effectiveness or incentive compatibility. However with regard to the criteria representativeness and quantified and staged objectives, the consultants identified some improvement potential. This will be elaborated in the following sections.

7.2 Representativeness: scope, market coverage

According to the Commission Recommendation (EU) 2016/2125 of 30 November 2016 on guidelines for self-regulation measures concluded by industry under Directive 2009/125/EC[217] the representativeness in terms of market coverage is vital for the recognition of a self-regulation: the signatories of a measure should represent at least 80% of units of the products placed on the EU market each year. In addition, a minimum share of 90 % of the units placed on the market by each signatory must conform to the requirements.

According to the Independent Inspector Annual Compliance Report for the reporting period 2018, the SRI which covers games consoles placed on the market by three Signatories from which only two reported sales of games consoles which fall into the scope of the SRI, represent 100 % of the games consoles within the scope.

In Chapter 2, the scope for this review study has been defined. The main differences to the scope definition of the VA are

- Omitting the 20 W threshold and
- Including handheld devices in accordance with the definition of games consoles in Regulation 617/2013.

Both criteria mean the inclusion of devices with low energy consumption (handhelds as battery-powered devices are typically designed to minimize power consumption). From an energy efficiency perspective this can be justified by the fact that the energy efficiency of games consoles with a capability for both handheld and stationary gaming, such as the Nintendo Switch, is in the interest of the manufacturers. A higher energy efficiency leads directly to longer use time without recharging, which can be used as a sales argument to buy such a games console.

From a material efficiency perspective, handheld devices and stationary consoles with a power intake below 20 W should fulfil the same requirements as stationary games consoles with a power intake above 20 W to account for the growing importance of material efficiency under the Ecodesign

[216] Microsoft. Sony & Nintendo (13.10.2017): Report on the 2017 review of the game console self-regulatory initiative.

[217] Commission Recommendation (EU) 2016/2125 of 30 November 2016 on guidelines for self-regulation measures concluded by industry under Directive 2009/125/EC of the European Parliament and of the Council, OJ L 329 of 3.12.2016, p. 109.

Directive (see also section 7.4). The case of the Nintendo Switch as a games console with stationary and handheld gaming capability with a power consumption below 20 W illustrates that the respective criteria can result in the exclusion of relevant market players from the VA.

Another more relevant aspect which concerns energy consumption of games consoles and other devices with gaming capability results from the trend towards cloud gaming (see section 5.5). Here, it can make sense to include the aspect of where the active gameplay is rendered. Devices which are able to render the gameplay of platform specific games without the need for an additional device or service, which would provide the computational or graphical processing power, differ (in terms of material as well as energy efficiency) significantly from devices which (exclusively) rely on such external infrastructure. There – to keep the SRI operational – it can make sense to focus on the former devices while the trend towards cloud gaming and respective devices needs to be observed carefully and possibly covered in the future by specific requirements within the same or in another SRI or Regulation.

In this regard, two console categories should be introduced: stationary games consoles and games consoles which can be used as both stationary and handheld. Based on the existence of a built-in battery and the rendering of the video output, Games Consoles can be categorized as follows:

- Stationary Games Console: Games Console without a built-in battery requiring an external display to render video output.
- Games Console with a capability for both stationary and handheld gaming: Games Console with a built-in battery having the potential to render video output via an external display and an integrated display. These Games Consoles are capable of operating in either one of two distinct modes at the same time:
  - Handheld Mode: Games Console renders video output via an integrated display.
  - Stationary Mode: Games Console renders video output via cables or wireless connection to an external display.

Therefore, the suggested scope for a revised VA is:

"*'Games console' means a device which is designed to provide video game playing as its primary function. Games consoles either use an external or an internal display as the game-play display or both. Games consoles typically include a CPU, system memory and a graphics processing unit(s) (GPU), and may contain hard drives or other internal storage options, and optical drives. Game consoles typically utilise handheld controllers or other interactive controllers as their primary input device rather than an external keyboard or mouse. Games consoles do not typically include conventional personal computing operating systems but instead utilise console-specific operating systems and are capable of rendering the gameplay of platform specific games standalone. Handheld gaming devices, with an integrated display as the primary game-play display, and which primarily operate on an integrated battery or other portable power source rather than via a direct connection to an AC power source, are considered to be a type of games console*."

In addition to the arguments regarding material efficiency, this definition is in-line with Regulation 617/2013's definition of games consoles and avoids a gap in a patchwork of Ecodesign Regulations and VAs. Furthermore, it is a possibility that games consoles with the capability for mobile gaming / handheld mode will have a greater importance in the future. The inclusion of handhelds in the suggested revised scope ensures in this regard that the SRI will still achieve an appropriate coverage of the games consoles market and maintain a position favourable to other policy options.

Concerning devices currently placed on the market, this scope definition implies:

Table 59: Devices within and outside of the suggested VA scope

Devices currently placed on the market	Within suggested scope
PS4	Yes
Xbox One	Yes
Nintendo Switch	Yes
Arcade consoles	Yes
Steam Machines	No
Smart TV, e.g., Apple TV, Samsung Smart TV	No
NVIDIA Shield TV	No
Oculus Go	No

So, the main difference from the current SRI scope definition with regard to devices is the coverage of Nintendo Switch and Arcade consoles. As described in section 2.1.2, the Oculus Go cannot be considered a "serious" gaming device. Future versions of the Oculus Go or other VR headsets, however, might fall under the suggested scope and their relevance for the VA should be re-examined in the future. Other handhelds are – to the consultants' knowledge – currently not placed on the market in relevant numbers.

For the suggested revised scope and the current market situation, the requirements for market coverage, would still be fulfilled by the current signatories. Nintendo Switch as well as the main arcade consoles (Nintendo's and Sony's arcade consoles) are placed on the market by the current signatories.

Furthermore, it needs to be pointed out that as information technology and applications become more integrated, there is an increasing overlap between products in that applications can be operated on multiple platforms and/or products offer an increasingly wide range of applications. This poses considerable difficulties for a regulatory regime based on the assumption that products are distinctively different from each other and can be subject to their own dedicated regulation. In the case of devices with video gaming capability other than video games consoles considered under the suggested VA scope, it is increasingly unclear whether or not new products are covered by other regulations. It is recommended that this issue of the implications of growing technological and product integration is raised and discussed in the appropriate fora.

7.3 Energy efficiency and energy savings

In this section the energy savings achieved to date and the estimated energy savings by the SRI over the console lifetime are presented. Although some developments are the result of technological evolution, understanding and, above all cooperation between the manufacturers became possible through the SRI. For a revision of the SRI, several recommendations are given, such as including games consoles with handheld gaming ability and increasing the measurement window for energy use assessment. A baseline, determined corresponding to the energy consumption values as presented in the doctoral thesis by Amanda Webb[117], was used by the study team for calculating the energy savings achieved compared to this baseline. This choice of baseline has a significant impact on the calculation of energy savings and can be adapted to sales and stock numbers of the games consoles and the adopted usage scenario. A re-evaluation of the chosen baseline was however not part of this study. For a future SRI, it is therefore suggested that the minimum energy consumption of stationary games consoles from the 8th generation should be used as the baseline for the energy consumption of stationary games consoles from the 9th generation.

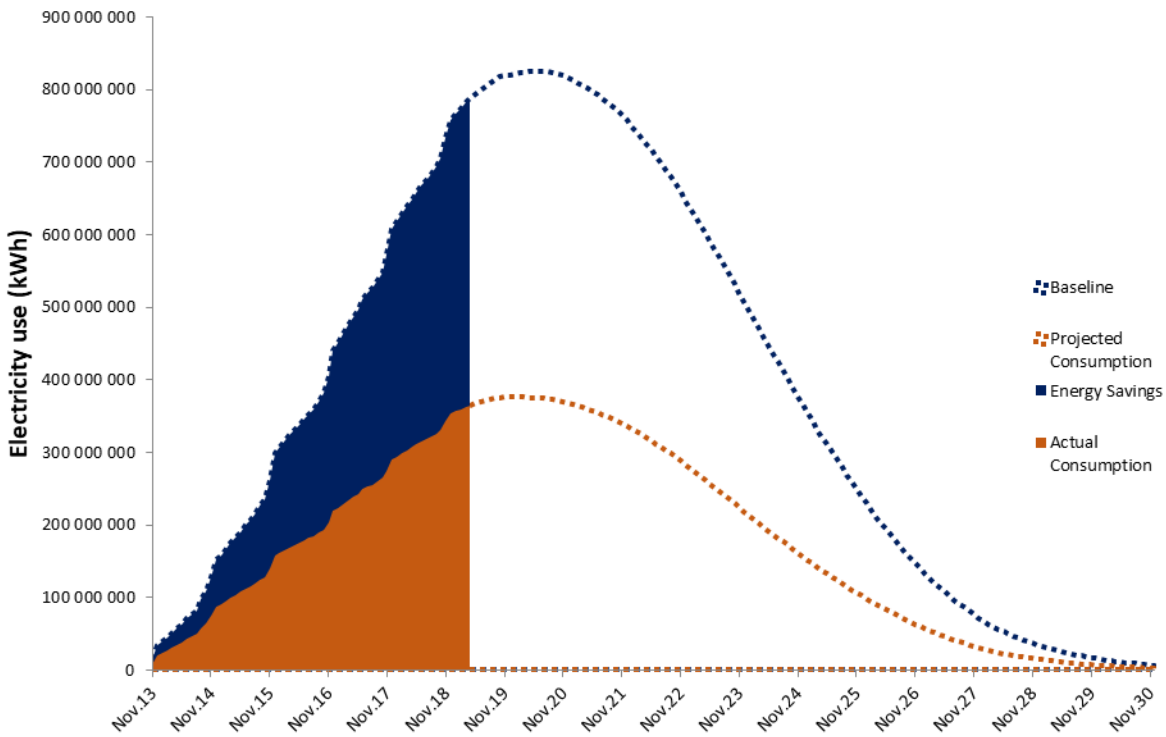
7.3.1 Evaluation of the energy savings achieved by the SRI to date

This chapter describes the baseline electricity consumption, estimated electricity consumption and energy savings of the PlayStation 4, Xbox One and Nintendo Switch consoles in Europe. The calculated electricity consumptions and energy savings are based on the calculation of TECs, which is described in chapter 4.1.8. In contrast to the SRI report from 2017, in this report another usage scenario was used for the calculation of the TECs. The TECs were calculated based on refined usage data from LBNL, which is described in chapter 4.1.7. The real electricity consumption and energy saving values are probably located in between the values from the SRI report from 2017 and this report. The figures and calculation spreadsheets in this chapter are based on the work of Amanda Webb[186] and Joshua Aslan[218] and have been provided by the signatories during the course of this study.

7.3.1.1 Energy savings for PlayStation 4

In Figure 54, the baseline electricity consumption, the estimated electricity consumption and the estimated energy savings of PlayStation 4 consoles in Europe over their lifetime are displayed. While the orange area corresponds to the estimated electricity consumption based on reported sales data from VGChartz up to May 2019, the blue area corresponds to the energy savings for the same period. The dotted lines represent the estimated electricity consumption, which is based on projected sales, and the corresponding baseline electricity consumption.

Figure 54: Electricity consumption of PlayStation 4 consoles in Europe compared to the baseline (kWh)



The energy savings achieved by the SRI for PlayStation 4 consoles in Europe up to May 2019 are estimated to be 13.61 TWh. By comparing the estimated electricity consumption to the baseline, an annual energy saving in 2020 of around 5.39 TWh is calculated. The total energy saving over the lifetime for PlayStation 4 consoles is 42.99 TWh, which is just 6.54% lower than Portugal's electricity

[218] Aslan, J. (2018) Climate change implications of gaming products and services. Unpublished EngD thesis. University of Surrey.

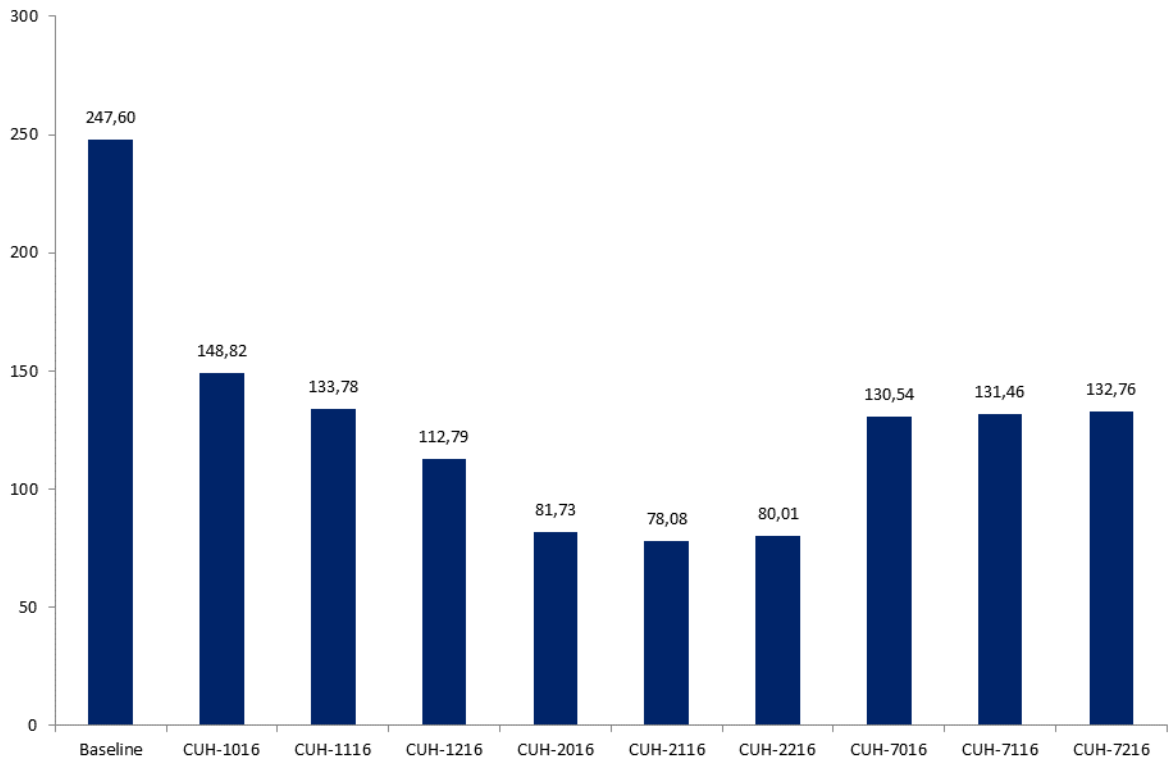
consumption in 2014 (46.0 TWh). The baseline electricity consumption, estimated electricity consumption and energy savings for PlayStation 4 consoles are summarized in Table 60.

Table 60: Baseline electricity consumption, estimated electricity consumption and energy savings for PlayStation 4

PS4 Model	Baseline electricity consumption (TWh)	Estimated electricity consumption (TWh)	Energy savings (TWh)
Launch to date	26.81	13.21	13.61
Annual in 2020	9.87	4.49	5.39
Lifetime	79.51	36.51	42.99

The annual TEC values for the PlayStation 4 models are displayed in Figure 55. As can be seen, compared to the first PlayStation 4 models (CUH-1016, CUH 1116, CUH-1216) the electricity consumption of the PS4 Slim models (CUH-2016, CUH-2116, CUH-2216) is significantly lower. Although the PS4 Pro models (CUH-7016, CUH-7116, CUH-7216) have a higher electricity consumption, they provide a higher resolution (4K) and better performance.

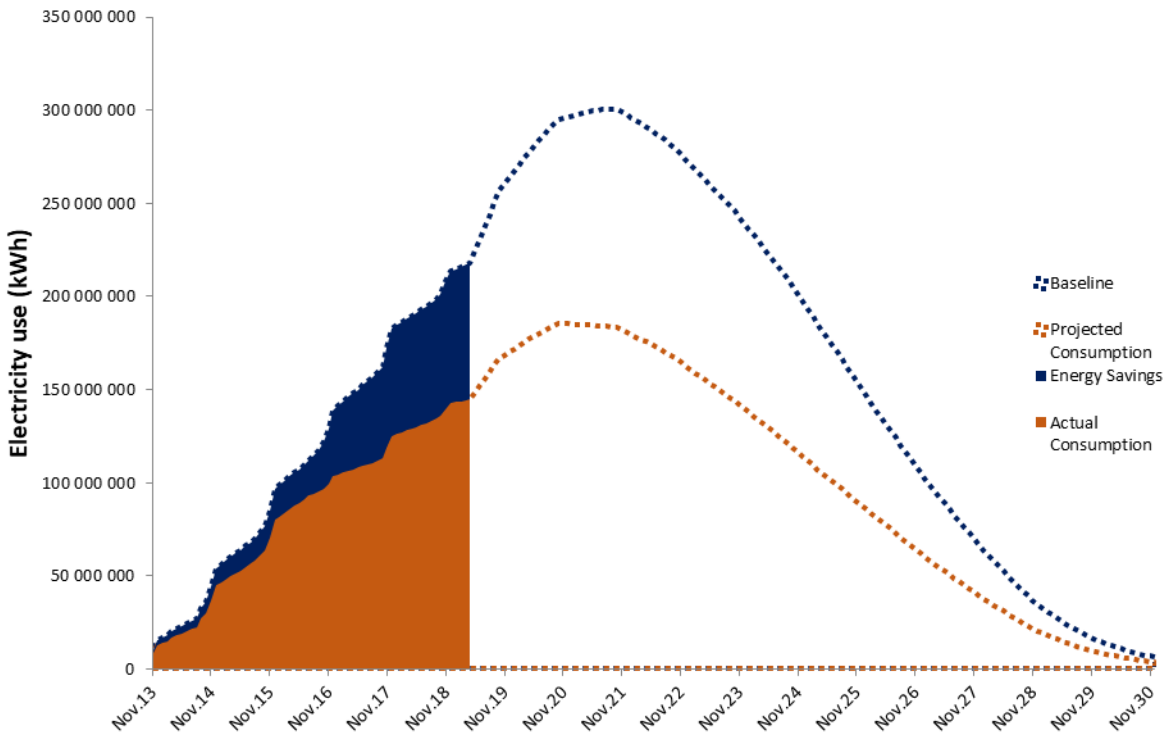
Figure 55: Annual TEC of PlayStation 4 models (kWh)



7.3.1.2 Energy savings for Xbox One

The baseline electricity consumption, the estimated electricity consumption and the estimated energy savings for Xbox One consoles in Europe over their lifetime are shown in Figure 56. Contrasting the estimated electricity consumption displayed as the orange area which is based on reported sales data from VGChartz until May 2019, the estimated energy savings for the same period are represented by the blue area. The projected estimated electricity consumption and the baseline electricity consumption are depicted by the dotted lines.

Figure 56: Electricity consumption of Xbox One consoles in Europe compared to the baseline (kWh)



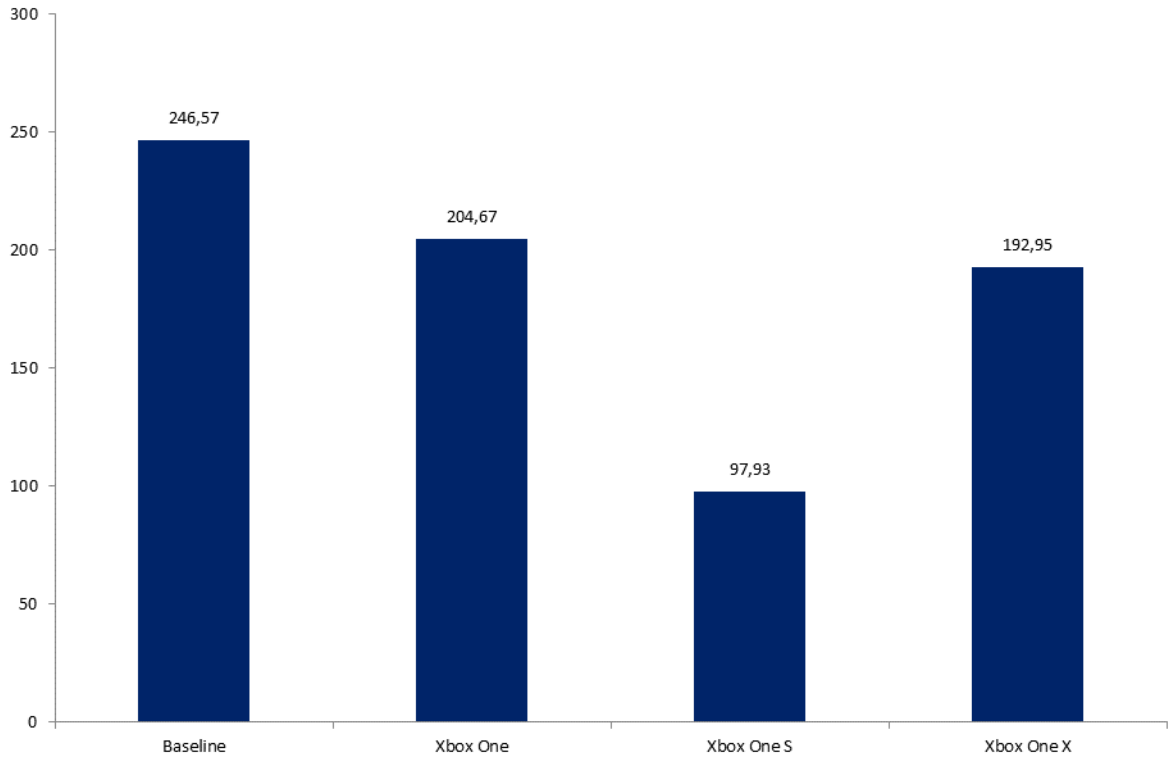
The estimated energy savings achieved by the SRI for Xbox One consoles in Europe up to May 2019 are a total of 2.2 TWh. In 2020, an annual energy saving of around 1.25 TWh is estimated. Over the lifetime of the Xbox One consoles the total energy savings are estimated to be 11.43 TWh, which is almost identical to Georgia's electricity production in 2014 (11.57 TWh). The baseline electricity consumption, estimated electricity consumption and energy savings for Xbox One consoles are summarised in Table 61.

Table 61: Baseline electricity consumption, estimated electricity consumption and energy savings for Xbox One

Time period	Baseline electricity consumption (TWh)	Estimated electricity consumption (TWh)	Energy savings (TWh)
Launch to date	8.1	5.9	2.2
Annual in 2020	3.41	2.16	1.25
Lifetime	31.36	19.93	11.43

As shown in Figure 57, the annual TEC of the Xbox One S is significantly lower than the annual TEC of the standard Xbox One. Compared to the Xbox One S the Xbox One X has a twice as high annual TEC due to the support of 4K without upscaling and better performance.

Figure 57: Annual TEC of Xbox One models (kWh)



7.3.1.3 Energy savings for Nintendo Switch

The Nintendo Switch is a games console with both stationary and handheld gaming capability and the first of its kind. This means that there is no predecessor for it and also there is not yet a successor. New similar products from other manufacturers or other Nintendo Switch models may be coming to the market, as the Nintendo Switch finished 2018 as the best-selling hardware platform. From the TEC point of view, there is no baseline or analogous product to compare the electricity consumption and potential energy savings. Also, the electricity consumption of the Nintendo Switch, which is less than 20 W in Active Game mode, excludes it currently from the Self-Regulatory Initiative. Nevertheless, the estimated electricity consumption of Nintendo Switch consoles in Europe, to date, is around 0.09 TWh, and will reach an annual electricity consumption of 0.11 TWh in 2020. It is estimated that the electricity consumption of the Nintendo Switch consoles in Europe will reach a total of 1.78 TWh over their lifetime. Therefore, the Nintendo Switch should act as baseline for future games consoles with both stationary and handheld gaming ability.

Table 62: Estimated electricity consumption for Nintendo Switch

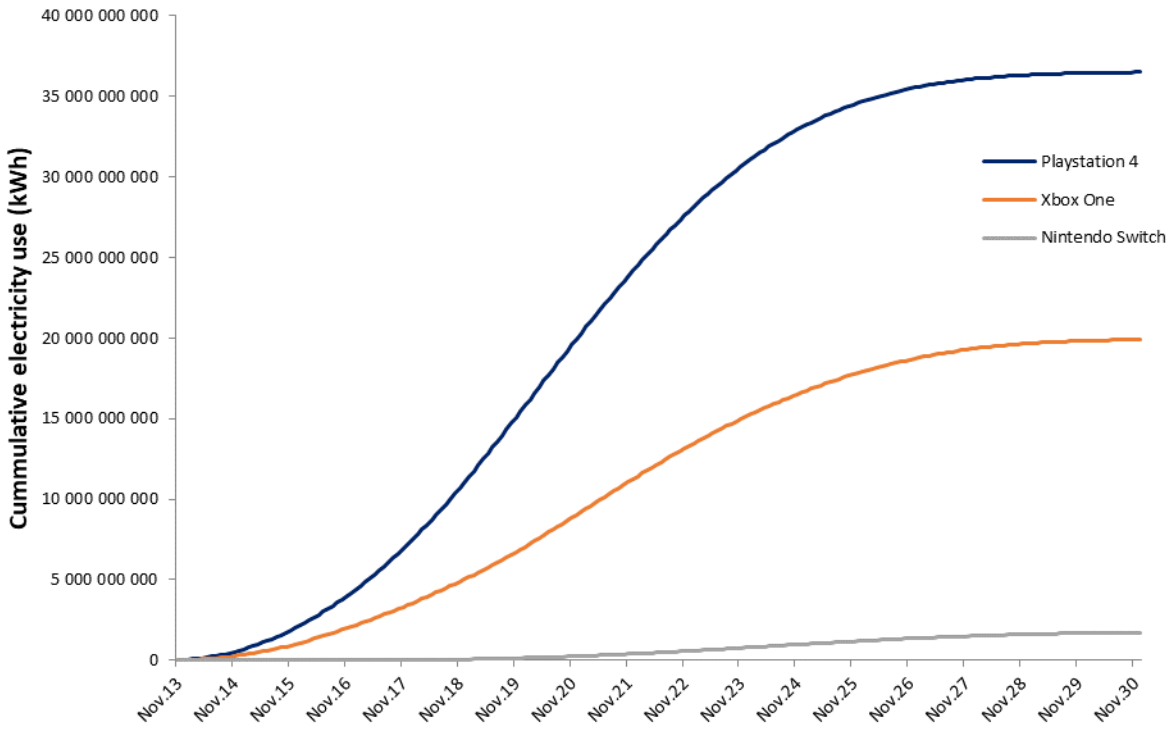
Time period	Estimated electricity consumption (TWh)
Launch to date	0.09
Annual in 2020	0.11
Lifetime	1.78

7.3.1.4 Energy savings by SRI

Although no baseline exists to compare the electricity consumption and potential energy savings of the Nintendo Switch, the estimated electricity consumption of Nintendo Switch consoles in Europe over their lifetime is a magnitude lower than that of PlayStation 4 and Xbox One consoles. This is depicted in Figure 58. While the projected stock of PlayStation 4 consoles in Europe (46 146 316

consoles) is 152.57% higher than the projected stock of Xbox One consoles in Europe (18 277 592), the electricity consumption over their lifetime (36.51 TWh) is only 83.19% higher than the electricity consumption of Xbox One consoles in Europe over their lifetime (19.93 TWh).

Figure 58: Cumulative electricity consumption of PlayStation 4, Xbox One and Nintendo Switch consoles in Europe (kWh)



As summarized in Table 63, the energy savings achieved by the SRI for PlayStation 4 and Xbox One consoles, to date, are estimated to be 15.81 TWh. In 2020, the energy saving achieved for these consoles will be around 6.64 TWh, which is slightly higher than Luxembourg's energy consumption in 2014 (6.2 TWh). Over the lifetime of the PlayStation 4 and Xbox One consoles, it is estimated that the SRI will achieve an energy saving of around 54.42 TWh, which corresponds almost to Greece's energy consumption (53 TWh) in 2014.

Table 63: Baseline electricity consumption, estimated electricity consumption and energy savings for PlayStation 4 and Xbox One

Time period	Baseline electricity consumption (TWh)	Estimated electricity consumption (TWh)	Energy savings (TWh)
Launch to date	34.91	19.11	15.81
Annual in 2020	13.28	6.65	6.64
Lifetime	110.87	56.44	54.42

7.3.2 Benchmarking and consumption restriction in gaming mode

Currently, the SRI as of v.2.6.3 excludes any power caps during the gaming mode. The popularity of video games and the sales numbers for the games consoles units have been discussed already in Chapter 3. The difficulties of benchmarking have been discussed in the "Report on the 2017 Review of the Game Console Self-Regulatory Initiative from July 5th 2017" together with the requirements

necessary. The games console producers have no control of the features implemented or worlds created by Software Studios, except on in-house development. Games consoles offer high computational performance (with hardware / model specific limitations) that game developers have to consider more strictly in the game development process than for the PC-game market. As games console users are not able to upgrade their consoles (except for the storage unit) on their own, console game developers have to limit the performance required for their games for each game of the currently targeted console generation. The expectations of users choosing a games console over a gaming PC are (despite exclusive game titles) motivated by the promise of a fluent gaming experience, regardless of the game, from a games console model of the corresponding generation.

Furthermore, a power limitation on power consumption during gaming could lead to a differentiation in future models on the European market, if less computational power is made available in order to meet power limitation requirements. Another very unlikely but possible outcome could be, that certain games are not offered in Europe, because the computational power required for rendering the game would lead to a violation of a power cap. However, a "technical power cap" exists, which is defined by the maximum power intake of the games consoles power supply..

For comparison with the PC gaming market: a currently popular new graphic card model "GeForce RTX 2080 Ti" has a graphic cards power of 260 Watts in the technical specs[219] and tests carried out show a consumption of 258 Watts[220].

7.3.3 Increasing measurement window for energy use assessment

Predictions for the TEC are highly dependent on measurements undertaken by either the SRI signatories or the independent inspectors. Gathering and comparing data at the highest level possible, measurements made with a duration of 30 minutes showed either slightly higher or slightly lower average power consumptions than reported. Depending on the usage scenario for the predictions, these small differences can lead to impacts on the TEC of each console as well as on the predicted overall consumption of all consoles. Figure 59 shows an average measurement of 13.48 Watts for an Xbox One X in the Instant-On Power mode (turn off storage is selected on). Figure 60 shows the same measurement with two different example slots of 5 minutes which reflect the minimum required measurement time of 5 minutes of the active power as stated in the current SRI 2.6.3. Example 1 shows an average consumption of 12.67 Watts whereas example 2 shows an average of 14.64 Watts. Taking into account an estimated use of this mode of 5.12 hours per day, multiplied by the amount of Xbox One Consoles, the following 3 values for a realistic TEC could occur:

- Measurement scenario (30 minutes, 13.48 Watts): 25.19 kWh per year
- First example slot (12.67 Watts): 23.68 kWh per year
- Second example slot (14.64 Watts): 27.36 kWh per year

The example given was taken as the small consumption peaks occur regularly. In other active modes, such particular example windows might occur especially during active gaming, if the way a game is played can differ (rendering sequences, loading screens, etc.). The console was set with standard settings and 4k UHD video output resolution. Other relevant information for this scenario were:

- OS version: 10.0.18362.3055 (19h1_release_xbox_dev_1905.190510-1845)
- Global Device ID: 6896137951303678
- Humidity: 34%

[219] https://www.nvidia.com/en-gb/geforce/graphics-cards/rtx-2080-ti/#specsmodal Accessed 24.05.2019
[220] https://www.golem.de/news/geforce-rtx-2080-ti-im-test-nvidias-turing-grafikkarten-sind-konkurrenzlos-1809-136185-6.html Accessed 24.05.2019

- Room temperature: 23.4 ° C

Based on measurements in the lab, the study team also encountered lower energy consumption than reported by the SRI. A realistic usage scenario (with average customers) should be reflected in the measurements. Thus, a recommendation that an increased measurement time window should be considered in future versions of the SRI. The study team advises 30 minutes as a good starting point, since this time window also reflects a certain minimum usage time per console for leisure activities.

Figure 59: Average measurement of Instant-On Mode over 30 Minutes of Xbox One X

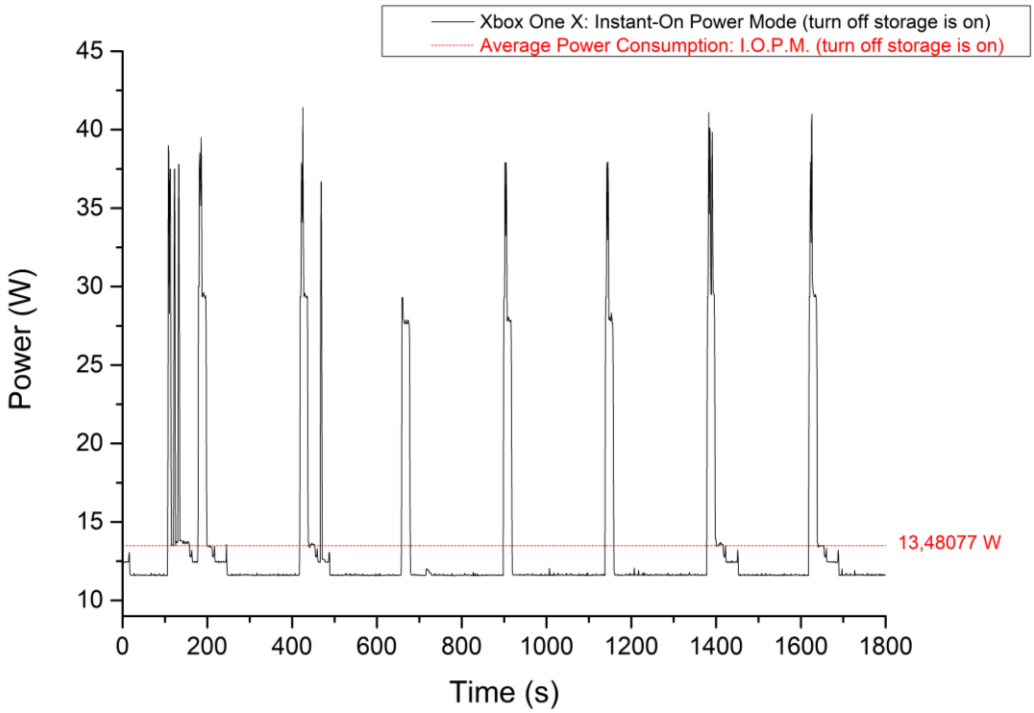
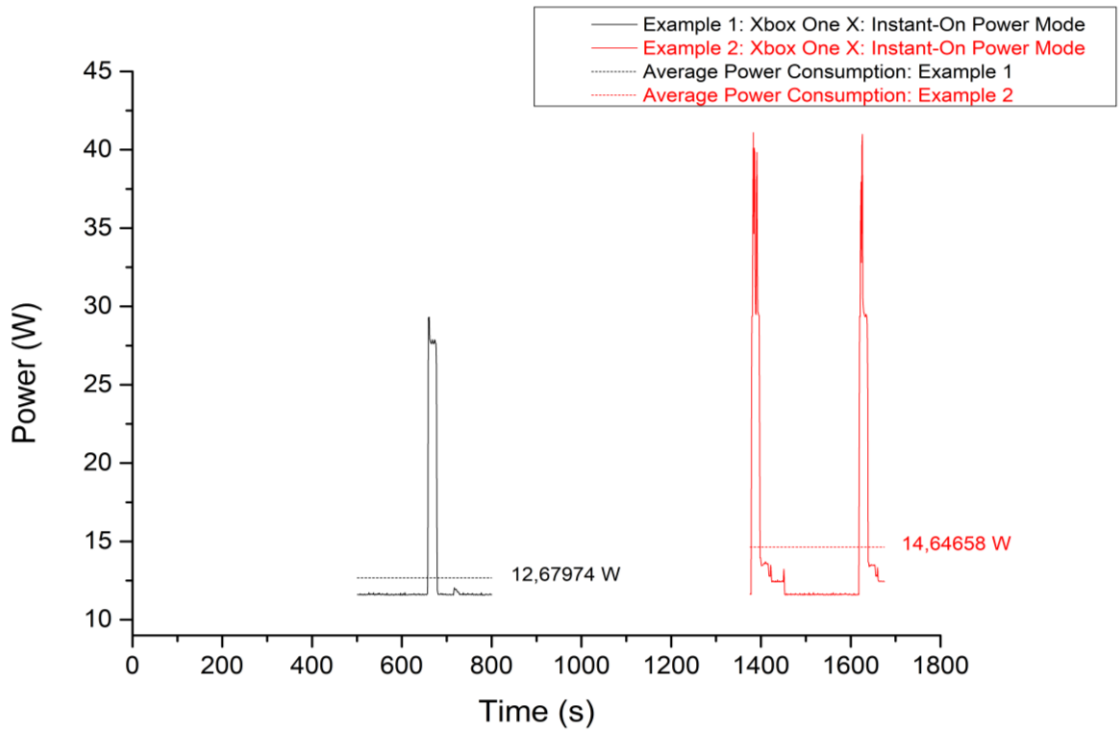


Figure 60: Selection of two different five minute windows and their averaged consumption



7.3.4 Proposed Energy Efficiency Requirements

Reducing the everyday energy consumption of popular products such as the games consoles relies partly on the consumers' behaviour with the products. Design choices, of either hardware or software- are therefore crucial in having an impact on average customers.

The following requirements for improved energy efficiency are therefore recommended for inclusion in the Voluntary Agreement for games consoles:

Easy turn off options

Currently, the VA does not anticipate any steps or regulation on the design of hardware or software shut down of games consoles. As described in chapter 6.7.2, a considerable impact could be expected by redesigning the steps necessary to turn off the console. Regulating such a procedure in the VA would give a coherent user experience across games consoles, independently of the manufacturer. The current software implementations have a highly different number of steps necessary to completely shut down the consoles in comparison to the energy saving mode.

Introduce Power Cap for Rest Mode

Since the feature of being able to resume a game or application state after the console switches to a lower power consumption mode can be found among all the signatories under different names, a power cap similar to the power limitations as, for example, for the Media Playback Mode could be envisaged. The in-depth insights of the specific console architecture are unavailable to the consultants, but the current technical possibilities for the rolled out 8th games console generation seem to be exhausted to a certain extent. Future generations could implement such features more easily. The VA does not contain any power cap on low power modes for Rest yet. Therefore, it is recommended that a motivated power cap of <5W be introduced for the rest mode for the next generation consoles.

The Power cap requirements for other operational modes (navigation, media playback) formulated within the SRI are considered to be appropriate for the multi-functional entertainment system a games console offers based on the measurements made and the assessment of available technologies. Nevertheless, the resolution detail is one key factor in power consumption. For example, the Navigation Mode in UHD needs 9 Watts more power than in HD resolution for the PlayStation 4 Pro (CUH-7216b) and about 6.5 Watts for the Xbox One X. The necessity of UHD for the navigation mode should be discussed. The SRI states that this is necessary for the interactive promotion of media and gaming content. The 30 minutes window measurements showed, that that the definition of a power cap for UHD Media Playback of 110W for UHD gaming capable consoles could be reduced to 90W without any impact or actions needed by the signatories, although there could be variations in power consumption caused by different components in the same model series. This could lead to slightly different behaviour, which could exceed this limit.

The introduction of a power cap for active gaming is not considered meaningful by the consultants. Additionally, the power supply limits the devices' power consumption automatically.

It is advised that new separate caps for the next generation (9th generation) of the gaming consoles should be introduced, since they are using more advanced technology (new and downscaled architecture) and should be able to meet lower restrictions.

Provision of updates to meet upcoming standby power regulations

As described in section 2.2.2, the EU Commission Regulation 1275/2008 (incl. amendment 801/2013) contains Ecodesign requirements related to standby, networked standby and off mode. Since 1

January 2019, new requirements for this regulation apply. These new requirements limit the maximum power consumption of networked standby to 2W for not high network availability network equipment, such as game consoles. The VA should therefore include a provision that in the future the manufacturers ensure that already existing consoles can be updated to satisfy these requirements.

Introduce flexible update time slots for consumption of renewably produced energy

As described in section 5.3.4, this feature won't change energy consumption as such, but if there is a chance to use green or cheaper energy then postponing the update process is a great choice. A considerable portion of non-gaming activity is in networked standby mode, in which the games console remains connected to the internet and can provide limited secondary functions. If updates are provided in the predefined or prescheduled timeslot of the day/week then there is a chance to reduce the internet connection (turn off networking). The consultants suppose, that the frequent peaks that can be seen in the Xbox One measurements (see Figure 67) are pings for updates. If prescheduled, the system can check for the new updates according to a prior saved schedule and there is no need for continuous connections. Small impacts on the energy consumption are likely to go hand in hand with this approach. Flexible update time slots for consumption of renewably produced energy should therefore be introduced but require several challenges to be overcome in cooperation with e.g. energy system operators.

Faster technologies to reduce loading/startup time

According to the announcements made by Microsoft and Sony, the next games consoles generation will come with SSD technology. Considerably reduced games loading times have been shown by Sony, bringing load times down from an average of 8.10 seconds to 0.83 seconds[167]. The consultants welcome the technological development and expect that reduced loading times will lead towards different customer behaviour (and therefore a shift in the usage scenario), especially if combined with easy turn-off options as described above. Therefore, faster technologies to reduce loading/startup time should be introduced. Due to the reduced loading/startup time of game consoles with such technologies, e.g. SSD, games consoles of the new upcoming generation should have a networked standby mode compliant with Regulation 801/2013. Additionally a rest mode could be considered, as proposed in section 6.7.4.

Handheld mode

For the handheld mode of games consoles where such a mode is available, no additional energy requirements are proposed since this mode is typically optimized for high energy efficiency.

Battery technology efficiency

From an energy efficiency perspective, the efficient use of the energy stored in the batteries built into games consoles with both stationary and handheld gaming capability, such as the Nintendo Switch can be seen to be in the interests of the manufacturers. A higher energy efficiency leads directly to longer use-time without recharging, which can be used as sales argument for such a games console.

Further proposals that should be considered:

- Reduced energy consumption when inactive as described in section 6.7.4
- the number of full charge cycles for batteries (see section 6.7.4; 500 full charge cycles after which the battery should still have a capacity of a minimum of 90% of the nominal capacity)Adapted test procedures and reporting on commonly advertised features such as HDR.
- HDR did not have a noticeable effect on energy consumption, but it is highly advertised. Future developments such as Ray-Tracing however are expected to have a noticeable impact on energy

consumption. Ray-Tracing is a graphics rendering method, which may not be available as a specific feature to be enabled or disabled by the consumer but as an obligatory feature. Future developments from the game developers will show the general direction of Ray-Tracing availability. In the case that it will be a feature which can be enabled or disabled in general, it should be tested and reported.

7.4 Proposed Material Efficiency Requirements

Ecodesign means the integration of environmental aspects into product design with the aim of improving the environmental performance of the product throughout its life cycle (Art. 2 No. 23 Ecodesign Directive). In recital 3 of the Ecodesign Directive it is laid down that energy related products account for a large proportion of the consumption of natural resources in the Community and in recital 4 that these products have a significant potential to be improved in order to reduce environmental impacts. That is why the Commission has to consider the life cycle of the product and all its significant environmental aspects when preparing a draft implementing measure.

Reducing environmental impact by improved material efficiency can be fostered by several strategies, such as a durable design, which allows for repair, upgrade and second use, the use of recycled materials or improved recyclability (see also analyses in sections 4.3 and 5.2 as well as the design options described in sections 6.7 and 6.8).

Annex 1 of the Ecodesign Directive also lists several approaches to be considered in implementing measures addressing specific material efficiency aspects, such as:

- the use of recycled materials
- the avoidance of technical solutions detrimental to reuse and recycling of components and whole appliances
- easy access to valuable and other recyclable components
- easy access to components and materials containing hazardous substances
- extension of the lifetime through a minimum guaranteed lifetime, minimum time for availability of spare parts, modularity, upgradeability and reparability.

Durability is also a core issue in the Circular Economy Action Plan: the Commission Staff Working Document on Sustainable Products in a Circular Economy[221] stresses the prolonged product use approach:

"*In a circular economy, products maintain their potential to create value for as long as possible. Products have a long lifetime, due to a durable design. In case a product breaks, it is repaired. When a consumer no longer needs a product, it is passed on and reused by another consumer, or products are shared from the outset".*

With regard to the use of recycled material, the WEEE Directive[222] states that "producers should be encouraged to integrate recycled material in new equipment" – a principle which however remains without further enforcement within the WEEE Directive.

[221] http://ec.europa.eu/environment/circular-economy/pdf/sustainable_products_circular_economy.pdf
[222] Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE)

In the current product-specific regulations, requirements for the use of post-consumer recycled plastics have been implemented in the Voluntary Agreement on imaging equipment[223]. The requirements are limited, however, to information requirements on the share of post-consumer recycled plastics used in the casing of new products and does not include requirements on a minimum share. The Japanese Eco mark label already defines a minimum share of 10% post-consumer recycling plastic as an optional requirement for notebook producers seeking to receive the label.[224]

Given these prerequisites, the following requirements for improved material efficiency are recommended for inclusion in the Voluntary Agreement for games consoles to further align the VA with the EU product policy framework:

Measures with regard to product design

1. Use of a minimum of 10 % post-consumer recycled plastic
2. Batteries that are easy-to-replace by end-users
3. Improved disassemblability through the use of fasteners that can be removed with common tools and/or providing assistance in obtaining more specialised tools
4. Standardized interfaces for external power supply
5. Phasing out hazardous substances

Non-design-related measures

1. Binding guarantee for free of cost update support at all times
2. Availability of spare parts for any professional repair centres for at least seven years after placing the last unit on the market
3. A commitment to free repair as the first remedy within the guarantee time
4. Providing take-back schemes for the separate and non-destructive collection of the device

7.5 Proposed Information Requirements

In order to support the measures on material efficiency outlined above, the following information requirements should be considered in the VA:

1. Information on the technical durability, upgradeability and reparability of a device
2. Provision of technical information (about disassembly steps etc.) to any professional repair centre
3. Marking plastic parts > 25g and > 100mm^2 in accordance with ISO 11469
4. Information on the content of flame retardants in plastic parts
5. Provision of a spare part inventory to any professional repair facility
6. Information on the timespan of spare parts availability for customers

[223] Industry voluntary agreement to improve the environmental performance of imaging equipment placed on the European market, VA v. 5.2

[224] „The rate of post-consumer recycled plastics contained in the plastics used in the devices relative to the total plastic weight (excluding printed circuit boards and electronic components) is equal to or more than 10 %."

7. Information on the percentage of the PCR material content
8. (Easily accessible) Information on energy consumption in different operating modes

7.6 Conclusion

The current SRI fulfils the requirements of the Commissions "Guidelines for self-regulation measures concluded by industry under Directive 2009/125/EC" which concern openness to participation, added value, representativeness, quantified and staged objectives, involvement of civil society, monitoring and reporting, cost-effectiveness of administering a self-regulatory initiative, and incentive compatibility.

The current scope meets the requirements regarding representativeness and market coverage. However, this scope, which excludes devices with a comparatively low energy consumption, does not appropriately reflect

- the importance of material efficiency within Ecodesign,
- the definition of the Ecodesign Regulation for computers, as well as
- relevant technological developments in the sector of games consoles.

In this regard, an adapted scope has been suggested. The main differences from the scope definition of the VA are the deletion of the 20 W threshold and including handheld devices in accordance with the definition of games consoles in Regulation 617/2013, plus including the capability to render the gameplay of platform-specific video games standalone. With regard to currently available devices for gaming, this only results in minor changes, namely the inclusion of Nintendo Switch and arcade consoles.

For the future, it is possible that games consoles with the capability for a mobile gaming / handheld mode will have a greater importance. The inclusion of handhelds in the suggested revised scope ensures that the SRI still achieves an appropriate coverage of the games consoles market and remains open to other policy options. Furthermore, it will be necessary to carefully evaluate if additional devices (possibly from additional manufacturers) fall under the scope definition. Possible candidates might, for example, be future versions of the Oculus Go. Also, technological trends such as the trend towards cloud computing need to be observed carefully and considered for future revisions.

The estimated energy consumptions and energy savings in this report were calculated based on a modified usage scenario from LBNL (described in section 4.1.7) and calculated TECs. Compared to the SRI report from 2017, which indicates energy savings of 36.3 TWh for the PlayStation 4 and Xbox One consoles over their lifetime, our calculations indicate an energy saving of 54.42 TWh, which is comparable to the energy consumption of Greece in 2014 (53 TWh). This can be explained e.g. by the applied LBNL usage scenario and significantly decreased TECs in comparison to the baseline from the games consoles. In comparison to the PlayStation 4 and Xbox One, the electricity consumption of the Nintendo Switch is a magnitude lower. However, a number for estimated energy savings cannot be given for the Nintendo Switch because of its hybrid character and therefore a missing baseline.

As mentioned, the calculations of the estimated electricity consumption and energy savings are based on the calculated TECs, which in turn depend on the measurements. The measurements gathered over a period of 30 minutes differ slightly from the consumptions reported by the SRI signatories. These differences lead to other TEC values and then to other electricity consumption and energy savings estimations. The power consumption measurements with a comparison of windows of 30 minutes and measurements according to the SRI specification as of Version 2.6.3 can be found in Table 64 to Table 69 in the Annex. For higher quality measurements, the measurement time window should be increased in a future version of the SRI from 5 to 30 minutes, thereby approaching a more realistic usage scenario.

The power consumption in gaming mode is not restricted by the SRI as of v2.6.3. Restricting the power consumption in gaming mode could disrupt the gaming market and lead to unforeseeable consequences, such as a reduction of available games in Europe and corresponding job cuts. Furthermore, a power cap could push users from games consoles to gaming PCs, thereby increasing the overall energy consumption arising from gaming.

Although due to time constraints, only PS4 Slim (CUH-2216) and Xbox One S were thermally analysed, the results indicate that no fatal weak points are present in the console designs. Furthermore, VRAM measurements confirm that the VRAM processing power is limited for modes besides the Active Gaming mode, thereby avoiding its unnecessary use. As a practical recommendation, the placement of the capacitor in the Xbox One S power supply close to the border of the power supply leading to higher temperatures than expected, could be revisited.

Concerning material efficiency, the current VA includes several important aspects which are also listed in Annex 1 of the Ecodesign Directive to be considered in implementing measures such as design for non-destructive disassembly and access to valuable and recyclable components. Furthermore the current measures include access to spare parts and provision of information on proper maintenance, end of life treatment and proper collection of waste electrical devices and out of warranty repair. These measures already address some of the main aspects of material efficiency namely the upgradeability, reparability and information on repair/maintenance of devices. However some additional measures have been identified by the study team as relevant to further improve the material efficiency.

The further measures identified have the potential to reduce negative environmental impacts resulting from the production of the devices, their use and end of life and can be categorized as measures with regard to product design (section 6.9.1), non-design-related measures (6.9.2) and information-related measures (6.9.3).

To further align the VA with the EU policy framework, measures on material efficiency implemented in other voluntary agreements and implementing measures under the Ecodesign Directive should be considered. The Voluntary Agreement on imaging equipment e.g. includes a requirement to provide consumer information on the use of recycled material, information which can lead to more informed customer decisions and increased market competition with regard to the share of recycled material content. This measure could furthermore be enforced with a binding minimum share of post-consumer recycled plastic to be used in the housings and controllers, which has been identified as having a high potential for saving energy and emissions related to the production phase of the games consoles (see 6.8.1). Recycled content in products forms an important step in closing the loop and create a circular economy for plastics by supporting the market for secondary raw materials and preserving embedded energy as part of the circular value chain.

Further measures regarding product design are easy-to-replace batteries in controllers and handheld consoles, which is in line with avoiding the use of non-proprietary screws or security screws that hinder the owners of the devices from repair, refurbishing and upgrading their games consoles. Both measures also potentially lead to increased recyclability if devices were collected and treated separately. To further increase the material efficiency in the product design, technology with lower material intensity should be applied where possible such as SSD instead of HDD storage technology and standardized interfaces for external power supplies should be used in order to enable the use of similar power supplies from other devices thereby saving resources.

Measures not addressing the design of the games consoles would be the provision of updates of the operating system, software and firmware at reasonable cost for the time span of the products' guarantee period to enhance the products' service life. The products' service life can furthermore be prolonged by provision of spare parts, which is already part of the VA, but without specification of the

timespan the spare parts are to be made available. Here, further information requirements should be implemented in the VA, specifying the duration of the availability of spare parts both to consumers of games consoles for an informed customer decision and to professional repair centres. Further non-design related measures identified by the study team are a commitment to free repair instead of replacement of games consoles received for repair with new devices as well as the provision of individual take back schemes for the separate collection of games consoles, enabling separate treatment and recovery of relevant components for refurbishment, reuse or recycling.

8. Summary

In this study, an independent review of the current version of the Voluntary Agreement on games consoles has been undertaken and possible proposals for change have been made. In particular, this has covered:

- An assessment of present and future market size of the sector;
- An assessment of the appropriateness of the energy efficiency requirements;
- An evaluation of the energy savings achieved to date;
- The identification of improvement potential with regard to future energy savings;
- An assessment of the appropriateness and effectiveness of resource efficiency requirements and the identification of improvement potential;
- An assessment of the appropriateness and effectiveness of information requirements and the potential for identification improvement;
- An assessment of the adequacy of the current policy options

The methodological approach included desk research, expert consultations, stakeholder involvement and extensive laboratory measurements.

Present and future market size of sector

Since the first video games console was released in 1972, the numbers of games consoles placed on the market has grown, so that in 2017, the global games console market reached $ 41 billion (€ 36.1 bn).

The market is dominated by three major players: Sony, Microsoft, and Nintendo, none of which are primarily based in Europe. These are the three signatories of the SRI and they account for more than 80 % of the total games console market.

2017 was the best games console market performance since 2011, largely due to Nintendo's record-breaking sales of the Switch console. However, sales at $ 41 billion (€ 36.1 bn) were still short of 2008 when the market was worth $56 billion (€ 49.3 bn).

Over the last six or seven years, mobile phone games revenue has been steadily increasing while the share of games console sales in the global market has been decreasing. However, despite this decline in market share, the video console gaming market is continuing to grow and continues to be particularly important in Europe. While Asia-Pacific accounts for 52% of the global games market and Europe, the Middle East and Africa only 21%, when it comes specifically to video games consoles, Europe accounts for 50.6% of the global market, with the UK, Germany, and France accounting for most sales. One factor in this, is that the price of games consoles varies across EU Member States.

In considering evolution within the market, there are a number of developments to be taken into account. One is that there have been significant changes in how games consoles are used. This takes two forms: the first is in a divergence between the Nintendo strategy (portable, family-friendly, casual gaming) and the Sony/Microsoft strategy (high-end graphics, exclusive games, and a focus on "hardcore gamers"). The second, which applies across the video console market, is the necessity for a constant Internet connection for some of the most popular games, both as a medium for playing games and for participating through viewing. This implies a higher energy usage. Traditionally, games consoles have been released in 5-7 year cycles. However, the demand for high-end graphics and complex programming means that design teams and attendant costs have similarly risen. The rising overheads have made less resource heavy platforms more appealing, chief amongst them being

mobile gaming. Moreover, the actual lifetime of games consoles is likely to be far longer than the development cycle. There is a second-hand market across Europe, which is difficult to measure, but it appears that it represents a significant proportion of the total games console market. This has implications for the energy efficiency of the current stock.

The growth of the games console market in 2018 suggests that the demand for games consoles remains strong (despite constant fears that it has peaked) and perhaps the most reasonable assumption is of continued growth with the release of the next generation of console in the next two to three years. However, competition from PC gaming, mobile games, and other avenues of consumption mean that the focus is likely to shift from simply selling games consoles to encouraging console owners to buy a larger number of games. In this context, it is worth noting that, although there are smaller independent producers in the game development market, the three SRI signatories are again the major players.

Reports in the press suggest that Microsoft and Sony will launch new games consoles in the next two to three years and that these will continue down the path of high-quality graphics and increasingly powerful machines (with attendant high energy usage). Reporting on the Switch has focused on whether it represents a shift in Nintendo's strategy, away from simply selling games consoles to encouraging users to buy larger numbers of games. It is likely that the future direction for Nintendo is attempting to turn strong early hardware sales into long-term games sales from third-party developers. It is difficult for the signatories to comment on this speculation or to comment on factors such as the growing importance of streaming.

One final consideration that the study has commented on is the rerelease of 'classic' or 'Arcade' games consoles. There are no comprehensive statistics on sales available, but it appears that this market could be significant.

Energy savings achieved to date

In the review report of 2017, on the basis of the energy savings measures achieved up until then, the energy savings over the life time were expected to be in the order of 36.3 TWh for the PlayStation 4 and Xbox One consoles. This has been described as comparable to the annual energy production of Denmark. The estimated energy consumption and energy savings in this report have been calculated based on a modified usage scenario from LBNL (described in chapter 4.1.7) and calculated TECs developed from the study's own power consumption measurements as well as measurements reported by the SRI.

The energy savings achieved by the SRI for PlayStation 4 consoles in Europe up to May 2019 are estimated to be 13.61 TWh. The calculations are made by comparing the energy efficiency achieved through the measures currently implemented by the SRI with a baseline of no energy efficiency improvements. By comparing the estimated electricity consumption to the baseline, an annual energy saving in 2020 of around 5.39 TWh is calculated. The total energy savings over the lifetime for PlayStation 4 consoles is 42.99 TWh, which is just 6.54 % lower than Portugal's electricity consumption in 2014 (46.0 TWh). The baseline electricity consumption, estimated electricity consumption and energy savings for PlayStation 4 consoles are summarized in Table 60.

The estimated energy savings achieved by the SRI for Xbox One consoles in Europe up to May 2019 are a total of 2.2 TWh. In 2020 an annual energy saving of around 1.25 TWh is estimated. Over the lifetime of the Xbox One consoles, the total energy savings are estimated to be 11.43 TWh, which is almost identical to Georgia's electricity production in 2014 (11.57 TWh). The baseline electricity consumption, estimated electricity consumption and energy savings for Xbox One consoles are summarized in Table 61.

Compared to the SRI report from 2017, our calculations indicate an energy saving of 54.42 TWh, which is comparable to the energy consumption of Greece in 2014 (53 TWh). This can be explained e.g. by

the applied LBNL usage scenario and significantly decreased TECs in comparison to the baseline for the games consoles and also updated sales numbers. In comparison to the PlayStation 4 and Xbox One, the electricity consumption of the Nintendo Switch is a magnitude lower. A number for estimated energy savings cannot be given for the Nintendo Switch due to its character of being used both as handheld and stationary and consequently the absence of a baseline.

Appropriateness of the energy efficiency requirements

The consultants carried out their own extensive measurements and drew conclusions from them. The results of the power supply efficiency and power factor measurements have surpassed their expectations by far and in a positive way. The SRI as of Version 2.6.3 provides no numbers, only a very generalized statement on “adoption of best available technologies” including efficient power supplies. The measurements have shown, that the power supplies rated at 12V or 15V output voltage have more than 88.0 % efficiency. The power supply efficiency describes the amount of the actual power delivered to the device as a ratio of the electrical power drawn from the mains supply socket. The highest average efficiency for one games console has been documented at 92.84 %. The consultants agree that, based on the measurements, for power supplies the best available technologies have been used.

The VA agreement and default settings have proven to have a positive impact on the energy savings achieved as described in the previous section but several further measures and improvements were identified by the consultant team. Firstly, the current state of the General Auto Power Down Requirements as defined in the SRI states that the last user input as well as user inactivity are key events for APD. Automatic switching of the console to “Idle” mode should not be counted as an event and extend the time until APD is activated. This should be stated more clearly in the VA and implemented accordingly.

Based upon measurements and thermal inspections during the study, the power cap requirements for the operational modes of navigation and media playback formulated within the SRI are considered appropriate for the multi-functional entertainment system a games console offers. The results have shown that more than half of the VRAMs within the consoles stay rather inactive in these two modes. Nevertheless, further reduction of the power consumption in modes such as “Navigation” or “Media Playback” should remain a goal in the VA. The resolution detail is one key factor of the power consumption. For example, the Navigation Mode in UHD needs 9 Watts more power than in HD resolution for the PlayStation 4 Pro (CUH-7216b) and about 6.5 Watts for the Xbox One X. The necessity of UHD for the navigation mode should be discussed. The 30 minutes window measurements showed, that that the definition of power cap of UHD Media Playback of 110W for UHD gaming capable consoles could be reduced to 90W without any impact or actions needed by the signatories.

With the upcoming trend of cloud gaming, the place of required computational resources shifts towards servers. As the variety and complexity of server structures are difficult to assess and also for intellectual property purposes difficult to access, estimations of the power consumption of cloud gaming have not been investigated beyond desk-research.

If the cloud gaming mode should be fitted into the defined existing modes, at a first glance it looks like an active gaming mode, but in fact, the rendering and game logic is executed on the server-side, and on second thoughts, cloud gaming is more similar to the media streaming mode than the active gaming mode. Clearly, this is a topic where there are differing views and it needs a more in-depth investigation. If the cloud gaming is categorised under the media streaming mode, then, of course, it follows the regulations and associated power caps. Table 35 and Table 39 show that there are considerable differences between media streaming and active gaming modes from an energy consumption point of view. Also in the current version of the SRI, an energy consumption cap on active gaming is currently not stated and different power caps are defined for these modes.

Section 5.5 presents a perspective on the required energy for data transfer from an energy consumption point of view and this is related to cloud gaming. For different gaming resolutions, frames per seconds or other adjustable factors, different data transfer rates during cloud gaming are required, which impact on the overall energy consumption. In addition to energy consumption, there are some other factors that relate to the users. The performance of cloud gaming at the customer's home is heavily dependent on the local connection, provider and data tariff. Providing clear information about the actual need (or limits) of data for using cloud gaming services, is useful for customers and they could assess the expected latency, performance and gaming service experience and the cloud selected for the matching service. Having some options to limit the data transfer by the user seems practical. For example, in most media streaming portals such as YouTube, users can select the quality of streaming; consequently, the transferred data rate is affected.

Improvement potential with regard to future energy savings

In section 6.7, different design options with the possible impact of improved energy efficiency have been described. Design Option 1 describes a hardware change in the Base Case 1 console from the start of sale (and is rather difficult to implement in already sold products), whereas the other proposed design options are generalizable and can be deployed with software updates.

Design option 1 suggested having a look at the currently most used storage technology, the hard disk drive (HDD). With the need for a rotating platter inside the device an HDD consumes a non-negligible amount of energy. Solid State Drives (SSDs) are more and more common in today's computer world. Solid State Drives are flash-based memories that use the standard interfaces of HDDs to be compatible or newer interfaces, such as NVMe or PCI Express, to have even faster connections. Their main advantage over HDDs is that they are less sensitive to mechanical shock, their form factor can be significantly smaller and their much higher data transfer rates. Reduced gaming load times by 63 seconds (PlayStation 4 CUH-7216b) and 42 seconds (Xbox One X) have been observed. The implementation of SSDs from the PS4 Pro and Xbox One X release dates onwards could have reduced the energy consumption of modes "Media" and "Connected Standby" games consoles by 2.6% for the Xbox One X models and 1.61 % for the PlayStation4 Pro (CUH-7216b).

For the Design Option 2 (see section 6.7.2), the consultants propose that turning off the console should have a higher priority than putting the console into standby. This could be implemented by displaying the option "Turn off" before the option "Standby" in the graphical user interface. By setting the "Turn off" option as default, the percentage of users, who turn off the console, could be increased. The impact of setting the turn off option as default was calculated on the basis of a survey for games consoles of the seventh generation carried out for a doctoral thesis by Amanda Webb[225]. According to this survey, 65 % of the users would turn off their consoles. For games consoles of the eighth generation this value is assumed to be around 40%. The TEC calculations provided by the signatories have had no time in "Off"-Mode.

Implementing the turn off option in the Xbox One models would lead to an energy saving of 3.27 TWh, thereby reducing the energy consumption of all Xbox One consoles by 16.41% over their lifetime.

If implemented since the release of the games consoles, a default turn off option in the PS4 models could have achieved an energy saving of 1.11 TWh, which corresponds to an energy consumption reduction by 3.05% of all PS4 consoles over their lifetime.

For the Design Option 3, the impact of adaptive APD from July 2019 onwards on the energy consumption was calculated under the assumption that it would reduce the on-time by the same percentage as the standard APD. By using programs and algorithms to analyse user behaviour patterns, adaptive mechanisms for optimizing auto-power-down timeframe could be implemented.

[225] http://epubs.surrey.ac.uk/809999/

By using adaptive APD the on-time, which includes the modes “Active Gaming”, “Media” and “Other functions”, could be reduced through earlier APD. In addition, this would increase the standby and off time. In the SRI 2.6.3 a reduction of the on-time by 7 % due to standard APD was assumed. Based on this number, the impact of adaptive APD was calculated.

Adaptive APD in Xbox One models from July 2019 onwards would lead to an energy saving of 499.93 GWh, thereby reducing the energy consumption of all Xbox One consoles by 2.51% over their lifetime.

For the PS4 models from July 2019 onwards, adaptive APD would have achieved an energy saving of 1.42 TWh, which corresponds to an energy consumption reduction by 3.89% of all PS4 consoles over their lifetime.

In conclusion, regardless of any technological developments, the user behaviour and usage time is currently crucial for the energy consumption of games consoles. By designing the default options in such a way, that users are encouraged to really turn off the console rather than putting them in the currently easily accessible (in terms of interaction steps needed) standby mode or variations of the “Rest” mode, significant energy savings can be achieved. Another possibility could be, that users are rewarded with trophy rewards for their account when they keep their game consoles turned off rather than in standby for a specific time, as has been developed in a virtual points system under different names for other actions (completing a game level, etc.). By giving additional (online-) rewards, users are likely to be more encouraged to put for example even lower APD-times in Media Mode as a standard setting.

Furthermore, standby power regulations (see section 2.2.2 and 7.3.4) are currently not part of the SRI, therefore, the implementation through updates should be considered in order to meet the new requirements. From 01.01.2019 onwards, high network availability network equipment may use 8 Watts, other equipment 2 Watts.

With the success of a games console with both stationary and handheld gaming capability such as the Nintendo Switch, ensuring a minimum battery lifespan (in terms of minimum number of full charge cycles; for details see section 5.4.2 and 7.3.4) should be envisaged. Batteries are currently implemented for the interaction of each console, while some controllers enable customers to replace the batteries by themselves. Built-in and unchangeable (by customers) batteries therefore should envisage a minimum battery lifespan especially with regard to material efficiency. Recycling with new battery technologies as described in section 5.4.2 is not yet quantifiable, because recycling and collection systems are not available or are only at a pilot scale.

The “Rest” mode as defined within the current scope is a feature enabling the user to resume the game or application state after the console has switched to a lower power consumption mode. This mode can be found among all signatories under different names. A power cap similar to the power limitations as for example for the “Media Playback” mode could be envisaged. Future generations could implement such features easier than the already rolled out 8th generation. The VA does not yet contain any power cap on low power modes for “Rest”. Therefore, it is recommended that a power cap of less than 5 W be introduced for the “Rest” mode for next generation consoles.

As Sony and Microsoft have formed a partnership for cloud gaming (see section 5.5) the use of renewable energy sources in data centres can reduce the carbon footprint. Since 2018, Microsoft has been supplying half of its data centre’s energy usage from renewable sources and Microsoft is on track to power 60 percent with renewable energy by the end of 2019. Reaching 70% of renewable energy by 2023 is a further plan. By introducing flexible update time slots, a part of the local energy needed for games consoles could be shifted towards the consumption of renewably produced energy (see section 5.3.4).

Appropriateness of resource efficiency and information requirements and improvement potential

Resource (or material) efficiency is becoming increasingly important in the context of Eco-design. In recital 3 of the Ecodesign Directive it is laid down that energy related products account for a large proportion of the consumption of natural resources in the Community and in recital 4 that these products have a significant potential to be improved in order to reduce environmental impacts. Reducing the environmental impact by improved material efficiency can be fostered by several strategies, such as a durable design, which allows for repair, upgrade and second use, the use of recycled materials or improved recyclability.

In general, it can be stated that games consoles already perform well with regard to some of these strategies. They have a relatively long lifetime (including second-hand use) and apparently there is significant repair activity. The current VA already includes some important aspects, namely the upgradeability, reparability and information on repair/maintenance of devices. However some additional measures have been identified by the study team as relevant to further improve the material efficiency. The further measures identified have the potential to reduce negative environmental impacts resulting from the production of the devices, their use and end of life and can be categorized as measures relating to product design, non-design-related measures and information related measures. Suggested requirements in this regard are:

Measures with regard to product design (see section 6.8 and 6.9.1)

1. Use of a minimum of 10 % post-consumer recycled plastic
2. Batteries that are easy-to-replace by end-users
3. Improved disassemblability through the use of fasteners that can be removed with common tools and/or providing assistance in obtaining more specialised tools
4. Standardized interfaces for external power supply
5. Phasing out hazardous substances

Non-design-related measures (see section 6.9.2)

1. Binding guarantee of free of cost update support at all times
2. Availability of spare parts for any professional repair centre for at least seven years after placing the last unit on the market
3. A commitment to free repair as the first remedy within the guarantee time
4. Providing take-back schemes for the separate and non-destructive collection of the device

Information related measures (see section 6.9.3)

1. Information on the technical durability, upgradeability and reparability of a device
2. Provision of technical information (about disassembly steps etc.) to professional repair centres
3. Marking plastic parts > 25g and > 100mm^2 in accordance with ISO 11469
4. Information on the content of flame retardants in plastic parts
5. Provision of a spare part inventory to any professional repair facilitie
6. Information on the timespan of spare parts availability for customers
7. Information on the percentage of the PCR material content.

8. (Easy accessible) Information on energy consumption in different operating modes

Adequacy of the current policy options

The current SRI fulfils the requirements of the Commission's "Guidelines for self regulation measures concluded by industry under Directive 2009/125/EC" which concern openness to participation, added value, representativeness, quantified and staged objectives, involvement of civil society, monitoring and reporting, cost-effectiveness of administering a self-regulatory initiative, and incentive compatibility. The current scope meets the requirements regarding representativeness and market coverage.

However, some improvement potential has been identified by the study team with regard to scope, energy efficiency, material efficiency and information requirements. The improvement potential with energy efficiency has been described in section 7.4 and the effects on energy efficiency of multiple measures have also been quantified through the study's own measurements described in section 6.7. Material efficiency improvements have been analysed based on the current situation with regard to games consoles design, user behaviour with regards to repair and end of life treatment of the consoles. They are described in detail in sections 6.8 and 6.9. The main differences from the proposed change to the scope definition of the VA are the deletion of the 20 W threshold and the inclusion of handheld devices in accordance with the definition of games consoles in Regulation 617/2013 plus including the capability to render the gameplay of platform-specific videogames standalone. For the future, it is possible that games consoles with the capability for mobile gaming / handheld mode will have a greater importance. The inclusion of handhelds in the suggested revised scope ensures in this regard that the SRI still achieves an appropriate coverage of the games consoles market and remains open to other policy options. Furthermore, it will be necessary to carefully evaluate if additional devices (from additional manufacturers) will fall under the scope of such an amended definition.

Finally, there is a general issue for the future arising from the growing integration of technologies and applications and the implications for the Ecodesign approach that relies on separate regulation for specific products. This will need raising in the appropriate fora.

Annex 1 Measurement Plot Results

Figure 61: PS4 Pro (CUH-7216b) – Rest Mode (All options on)

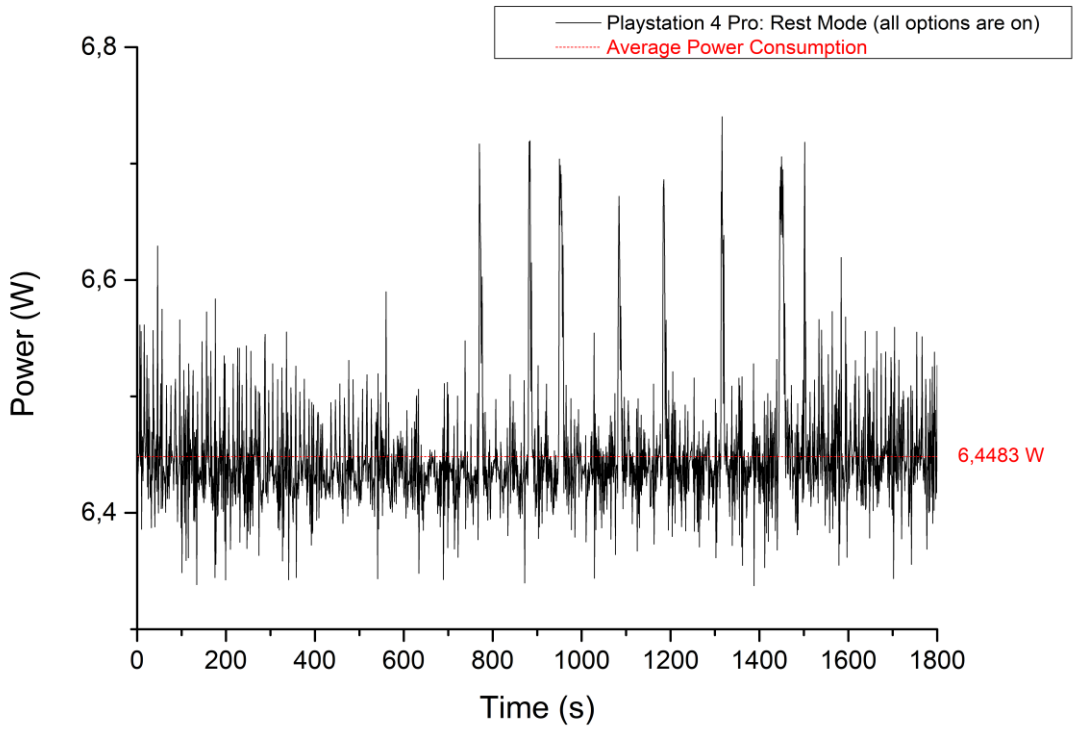


Figure 62: PlayStation 4 Pro (CUH-7216b) Rest Mode: Controller Charging

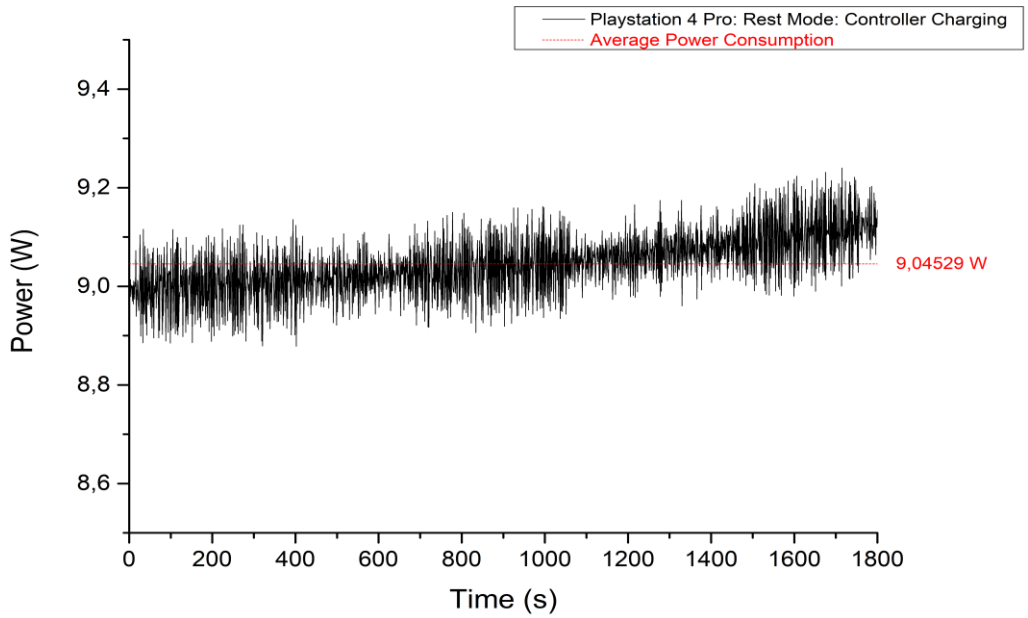


Figure 63: PlayStation 4 Pro (CUH-7216b) Rest Mode - Supply Power to USB

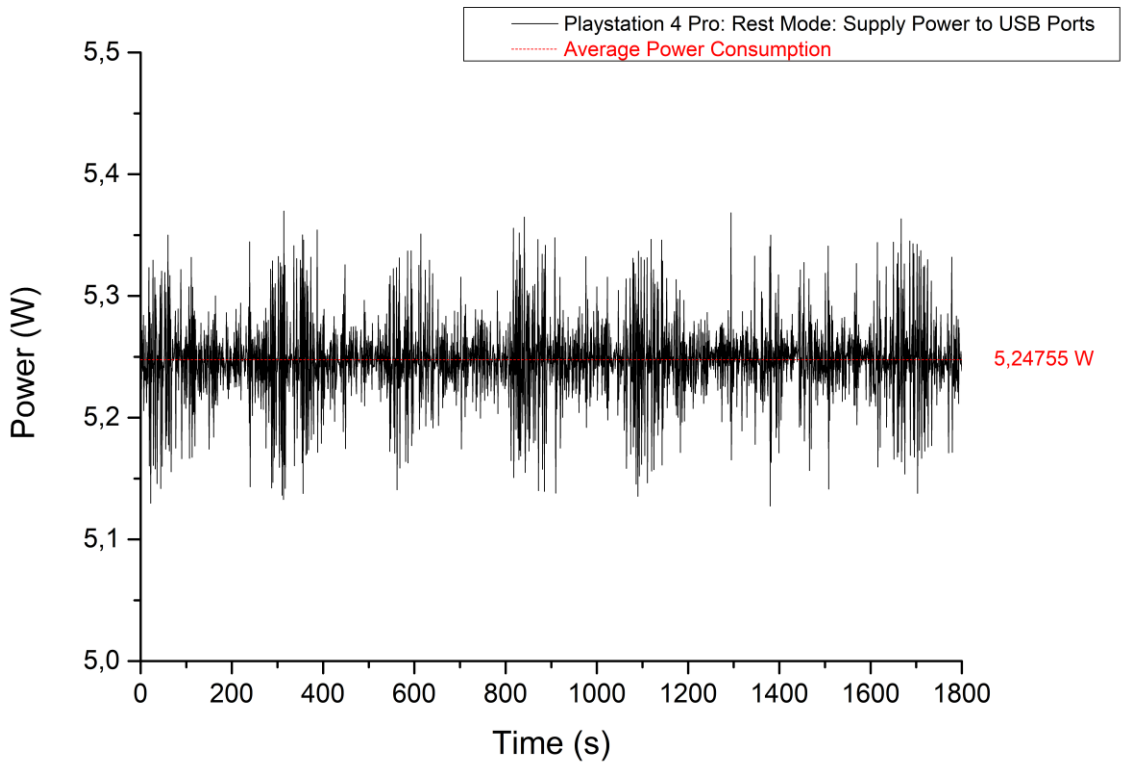


Figure 64: PlayStation 4 Pro - Stay Connected to Internet

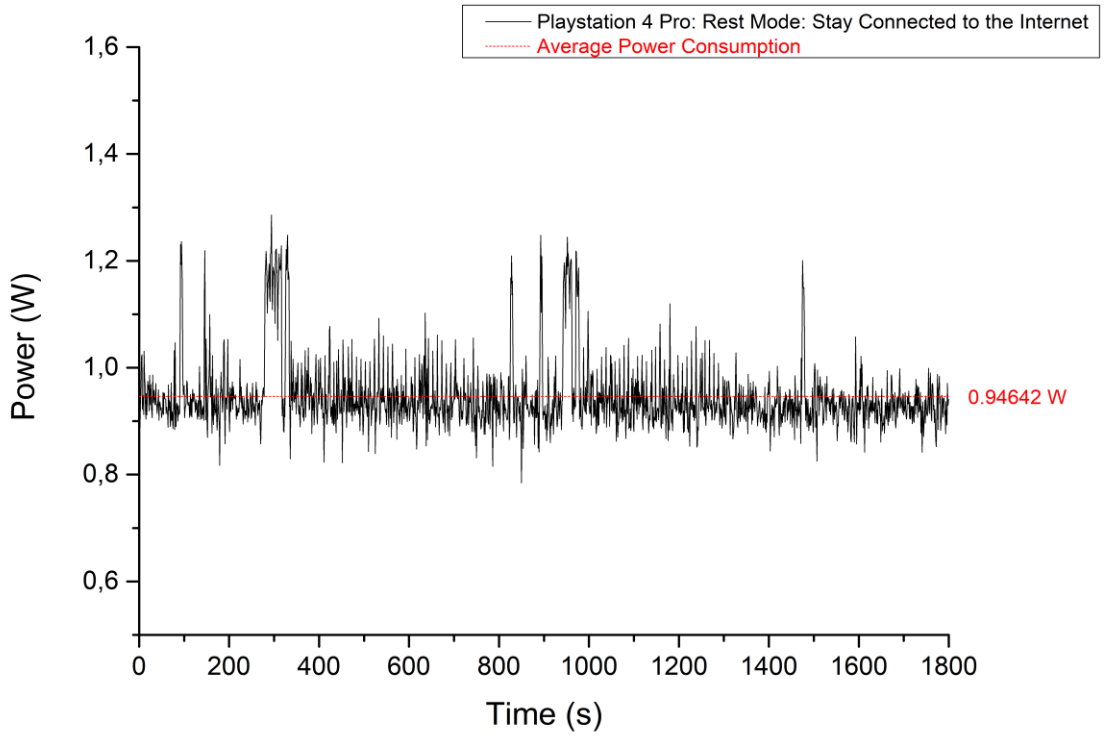


Figure 65: PlayStation 4 Pro CUH-7216 – Keep Application Suspended: RDR2

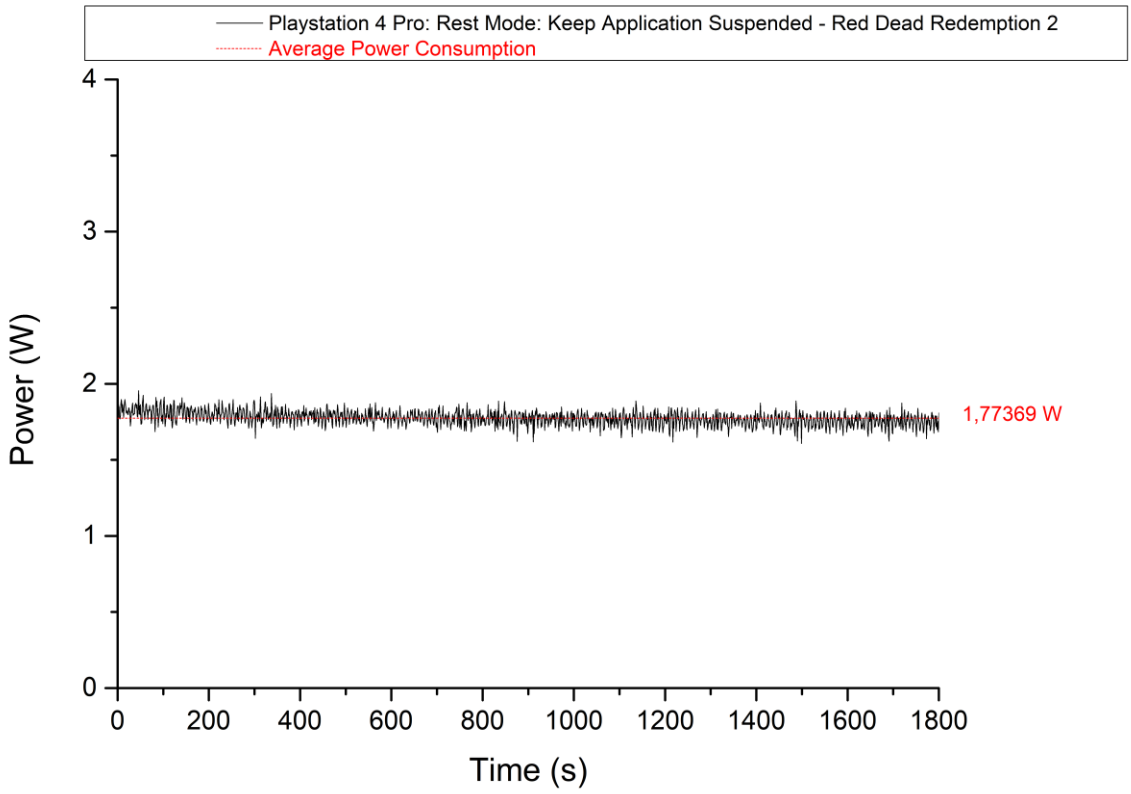


Figure 66: PlayStation 4 Pro (CUH-7216b) – Rest Mode - Connected to Internet - Installing Update

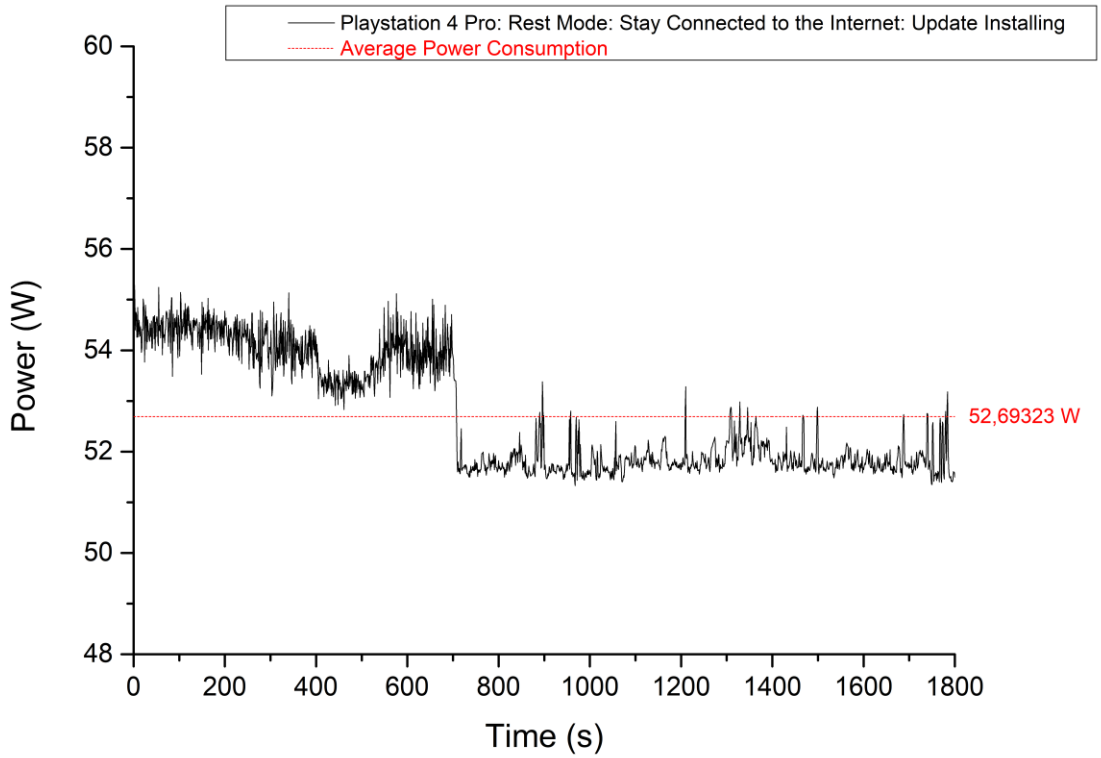


Figure 67: Xbox One X - Instant-On Power Mode (Both Options On)

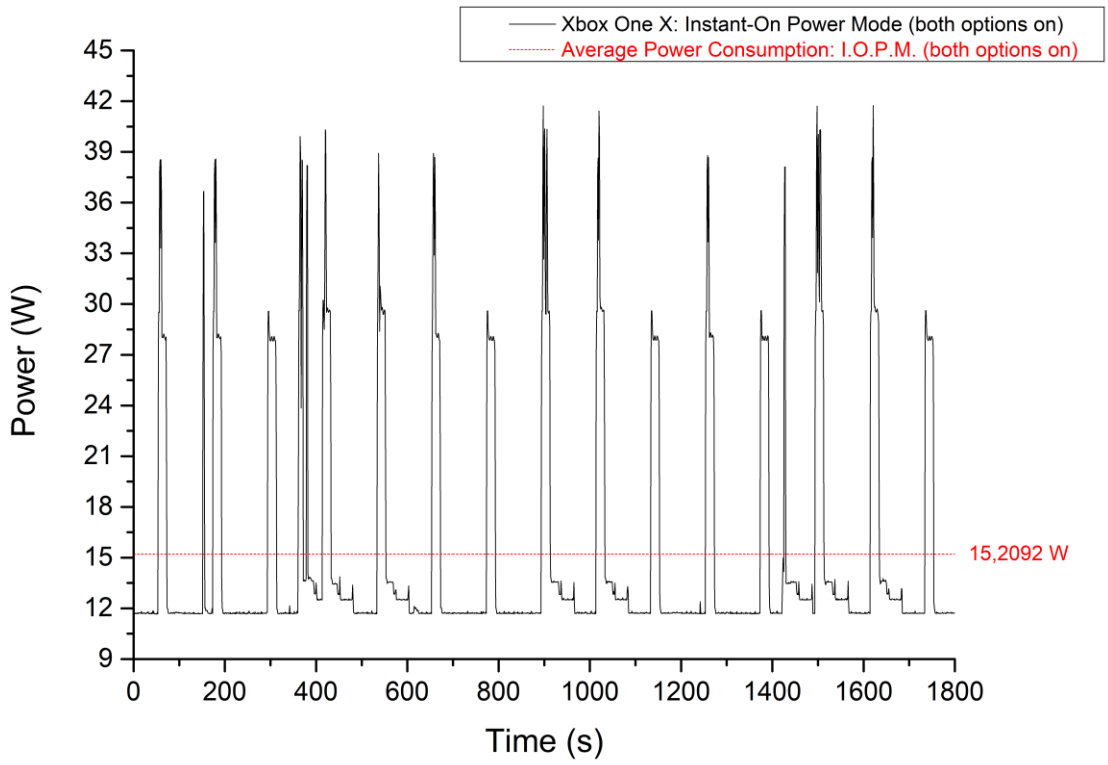


Figure 68: Instant-On Power Mode (Both Options Off)

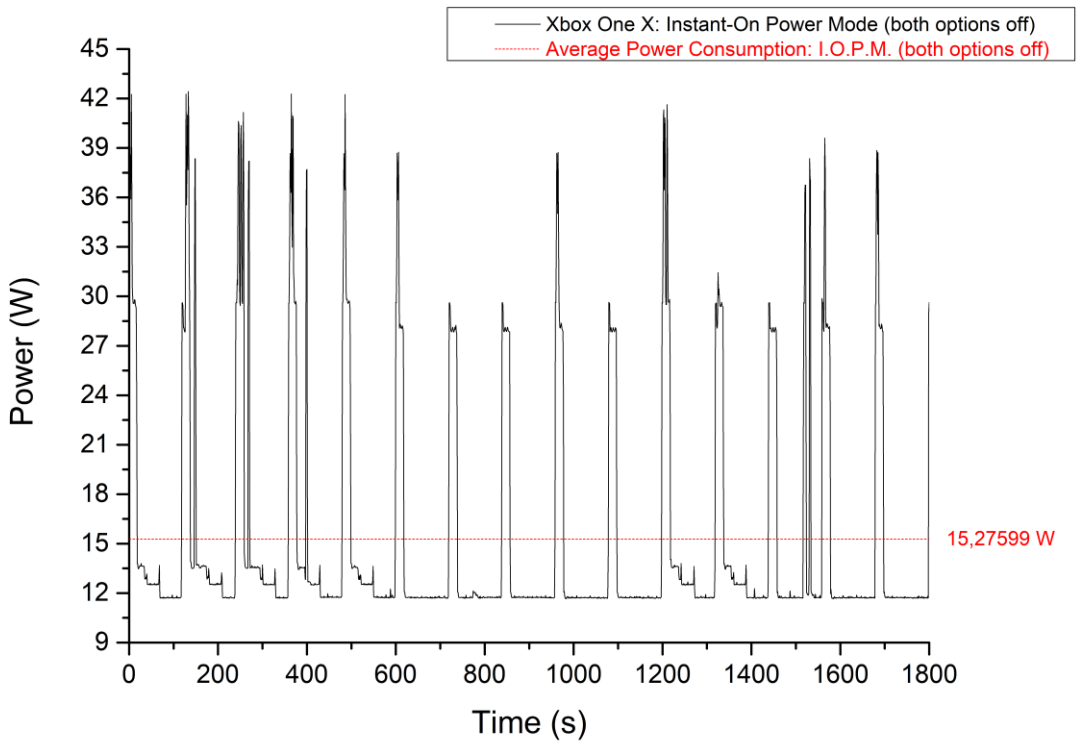


Figure 69: Xbox One X - Instant-On Power Mode - Installing Update

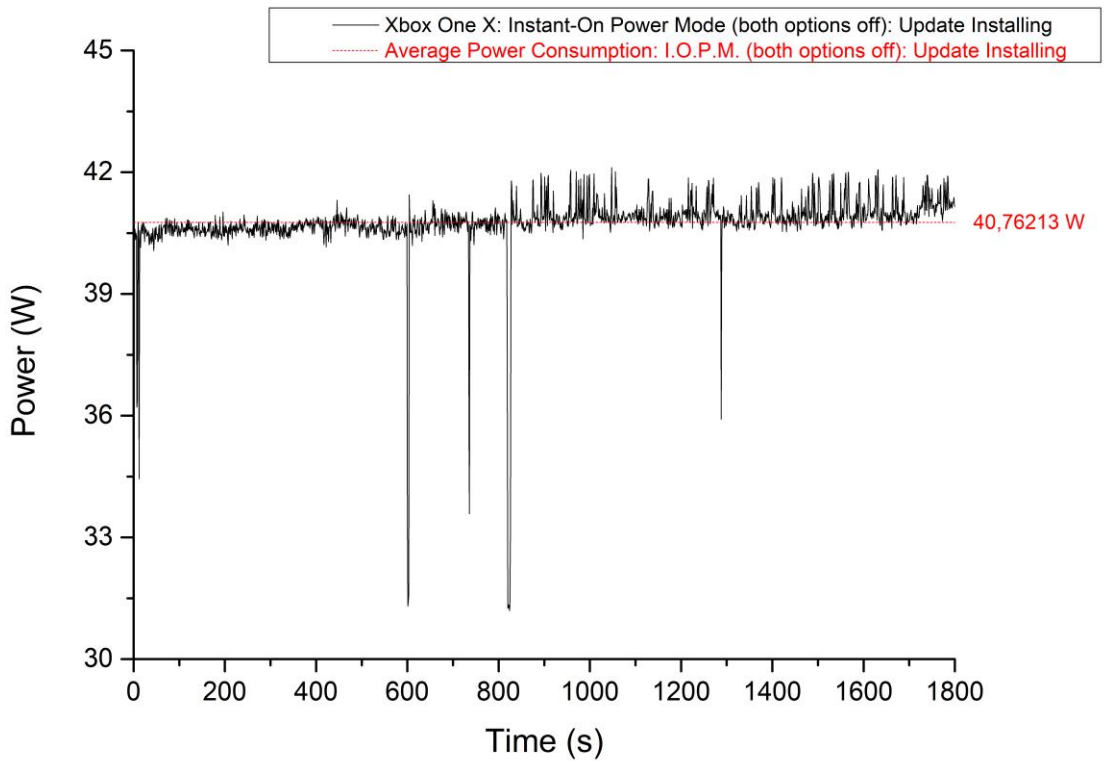


Figure 70: Xbox One X - Energy Saving Power Mode

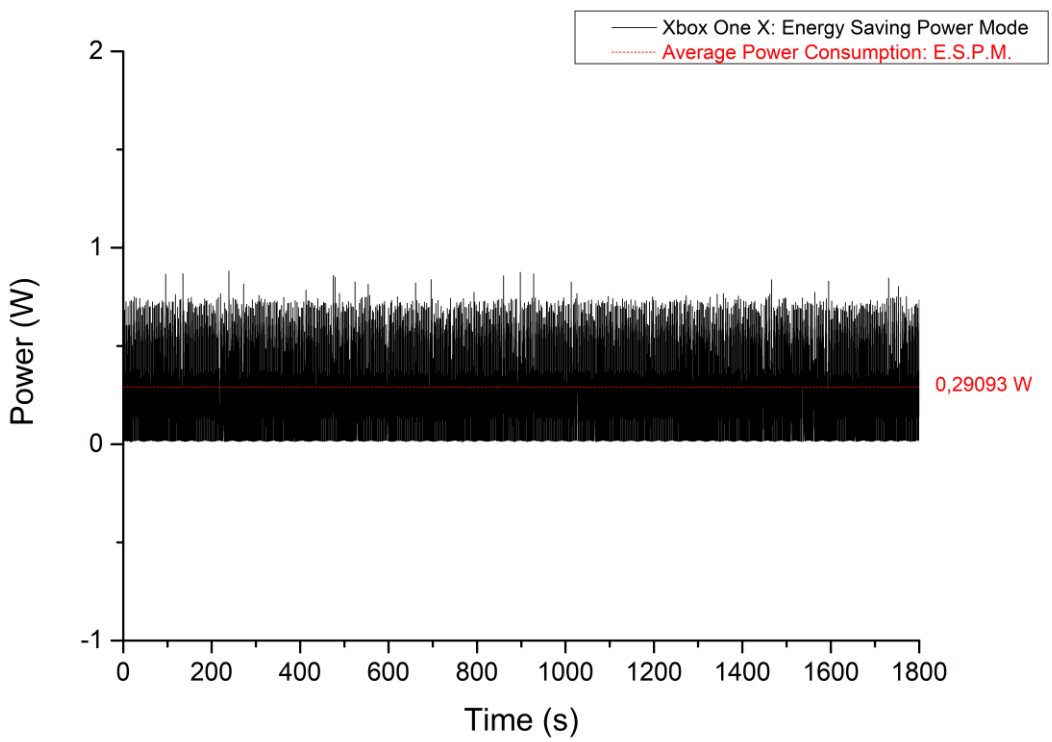


Figure 71: Xbox One X - Navigation Mode at different resolutions

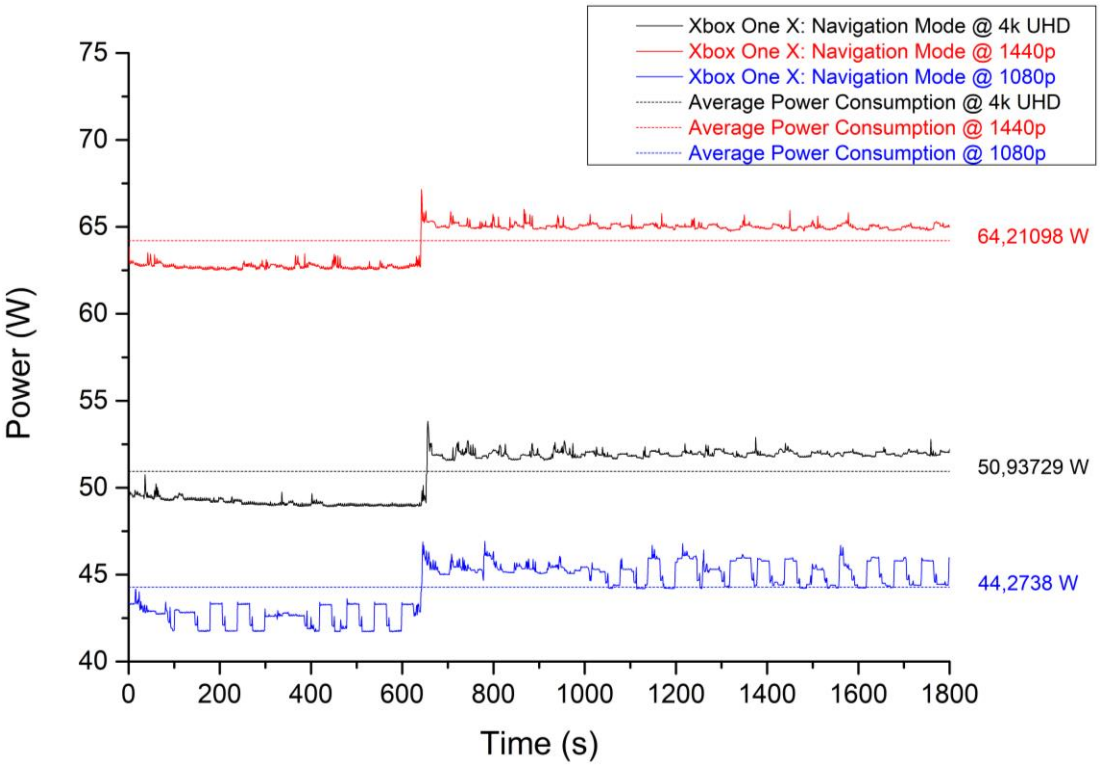


Figure 72: Xbox One X - Navigation Mode at different resolutions without console restarting

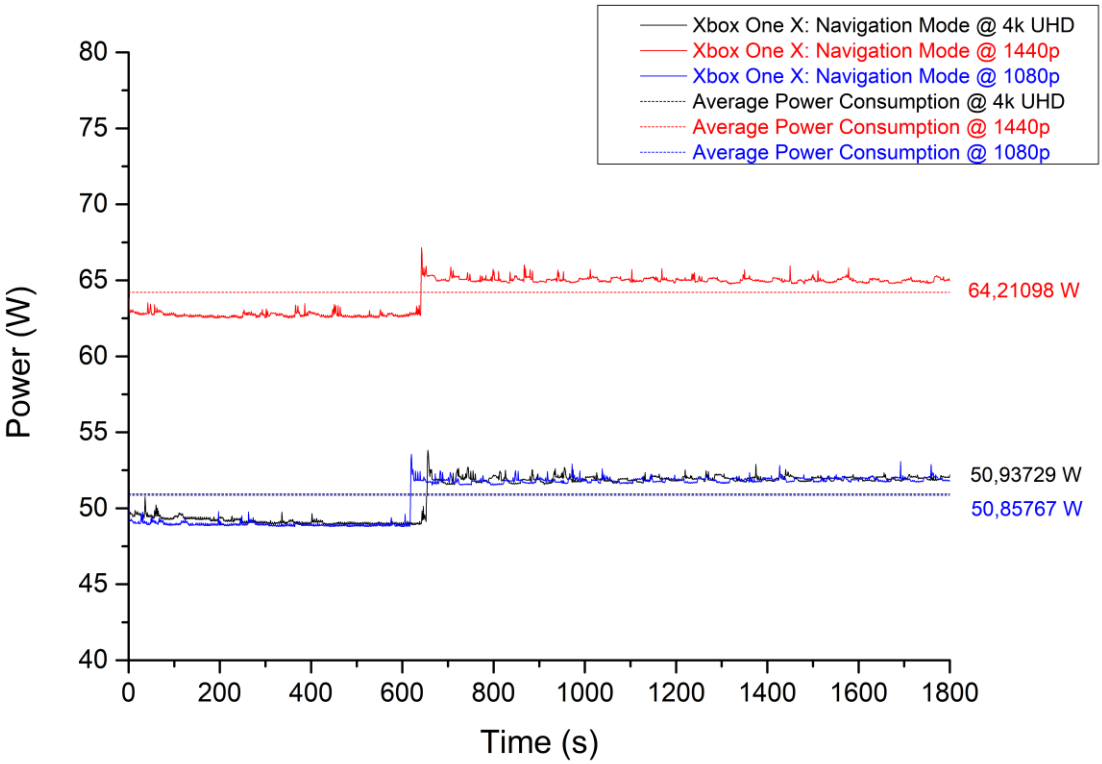


Figure 73: Nintendo Switch - Charging Handheld / Handheld and JoyCons in Dock

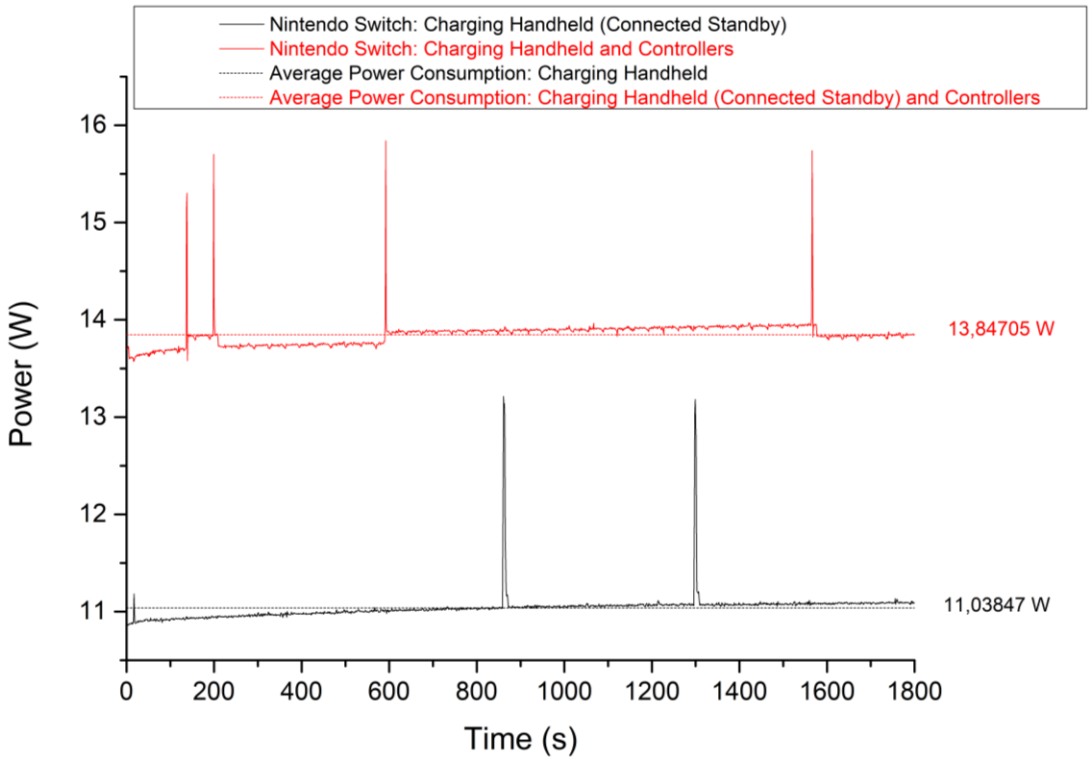


Figure 74: Nintendo Switch TV Mode: Navigation Mode

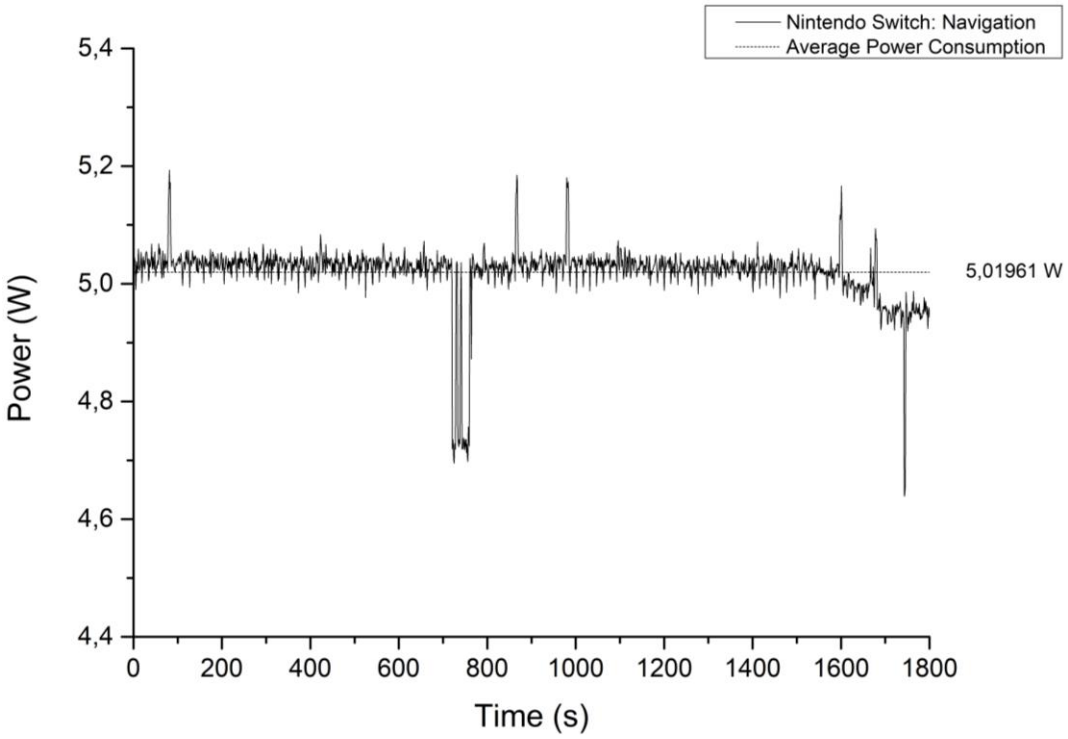


Figure 75: Nintendo Switch TV Mode: Media Streaming HD

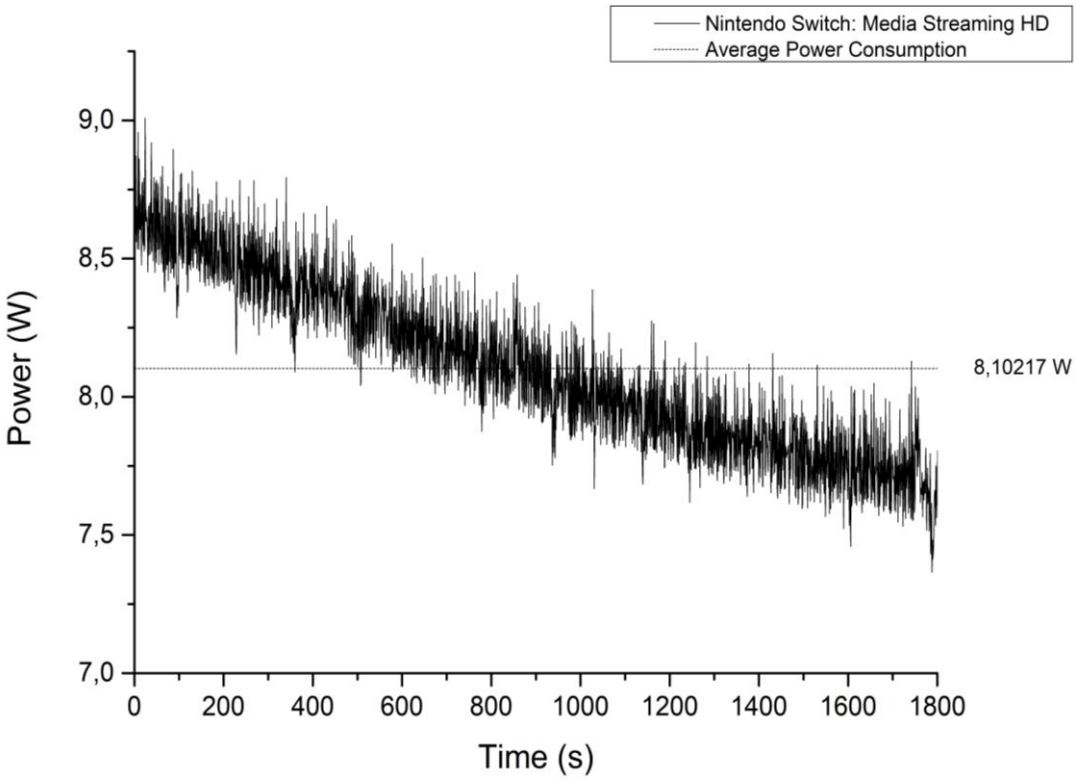


Figure 76: Nintendo Switch TV Mode - Connected Standby, Off, USB-LAN Adapter

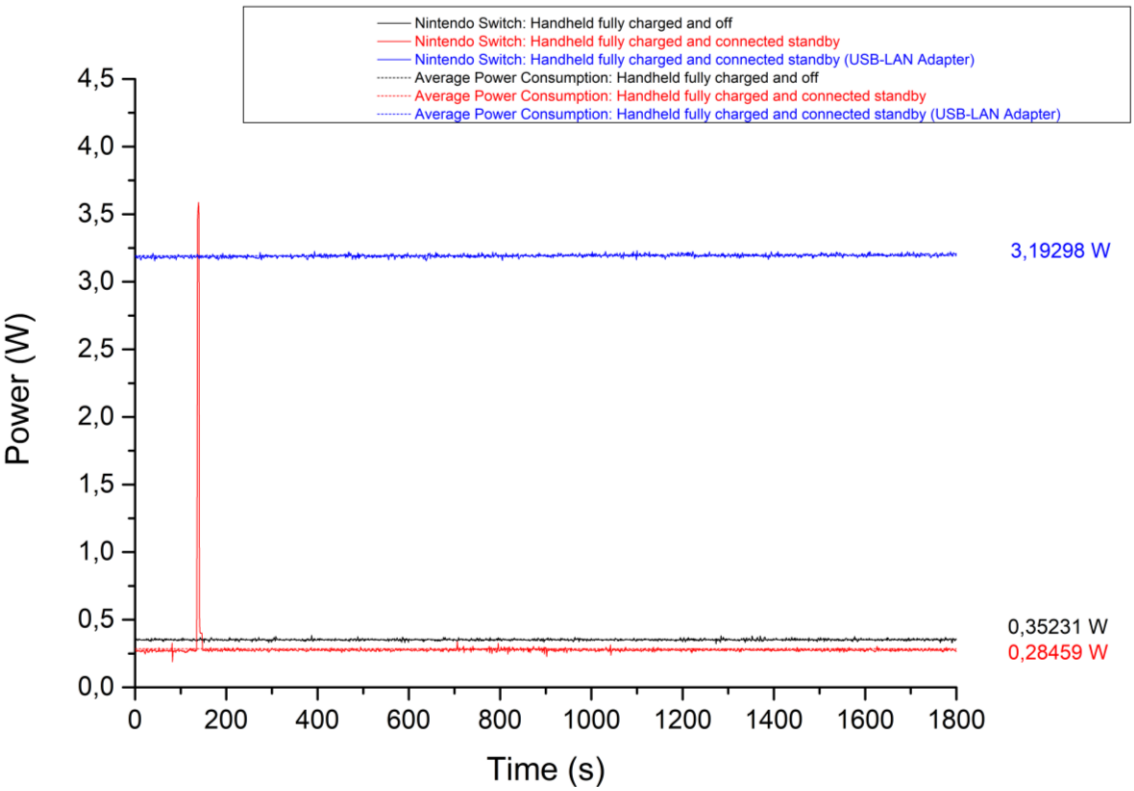


Figure 77: Nintendo Switch – Gaming Mode in TV Mode – Selection of different games

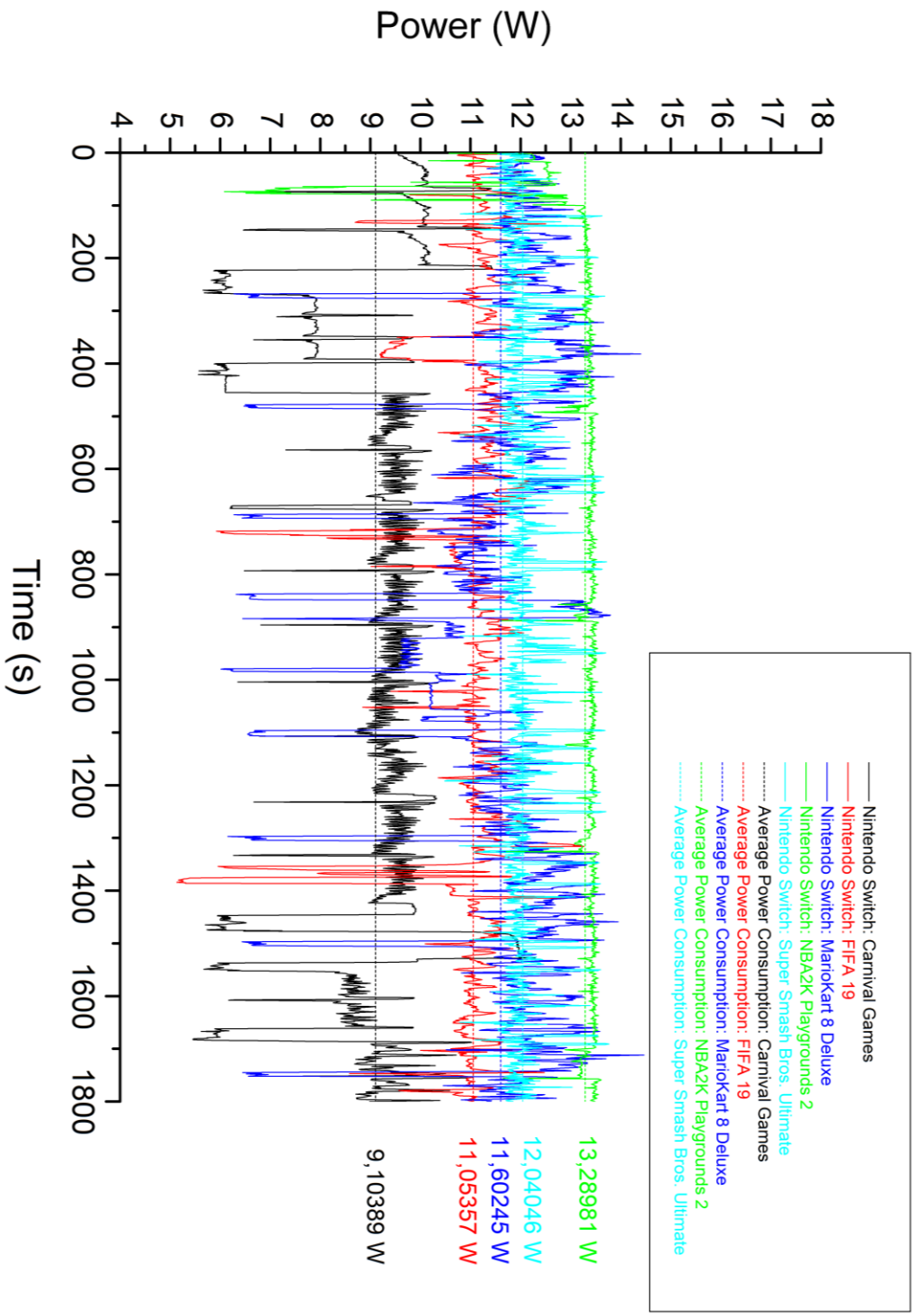


Figure 78: Empty Switch and Empty JoyCons in Handheld mode while charging - Active Gaming MarioKart 8 Deluxe

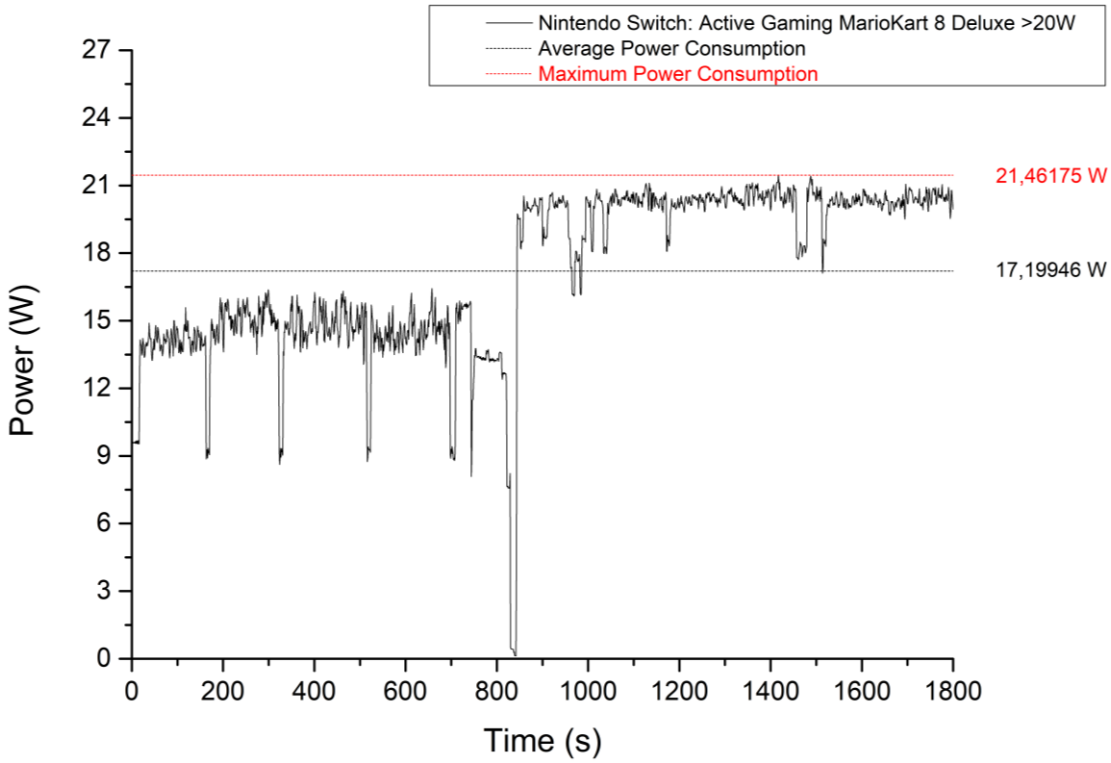
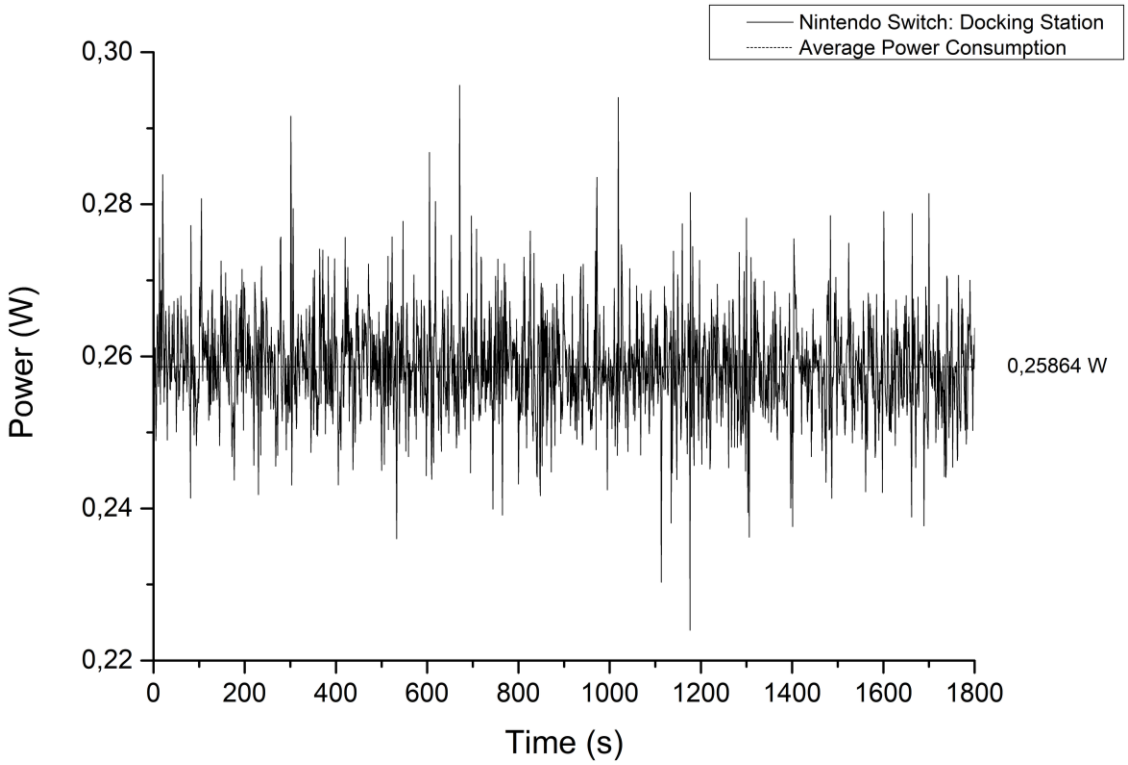


Figure 79: Nintendo Switch Docking Station Only



Annex 2 Power Consumption Measurement Results

A variety of measurements have been done in the course of investigating further energy related improvements. First, to deepen the understanding of different games consoles modes and options offered to customers. Second, the possibilities of further improvements should also go beyond the current scope of the SRI as of Version 2.6.3 and maybe extend it by generalizable requirements. In total, more than 215 hours have been recorded over the different consoles in the lab. With measurement repetitions and setup time, the consoles have been observed and ran for a total of over 350 hours. Table 64 to Table 67 give the comprehensive overview of the overall average energy consumption in Watts. Blue columns indicate measurements as descripted in the SRI measurement procedure as of Version 2.6.3. In Table 67 and Table 68 the plots of the APD are coloured in red for navigation and active gaming mode, as the time taken for activating the auto power down is beyond the described limits of the SRI (= 1 hour). The explanation is the “Idle”-Mode of the Xbox One, which resets or rather extends the APD time by the default value of 10 minutes.

Table 64: PS VR Headset Measurements and Consumption

Measured by Mirsad Karat BSc.		**PS VR Headset**
Measurement Scenarios	**Media**	
Active Gaming Playstation VR	The Playroom VR	16.97
VR Headset On (Box+Headset) and mounted, Game Console is On	N/A	18.84
VR Headset On (Box+Headset) and not mounted, Game Console is On	N/A	15.78
VR Headset Off (Box is On) and not mounted, Game Console is On	N/A	11.49
VR Headset On (Box+Headset) and not mounted, Game Console is Off	N/A	3.66
VR Headset Standby, Game Console Off	N/A	0.11

Table 65: PS4 Pro (CUH-7216b) Measurements and Consumption

Measured by Mirsad Karat BSc.		PS4 Pro					
Measurement Scenarios	**Media**	**4k**	**4k SRI**	**1080p**	**1080p SRI**	**720p**	**720p SRI**
Navigation	N/A	65.59	65.60	56.32	56.18	56.20	55.94
Navigation + Passive Gaming	Red Dead Redemption 2	131.76		112.58		112.87	
Navigation + Game Installation	Red Dead Redemption 2	63.37					
Media Playback Blu-Ray	Avatar	72.31	72.23	53.75	53.66	56.84	56.86
Media Playback DVD	Avatar / SRI: Conan der Zerstörer	81.69	81.11	50.02	50.17	49.88	49.87
Media Streaming SD	YouTube					76.36	
Media Streaming HD	Game of Thrones S1E1	86.38	86.32	54.35	54.23		
Media Streaming UHD	YouTube	88.85	90.49				
Audio Streaming	Spotify	58.38	58.12	57.33	57.65	57.05	57.75
Active Gaming:	Red Dead Redemption 2	161.13	162.85	127.62	128.51	126.76	128.75
	FIFA 19	136.95	135.87	107.39	106.64	106.56	106.50
	Need for Speed Payback	136.98	139.01	121.45	116.88	114.51	115.80
	World of Tanks	115.90		107.02		108.97	
	Fortnite	148.83		135.67		133.66	
	Arith. Mean of Active Gaming	139.96	145.91	119.83	117.34	118.09	117.02
Active Gaming + Audio Streaming	Red Dead Redemption 2 + Spotify	165.20					
Video Streaming + Passive Gaming	YouTube + Red Dead Redemption 2	87.50					
Playstation Remote Play	Red Dead Redemption 2	160.31		124.52			
Playstation Now	Mortal Kombat X	69.05		68.71			
Playstation Share Play	Fortnite	154.02		129.43			
Active Gaming Playstation VR	The Playroom VR			138.47			
Navigation Mode APD	N/A	plot: 1206s					
Active Gaming APD	Need for Speed Payback	plot: 1211s					
Disc-Based Media Playback APD	Blu-Ray: Avatar	plot: 14402s					
Media Streaming Playback APD	Game of Thrones S1E1	plot: 14415s					
Full Shutdown	N/A	0.25					
Rest Mode (Supply Power to USB Ports)	N/A	5.25					
Rest Mode (Stay Connected to the Internet)	N/A	0.95					
Rest Mode (Keep Application Suspended)	Red Dead Redemption 2	1.77					
Rest Mode (All Options are On)	N/A	6.45					
Rest Mode (Update Installation)	Fortnite	52.69					
Rest Mode (Controller Charging)	N/A	9.05					
Rest Mode (Update Installation + Controller Charging)	Red Dead Redemption 2	57.07					
Starting a Game HDD vs. SSD	Red Dead Redemption 2	plot					
Starting the Game Console HDD vs. SSD	N/A	plot					
Shutting Down the Game Console HDD vs. SSD	N/A	plot					
Rest Mode (All Options are On) HDD vs. SSD	N/A	plot					

Table 66: PS4 Slim (CUH-2216A) Measurements and Consumption

Measured by Mirsad Karat BSc.		PS4 Slim			
Measurement Scenarios	**Media**	**1080p**	**1080p SRI**	**720p**	**720p SRI**
Navigation	N/A	44.07	43.58	43.41	43.58
Navigation + Passive Gaming	Red Dead Redemption 2	66.18		66.24	
Navigation + Game Installation	Red Dead Redemption 2	49.10			
Media Playback Blu-Ray	Avatar	47.72	47.50	49.61	51.26
Media Playback DVD	Avatar / SRI: Conan der Zerstörer	42.46	44.24	42.41	44.19
Media Streaming SD	YouTube			46.42	
Media Streaming HD	Game of Thrones S1E1	47.36	47.74		
Audio Streaming	Spotify	48.30	48.54	46.90	48.34
Active Gaming:	Red Dead Redemption 2	82.75	84.70	79.74	84.63
	FIFA 19	64.38	65.37	66.07	63.66
	Need for Speed Payback	74.50	75.27	74.57	76.70
	World of Tanks	64.81		66.95	
	Fortnite	79.24		79.29	
	Arith. Mean of Active Gaming	73.14	75.11	73.32	75.00
Active Gaming + Audio Streaming	Red Dead Redemption 2 + Spotify	83.16			
Video Streaming + Passive Gaming	YouTube + Red Dead Redemption 2	47.76			
Playstation Remote Play	Red Dead Redemption 2	82.14		82.07	
Playstation Now	Mortal Kombat X	58.02			
Playstation Share Play	Fortnite	77.68			
Active Gaming Playstation VR	The Playroom VR	72.74			
Navigation Mode APD	N/A	plot: 1230s			
Active Gaming APD	Need for Speed Payback	plot: 1211s			
Disc-Based Media Playback APD	Blu-Ray: Avatar	plot: 14423s			
Media Streaming Playback APD	Game of Thrones S1E1	plot: 14421s			
Full Shutdown	N/A	0.24			
Rest Mode (Supply Power to USB Ports)	N/A	4.43			
Rest Mode (Stay Connected to the Internet)	N/A	1.00			
Rest Mode (Keep Application Suspended)	Red Dead Redemption 2	1.88			
Rest Mode (All Options are On)	N/A	5.51			
Rest Mode (Update Installation)	Fortnite	41.55			
Rest Mode (Controller Charging)	N/A	8.20			
Rest Mode (Update Installation + Controller Charging)	Red Dead Redemption 2	44.69			

Table 67: Xbox One X Measurements and Consumption

Measured by Mirsad Karat BSc.		Xbox One X					
Measurement Scenarios	**Media**	**4k**	**4k SRI**	**1440p**	**1080p**	**1080p SRI**	**720p SRI**
Navigation	N/A	50.94	49.36	64.21	44.27	43.95	42.79
Navigation + Passive Gaming	Red Dead Redemption 2	64.95		74.28	60.95		
Navigation + Game Installation	Red Dead Redemption 2	55.24					
Media Playback Blu-Ray	Avatar	54.47	54.33	67.81	54.42	55.07	54.81
Media Playback Blu-Ray UHD	Unsere Erde 2 in 4k UHD	58.55	57.98	70.62	58.09	58.27	58.58
Media Playback DVD	Avatar / SRI: Conan der Zerstörer	54.53	54.33	67.53	54.00	54.74	54.69
Media Streaming HD	Game of Thrones S1E1	50.27	49.82	63.32	49.37	48.85	50.01
Media Streaming UHD	YouTube	55.20	55.30				
Audio Streaming	Spotify	49.38	49.43	62.70	43.11	42.99	44.08
Active Gaming:	Red Dead Redemption 2	166.17	174.32	171.84	170.78	172.05	173.55
	FIFA 19	125.37	127.05	126.67	123.77	128.34	127.18
	Need for Speed Payback	143.24	145.03	149.93	145.43	144.26	146.11
	World of Tanks	130.65		136.91	135.59		
	Fortnite	160.19		160.34	160.00		
	Arith. Mean of Active Gaming	145.13	148.80	149.14	147.11	148.22	148.95
Active Gaming + Audio Streaming	RDR2 + Spotify	172.14					
Video Streaming + Passive Gaming	YouTube + RDR2	55.99					
Microsoft Game Streaming	Red Dead Redemption 2	170.00		170.59	170.42		
Navigation Mode APD	N/A	plot: 4290s					
Active Gaming APD	Need for Speed Payback	plot: 4271s					
Disc-Based Media Playback APD	Blu-Ray: Avatar	plot: 14142s					
Media Streaming Playback APD	Game of Thrones S1E1	plot: 7979s					
Full Shutdown	N/A	0.29					
Power Mode: Energy-saving	N/A	0.29					
Power Mode: Energy-saving (Controller Charging)	N/A	3.48					
Power Mode: Instant-on (When Xbox is off. turn off storage)	N/A	13.48					
Power Mode: Instant-on (On start. go to TV)	N/A	14.57					
Power Mode: Instant-on (All Options are On)	N/A	15.21					
Power Mode: Instant-on (All Options are Off)	N/A	15.28					
Power Mode: Instant-on (All Options are Off): Update Installation	Star Wars Battlefront 2	40.76					
Power Mode: Instant-on (All Options are Off): Controller Charging	N/A	17.56					
Into Power Mode: Instant-on (When Xbox is off. turn off storage) HDD vs. SSD	N/A	plot					
From Power Mode: Instant-on (When Xbox is off. turn off storage) HDD vs. SSD	N/A	plot					
Into Power Mode: Energy-saving HDD vs. SSD	N/A	plot					
From Power Mode: Energy-saving HDD vs. SSD	N/A	plot					
Starting a Game HDD vs. SSD	Red Dead Redemption 2	plot					
Starting the Game Console HDD vs. SSD	N/A	plot					
Shutting Down the Game Console HDD vs. SSD	N/A	plot					

Table 68: Xbox One S Measurements and Consumption

Measured by Mirsad Karat BSc.		Xbox One S				
Measurement Scenarios	**Media**	**4k**	**4k SRI**	**1440p**	**1080p**	**1080p SRI**
Navigation	N/A	30.26	28.51	30.05	25.48	23.24
Navigation + Passive Gaming	Red Dead Redemption 2	33.88		33.51	30.81	
Navigation + Game Installation	Red Dead Redemption 2	33.83				
Media Playback Blu-Ray	Avatar	37.16	36.89	37.23	36.90	38.06
Media Playback Blu-Ray UHD	Unsere Erde 2 in 4k UHD	41.26	42.28	41.54	41.23	41.82
Media Playback DVD	Avatar / SRI: Conan der Zerstörer	36.48	37.50	36.62	36.50	37.07
Media Streaming HD	Game of Thrones S1E1	30.55	31.24	30.19	28.01	27.68
Media Streaming UHD	YouTube	46.57	49.52			
Audio Streaming	Spotify	27.49	27.66	27.04	23.12	23.34
Active Gaming:	Red Dead Redemption 2	75.18	74.19	73.28	73.54	73.77
	FIFA 19	60.89	60.65	61.28	61.38	59.46
	Need for Speed Payback	64.97	65.51	63.31	64.35	64.29
	World of Tanks	55.60		59.70	58.58	
	Fortnite	69.54		69.45	69.13	
	Arith. Mean of Active Gaming	65.24	66.78	65.41	65.40	65.84
Active Gaming + Audio Streaming	Red Dead Redemption 2 + Spotify	75.68				
Video Streaming + Passive Gaming	YouTube + Red Dead Redemption 2	48.17				
Microsoft Game Streaming	Red Dead Redemption 2	73.46		74.54	73.77	
Navigation Mode APD	N/A	plot: 4291s				
Active Gaming APD	Need for Speed Payback	plot: 4326s				
Disc-Based Media Playback APD	Blu-Ray: Avatar	plot: 14071s				
Media Streaming Playback APD	Game of Thrones S1E1	plot: 7991s				
Full Shutdown	N/A	0.33				
Power Mode: Energy-saving	N/A	0.34				
Power Mode: Energy-saving (Controller Charging)	N/A	3.25				
Power Mode: Instant-on (When Xbox is off. turn off storage)	N/A	7.12				
Power Mode: Instant-on (On start. go to TV)	N/A	6.59				
Power Mode: Instant-on (All Options are On)	N/A	6.68				
Power Mode: Instant-on (All Options are Off)	N/A	6.91				
Power Mode: Instant-on (All Options are Off): Update Installation	Star Wars Battlefront 2	16.91				
Power Mode: Instant-on (All Options are Off): Controller Charging	N/A	9.37				

Table 69: Nintendo Switch TV Mode - Measurements and Consumption

Measured by Mirsad Karat BSc.		Nintendo Switch	
Measurement Scenarios	**Media**	**1080p**	**1080p SRI**
Navigation	N/A	5.02	6.19
Navigation + Passive Gaming	Super Smash Bros. Ultimate	5.06	
Media Streaming HD	YouTube	8.10	7.81
Active Gaming:	MarioKart 8 Deluxe	11.60	11.44
	FIFA 19	11.05	12.02
	Super Smash Bros. Ultimate	12.04	12.16
	Carnival Games	9.10	
	NBA2K Playgrounds 2	13.29	
	Arith. Mean of Active Gaming	11.42	11.87
Navigation Mode APD	N/A	plot: 3600s	
Active Gaming APD	MarioKart 8 Deluxe	plot:3604s	
Media Streaming Playback APD	YouTube	plot: 14400s	
Handheld (Turned Off) Charging	N/A	12.45	
Handheld (Turned Off) + Controllers Charging	N/A	12.08	
Handheld (Standby) Charging	N/A	11.04	
Handheld (Standby) + Controllers Charging	N/A	13.85	
Handheld Charging + Active Gaming	Super Smash Bros. Ultimate	12.43	
Handheld + Controllers Charging + Active Gaming with other Controllers	Super Smash Bros. Ultimate	16.60	
Docking-Station without Handheld	N/A	0.26	
Handheld (Completelly Charged and turned Off) in the Docking-Station	N/A	0.35	0.36
Handheld (Completelly Charged and Standby) in the Docking-Station	N/A	0.28	0.28
Handheld (Completelly Charged and Standby with USB-Network Adapter) in the Docking-Station	N/A	3.19	