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Circular Economy's role in waste reduction and new business generation

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Master's in management

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ISCTE Business School

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Resumo

As tendências de comportamento dos consumidores, o risco de disrupção da cadeia de abastecimento devido à escassez de recursos, os rápidos avanços tecnológicos e o olhar atento dos governos e dos investidores para o desempenho ambiental das empresas estão a impulsioná-las no sentido de adotarem modelos de negócio alternativos e mais sustentáveis.

Este impulso deu origem a uma série de conceitos, incluindo o conceito de Economia Circular, na qual se visa otimizar a utilização de recursos através da criação de ciclos de materiais fechados.

Existem inúmeras estratégias que podem levar ao chamado ciclo fechado de materiais, mas medidas eficazes de gestão de resíduos e a capacidade de inovar constantemente parecem ser os fatores de sucesso determinantes nesta área.

Com base no exemplo prático das ações desenvolvidas pela Signify, empresa que atua no setor da iluminação, este caso de estudo pedagógico pretende ilustrar os impactos positivos gerados pela aplicação da abordagem circular num contexto real.

A metodologia da Signify para criar valor a longo prazo é fortemente influenciada por princípios circulares, como o produto como serviço e o *design* para a reciclabilidade através de melhores canais de logística inversa e o envolvimento de várias partes interessadas no processo de inovação. Desta forma, a empresa consegue gerir os seus resíduos de forma eficiente, lançar novos produtos alinhados com as últimas tendências de consumo e aproveitar as oportunidades de negócio decorrentes da sua abordagem ao mercado.

Palavras-chave: Sustentabilidade; Economia circular; gestão de resíduos; produto como serviço; eco inovações; oportunidades de negócio.

Classificação do sistema JEL:

Q01 - Desenvolvimento Sustentável

Q3 - Recursos Não Renováveis

Q51: Avaliação dos efeitos ambientais

Q53 - Poluição da Água • Resíduos Perigosos • Resíduos Sólidos • Reciclagem

Q56 - Meio Ambiente e Desenvolvimento; Sustentabilidade

Abstract

Trends in customer behaviour, the risk of supply chain disruption due to resource scarcity, rapid technological advances, and the watchful eye of governments and investors on companies' environmental performance are forcing them to adopt alternative and more sustainable business models.

This drive has given rise to several concepts, including the Circular Economy, which aims to optimise the use of resources by creating closed material loops.

Numerous strategies can lead to a so-called closed material loop. Still, effective waste management measures and the ability to constantly innovate are critical success factors in this area.

Based on the practical example of the actions taken by Signify, a company operating in the lighting sector, this pedagogical case study aims to illustrate the positive impacts of applying the circular approach in a real-world context.

Signify's methodology to create long-term value is heavily influenced by circular principles, such as product-as-a-service and designing for recyclability through improved reverse logistics channels and involving various stakeholders in the innovation process. In this way, the company can manage its waste efficiently, launch new products in line with the latest customer trends, and take advantage of business opportunities from its market approach.

Key words: Suistainability; Circular Economy; waste management; product-as-a-service; eco-innovations; business opportunities.

JEL Classification System:

Q01 - Sustainable Development

Q3 - Nonrenewable Resources

Q51: Valuation of Environmental Effects

Q53 - Water Pollution • Hazardous Waste • Solid Waste • Recycling

Q56 - Environment and Development; Sustainability

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List of abbreviations

CE- Circular Economy

CPFR- Collaborative planning, forecasting and replenishment.

DFR- Design for Recycling

EC- European Commission

EEEI-Electric and Electronic Equipment industry

EI-Eco-Innovation

EP- European Parliament

EOL-End of life

ESG- Environmental, Social and Governance performance

EU- European Union

FSC- Forest Stewardship Council

LE- linear Economy

LED-Light Emitting Diode

PEFC- Programme for the Endorsement of Forest Certification

PLE- Product Life Extension

PIR-Post industrial Residuals

PCR-Post-Consumer Residuals

RoHS- Restriction of Hazardous Substances

RPO- Retain Product Ownership

R&D- Research and Development

SCM- Supply chain Management

SDG- Sustainable Development Goals

SI- Systemic Innovation

SFI- Sustainable Forestry Initiative

SSL´s- Solid-state lighting

UN- United Nations

WEEE- Waste Electrical and Electronic Equipment

Introduction

Sustainability is increasingly important in the managerial field (Geissdoerfer et al., 2017). As the fundamental economic concern is how to fulfil the unlimited human needs with the limited existing resources (Samuelson & Nordhaus, 2010), being sustainable means ensuring the population's current needs without compromising the future generation's access to the same resources used nowadays (OECD, 2003).

Sustainability presupposes a "two-stage management", one that avoids resource scarcity in the present and another that avoids that resources needed in the current days generate resource scarcity in the future (Peattie & Charter, 2003:730).

Throughout the years, the expected sustainable behaviour has been transferred from individuals to companies and, in line with geopolitical and social pressure, concepts such as the *Triple bottom line* and *Corporate social responsibility* have emerged (Elkington, 1997 *cit in* Norman & MacDonald, 2004). The triple bottom line (3BL) concept relies on the assumption that as massive users of resources, the companies' responsibilities surpass the mere generation of profit - Financial bottom line - being firms also responsible for the societal and environmental well-being - People and the Planet's bottom lines (Norman & Macdonald, 2004). Corporate Social Responsibility (CSR) is a managerial field that stands for all the initiatives companies partake in to comply with its different stakeholders' needs (Lindgreen & Swaen, 2010).

More variables have been added to the sustainability equation to address environmental concerns, and even the traditional product life cycle has been challenged. What if we could still extract value from a product at the end of its life cycle?

A new paradigm emerged from the idea of the above paragraph, and the linear economy models gave way to Circular Economy (CE) ones that consist of "an industrial economy that is *restorative* or *regenerative* by intention and design" (MacArthur, 2013:14 cit in Nascimento et al., 2019:609).

Giving a disposable product a second chance may mitigate the impacts of waste produced by a given industry as companies "explore additional value via developing secondary products and services, generating new business models without the need to consume additional natural resources" (Zaleski & Chawla, 2020; Gil Munoz et al., 2020 *cit in* Felix et al., 2021:1).

Considering the above, the primary purpose of this master's dissertation is to measure how applying a circular economy model helped ***Signify*** reduce waste produced by its activity and to study how it generated new business opportunities and impacted the company's activity.

As markets are increasingly competitive, new and stricter government legislation about the impact of companies on the environment has entered into force, and consumers have become more aware of environmental concerns. Therefore, adopting a circular economy approach may become fundamental to companies' survival (Dubey et al., 2018). In this manner, using the example of Signify, this research aims to evaluate and quantify the beneficial impact of adopting that approach in waste management and its potential for creating new business opportunities.

Two research questions emerge from that aim:

Q1: How do CE practices at Philips Signify affect the company´s waste management?

Q2: How has CE helped Philips Signify innovate and create new business opportunities?

The research objectives that arise from the research questions are as follows:

1) Summarize the most relevant literature on European waste management directives, covering the specific case of e-waste.

2) Identify the impact of the CE approach on the waste management of Philips Signify.

3) Measure those effects using Circular Economy Micro level indicators.

4) Identify and classify the innovations associated with adopting CE-based business models.

5) Classify changes in the Supply Chain arising from CE approach implementation and how it generates new business opportunities in the EEE industry.

The present work assumes great importance considering the negative environmental impact of companies' activities, especially companies in the EEE sector, where Philips is integrated (European Parliament, 2023a). Every year, 2 billion tonnes of waste are produced, and if measures are not put in place by 2050, an increase of 70% in the total waste produced is expected. By then, no land will be available to accommodate the waste generated (World Bank, 2018). Also, to note that, to the present date, no papers have attempted to measure the impact of CE practices in businesses using quantitative metrics.

This dissertation is structured in four parts: the case study, the methodology, the Academic Note, and the conclusion.

The first chapter will delve into the topics covered by the case study. These include a detailed description of the lighting sector and the legal framework within which it operates. It will also examine the practices employed by the selected company that promote the circular economy and the innovative solutions introduced to the lighting market.

The second part encompasses a description of the methodology used.

At the beginning of the third part, the case's target audience and the pedagogical objectives to be achieved with the case study are delimitated. Those themes are followed by a literature review where the Circular Economy concept is explained, as well as the strategies related to the approach, and a review of the existing indicators to measure the effects of Circularity in businesses. This chapter ends with the presentation of the animation Plan, where the tasks and time per animation phase are specified, and the Case resolution that results from the data analysis, which includes the resolution slides.

Finally, the report's conclusions are presented with the highlights of each chapter's main ideas.

Chapter 1: The Case Study

This chapter will delve into the topics covered by the case study. These include a detailed description of the lighting sector and the legal framework within which it operates. It will also examine the practices employed by the selected company that promote the circular economy and the innovative solutions introduced to the lighting market.

1.1 Presentation of the issue

Natural resources scarcity, political, legal, and societal pressures, as well as new customer trends are forcing companies all over the world to rethink their modus operandi and shift to more sustainable business models (Geissdoerfer et al., 2017; Rodrigues et al., 2020).

Regarding the *resource availability and pricing* challenge mentioned earlier, we are at the end of the period when oil and resources are available at low prices. A shortage of fossil coals and limited natural reserves worldwide, combined with the increased demand, create challenges in managing production. More than just using fewer resources is required to contain the problem. In addition, rising inflation creates volatility in commodity prices, slowing economic progress and discouraging industries from taking supply-related risks (Adibi et al., 2017).

On the one hand, the procurement process is becoming more complex; on the other hand, companies must deal with the *increase in the world population***,** mainly medium-class buyers (Donmaz et al., 2017). Historically, the world passed for two major extensions of the medium class, and we are currently at the third one. On the Asian Continent, 525 million individuals are considered middle class, more than the entire population of the European Union (Ernst & Young, 2013b). In 20 years, it is projected that the middle class will increase by another three billion people, primarily prevenient from the emerging economies markets, widening demand and ultimately waste (Ernst & Young, 2013)

Those undesirable effects are especially problematic for the Electrical and electronic equipment that remains one of the fastest-increasing waste industries in the European Union, with current annual growth rates of 2% (European Commission, 2020a). It is projected that from the 12.4 million tons of products on the market, only 45.9% of electronic waste was recycled in the EU in 2020 (Eurostat, 2020a). That percentage is calculated based on the equation between the weight of WEEE collected and the average weight of electronic equipment put on the Market in the three preceding years, i.e., 2017-2019. The main reasons for that phenomenon are that products are not built in a way they can be reparable; their battery cannot be substituted; it is impossible to update the software for a new version; or the raw materials used in the equipment cannot be recuperated. A recent study found that two in three Europeans would prefer to preserve their present digital devices for more if possible (European Commission, 2020b).

The circular economy might create EU businesses' yearly net cost savings, varying from €250 to €465 billion, corresponding to a cut from 12 to 23 per cent of their current material expenses (European Parliament, 2023b).

Also, E-waste contains costly and scarce metals from a rising international supply scarceness viewpoint but also hazardous constituents (Akcil et al.,2019) that, if not appropriately discarded, can contaminate soils and waters and put at risk ecosystems (European Commission, 2020) and so the European Union set a group of directives with the intention of specifically mitigate those waste streams which are going to be explored in more detail afterwards.

Finally, in terms of the investor's point of view, one of the critical threats that the group ponder when they are making their investing decisions are the Climate risk and natural resource constraints (37%) as well as supply chain disruptions (21%) (Ernst & Young, 2023). On the other side, they see as the biggest driver of strategic success the Integration of material Environmental and Social Governance risks and opportunities into strategy (60%). Sustainable investing is the primary force across financial markets, so 35.9% of total assets under management are sustainable investments (GSI-Alliance, 2020). So, to attract and retain capital, companies more than ever need to commit to efficiency on ESG.

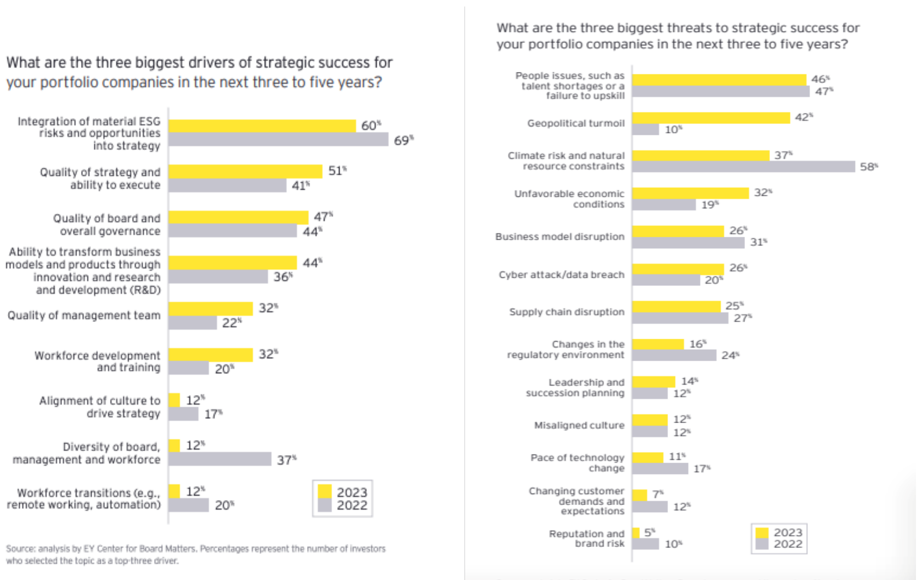


Figure 1.1: Investors perspective on the Drivers and Threats of strategic success Source: Ernst & Young, 2023:2

1.2 The Lighting Sector

Since its invention in the 19th century, artificial lighting has enjoyed great popularity among the public and has been the subject of continuous development (Zissis et al., 2021).

The production of artificial light captivates about 2 900 TWh, which is 16.5% of the annual world electricity production (Annex A). Although it is a highly profitable industry, the market is constantly growing, with a $1200000000 annual turnover (Zissis et al., 2021)

As a result of continuous industry innovation, the first phase saw the replacement of incandescent and halogen lamps worldwide with fluorescent technologies that are much more efficient than their predecessors (Zissis et al., 2021)

The last decade has seen an even more significant leap in efficiency with the introduction of SSL's solid-state lighting solutions, most notably Light Emitting Diode (LED) types. LED Tubes contain no hazardous substances, save energy (and therefore CO2 emissions), and their lifespan is typically 2 to 3 times longer than fluorescent tubes. Thus, LED has proven to be a trailblazer in every respect, outperforming conventional technologies and accounting for 46.5% of the global lighting market in 2019 (the latest available data) (Zissis et al., 2021).

As the market for fluorescent lamps continues to shrink, all electric lighting is expected to be based on SSLs (LED) soon. This change is occurring particularly rapidly in Europe, where the RoHS (Restriction of Hazardous Substances) Directive mandates the phase-out of all general-purpose fluorescent lamps by 2023 because they contain mercury, a chemical of significant public health concern. The region also adopted a minimum energy standard (MEPS) set at 85 lm/W, a figure that is much easier to achieve with solutions based on LED (Dermatini et al., 2022)

As for market trends (figure 2), as expected, they have been strongly influenced by the "LED-fiction" of the market, but similarly to all other sectors in the current era of digitalisation, by the impact of new disruptive technologies (Zissis et al., 2021)

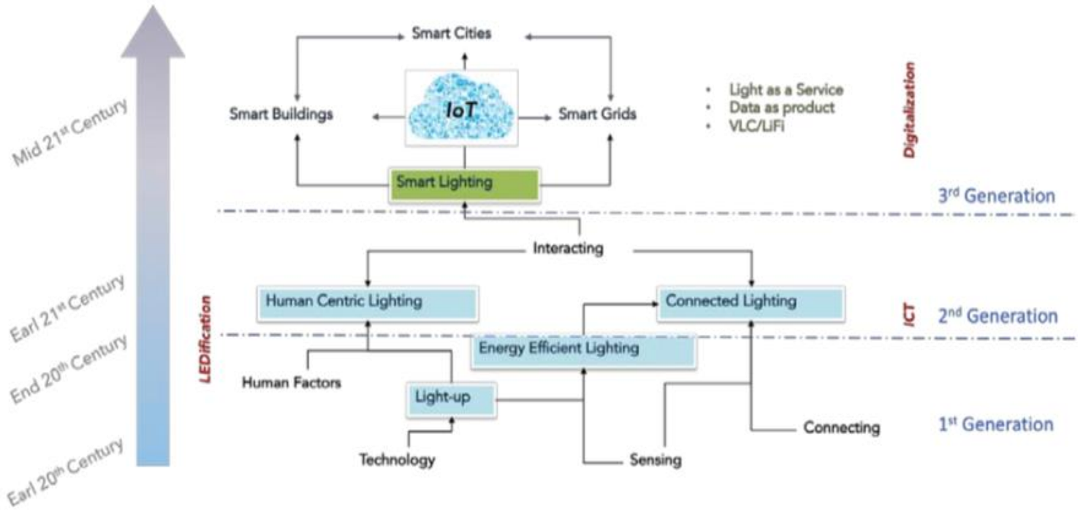


Figure 1.2: Lighting sector trends evolution Source: Zissis et al., 2021:6

Those trends are resumed in the table 1:

Table 1.1: Lighting sector market trends Inspired by Zissis et al., 2021.

Trends	Description
Human Centric Solutions (HCL)	Based on the scientifically proven assumption that different types of lighting have a physiological effect on living organisms, even in more abstract areas such as emotional state and motivation, this trend represents biologically effective lighting systems. Human-centred lighting solutions consider our need for clear vision and emotional and biological conditions to create an environment that enhances cognitive performance.
Connected lighting systems	This trend comprises all the data collection platforms integrated into lighting systems and contributes to superior energy performances in skyscrapers, homes, and towns. Connected lighting is an umbrella term for any lighting equipment that has a component of intelligence or connectivity. Each function or bulb in a networked lighting system has its exclusive hardware code connected to the common element of the system, usually called a “bridge."
Smart lightning	Innovative lighting solutions can be managed at a distance through smartphones or voice assistants and offer various functions, such as colour swapping, darkening, and scheduling. The system can include self-healing and realignment features.
Light as a Service	Represents the leasing-type models and ‘pay-per-use’ services applied to the light industry.

1.3 Legal Context

The waste prevenient from electrical and electronic equipment (widely known as WEEE or e-waste) in the EU is increasing rapidly. EU guidelines on WEEE's intent to contribute to sustainable production and consumption. They cover environmental and other concerns triggered by the rising amount of discarded electronics in the area (European Commission, 2020c).

WEEE comprises many devices such as computers, mobile phones, home appliances and lamps. These products are composed of a combination of resources, some harmful to the environment and may threaten public health if not discarded appropriately. Also, an essential factor to consider is that contemporary electronics encompass rare and costly resources, which can be reused if the discarded materials are efficiently collected, treated and recycled (European Commission, 2020c).

The European Union directives that regulate the e-waste management of their member states are based on two essential premises: The prolonged producer responsibility and the polluter pays principle (Andersen, 2022).

The implementation of *prolonged producer responsibility* in legislation obligates the original product manufacturers to upkeep their products even when they have no more utility to their final users and are thrown away by them (Alamerew & Brissaud, 2019).

On the other hand, the *polluter pays principle* delegates all the costs inherent to adequately handling the e-waste to the one responsible for producing those residuals (Andersen, 2022).

The amount of e-waste that has to be recovered or recycled by the producers of EEE is stipulated by the EU in Annex V of Directive 2012/19/EU (European Commission, 2012). Those targets are set based on the different EEE categories previously designated in Annex III of the same law, which are mutually exclusive. Table 2 summarises those targets:

Table 1.2: EEE recovery, reusing, and recycling targets based on categories Adapted from Annex V of the EU directive 2018/849)

EEE Category	Recovery target	Re-using/ Recycling target
1 or 4 **Temperature exchange equipment (1) and large equipment with external dimensions more than 50 cm (4)***	85%	80%
2	80%	70%

Screens, monitors, and equipment containing screens having a surface greater than 100 cm^2		
3 **Lamps**	-	80%
5 or 6 **Small equipment with external dimension below 50 cm (5)** and small IT and telecommunication equipment (dimension below 50 cm)**	75%	55%

***Includes large Household appliances; IT and telecommunication equipment; consumer equipment; luminaires; equipment reproducing sound or images; musical equipment; electrical and electronic tools; toys; leisure and sports equipment; medical devices; monitoring and control instruments; automatic dispensers; equipment for the generation of electric currents.**

****Includes small household appliances; consumer equipment; luminaires; equipment reproducing sound or images; musical equipment; electrical and electronic tools; toys; leisure and sports equipment; medical devices; monitoring and control instruments; automatic dispensers; equipment for the generation of electric currents**

Therefore, implementing a CE approach is fundamental for the EEE industry companies as they are forced by the legislation to meet the targets of recovery, reusing, and recycling of the e-waste generated by their activity.

Whereas enterprises may view the law observation as a means to escape the payment of a penalty, a business with an efficient WEEE observance structure can detect opportunities for improvement and decrease expenses that allow the entry of those companies as suppliers in recycling markets and government-supporting funds.

To help companies in that task, the EU set a new initiative called the ‘Circular Electronics Initiative’, mobilising existing and new instruments. Some of those instruments and actions are the following (European Commission, 2021):

- Eco-design Directive, so that devices are planned for energy efficiency and durability, reparability, upgradability, maintenance, reuse and recycling.
- The upcoming Eco-design Working Plan that will add more details to the Eco-design directive
- Regulatory procedures on chargers for mobile phones and similar devices, including the introduction of a standard charger, improving the durability of charging cables
- Refining the collection and treatment of WEEE by exploring options for an EU-wide take-back scheme to return or sell back old mobile phones, tablets and chargers;

- Review EU rules on restrictions of hazardous substances in electrical and electronic equipment and guide to improving coherence with relevant legislation, including REACH24 and Eco-design.

Another example of EU initiatives to enhance circularity is the *ecolabel regulation* (Regulation (EC) nº 66/2010 of the European Parliament and the Council of 25 November 2009). It consists of an ecolabel prize arrangement projected to endorse the production of goods with a low ecological footprint and offer buyers precise, non-deceptive, science-based evidence on the ecological influence of their purchases. The companies interested choose to apply for the prize as a volunteer procedure. The products and services provided by the applicant are going to be evaluated in terms of their *environmental performance***,** which can be depicted in the following criteria (European Commission, 2020d):

1. The sourcing process is wisely projected so that the raw materials elected can remain in a loop, implying that novel products have their origin in old ones.
2. Reduce discarded materials and environmental contamination.
3. Constrain the usage of hazardous substances.
4. Efficient production processes that allow the depletion of energy, water, and resource consumption
5. The products/services produced are inherently lifelong, reparable, and recyclable.
6. Stimulate eco-friendly innovations.

A set of new regulations regarding the topic is also on the verge of coming into existence. It is essential to highlight the right-to-repair law since it may primarily affect the EEE industry (European Parliament, 2020a).

The *right to repair law* will complement the contemporary customer policy mandatory items by stating that any customer will have the right to repair an electronic device that lost usability without any cost, *within the legal guarantee,* but also *beyond the legal guarantee,* a novel cluster of rights and instruments will be accessible the ‘repair' to accelerate and facilitate the repair process for costumers (European Commission, 2020e):

- **The customer´s right to request reparation from manufacturers for goods** that are officially repairable underneath the European Union regulation (e.g., a washing machine or a cell phone).
- The **A manufacturer must notify buyers about the products they** must repair themselves.

- An **online matchmaking repair platform** to link purchasers with repairers and sellers of restored products in their region.
- A **European Repair Information Form**, which consumers can request from any repairer, brings transparency to repair conditions and cost and makes it easier to compare repair offers.
- A **European quality standard for repair services** in the form of an indicator called ´easy repair` standard metric will be created to compare products and parts in terms of life extent and/or availability.

Regulations play an essential role as a variable in the companies' contingent environment since they can lead to drastic and not necessarily voluntary changes in the firms´ *modus operandi* (Elhossade et al., 2021). To be proactive and remain competitive, companies will have to adapt their demand not only to the existing regulations but also to the expected merging ones.

1.4 Company presentation

Signify, previously Philips Lightning, is a Dutch company and the world leader in the lighting sector. It has existed for over 130 years and has a core business in producing and selling indoor and outdoor lighting solutions for companies, individual customers and cities (Signify, 2020). Signify has around 40,000 employees and manufacturing facilities in over 70 countries (Ellen MacArthur Foundation, 2022).

The corporation´s product portfolio encompasses light bulbs, luminaires, controller mechanisms for ordinary users and experts, and Internet of Things-based equipment (Signify, 2023a)

The brands under their portfolio (Table 3) are Philips Lighting; Interact; Philips Hue; Color Kinects; Wiz; Vari-LIte; UHP; Modular lighting Instruments; Trulifi; Nature Connect, and BrightSites. In the table above, there is a brief description of each (Signify, 2023a)

Table 1.3: The Signify brands portfolio Inspired by: Signify, 2023a

Brands	Description
Philips lightning	It is the older and most traditional brand belonging to the Signify group. It is a well-known brand for domestic and business customers. It has recently expanded its market by providing tailored solutions to the horticultural lighting segment to meet the unique requirements of particular plants and vegetable growing conditions.

Interact	The Signify-protected, scalable IoT program gathers and shares data back and forth amid linked light locations, sensors and equipment incorporated in connected lighting systems networks.
Philips Hue	It is the Signify smart home lighting system. Philips Hue offers a wide range of smart light bulbs, lamps, fixtures and accessories. Lightning colours and intensity can be adjusted to the user's objective, whether concentrating, relaxing, energising, or just creating an ambience. It is also possible to sync the light with the music, movie or game the user is listening to or watching. (Philips Hue, 2023).
Color Kinects	Most of their products are designed to illuminate large buildings such as bridges, monuments and stadiums or even create artistic effects on facades. However, they also contain a smaller general offer of lighting applications indoors and outdoors.
Wiz	It is a smart lighting option based on sensors. Although as an intelligent solution, the system is programmed to make any adjustment needed, it also can be controlled by the user through voice commander, a remote console or independently of the user distance through the Wiz app.
Vari-Lite	It is an ultra-specialized and professional solution designed for the stage lighting of significant events such as theatre performances, music concerts and conferences.
UHP	It is another ultra-specialized solution based on ultra-high performance lamps for projecting applications. The line is designed so that the projected images gain incredible quality by enhancing the image's colours and creating more contrast.
Modular Lightning instruments	It is a premium line of architectural lighting designed to enhance a space's architectural beauty and character and attend to the needs of interior designers, architects and civil engineers.
Trulifi	It is a system that modifies light waves to transmit data. This technology enables, for example, a USB plugged into a computer to receive data and send data back to a light transceiver. Trulifi customers benefit from the lighting system and a consistent, secure, low-latency data connectivity mechanism. Trulifi can be retrofitted in existing luminaires or installed as a single system (Signify, 2023b)
Nature Connect	It is an intelligent lighting solution inspired by natural lighting conditions. It collects accurate- time information from outside and adjusts the indoor lightning conditions to what is more suitable and comfortable for the user, depending on the time of the day.
BrightSites	It is a solution that enables digital transformation among cities by using the existing streetlight structure to create a connectivity grid of end-to-end wireless points. Since outdoor lighting structures are everywhere, ending those points with Gbit technology can create a city where Wi-Fi and 4G/5G coverage are available ubiquitously.

1.4.1 The Signify Approach to Circular Economy

Each year, signify does a Strategic Review and a Sound Sustainability materiality assessment that combines the opinions of numerous internal and external agents, which are the future trends for the sector. The main conclusion of the last process was the global shift to *Energy effective solutions* guided by the supply disruptions in the energy sector due to the Ukraine-Russia conflict and consequent atypical inflation levels (Signify, 2023c)

Although Signify strategic priorities are guided by global trends and stakeholder expectations, they are also heavily directed to the accomplishment of six priority *Sustainable Development Goals* defined by the United Nations (UN SDGs): Affordable and Clean Energy (SDG 7), Responsible production and consumption (SDG 12); Climate Action (SDG 13); Health and Well-being (SDG 3); Decent Work and Economic growth (SDG 8) and Sustainable Cities and Communities (SDG 11). Its value proposition is "unlocking the extraordinary potential of light for *brighter lives* and a *better world*" (annexe B), denoting the company´s focus on creating long-term value beyond financial performance (Signify, 2023c)

The company makes sure to denote the Circular approach contributing to its sustainability commitment (annexe C), especially in three segments: Light for circular products, lighting for circularity services and lighting for circularity systems (Signify, 2023d).

1.4.1.1Lighting for circularity services

Signify pioneered the market in developing the *Light as a Service* program (Signify, 2023d)

By moving from a one-time sale to 'Light as a Service, Philips retains ownership of the materials. Managed services also extend the life and performance of products because, at the end of the service period, lighting products can be reinserted in the production cycle and given a new life by refurbishment, spare parts recovery or the recycling loop (Signify, 2023d).

Circular services aim to extend the service life and provide customers with services (annexe D) that combine lighting design, installation, and maintenance in a single contract with a five-year duration (Signify, 2023d).

By shifting its revenue model to a service-based one, the company has been able to proactively respond to several changes in its macro and microenvironment, including the legislative phase-out of incandescent bulbs, the quick progress of LED technology and rising price competition in the lighting commerce (Kramer et al., 2019 cit in Bocken, 2021).

The main advantages for Philips are establishing long-term relationships with customers, control over assets and substituting incandescent lamps facilitated, and the opportunity to sell other services in a bundle like IoT-Scalable transaction (Signify, 2023e).

The significant advantages for the customers are hassle-free experience from design, installation, operation and maintenance; no upfront investment, generating a positive cash flow from day one; their site monitored and maintained over time; and performance commitments on light levels and energy saving (Signify, 2023e).

1.4.1.2 Lighting for Circularity Products

Signify's LED drivers, LED modules and LED light sources are designed with *energy efficiency* in mind, as energy consumption during the use phase is the most significant part of life cycle analysis (LCA) for luminaires. As a result, all products meet the minimum luminous intensity (lm/W) required by the EU Lighting Regulation and have a lifetime of at least 50,000 hours. The wide range of optics also ensures that the placement of the luminaire can be optimised for each application (Signify, 2017).

The circular components are replaceable and have recyclable parts, such as drivers, controls and LED circuit boards. Instead of substituting the entire luminaire, the modules can be exchanged, preserving value and eliminating waste because spare parts are available for at least five years. The luminaires are also built to be upgraded, as they are equipped with an interface for a sensor that allows it to acquire attributes of intelligence or connectivity (Signify, 2017)

Another important aspect is that they are built to make *disassembly as easy as possible* (annexe E), as it is non-destructive and require only five steps. Signify also avoids mixing materials in components so that product dismantling at the *recycling* stage results in materials destined for different waste streams, for no glue or potted drives are used (Signify, 2017).

The *3D-printed luminaires* are part of the Green Switch program (Annex F) and aligned with Signify's Lighting for Circularity approach (Philips, 2023a).

One of the factors contributing to the circularity of these products is the *on-demand production* that 3D printing manufacturing technology enables, as it can guarantee extremely short production lead times. As a result, the company can eliminate the need to stock finished goods, reducing the risk of possessing obsolete inventory. This approach reduces idle capital and inefficient energy and material consumption and eliminates the need to maintain a warehouse (Philips, 2023a).

3D printing technology also allows combining multiple functions into a single component, requiring up to 40% fewer parts for these goods than analogous products made by conventional technologies (Philips, 2023a).

The printed parts of the luminaires are made from plastics consisting of at least 55% secondary raw materials. Three types of sources are preferred: post-consumer recycling, bio-circular materials and post-industrial recycling (Philips, 2023a)

Post-consumer recycling (PCR) is waste generated after the use phase of a product and used to make new products, such as fishing nets collected from the sea. Bio circular materials are made from wastes and residues of biological origin from agriculture, forestry and related industries (Graduzik et al.,2021), such as tall oil from the wood processing industry and used cooking oil. Post-industrial recycling (PIR) is waste material generated by another production process and later used to manufacture new products. Signify's post-industrial recycled material comes from producing polycarbonate panels for carports, swimming pools and neon signs. Their waste is shredded and turned into filament, used to make printed parts (Philips, 2023a).

Each printed part is *reusable and recyclable*. For this purpose, no paint, no glue and fewer screws are used, which facilitates the disassembly of the product and its recyclability when it reaches the end-of-life stage (Philips, 2023a).

1.4.1.3 Package requirements

As part of Signify's "zero plastic packaging programme" called Poseidon, the company has created a packaging requirements document (Signify, 2021a).

The scope of the document applies to (Signify, 2021a):

1. Packaging for all newly launched products and changes to packaging in the existing portfolio
2. Transport containers (e.g. A-boxes and pallet boxes)
3. Individual product packaging (e.g., boxes, blisters, and sleeves)
4. Supporting packaging materials (e.g., pallets, stretch film, dunnage).

These requirements apply to the entire supply chain, including the packaging they receive from their suppliers (Signify, 2021).

One of the main aspects of this policy is that the company promotes using *paper as the primary packaging raw material*. In addition, paper-based packaging must contain more than *80% recycled paper* on average, and the remaining 20% of virgin material must come from certified renewable sources such as FSC, SFI or PEFC (Signify, 2021a).

In cases where paper-based materials are not applicable, they look into other non-plastic alternatives, such as *bio-based materials* like bamboo and sugar cane (Signify, 2021a).

To further support the fight against global plastic waste, plastics in consumer goods packaging will be phased out to be plastic-free by the end of 2023. The company is expected to avoid using more than 2,500 tonnes of plastic annually by phasing out plastic for consumer goods packaging (Signify, 2021a).

The company is also improving its packaging design to make it *lighter and more compact.* This is not only predicted to positively impact the resource consumption of the packaging (by saving 6,000 tonnes per year of materials) but also to optimise transport, as smaller packaging provides more space in the transport units, which culminates in more quantity that can be transported (Signify, 2021a).

1.4.1.4 Renewable energy products

In Europe, 75% of greenhouse gas emissions come from energy production and use, making this a critical area for climate action. Solar lighting helps by being up to 75% more energy efficient and eliminating dependence on fossil fuels. In addition, solar modules require little maintenance and have a lifespan of up to 30 years (Signify, 2021b)

Signify's solar lighting offering (annexe G) consists of solar lights, solar modules and solar battery subsystems (Signify, 2021b).

For areas with low sunlight, there is also a hybrid solar technology solution that uses clean solar power when there is sunlight and the grid when there is no sunlight (Signify, 2021b).

The company considers solar lighting an essential element of its climate change action plan, allowing cities to reduce emissions and accelerate the use of renewable energy sources (Signify, 2021b).

Aside from the significant environmental benefits, solar lighting allows people not connected to the power grid to access lighting. Solar lighting is the perfect solution for these communities to improve health, safety and economic growth by reducing the burning of toxic materials to generate light and allowing business and educational activities to continue after sunset. In this sense, the company promotes social projects to procure solar light in different places such as Morocco, India, Mexico and the Philippines (Signify, 2021b).

1.4.1.5 Lighting for Circularity Systems

By 2020, more than 50 billion devices will be connected to the Internet (annexe H), the vast majority of them wireless (Signify, 2023f). Global data communications volume doubles every two years, resulting in Internet saturation. The trigger for this is the number of connected devices multiplied by the data consumption of each of these devices (Signify, 2023g).

However, today's most widely used Internet technology does not provide enough space to handle this growth. This results in unstable and less effective wireless connectivity coverage and slower throughput, disappointing user needs and expectations (Signify, 2023f).

There is also a growing concern about wireless security. Radio provides a layer of protection that anyone can sneak under. Unsecured or "open" networks are a haven for eavesdroppers (Signify, 2023g).

To address these needs, Signify's technology developments have led to the development of LiFi (short for Light Fidelity): LiFi is a wireless communications technology that uses light as a data carrier. A light communication system can transmit data quickly across the visible light, ultraviolet and infrared spectrums (annexe I). Currently, only LED lamps can be used to transmit visible light. Regarding the end application, the technology is comparable to WiFi - being the most evident variance, WiFi uses radio frequency to propagate data, and as already mentioned, Lifi does not (Signify, 2023g).

In order to work, a Trulifi system modulates light waves to transmit data using a transceiver. Then, all you need is a USB access key (annexe J), which can be plugged into your laptop to receive and send data (Signiify, 2023g).

The signify LiFi solution, unlike other LiFi systems, works whether the room lights are on, dimmed, or off, maintaining the transmission of data 24/7 (Signify, 2023g)

One of the fundamental competencies for enabling circular economy business models is the ability to track commodities, components, and material data to enable resource optimisation. Asset tracking and tracing support reverse logistics processes. On the other hand, asset composition information (subcomponents and materials) contributes to improved categorisation and collection of components. The usage information of a product or component determines the reusability and residual value of that asset (Laubscher & Marinelli, 2014).

Lifi provides this expertise by enabling *intelligent asset management*; in other words, monitoring serviceable luminaires to enable preventive maintenance is possible. Signify's connected systems tell us exactly when and where maintenance needs to be performed, saving waste, cost, downtime, and person hours (Signify, 2023c).

1.4.2 Environmental results and Sustainable operations

To better measure their environmental impact, the company ensures that their policies' value-added contribution is expressed in monetary terms. Therefore, the revenues arising from projects focusing on sustainability, including the circular economy revenues, climate change revenues, and Brighter Lifes Revenues, are separated from the remaining ones (Signify, 2023c).

Circular economy revenues are revenues from their circular portfolio, which includes lighting products, systems and services that maximise (re)usability, maintainability and upgradability and minimise value destruction to preserve value and avoid waste. Lighting solutions that contribute to this definition include (Signify, 2023h):

- Serviceable luminaires: Luminaires with easily replaceable (with standard tools) drivers and controls and LED circuit board to extend life or designed as recyclable luminaires that require an EPD.
- Circular components: replaceable and recyclable LED and conventional drivers and modules, most sensors that support system functionality, and 3D-printed enclosures.
- Intelligent systems: lifetime monitoring and preventive maintenance scheduling
- Circular services: services to prolong luminaire lifetimes and managed services with end-of-contract return options like LaaS.

Brighter Lives revenue emphasis on benefiting the community mainly in three areas (Signify, 2023h):

- Food availability: Lighting that enables the production of more and better quality food while optimising land, water and energy use and avoiding pesticides. This includes all dedicated products and systems for horticulture, all dedicated products and systems for urban agriculture, all dedicated products and systems for marine and terrestrial aquaculture, and all dedicated products and systems for animal agriculture.
- Safety and security: lighting that has a positive impact on reducing crime, such as burglary and theft in cities and homes, and increases security in traffic and protection against cybercrime and fraud. These include Interact solutions for cities, system solutions for tunnels, outdoor lighting with special sensors, emergency lighting and Lifi systems, Black Light Blue lamps and luminaires.
- Health and well-being: Lighting that supports human health, well-being and performance by harnessing the visual, biological and emotional benefits of light, as well as lighting that supports wildlife well-being. These include Eye Comfort, lighting for well-being, tunable products during use, non-invasive health-promoting products, disinfection and wildlife well-being.

Climate action revenues encompass revenue from lighting systems designed to save energy and reduce CO2 emissions. These include Solar solutions such as products and systems powered by renewable energy; Systems and managed services that enable further energy savings; Electronic ballasts (components) that meet the limits of the Uniform Lighting Ordinance; and Energy-efficient products that meet stringent luminous efficacy requirements, depending on lumen output that must be at least 80 lm/W (Signify, 2023h).

In 2022, the company was able to maintain its Brighter Lives revenues, which represent 27% of its total revenues and increased both its Circular Revenues and Climate action ones in comparison with the previous year (figure 3) (Signify, 2023c).

Brighter Lives highlights	2021	2022
Brighter lives revenues	25% - 27%*	27%
Women in leadership	25%	28%
Safety at work (TRC rate)	0.17	0.16
Supplier Sustainability Performance	98%	94%
Lives lit since 2017 (in million)	7.2	8.3

Better World highlights	2021	2022
Carbon reduction over value chain against Paris Agreement	On track*	On track*
Circular revenues	21% - 25%*	29%
Climate action revenues	61% - 64%*	65%
Carbon neutral operations	100%	100%
Total waste to landfill	<1%	<1%

* Results/assessments are based on current level of availability and accuracy of data

Figure 1.3: Sustainability projects revenues Source: Signify annual report 2022: 6

1.4.2.1 Water usage

The company recognises the growing importance of water usage, so they set a reduction goal of 5% a year of resource use in their facilities (Signify, 2023c).

In order to achieve that goal, the company is implementing water reuse schemes in their facilities and developing technology and business models that have a lower dependency on water (Signify, 2023c).

They also access the water stress level in their locations and prioritise implementing their saving measures in those regions (Signify, 2023c).

The company has been evolving positively in terms of its water consumption (figure 4).

Water intake in thousands of m³

	2020	2021	2022
Total water	971	1,432	1,164

Figure 1.4: Signify Water usage in the past three years Source: Signify annual report 2022:164

1.4.2.2 Co2 emissions

The *European Green Deal* is the world’s most comprehensive climate action initiative, with ambitious goals to achieve a carbon-neutral continent by 2050 and reconcile how we consume resources. The Signify Green Switch program allows the company to take action in that area without delay. LED and connected lighting offers were the company's main proposal to manage Carbon emissions (Signify, 2021b).

Over the last decade, Signify reduced its operational footprint by more than 70% and has been driving hundreds of initiatives to reduce emissions in factories, offices, logistics, and business travel. As a result, Signify was the *first lighting company in the world to become carbon neutral in September 2020*. This means GHG emissions from their manufacturing and non-industrial locations (scope 1 and 2), upstream and downstream logistics activities (scope 3), and business travel (scope 3) are all carbon neutral (figure 5) (Signify, 2021b).

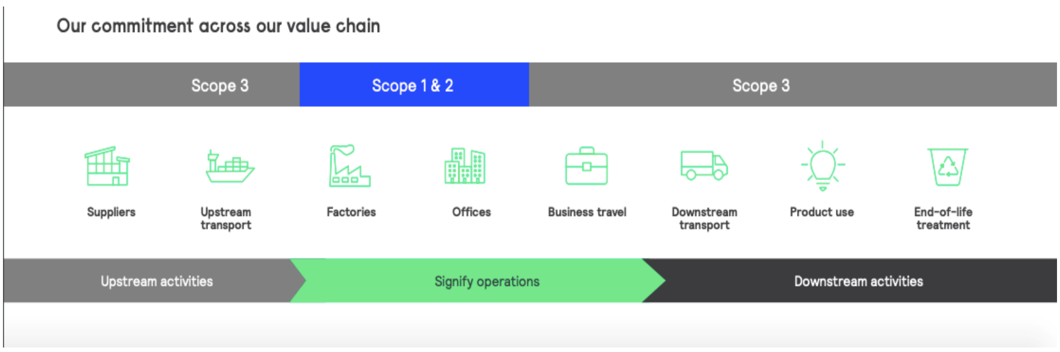


Figure 1.5: Signify value chain activities Source: Climate Action Report 2021:9

The company achieved carbon neutrality (annexe K) by investing in more efficient and cleaner products, using renewable energy in operations, changing the transport modes (logistics) and reducing business travel (Signify, 2021b).

Regarding investing in cleaner and more efficient products, the company recognises that many of the value chain emissions occur in their products' use phase.

As mentioned earlier, Led luminaires are known for their carbon emission savings and high efficiency. Switching to LED can reduce electricity consumption by up to 50%. Since 70% of the company's total sales are based on LED, this shows the company's efforts in this area (Signify, 2021b).

However, when LEDs are connected, the electricity consumption reduction can reach 80%. Signify's networked lighting systems consist of LEDs with integrated sensors connected to application software. This makes it possible to automate and optimise light settings for different applications and provide the right light level in the right place at the right time (Signify, 2021b).

Operational neutrality was also strongly influenced by the fact that Signify purchases 100% renewable electricity for its global operations and contributes to the green energy transition through Power Purchase Agreements (PPA). A corporate power purchase agreement (renewable energy) PPA is a long-term contract between a green power producer and a company that purchases electricity to buy green power. A company's participation in a PPA makes the project financially feasible, helping to accelerate the green energy transition. In recent years, Signify has invested in three different PPAs in the U.S., Poland and Finland. PPAs for companies not only help them achieve their goals but also play a role in accelerating countries' transition to greener power grids (Signify, 2021b).

By switching to digital learning in 2021, the company has reduced business travel and avoided 500 tonnes of CO_2 emissions. When travel is unavoidable, companies prefer means of transport that are more environmentally friendly, such as terrestrial ones (Signify, 2021b).

Another important initiative in which the company is involved is the *Paris Agreement***.** In November 2015, 197 countries agreed to limit global warming to well below two °C above pre-industrial levels and to continue efforts to limit warming to 1.5 °C. To achieve this, halving global greenhouse gas emissions by 2030 is imperative (Signify, 2021b).

CE operational models, as well as climate action, are needed to help countries meet the Paris Agreement (Circle Economy, 2021, cit in Jesus et al. 2021)

In line with its commitment to climate action (SDG 13) and affordable and clean energy (SDG 7), the company has pledged to double the pace of the Paris Agreement’s 1.50C scenario to reduce greenhouse gas emissions across the value chain by the end of 2025. This means the company plans to reduce emissions in the value chain at twice the pace of the Paris Agreement's 1.50C scenario. In other words, the company plans to reach the 2030 Paris Agreement targets five years earlier. This means that the company is increasing the energy efficiency of its portfolio, helping its customers to reduce emissions, and driving carbon reduction at suppliers (Signify, 2021b).

Regarding the last topic mentioned, it is essential to remark that Signify works with many global and local suppliers. As a baseline to build a sustainable business relationship with their suppliers, they require them to conform to the Signify *Supplier Sustainability Declaration* that sets out the standards and behaviour required of their suppliers to improve conditions in the chain, including regarding climate change actions. Consequently, suppliers must report and provide evidence of compliance with the requirements imposed by Signify, which also regularly carries out audits (Signify, 2021b).

Additionally, they have engaged their suppliers in their climate action journey by proactively initiating, developing and supporting carbon emission reduction activities through their partnership with the CDP Supply Chain program (Signify, 2021b).

1.4.2.3 Waste to Landfill

The company is committed to sending zero manufacturing waste to landfills and keeping the recycling rate as high as possible. For that reason, in 2022, their focus was driving continuous improvements and process optimisation across the globe. At the end of the year, Signify was sending zero waste to landfills in all its sites, except one that was recently acquired and was still transitioning to reach that status (Signify, 2023c).

That result was achieved by improvement of their practices regarding waste segregation, waste awareness training and sharing best practices across regions (signify, 2023c).

Their recycling programs address waste from manufacturing activities, such as glass or canteen waste and suppliers, such as packaging materials. 89% of total waste was recycled in 2022, and the company continued to recycle 100% of its metal and glass waste (annexe L). Those recycling rates were only possible through their engagement with the Collection and Recycling Organizations (CRSOs) union (Philips, 2015).

After perceiving that municipal recycling programs were insufficient, in 2003, European lamp manufacturers (including Philips) created CRSOs dedicated to lamps. The need for this was driven by the fact that the collection and treatment of lamps are costly. In contrast, most other waste categories contain valuable materials that generate a residual value. The high cost of lamps is mainly due to the high volumes with low average weight and the special treatment required due to their fragility and the mercury included in most lamp types (Philips, 2015).

Separate CRSOs have been established in each EU Member State. The CRSOs are responsible for disposing of WEEE on behalf of all producers or importers participating in these collective schemes (so-called participants). The CRSOs are financed via a WEEE fee that participants pay as part of a pay-as-you-go scheme based on products on the market (Philips, 2015).

Total manufacturing waste consists of waste that is delivered for recycling, incineration or landfill, and the leading figures are presented in Annex J.

1.4.3 Innovations

As the company's strategic vision relies heavily on sustainable development, critical innovation investments are also being made. In 2022 alone, Signify invested € 264 million in sustainable innovation (figure 6), representing 89.5% of Signify's R&D spend (92.9% in 2021). This underscores the company´s belief that sustainable innovation will help create an increasingly future-proof and purposeful portfolio of products, systems and services (Signify, 2023c).

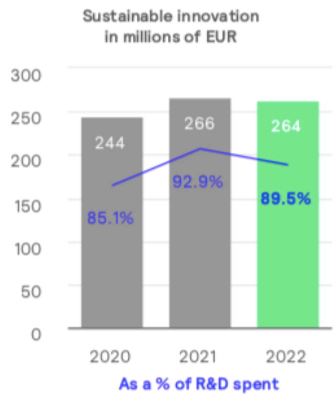


Figure 1.6: Investiment in suistanaible innovation Source: Signify anual report 2022:143

Some of the innovations Signify has brought to market have already been mentioned, such as 3D printing technology, LiFi and Light as a Service. However, the company is also highlighting other key innovations, such as *UVC lighting* and *Philips LED Horticulture* offerings, that have allowed the company to enter other markets beyond traditional lighting (Signify, 2023c).

The air quality and the cleanliness of the surfaces we touch significantly impact our health and well-being. We are all at risk of contracting and spreading viruses and bacteria, especially in busy public areas such as offices, stores, schools, museums and public transportation. UV-C radiation is a proven and effective means of neutralising viruses (Annex M). In laboratory tests, Signify's UV-C light sources reduced the infectivity of the SARS-CoV-2 virus on a surface to undetectable levels in as little as 9 seconds (Philips, 2023b).

Scientists have used UV-C extensively for over 40 years, and it is a well-known disinfectant for air, water and surfaces. All bacteria and viruses tested to date respond to UV-C radiation.

Signify has been at the forefront of UV technology for many years and has a proven track record of developing innovative UV-C products and applications (Signify, 2023i).

UV systems can be used to disinfect surfaces, objects and even water. In the latter case, this light can take on various applications as a water disinfectant, including drinking water, wastewater, process water, swimming pools and ponds. UV lamps are available in wattages from 4W to 1000W, so it can design disinfection systems for small (litres/min) to extensive municipal facilities using several hundred lamps (Philips, 2023c).

Thanks to innovative cultivation technologies, plants can grow indoors without sunlight. This growing method, called vertical farming or city farming, is ideal for propagating young plants, growing complete plants, and growing healthier, pesticide-free crops. Some other advantages are enabling local production and *water use savings of at least 90%* compared to traditional types of cultivation. It also maximises production by using groundbreaking vertical farming lighting to illuminate multiple layers of plants for higher yields in less space. With its extensive lighting knowledge and crop expertise, *Philips LED horticulture* offers vertical farmers advice on successfully growing crops with their LEDs (Philips, 2023d).

The company also provides tips on the most reliable techniques and LED vertical farming lighting products for growing crops indoors, as it has its research centre. The *GrownWise research centre* comprises experts who study the conditions necessary for optimal plant growth. This includes the impact that different types of vertical lighting, climate systems, nutrition, irrigation, sensors, and data collection can have on plant health and quality (Philips, 2023d).

Signify's offering in this area goes beyond just commercialising products, as the company also provides a lighting control system that can easily create and run customised lighting recipes to meet the needs of specific plants and improve quality and productivity. The software is suitable for the GreenPower LED Dynamic production module and can be controlled via a mobile device or computer (Philips, 2023d).

1.4.3.1 Open Innovation and co-Creation as New business opportunities vehicles

Although Signify introduces many innovations on its own, many are also the result of collaborative efforts with other institutions, as the company believes that working with respected institutions creates a virtuous cycle and amplifies its voice in the corridors of power (Signify, 2023c).

One of its partners is the public sector, as governments actively address the climate crisis and sustainability issues. The company believes that public-private collaborations create a space for shared knowledge and faster development through advocacy, accountability and collaboration (Signify, 2023c).

The company also partners with several non-governmental organisations, including The Climate Group, a non-profit organisation that works with business and political leaders to address climate change. This United Nations partner helps organise Climate Week in New York City and helps organisations implement their pledges. They joined the company's RE100 initiative, which commits to 100% renewable electricity, and the EV100 program, which aims to make electric vehicles the standard by 2030. Other laudable initiatives, such as the World Green Building Council's (WGBC) Net Zero Carbon Buildings initiative, underscore the need to learn from each other, commit, and act. Working with these groups introduces the company to a network of other organisations following the same path. This enables the mutual transfer of inspiration, collaboration and, above all, action (Signify, 2021b).

To support its goal of carbon neutrality, the company has forged another critical partnership with Maersk, which has led to the launch of eight new ships powered by zero-carbon fuels. Maersk is one of the company's most essential partners in the field of maritime logistics (Signify, 2021b).

The collaboration with Collection and Recycling Operations (CROs) for the disposal of old equipment and participation in national WEEE schemes also opened doors that made waste management more efficient and helped the company find potential buyers for its old equipment (annexe N) (Philips, 2015).

To continuously improve its supplier base, Signify has implemented a supplier development program to help suppliers improve their performance. Through targeted activities, training courses and on-site audits and support, they help improve supplier quality and efficiency (Signify, 2023c).

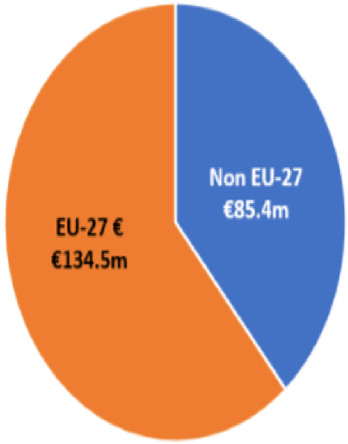
Last but not least, the company has also launched a co-creation platform called *Pioneers of Light*, a community composed of the world's best architects, lighting designers and engineers united by their passion for realising their visions through innovative lighting. We guide and inspire the next generation to develop sustainable lighting solutions that make the world better and brighter (Signify, 2023j).

1.5 Case Study Questions

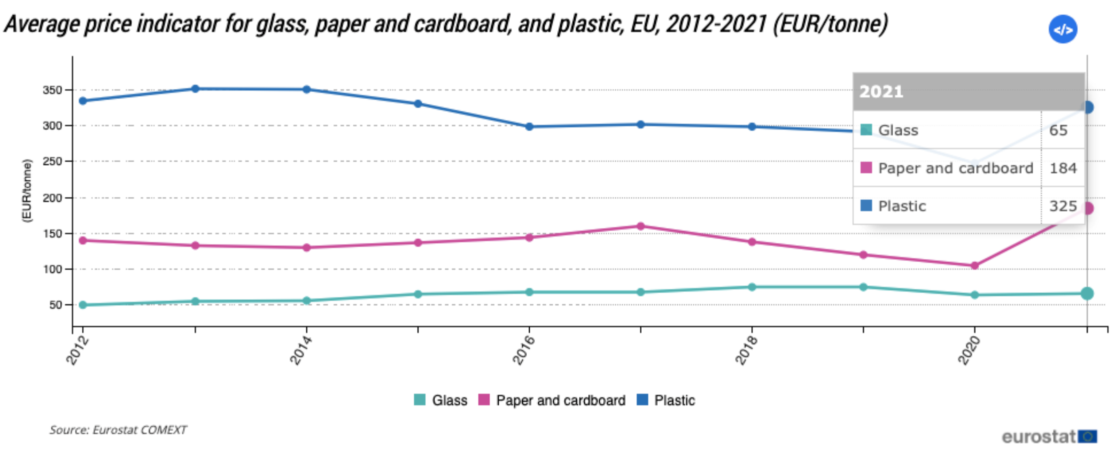
1) Describe the Circular Economy concept, how the model works, and the customers' behaviour trends that enabled that model. (The students can do additional research on the topic if wanted)

2) What three strategies can a manufacturing company use to achieve circularity? Are the Signify practices related to any of those strategies? If so, are the strategies chosen in accordance with the Circularity matrix proposed by Atasu et al., 2021?
3) As a company that belongs to the WEEE industry, what are the two essential duties established by the WEEE directive in terms of the waste management of Philips and is the company meeting the recycling target imposed by the law?
4) Are Philips lamps eligible for the Ecolabel? Justify mentioning policies that meet Ecolabel criteria.
5) Since the company has to gradually withdraw all its fluorescent lamps from the market due to the restriction imposed by the European Union on the use of Mercury, the following circular economy indicators should be calculated for them (use the data contained in the attachments and appendix 1):
    5.1 The Potential reuse indicator of mercury
    5.2 The Circular Economy Index of Glass
    5.3 The product level circularity of Plastic
6) Identify and classify the innovations Philips brought to their Circular approach to the market and how it affected their supply chain management and ability to create new business opportunities.

Attachments to the case study questions



Attachment 1:Trade value of fluorescnet lamps in 2020 Source: Dermatini et al., 2022:13



Attachment 2: Average price of secondary raw materiasl-Plastic, paper and glass in EU Source: Eurostat, (2029.) https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Recycling_%E2%80%93_secondary_material_price_indicator

5.7.2 Comparison of scenarios on potential value of materials recoverable from WEEE

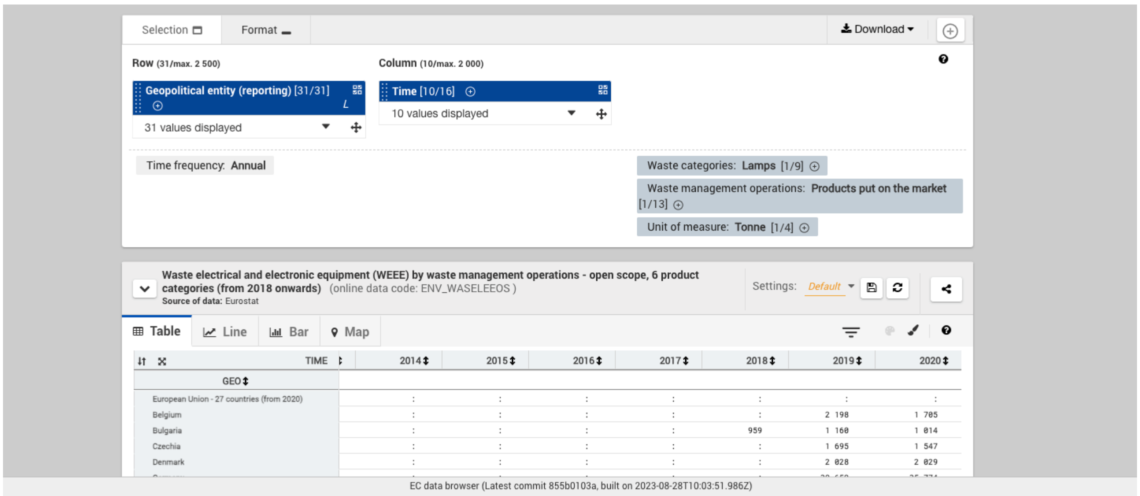
Identifying the different materials that can be recovered from the categories (Annex 9.5 and 9.6) and their resale prices (Annex 9.7) enable a comparison of the scenarios based on the potential value that could be gained from recycling materials that may be lost if no individual targets are implemented.

Potential value of materials (in M€)					
	Scenario 1	Per cent collected	Scenario 2	Per cent collected	Scenario 2 compared to Scenario 1
Cat 1	758	95%	678	85%	-80
Cat 2	904	95%	809	85%	-95
Cat 3	18	16%	93	85%	76
Cat 4 exc. PV	1.211	95%	1.083	85%	-127
Cat 5	1.591	70%	1.932	85%	341
Cat 6	439	70%	534	85%	94
PV Panels	25	85%	25	85%	0
Total EU	**4.946**	**85%**	**5.154**	**85%**	**208**

Table 19: Comparison scenarios on the basis of potential value of materials recovered (M€).

October 2014 I *64*

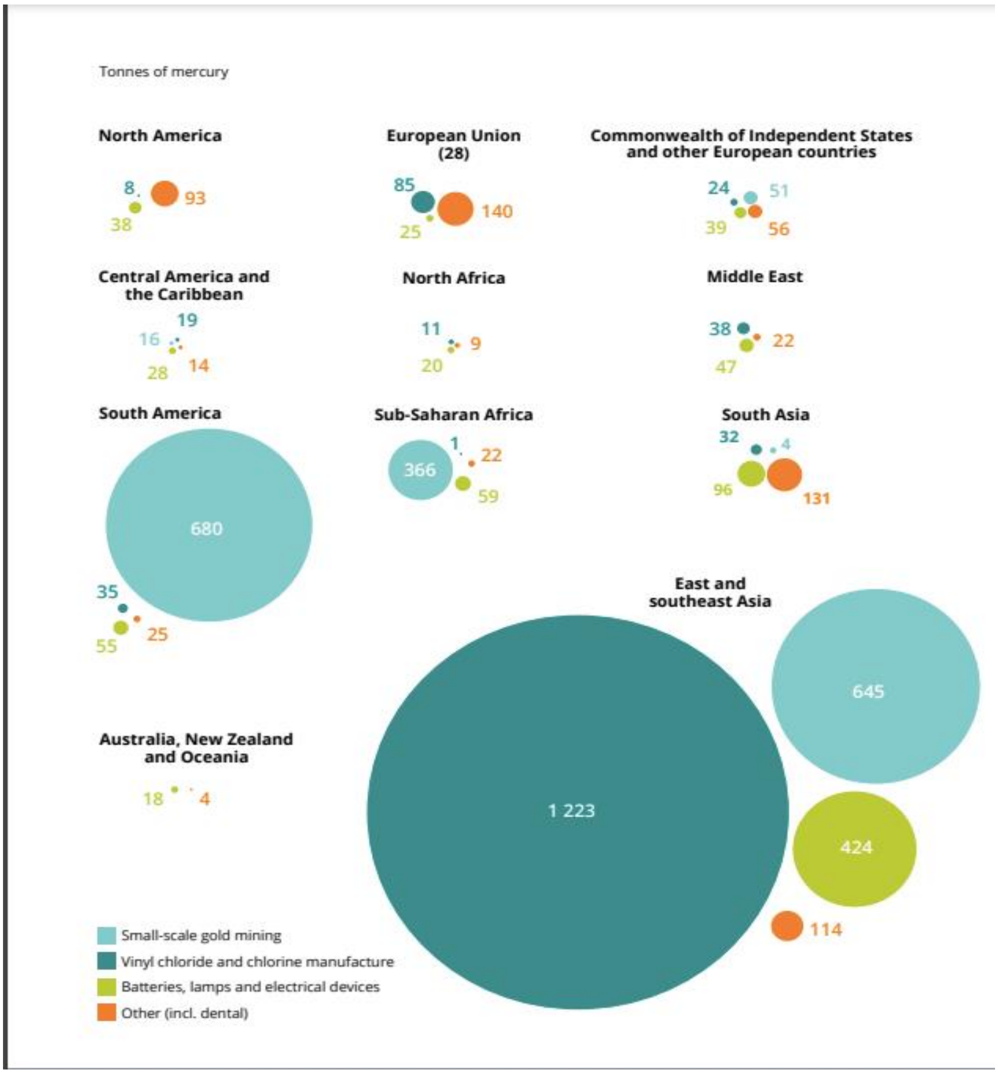
Attachment 3: Potential value of materials recovered in euros, per category of the WEEE directive Source: European Commission, 2014:64



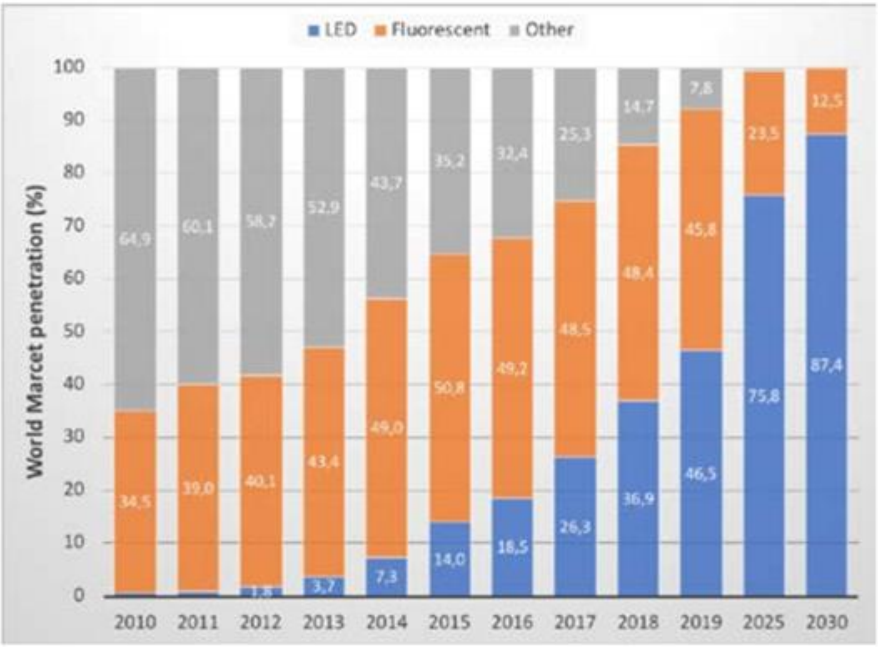
TIME / GEO	2014	2015	2016	2017	2018	2019	2020
European Union - 27 countries (from 2020)	:	:	:	:	:	:	:
Belgium	:	:	:	:	:	2 198	1 705
Bulgaria	:	:	:	:	959	1 160	1 014
Czechia	:	:	:	:	:	1 695	1 547
Denmark	:	:	:	:	:	2 028	2 029
Germany	:	:	:	:	:	39 659	35 774
Estonia	:	:	:	:	:	462	494
Ireland	:	:	:	:	:	1 364	1 259
Greece	:	:	:	:	:	3 169	2 797
Spain	:	:	:	:	:	5 475	4 717
France	:	:	:	:	:	10 008	9 291
Croatia	:	:	:	:	:	878	959
Italy	:	:	:	:	:	8 729	6 662
Cyprus	:	:	:	:	:	33	30 (ep)
Latvia	:	:	:	:	:	312	271
Lithuania	:	:	:	:	379	353	425
Luxembourg	:	:	:	:	:	167	149
Hungary	:	:	:	:	1 196	1 503	1 421
Malta	:	:	:	:	:	211	221
Netherlands	:	:	:	:	:	3 576	3 713
Austria	:	:	:	:	:	1 400	1 223
Poland	:	:	:	:	19 388	19 794	16 690
Portugal	:	:	:	:	2 280	1 367	1 370
Romania	:	:	:	:	:	:	:
Slovenia	:	:	:	:	:	241	250
Slovakia	:	:	:	:	:	947	947
Finland	:	:	:	:	:	1 327	1 163
Sweden	:	:	:	:	:	5 638	3 214
Iceland	:	:	:	:	:	142	154
Liechtenstein	:	:	:	:	:	:	:
	:	:	:	:	:	2 205	1 982

Information
Actions
Visualisations

Attachment 4: Put on market quantities in tonnes per WEEE directive category in the EU Source: Eurostat, 2023



Attachment 5: Quantities of mercury in tonnes used per activity Source: European Environmental Agency, 2018:37



Attachment 6: LED lamps, fluorescent lamps, and others market penetration Source: Zissis et al., 2021:28

Chapter 2: Methodology

Pedagogical case studies have been used previously as a didactic tool in many educational fields that seek to explore the impact of multifaceted social phenomena and subsequently have turned into a widespread technique for business and administration ones, since as physiology and other knowledge areas, management cannot be classified as an exact science (Yin, 2009 *cit in* Remenyi et al., 2002).

A case study portrays a real-life context that can illustrate a specific problem in which notions from the theory can be perceived (Barney & Hesterly, 2014). It aims to stipulate a foundation for reflection and debate deprived of the prerequisite for rigorous empirical analysis as other case study types require (Yin, 2009). Although there is not a rigid rule, it is also important to note that it is an adequate method to answer research questions aimed to describe "how" or "why" a particular phenomenon operates and provide an "extensive and in-depth description" of it (Yin, 2009:5).

Since this study's research questions are how to Signify circular-based practices affect the company´s waste management and how it helps create new business opportunities, and a broad description of the company's actions in a field is used along the study, the pedagogical case study method is suitable. In addition, the indicators used to perform the quantitative analysis of CE impact are built for a microeconomic logic, thus requiring data on the same scale.

The methodology used for this Case Study is mixed since both qualitative and quantitative data need to be used to complete it.

This case study is based on secondary data. The information presented in the literature review was gathered by searching for scientific articles from credible sources such as Research Gate, ScienceDirect and Harvard Business Press. The keywords used were "Circular Economy", "Circular Economy based models", "Measurement of Circular Economy practices", and "E-Waste management". Punctually, some books were used as references for explaining theoretical concepts, as well as Ellen MacArthur Foundation studies and website information.

The company data was gathered by consulting official reports such as the company's annual report, sustainability report and supplement, and website and academic articles that used the company as a Circular business model example. The legislation data contained in the legal context was gathered from the European Commission and European Parliament websites and the market prices used at Eurostat.

Signify was chosen as the Case company since it is a global enterprise that belongs to the EEE industry, which, as mentioned before, is one of the most impacting waste productions. Also, it has been recognised by several private and public entities like the Ellen MacArthur Foundation, the United Nations, and the Dutch Ministry of Economics as a successful reference for its commitment and action towards sustainability and Circularity but also for all the prizes it achieved in that area, serving as recent examples the (Signify, 2023l):

- **World Member of DJSI index 2022:** The Dow Jones Sustainability Indices (DJSI) initiative resulted from the collaboration between S&P Dow Jones Indexes and RobecoSAM that created several Sustainability indicators. Those indices allow for assessing the sustainability performance of the most significant international corporations.
- **A-List member of CDP 2022:** The Carbon Disclosure Project is an international non-profit association responsible for the world's ecological disclosure system for enterprises, cities, states, and regions. The yearly Climate A List stipulates the world's front-runners in ecological transparency. In 2022, around 20,000 candidates were evaluated.
- **Prime Status of ISS ESG 2022:** The Prime Status award is given by ISS Corporate Solutions based on the assessment of candidates' Environmental, Social and Governance (ESG)performance. That recognition guaranteed a position on the 1st Decile Rank within the EEE industry group.

Chapter 3: Academic Note

This chapter comprises the target audience of the case definition and the pedagogical goals to be achieved by the case solution and the corresponding lecture plan. These topics are followed by a literature review explaining the concept of circular economy, the strategies related to the approach, and the role of eco-innovation in these systems. This part of the report ends with presenting the case resolution, which is the result of integrating information about the company and the theoretical concepts presented in the literature review and includes the corresponding solution slides.

3.1 Target

Given its nature, the present case study target is bachelor's or master's degree students from the management field or whose courses are related to Corporate Sustainability, but also professionals who want to learn more about Circular Economy models and their impact in the real organisational contexts qualitatively and quantitatively.

3.2 Learning Objectives

This case study aims to create awareness of the Circular Economy approach as an alternative to the Linear Economy, where most companies still operate nowadays. Having as a reference point the Signify business model based on sustainability and Circularity, it is crucial that at the end of the case, students can recognise Circular practices, have a clear idea of how a circular-based business model operates, as well as the positive outcomes that arise from their adoption namely their impact in the waste management of companies, both qualitatively and quantitatively, and compliance with current legislation regarding the subject. Nevertheless, there are also business opportunities that arise from adopting that model. In order to correlate the theoretical concepts with the practical example, this case study is also expected to develop the analytical and critical competence of the target. For the professionals using this case study, it is intended to be used as a benchmarking instrument for their businesses.

3.3 Lecture plan

Table 3.1: Lecture plan Source: Self-made

Session	Activity	Activity Time
Before Class preparation	Teachers should make The Case study material available before the first session so that students can read the case at home.	1 hour
Session 1	The teacher must promote a collective discussion about the main ideas from the Case Reading, namely the main theoretical concepts and the strategies the company used to achieve Circularity.	45 minutes
Session 2	Students must create groups of 4 to 5 elements and answer questions 1, 2, 3 and 4. Each group must deliver a document containing their question answers at the end of the class	2 hours
Session 3	Students must answer questions 5 and 6 individually during the class and deliver a final document containing their answers at the end of the class.	1 hour
Session 4	The teacher must give feedback on the work delivered and present the Case resolution to students. Also, clarify doubts and ask students for examples of companies taking steps towards Circularity.	2 hours

3.4 Literature review

3.4.1 The Circular Economy Concept

As with many other multi-disciplinary concepts, the CE concept has been evolved throughout the time.

The CE concept appeared in 1966 by Boulding (cit in Rodríguez et al., 2020), which defined two opposite types of economies, the nowadays known as linear and the circular one. Following that author, the main difference between the two types of economies lay in the relationship they establish with the environment, being the linear environmental destructive and reckless type of economy led by the premise of "take, make, and dispose of" and the circular an environmentally friendly and cyclical approach.

The natural living systems inspire the circular economy approach with *no landfills*. Instead, materials flow and *one species' waste is another species' food*. All the energy required for the system to work is provided by the sun (*renewable energy*), and as the species grow and die, nutrients *return* safely to the soil (their *original point*) (Rodriguez et al., 2020).

To summarise, a circular economy can be defined as a new economic paradigm (figure 1), which emphasises preserving the materials as long as possible in the supply chains by maintaining or even elevating their value through reverse logistics flows or over services and *non-ownership-centred* consumption solutions such as the "*pay-per-use*" or *product as a service* one (Antikainen & Valkokari, 2016 and Stahel, 2016 cit in Ünal et al., 2018) mainly encouraged by the *sharing* and *collaborative consumption costumers behaviours trends (Belk, 2014).*

We are living in a *post-ownership* era, and *sharing* behaviour stands for "the act or process of distributing what is ours to others for their use or the act of receiving or taking something from others for our use" in a gift-giving type of transaction where only one of the parties benefits from it (Belk, 2007). The sharing trend emerged primarily through non-paid online platforms diffused mainly in the Internet 2.0 that allowed downloading music, videos and movies for free in a phenomenon that became known as the *Sharing Turn* (Belk, 2014)

On the other hand, a collaborative consumption event occurs when, instead of buying the good, the customer prefers to rent it, having *temporary access* to it. Unlike the sharing transactions in the collaborative consumption, both parties evolved in the transaction benefits from it (Belk, 2014).

A circular business model is premeditated to form and retain value while facilitating optimal resource usage (Lahti et al., 2018). As a result, the business model's objective moves from creating profits over the trade of products to generating profits by "the flow of resources, materials, and products over time, including reusing goods and recycling resources" (Lahti et al., 2018:3). The selection of raw materials in the sourcing and procurement business process must also attend to the criteria of holding the minor percentage of hazardous materials and be as purer as possible to facilitate the separation and reutilization processes. (Park & Chertow, 2014). The product design should consider the easiness of dissemble required to recover materials in reverse flows, and product package materials should also consider eco-friendly logic, being made of recoverable or at least recyclable constituents (Vanegas et al., 2016).

However, adopting Circularity also presupposes the optimal use of any resource involved in the production process, not only raw materials or minimum energy usage, and those must be preferably green (Linder et al., 2017).

3.4.2 How does a circular economy work?

Reverse logistics is the procedure "of planning, implementing and controlling the efficient and cost-effective flow of no longer serviceable materials in the inventory process. Moreover, it involves obtaining finished products, from the consumption point to origin point, to recapture value or discard them appropriately" (Sheriff et al., 2012 *cit in* Oliveira et al., 2019:1098).

A circular economy is formed by two locked circles representing two types of supply chains: a forward and a reverse one. A recovered product re-enters the forward chain through the reverse one (Wells & Seitz, 2005 *cit in* Antikainen & Valkokari, 2016). That process generates what is called a *closed material system* (ISO, 2006) where the life cycle of a given material is not finished at the EOL phase but instead is recycled and used for the same or a different purpose (Dubreuil et al., 2010 *cit in* Graedel et al., 2011).

It is also important to note that every time a material is cast off to landfills, due to neither their non-collection nor the inexistence of technology available to recapture their value, at least efficiently, we are in the presence of an *Open life cycle* instead of a closed one, which characterises linear economies and not circular ones (Graedel et al., 2011).

One of the ways of enabling reverse materials flows is through *product reconstruction.* Practising is one of the fundamental options available (Hazen & Mollenkopf, 2017). The activity promotes a decrease in the use of natural resources as companies purchase second-hand products from customers, recuperating their residual value and reintroducing those goods in the market as new sale options (Atasu et al., 2010). However, to reintroduce the goods in the market, organisations restructure them through one of three processes: remanufacturing, refurbishing or recycling (Gaur et al., 2018). The *remanufacturing* process requires substituting only the damaged components for new or even upgraded ones, re-establishing the product quality level (for example, changing an addicted battery for a new one in a cell phone). The *refurbishing* process, however, requires a more drastic change as most of the original product components are reconstructed or replaced with new ones. Lastly, *recycling* implies the total disassembly of the products into small parts used as raw materials to generate different products than the original ones (Gaur et al., 2017). However, the 3 R´s processes are often challenging to achieve since modern societies have severely augmented the extent and variety of what composes the modern discard streams, in the last instance, aggravating the management challenges of distinguishing what should be considered waste or resource-like. (Park & Chertow, 2014). Using no mixed materials is a way of enabling the Circular Economy.

Often, products are seen in a *cradle-to-cradle* logic in CE-based contexts, meaning that they are designed to reinforce the ecological system as biological nutrients and to restore industries being used as components or materials in a total *closed material circle* (McDonough & Braungart, 2002 *cit* in Homrich et al., 2018).

To summarise, applying CE to businesses implies that resources are no longer acquired in a direct way and at a cost to the environment. In other words, producing more no longer implies extracting more resources from nature. Instead, the resources are circular, meaning that primarily the resources are obtained from the environment, but subsequently, the discarded goods themselves are converted into resources and are indeterminately reused in the transactional process (Bonciu, 2014)

3.4.3 How to implement a CE business model?

In accordance with Grant (2016:727), a business model is "the overall logic of a business and the basis upon which it generates revenues and profits."

Potting et al. (2017, cit in Morseletto, 2020) stated that there are *ten strategies* (R0 to R9) that companies can use to implement a CE-centred business model that can be allocated into three categories: Smarter product use and manufacture, Extended the lifespan of the product and its parts; practical application of materials (figure 3).

Smarter product use and manufacture	**R0**	**Refuse**	Make product redundant by abandoning its function or by offering the same function with a radically different product
	R1	**Rethink**	Make product use more intensive (e.g. through sharing products or by putting multi-functional products on market).
	R2	**Reduce**	Increase efficiency in product manufacture or use by consuming fewer natural resources
Extend lifespan of product and its parts	**R3**	**Reuse**	Re-use by another consumer of discarded product which is still in good condition and fulfils its original function
	R4	**Repair**	Repair and maintenance of defective product so it can be used with its original function
	R5	**Refurbish**	Restore an old product and bring it up to date
	R6	**Remanufacture**	Use parts of discarded product in a new product with the same function
	R7	**Repurpose**	Use discarded products or its part in a new product with a different function
Useful application of materials	**R8**	**Recycle**	Process materials to obtain the same (high grade) or lower (low grade) quality
	R9	**Recovery**	Incineration of material with energy recovery

Figure 3.1: Strategies to implement a CE-based business model Source: Morseletto, 2020:4

The implementation of CE business models in the specific case of manufacturing companies, such as the EEI industries, is becoming more and more of a hot topic as many benefits are being identified as a consequence of that adoption.

According to Atasu et al. (2021), some of those benefits are lessening their ecological footprint, mitigation of industrial leftovers and by-products and making a more efficient consumption of rare and costly raw materials.

The same authors also defend that there are only three strategies that manufacturing companies can use in order to achieve an economically viable CE business model: Retain product ownership (RPO), product life extension (PLE), and design for recycling (DFR). The main ideas from each one are synthesised in Table X, followed by a real-life successful example of their implementation:

Table 3.2: Circular Economy Strategies Adapted from Atasu et al., 2021

	Definition	When is suitable	Successful example
Retain Product Ownership (RPO)	The main idea of this strategy relies on renting or leasing products rather than making them available for sale . There is also an emphasis on downcycling supply chain operations as the products are reintroduced in the producers´ supply chains when their utility ends for final customers.	Case 1: for corporations that sell intricate goods with much-entrenched value. However, before using this strategy, companies must guarantee that they have the maintenance and after-sales capabilities required and that the costs inherent to those activities are more affordable than the ones attached to the linear Economy strategy.	Case 1 Example: Xerox leases printers and photocopiers to other companies instead of selling them.
		Case 2: Products that are not intricate but are costly and only occasionally necessary	Case 2 example: The subscription deal provided by the fashion company Rent the Runway allows customers to rent designer garments when needed for a special occasion.
Product Life Extension (PLE)	As the name suggests, the central aspect of this strategy is designing the goods in a way that their life cycle is larger	Case 1: Extended product duration leads to rarer acquisitions over time, so that strategy is not the best option for first-tier suppliers. However, endurance is a distinguished product feature that increases how much customers are willing to pay for a product.	Case 1 example: Patagonia targeted environmentally concerned clients. Consequently, they launched the Worn Wear cause, which allowed customers to return used items and be rewarded with shop credit. The apparel is afterwards refurbished and ended on their website.
		Case 2: For enterprises that want to promote customer loyalty, avoiding losing them to competitors	Case 2 example: Bosch Power Tools prolongs the durability of its used items, refurbishing them to reach other segments

			such as the low-price tools.
Design for Recycling (DFR)	It consists in restructuring the goods and engineering processes to make the most of the ability to recover the resources contained in them and reutilise them in novel products.	DFR frequently implies associating with businesses that possess particular hi-tech know-how or are experts in recovering materials from second-hand products. So, having those types of partners is fundamental.	Adidas has a long-term partnership with Parley for the Oceans, which collects discarded plastic from the marine environment. The sports brand uses the material gathered to produce new products such as sneakers and sportive clothes.

The ultimate goal of a CE-based model is to achieve sustainability, meaning that the strategies presented above represent only different ways of achieving a common goal (Bonciu, 2014; Kopnina, 2014; Mathews et al., 2011; Qiao & Qiao, 2013; Lowe, 2015 cit in Linder et al., 2017).

3.4.4 How to access the CE business model feasibility

A circular business model is viable only if the value can be financially recuperated from the system outputs. Evaluating the viability of a given circularity strategy demands a cautious control of incomes and expenses but also testing and funnelling (Ellen Mcarthur Foundation, 2023)

Defining which arrangement of the three basic strategies will be more economically favourable for the business implicates the response to two specific interrogations:

1. How easy is it to get my product back?
2. How easy is it to recover value from my product?

Based on the two questions previously mentioned, the authors created a matrix to help the company's deciders situate and identify the most valuable combination of strategies for their businesses:

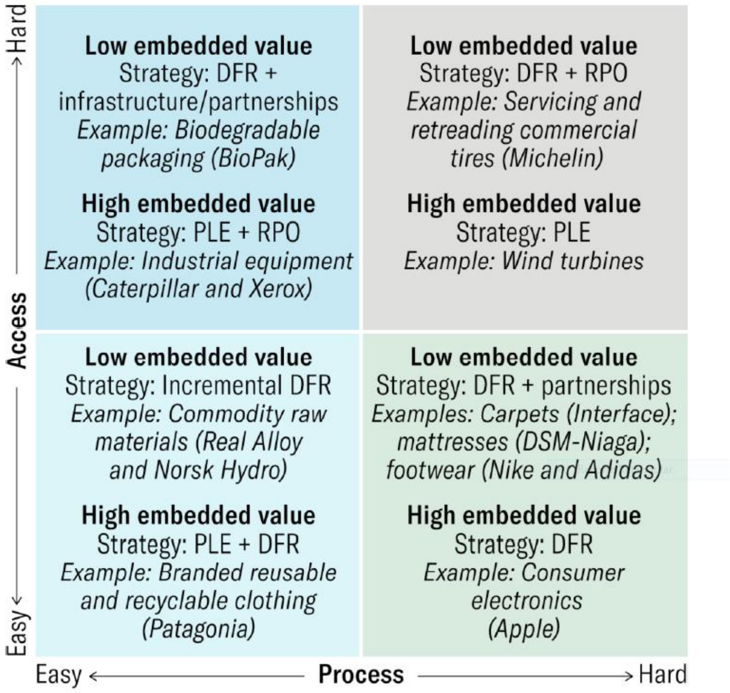


Figure 3.2: The circularity matrix Source: Atasu, Dumas & Wassenhove, 2021:7

Another way to assess the model's feasibility is by calculating indicators to measure Circularity dimensions (Appendix A). Indicators typically embody occurrences "which are difficult to quantify, or for which units of measurement do not exist" (Franklin-Johnson et al. 2016:590).

Although there is still a lack of authors that try to measure the effects of applying Circular Economy principles in businesses, Elia et al. (2016) did a critical review of the existing ones, having emphasised, for example, the Potential reuse indicator (Park & Chertow, 2014); Circular Economy Index (Di Maio & Rem; 2015) and the Product Level Circularity (Linder et al., 2017) that are explained in detail on annexe X.

3.4.5 Supply chain management in the context of a Circular Economy approach

Supply chain management is defined as the "planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. (…) SCM is an integrating function with primary responsibility for linking major business functions and business processes within and across companies into a cohesive and high-performing business model" (CSCMP, 2013:187).

We live in an ever-changing world, and organisations must adapt to this environment, especially regarding Supply Chain Management goals. *Adaptive Supply Chain Management* focuses on those constant changes so that the organisations do not collapse as soon as the market alters abruptly. Adaptive Supply Chain Management helps organisations with a better insight into the future regarding the dynamics, complexity and uncertainty in supply chains. It also helps consider adaptability, stability and crisis resistance (Fliedner, 2003).

Collaborative planning, forecasting and replenishment (CPFR) is used to help integrate the supply chain processes. Its main goal is the management of inventory and stock through implementing the visibility of existing products and replenishment plans at all stages of the supply chain. Thanks to the information shared between different stakeholders, it is possible to plan the customers' demand accordingly. It also allows adapting the supply of the products to the most recent needs demonstrated by the customers, making the adaptive supply chain network possible. CPFR increases the efficiency of the business processes – tailoring the forecasting and replenishment of the products decreases the planning uncertainties and costs of merchandising, stock inventory, logistics and transport among all partners (Homrich et al., 2018).

The main objective of CPFR is to exchange selected information on a shared Web base to provide reliable, longer-term future views of demand in the supply chain (Fliedner, 2003). The relationships established within those types of systems are based on mutuality (Sparks, 1994; Ellram & Edis, 1996 cit in Barrat, 2004) as the collaboration effort of the partners is made in order to achieve a common goal: maximise customer satisfaction at the lowest cost (Stank et al., 2001)

When we apply this subject to CE constructing a CPFR, we can discuss planning and gathering the required information about the direct materials flows and the reverse ones in that the waste produced by the initial production activity is reutilised during the subsequent economic cycles. There is evidence that collaboration between internal or external partners and supply chain members is mandatory to implement environmental practices properly (Zhu et al., 2010 cit in Homrich et al., 2018).

3.4.6 The role of innovation and new business opportunities in the CE context

Quality (of the product and service provided) is the hegemony of market share; customer focus emerges as a critical value of modern organisations. This change in organisational values leads to a series of consequences for organisations, including widespread concern about reducing costs (through, for example, increasing resource efficiency), resorting to the flexibility of labour in the workplace (adjustment of the volume of work, thus representing the cost of work increasingly as a variable and not a fixed cost); increased permeability of organisational boundaries, whether internal (flattening of structures) or external (organisations as open systems and therefore in constant interaction with the environment) (Legge, 1995 cit in Caetano, 2000)

Those values also force organisations to be in a *continuous process of change and innovation,* becoming *ambidextrous* ones (O'Reilly & Tushman, 2013)

Innovation can be defined as a result of a creative process that introduces a certain level of novelty or change and also possesses a degree of usefulness or success (Granstrand & Holgersson, 2020)

There are different types of innovations and ways to segment them. From the most classic perspective, innovations are divided into two groups per the degree of changes they provoke: Incremental and radical, respectively (Chiesa et al., 1996 cit in Koberga et al., 2003)

Incremental innovations or first-order innovations are part of the natural and regular organisational dynamics and show the effort to improve the processes or products of the corporation. They illustrate most organisational changes through quality projects and encompass minor adjustments. In short, it is the improvement of processes and products without significantly affecting the organisational structure and operation of the company (Koberga et al., 2003)

Radical innovation, or second-order innovation, on the other hand, occurs when profound changes are made to the central components of the organisation that result in a renewal or realignment of internal functioning and business operations. In other words, they involve changes to the organisation's strategy and structure.

CE has been considered to depend on the development and adoption of "greener products, processes, and business models at different levels, i.e., the adoption of transformative eco-innovations" (De Jesus et al., 2021:2).

Defining other innovations, such as Eco-Innovations (EI) and systemic innovations (SI), is vital to understanding the innovation role in CE contexts fully.

An *eco-innovation* is any innovation practice that leads to the creation of substantial and evident improvement of sustainable development purposes by diminishing the effect on the ecosystem or enabling a more efficient and responsible consumption of natural resources, including energy (European Commission, 2007 cit in Boons et al., 2012). The subject of the application of these innovations can be "products, services, and technologies, as well as new business and organisational models" (Charter et al., 2008; Charter & Clark, 2007, cited in Boons et al., 2012:3). The transference from products to services is an example of this type of innovation and has been a central topic to the design community's attempts to surpass mere eco-design (Boons et al., 2012)

New business models are usually depicted as enablers of CE that combine supply-side and demand-side innovation while driving other forms of innovation in design, product manufacturing, logistics and reverse logistics, and end-of-life management recovery (De Jesus et al., 2021)

EI is also essential to enlarging the existing information base and fostering collaboration among actors (Yu et al., 2014a cit in De Jesus & Mendonça, 2018). The large number of eco-industrial parks where industrial symbioses have been developed underscores how critical EI is to generating new opportunities for sharing services and reusing products among diverse industrial processes or players (De Jesus & Mendonça, 2018)

Systemic or transformative innovations are the ones that arise from an "evolving set of actors, activities, and artefacts, and the institutions and relations, including complementary and substitute relations, that are important for the innovative performance of an actor or a population of actors" (Granstrand & Holgersson, 2019:3) This approach to innovation recognises how companies are linked through networks with other stakeholders such as research actors, government, investors, competitors, and mediators that transfer knowhow and associate players (Boons et al., 2012)

Open innovation is a specific example of systemic innovation, which, as the name suggests, is based on the proposition of opening the innovation process. They represent targeted knowledge inflows and outflows to accelerate internal innovation or expand markets for external use of innovation (Chesbrough et al., 2006). Open innovation is usually contrasted with closed innovation, in which companies generate their innovation ideas and all the subsequent activities needed to put the innovation on the market (Chesbrough, 2003a, p. 20 cit in Huizingh, 2011)

An open innovation niche is the *co-creation* one**,** where customers assume a participative role and co-create value with the company (Kohler et al., 2011; Prahalad and Ramaswamy 2004a cit in Ranjan & Read, 2016) through direct and indirect cooperation throughout one or multiple steps of the product production (Hoyer et al., 2010; Payne et al., 2008; Payne et al., 2009; Roggeveen et al. 2012; Tynan et al. 2010 cit in Ranjan & Read, 2016)

The innovation types that are more commonly correlated to CE are the ones related to recycling and recovery of products (incremental innovations), business model innovations (radical innovations) and systemic/transformative innovations (De Jesus et al., 2021). Leading us to the conclusion that simple innovation is not enough to leave behind the linear economic market approach. To become Circular, corporations must invest in systemic, transformative, and effectually sustainable innovations (De Jesus & Mendonça, 2018)

3.5 Case resolution

Question 1:

The circular economy approach has as the primary reference the natural ecosystems with no landfills. In its place, resources flow, and one species' waste is another's food. All the energy required for the system to function is supplied by the sun (renewable energy), and as species grow and die, the nutrients return safely to the soil (to their original location) (Rodriguez et al., 2020).

When selecting raw materials as part of the procurement process, care must also be taken to ensure they contain the least hazardous materials and are as pure as possible to facilitate separation and reuse. (Park & Chertow, 2014). Product design should take into account that materials can be easily disassembled to be recovered in returns, and product packaging materials should also take into account an environmentally friendly logic and consist of recyclable or at least recyclable components (Vanegas et al., 2016).

In summary, a circular economy can be defined as a new economic paradigm whose focus is to keep materials in supply chains for as long as possible by maintaining or even increasing their value through reverse logistics flows or via services and non-ownership consumption solutions such as “pay-per-use” or "product as a service".

A circular economy consists of two closed loops, representing two types of supply chains: forward and reverse. A recovered product re-enters the forward chain in the reverse chain (Wells & Seitz, 2005, cited in Antikainen & Valkokari, 2016). This process creates a so-called closed-loop material system (ISO, 2006), where the life cycle of a given material does not end at the EOL stage but is recycled and used for the same or a different purpose (Dubreuil et al., 2010, cited in Graedel et al., 2011).

The shift to Circular models was fuelled primarily by customers’ trends toward sharing and collaborative consumerism (Belk, 2014).

We live in a non-ownership period, and sharing behaviour stands for “the act or process of distributing something that belongs to us to others for their use or the act of receiving or taking something from others for our use” in a type of gift transaction where only one of the parties benefits (Belk, 2007). The trend toward sharing emerged primarily through unpaid online platforms that became widespread in Internet 2.0, which enabled the free downloading of music, videos, and movies-a phenomenon that became known as the sharing turn (Belk, 2014)

On the other hand, collaborative consumption occurs when the customer does not buy the good but rents it to have temporary access to it. The idea behind this trend arises from the fact that much equipment individuals hold is used only a few hours in their lifetime. An effective Collaborative Consumption economy model would help realise underutilised potential. This movement disseminates access to a wide range of high-end equipment at an affordable rate for the consumer and extra revenue from idle assets for asset owners. In contrast to sharing transactions, collaborative consumption benefits both parties involved.

To sum what consumers nowadays value the most is access and performance, which are offered as services. Airbnb, Uber, Spotify and Netflix have all transformed how their activities work, and many more companies are following those steps.

Question 2:

Following Atasu et al. (2021), three strategies manufacturing companies can use in order to achieve an economically viable CE business model: Retain product ownership (RPO), product life extension (PLE) and design for recycling (DFR).

The main idea behind RPO is renting or leasing products rather than making them available for sale. This strategy also emphasises the down-cycling supply chain operations as the products are reintroduced in the producers´ supply chains when their utility ends for final customers.

On the other hand, PLE refers to any attempt to design the goods so that their life cycle becomes larger.

Finally, DFR consists of restructuring the goods and engineering processes to make the most of the ability to recover the resources contained in them and reutilise them in novel products.

It is possible to say that Philips uses all the strategies above cited in their approach to Circular Economy, and so the table above compiles the practices that can fall under each strategy type:

Table 3.3: Question 2 resolution auxiliary

Circular strategies	Signify examples
Retain product ownership	Lightning as a service: Instead of selling luminaires, Philips rent them, maintaining control over those assets
	Connected lighting solutions allow the company to maintain the traceability of their allocated resources.
Product Life Extension	Connected lighting solutions: That solution enables intelligent asset management, making it possible to monitor serviceable luminaires to enable preventive maintenance that contributes to the product life extension.

	Modular designs: Those products are built modularly, meaning their components are replaceable and have recyclable parts, such as drivers, controls and LED circuit boards. Instead of substituting the entire luminaire, the modules can be exchanged, preserving value and eliminating waste because spare parts are available for at least five years. The luminaires are also built to be upgraded, as they are equipped with an interface for a sensor that allows it to acquire attributes of intelligence or connectivity. That means if the customer wants to follow the technological advances in the sector, he does not need to discard the equipment they already have.
	Solar Lights: Solar panels have a lifespan of up to 30 years, which is much more superior than other lighting options
	Any product under other products under the Climate Action Revenues category: As those products focus on stringent luminous requirements
Design for Recycle	3D printing luminaires: Each printed part of those luminaires is reusable and recyclable. For this purpose, no paint, no glue and fewer screws are used, which facilitates the disassembly of the product and its recyclability when it reaches the end-of-life stage.
	Any product under the category of Circular Economy Revenues is built to make disassembly as easy as possible, as it is non-destructive and requires only five steps. Signify also avoids mixing materials in components so that product dismantling at the recycling stage results in materials destined for different waste streams, for no glue or potted drives, are used.

In terms of the circularity matrix proposed by Atasu et al. (2021), most of the products offered by the company would be situated on the first quadrant of the matrix, which stands for easy access and easy process. As luminaires usually are low embedded value items, the authors suggest that Signify opt exclusively for the Design for Recycling strategy; however, as stated before, Philips has practices that fit into all three proposed strategies by the authors, meaning that their choice is not following the most valuable combination of strategies proposed by the authors.

Question 3:

The two essential duties of Signify as an EEE industry in terms of waste management are prolonged producer responsibility and the polluter pays principle.

Those two duties translate into EE equipment being no longer proper to their user; the EOL must return to the producer responsible for giving that material a proper destiny and handle any inherent cost for that activity.

The recycling/reuse target for lamps (Category 3 of annexe V of the European WEEE directive) is 80%, and Signify has a lamp recycling rate of 80% (Collection and recycling Signify data), meaning that the company is achieving the EU fixed target.

Question 4:

The company is most likely eligible for the Ecolabel since it promotes actions that meet all the five Ecolabel criteria (table 7):

Table 3.4: Question 4 auxiliary resolution table

Eco label criteria	Signify practice
Minimise waste, pollution and CO_2 emissions	Minimise waste measures: At the end of 2022, Signify sent zero waste to landfills in all its sites, except one recently acquired and was still transitioning to reach that status.
	CO2 emissions: In 2022, the company achieved carbon neutrality more specifically by investing in more efficient and cleaner products, using renewable energy in operations, changing the transport modes (logistics), and reducing business travel Connected light systems lead to up to 80% of electricity consumption reduction (the primary factor affecting emissions in the value chain)
Restrict the use of hazardous chemicals.	Compliance with Rohs The company is taking all mercury-based lamps from the market Their Horticulture LED lights prevent the use of pesticides
Use energy, water and raw materials wisely.	Energy usage: Signify purchases 100% renewable electricity for its global operations
	Water usage: The company implements water reuse schemes in their facilities and develops technology and business models with lower water dependency. Their Horticulture LED lights can lead to up to 90 % water savings compared with other cultivation techniques.

	Raw Material usage: Their LED line is built in a modular logic, making spare parts replaceable, easily recycled, and upgradeable when needed. The 3D printed parts of the luminaires of the company are made of at least 55% secondary raw materials and follow an on-demand production, minimising stock levels. Their packaging is made of at least 80% recycled paper.
Are long-lasting, easy to repair and recycle	All Signify´s LED drivers, modules and light sources are designed with energy efficiency in mind. They are also built to make **disassembly as easy as possible**, as it is non-destructive and requires only five steps. Signify also avoids mixing materials in components so that product dismantling at the **recycling** stage results in materials destined for different waste streams, for no glue or potted drives, are used. Their solar panels are built to last at least 30 years.
Promote green innovation	The company's contributions in this field include 3D printed luminaires, TruLiFi, Light as a service, UVC Lightning and Philips Horticulture, collaboration with public and private companies to achieve sustainability goals and the Pioneers of Light Co-creation platform.

Question 5:

5.1 Mercury production in that year/Quantity produced of a particular material that can contain mercury in its composition + mercury quantity used on it

= (25+140+85)/(101479*0,458+25) ≈0,005

Auxiliary account (Quantity of fluorescent lamps puted on marked) = Put on Market quantities in EU * Penetration rate of fluorescent lamps in EU

5.2 CEI= Material value recycled from EOL product(s)/ Material value needed for (re −) producing EOL product (s)

CEI=65/139 ≈ 0,468

5.3 *C= economic value of recirculated parts/ economic value of all parts*

=325/809 ≈ 0,4

Question 6:

Considering the European Commission (2007 cit in Boons, et al.,2012) definition of Eco-Innovation as any innovation practice that leads to the creation of substantial and evident improvement of sustainable development purposes by diminishing the effect on the ecosystem or enabling a more efficient and responsible consume of natural resources, including energy we can consider Light as a service; 3D printing luminaires; connected and intelligent solutions; TruLifi; Modular designs; UV-C lighting; horticulture LEDs

Table 3.5: Question 6 auxiliary resolution table

Innovation types	Definition	Signify examples
Incremental	Represent improvement of processes and products without significantly affecting the organisational structure and operation of the company	3D printing: This represents a change in the technology used for the production process. Modular Designs: Represent a product design alteration. UVC/Horticulture lighting
Radical	Strategic changes are made to the central components of the organisation that result in a renewal or realignment of internal functioning and business operation.	Light as a service: This innovation changes the company's business model from a one-time sale to a pay-per-use one. It is a strategic change.
Systemic/Open Innovations	Arises from opening the innovation process to external agents such as suppliers, governments, researchers and customers, for example	Ships powered by zero-carbon fuels with Maersk as their supplier for their maritime logistics operations. Collaboration with CSROs to collect and recycle materials from their production and EoL products.
Co-creation	Customers assume a participative role and co-create value with the company.	Pioneers of Light community comprises architects, lighting designers and engineers united by their passion for realising their visions through innovative lighting.

In terms of their supply chain modifications, circular economies often require collaboration across the value chain. Companies can form partnerships with suppliers, customers, and other stakeholders to create closed-loop systems where materials and products are reused, reducing costs and environmental impact.

Some supply chain modifications that were provoked by the adoption of Circular Economy practices in Signify were:

In their Sourcing and Procurement, the company emphasised sourcing sustainable and recyclable materials (live, for example, the 3D luminaires raw materials and products packing), sourcing materials from suppliers committed to circular practices and considering the entire lifecycle of materials when making procurement decisions.

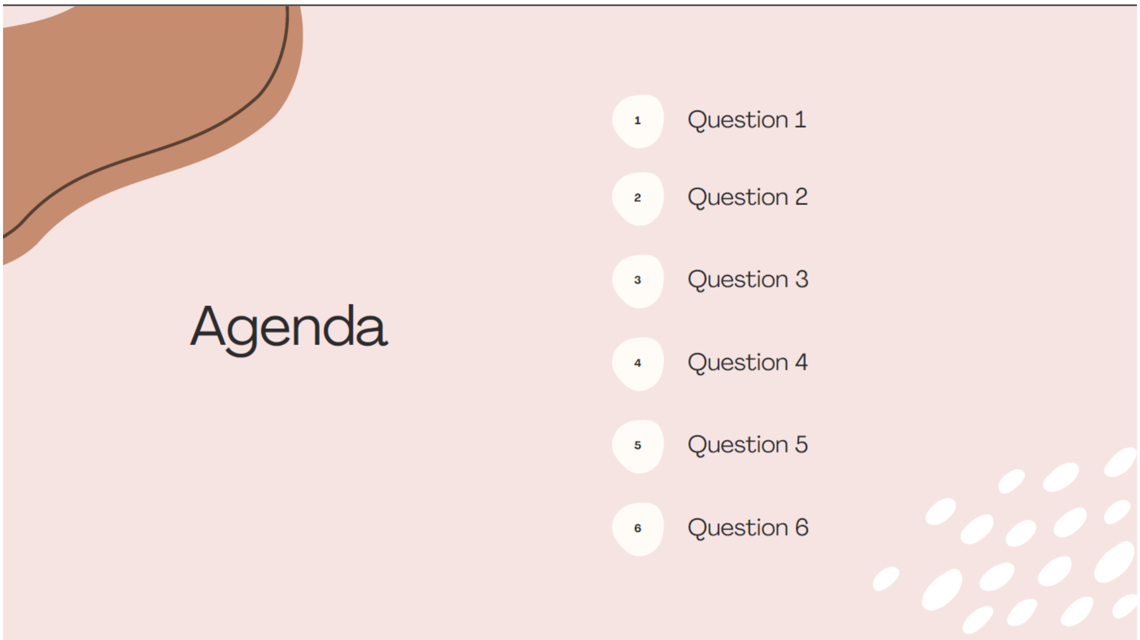
The 3D printing technology also enabled on-demand production, allowing more efficient inventory management as it minimises excess stock and waste. At that level, the company also started managing spare parts of their modular products for repair and maintenance.

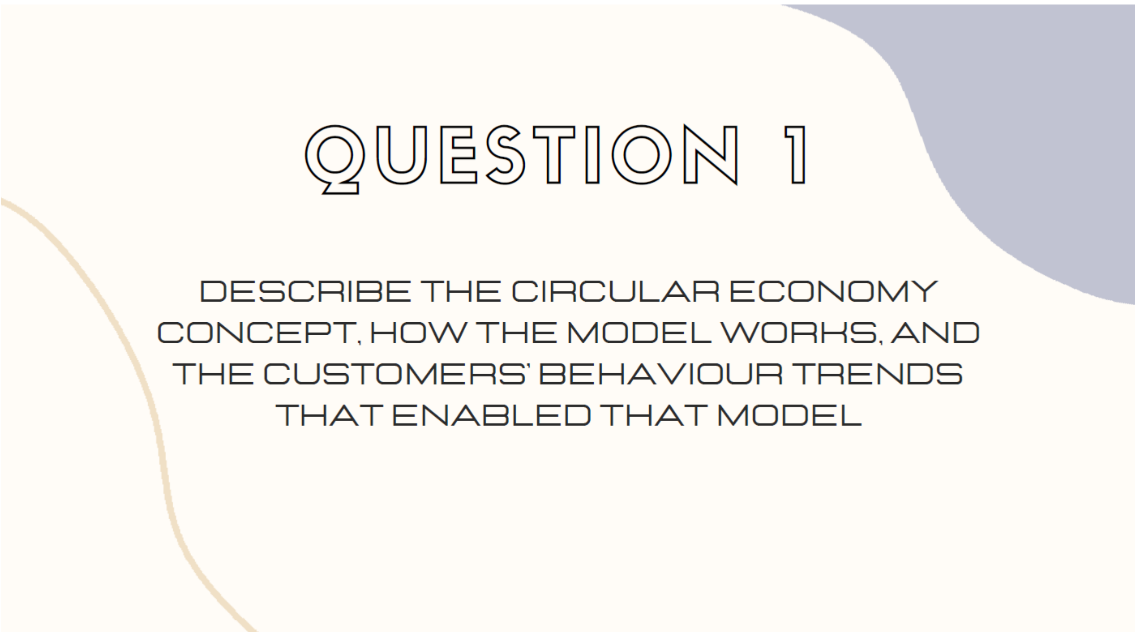
The eco-innovations also immensely impacted supplier relationship management since the company encourages its suppliers to adopt circular practices and sustainability initiatives, provides training, and evaluates their performance based on circularity criteria.

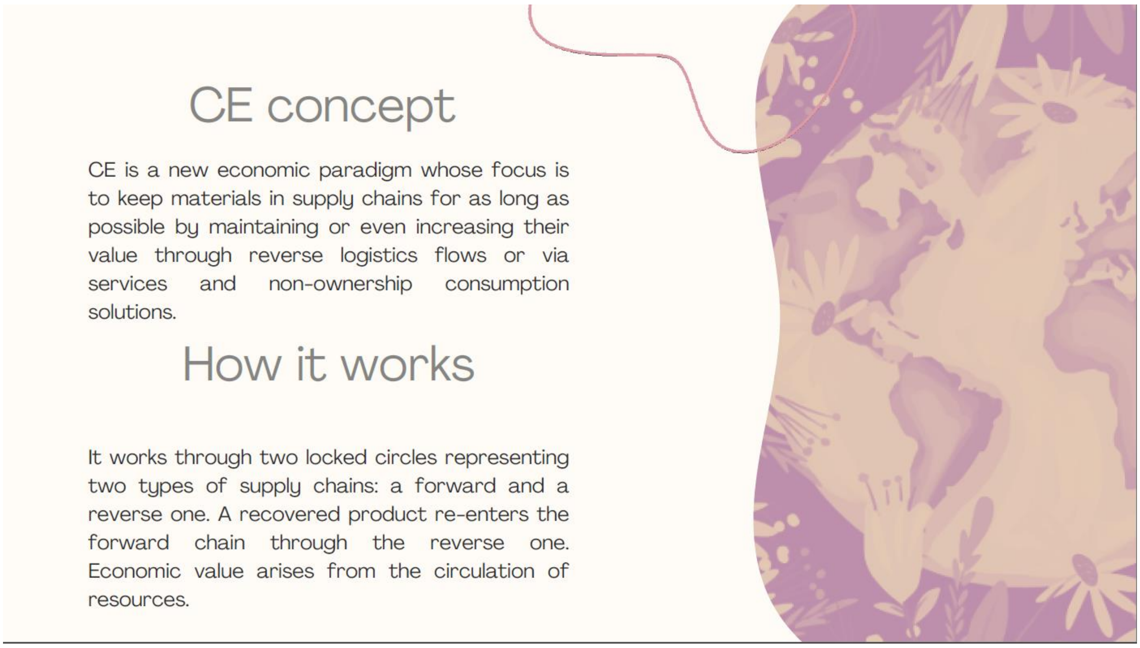
Customer relationship management was altered by establishing longer relationships by adopting Light as a service and the added value inherent in Connected Light Systems.

The collaboration with many other companies makes Signify an example of an organisation with an adaptive supply chain. It uses the information shared between different stakeholders, making it possible to plan the customers' demand accordingly. The company provides solutions for all the most recent trends demonstrated by the customers, making the adaptive supply chain network possible.

3.6 Resolution Slides




QUESTION 1
DESCRIBE THE CIRCULAR ECONOMY CONCEPT, HOW THE MODEL WORKS, AND THE CUSTOMERS' BEHAVIOUR TRENDS THAT ENABLED THAT MODEL


CE concept
CE is a new economic paradigm whose focus is to keep materials in supply chains for as long as possible by maintaining or even increasing their value through reverse logistics flows or via services and non-ownership consumption solutions.
How it works
It works through two locked circles representing two types of supply chains: a forward and a reverse one. A recovered product re-enters the forward chain through the reverse one. Economic value arises from the circulation of resources.

The 2 costumer trends that enabled CE

Sharing

Become popular with the appearance of Internet 2.0 and consists of giving something that is ours to another individual (Win-Loose scenario).

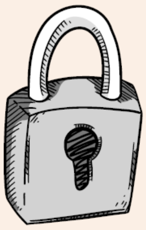
Collaborative Consumption

A lot of equipment owned by individuals is used only a few hours in its lifetime. An effective Collaborative Consumption economy model would help realise underutilised potential. It also promotes the access to a wide range of high-end equipment at an affordable rate for the consumer and extra revenue from idle assets for asset owners (Win-Win scenario).

QUESTION 2

WHAT THREE STRATEGIES CAN A MANUFACTURING COMPANY USE TO ACHIEVE CIRCULARITY? ARE THE SIGNIFY PRACTICES RELATED TO ANY OF THOSE STRATEGIES? IF SO, ARE THE STRATEGIES CHOSEN IN ACCORDANCE WITH THE CIRCULARITY MATRIX PROPOSED BY ATASU ET AL., 2021?

Strategies used and examples



Retain Product Ownership

Light as a service
Connected lighting systems

Product Life Extension

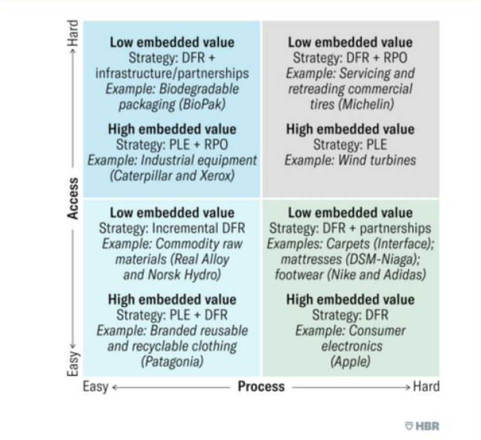
Solar Lights
Connected lighting system

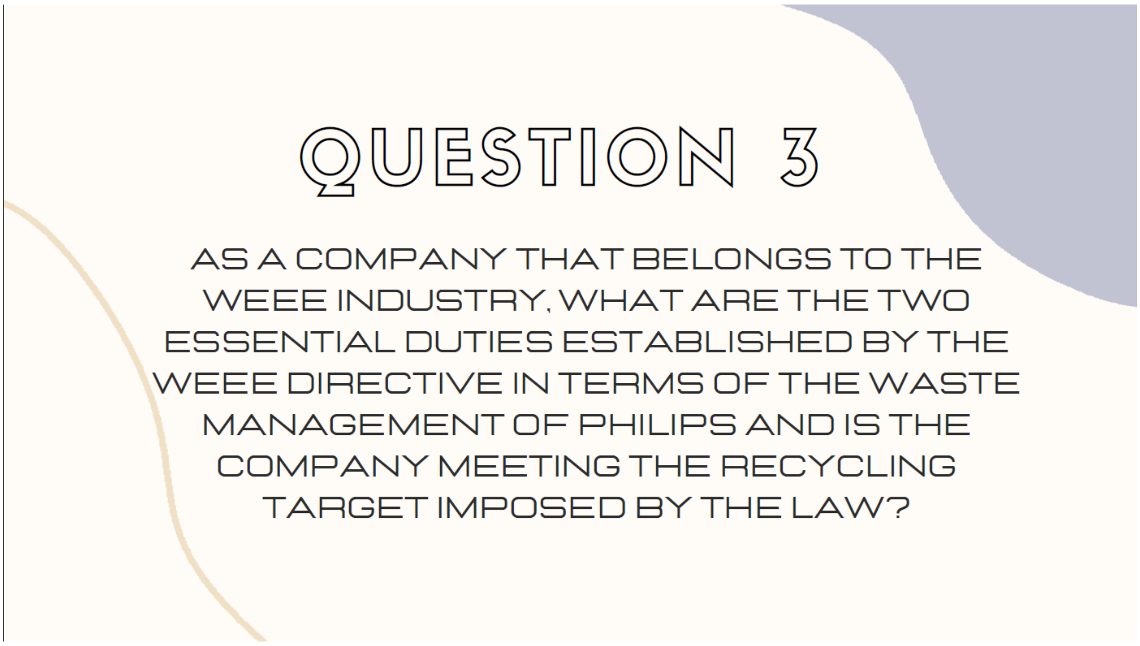
Design for Recyclability

Modular products
3D Printed Luminaires

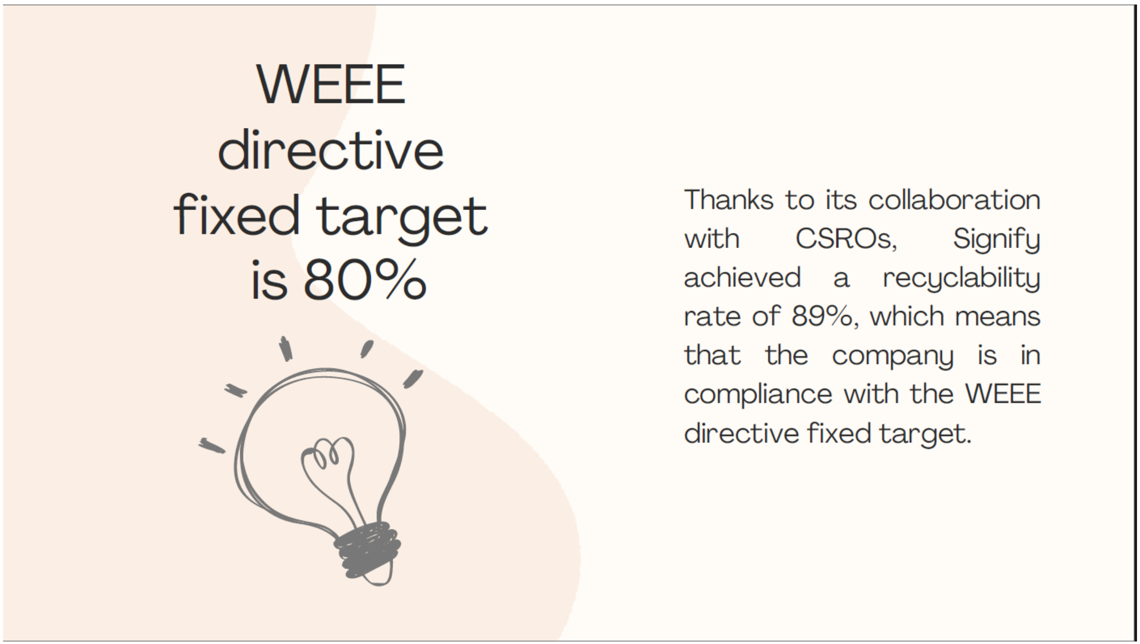
The circularity matrix (Atasu, et al, 2021)

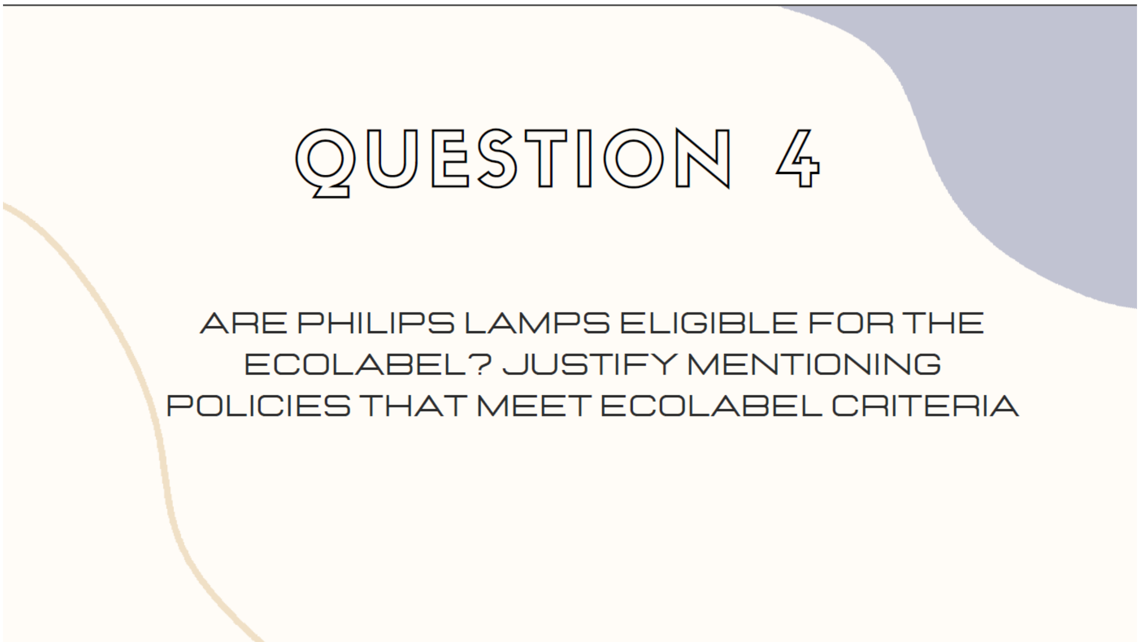
Signify should opt only for Design for Recyclability.




QUESTION 3
AS A COMPANY THAT BELONGS TO THE WEEE INDUSTRY, WHAT ARE THE TWO ESSENTIAL DUTIES ESTABLISHED BY THE WEEE DIRECTIVE IN TERMS OF THE WASTE MANAGEMENT OF PHILIPS AND IS THE COMPANY MEETING THE RECYCLING TARGET IMPOSED BY THE LAW?


WEEE directive stipulates two major producers´ duties
Prolonged producer responsibility
Legislation that obligates the original product manufacturers to upkeep their products even when they reach the EOL stage
Polluter pays principle
Delegates all the costs inherent to adequately handling the e-waste to the one responsible for producing those residuals


WEEE directive fixed target is 80%
Thanks to its collaboration with CSROs, Signify achieved a recyclability rate of 89%, which means that the company is in compliance with the WEEE directive fixed target.


QUESTION 4
ARE PHILIPS LAMPS ELIGIBLE FOR THE ECOLABEL? JUSTIFY MENTIONING POLICIES THAT MEET ECOLABEL CRITERIA

Eco label criterias and Signify pratices

Are long lasting, easy to repair and recycle

Products are designed to be energetically efficient, easy to repair, easy to disassemble and recyclable

Minimise waste, pollution and CO2 emissions

Zero Waste to landfill
Carbon neutrality in operations

Restrict harzadous substances

Compliance with RoHS
Phase-out of mercury based lamps

Water, energy and materials efficiency

100% renewable energy in operations
Water reuse schemes
Source recycled materials for products and packaging

Promote green innovation

Trulifi; UV-C lighting,
Connected lighting systems

QUESTION 5

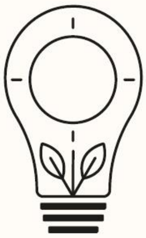
SINCE THE COMPANY HAS TO GRADUALLY WITHDRAW ALL ITS FLUORESCENT LAMPS FROM THE MARKET DUE TO THE RESTRICTION IMPOSED BY THE EUROPEAN UNION ON THE USE OF MERCURY, THE FOLLOWING CIRCULAR ECONOMY INDICATORS SHOULD BE CALCULATED FOR THEM

Potential Reuse Indicator	0,005
Circular Economy Index	0,468
Product Level Circularity	0,4

QUESTION 6

IDENTIFY AND CLASSIFY THE INNOVATIONS PHILIPS BROUGHT TO THEIR CIRCULAR APPROACH TO THE MARKET AND HOW IT AFFECTED THEIR SUPPLY CHAIN MANAGEMENT AND ABILITY TO CREATE NEW BUSINESS OPPORTUNITIES.

Eco-Innovations



Incremental

3D printing
UVC-lighting
Modular designs

Radical

Light as a service

Systemic

Collaboration with Maersk
Collaboration with CSROs

Co-creation

Pionners of Light platform

Supply chain modifications

The collaboration with many other companies makes Signify an example of an organisation with an adaptive supply chain. It uses the information shared between different stakeholders, making it possible to plan the customers' demand accordingly.

At the level of:

- Supplier Relationship Management
- Customer Relationship Management
- Sourcing and procurement
- Inventory Management


Thank you for your
attention!

Conclusion

This report was intended to carry out an analysis of the Signify Circular Economy approach, more specifically by answering the two initial questions: how its practices affected its waste management and the creation of new business opportunities. It is structured in three parts: the Case presentation, the methodology, and the Academic Note.

The first part begins with the presentation of the issue where we can conclude that a Linear Economy is no longer a viable option for businesses as resource scarcity, supply chain disruptions, new customer trends based on non-ownership consumption schemes, the government's participative role and the given importance to environmental issues by investors leads no option than adapt businesses to a new ecologic aware reality.

This theme is followed by an analysis of the sector to which the chosen company belongs, that is, the lighting sector. The lighting industry has been evolving since its creation two centuries ago, and the oldest technologies are being replaced by LEDs, a more competent technology in all environmental performance aspects, with particular emphasis on CO2 emissions and energy efficiency. However, the "LEDification" of the market is only one of the trends presented in this industry, as human-centric lighting, connected lighting systems, smart lighting, and Light-as-service solutions are also growing in number.

A particular remark on the industry's legal context is also made as the European Union developed a set of laws that directly affect the sector activity. Those laws are the WEEE directive, the Ecolabel regulation, and the upcoming right-to-repair law.

The company presentation is the next theme covered. Signify is the market leader in the lighting sector, owning several brands and having a long-term value-creation vision heavily based on the pursuit of Sustainable Development Goals.

To improve their performance towards those Sustainable goals, the company adopted a Circular approach to the market that can be divided into three categories: Lighting for Circularity products, services and systems. Some of the practices englobed in those categories are designing products in a modular way, so they become recyclable, upgradeable, and easy to maintain, betting on renewable energy-based products and ecological packaging, Light as a service and Lifi (a substitute to Wi-Fi based on the potential of light to be a data transmitter).

The company also measures their ecological performance by separating the revenues that arise from its sustainable-oriented products from the others and by keeping track of variables such as its Water Use, waste sent to landfills, energy used in its operations and CO2 emissions.

Signify has been reducing its ecological impact in all the mentioned variables and has already achieved carbon neutrality in its operations, as well as zero waste sent to landfills.

Innovation plays a crucial role in supporting the Circular vision of the company, and that is proved by the significant investments the company made in that area and the collaboration and partnerships it established with multiple stakeholders.

The case presentation part ends with the case questions to be answered by the target audience of the case.

The second part of the report is the methodology. The methodology used in this master's thesis was the pedagogical case study one, and that choice was based on the type of initial questions made and the primarily descriptive aim of the case. The case is found in secondary data prevenient from reliable sources. Signify was chosen as the company to study because it has been distinguished as a role model by multiple actors for its Circular approach to the market.

The third part of the report is the academic note. The target audience of the case is delimited, being bachelor's or master's degree students and professionals looking for a practical example of a company applying Circularity-based principles to its business. The primary learning objective of this case is to identify and integrate the company practices with the theoretical concepts of the Circular Economy field.

A literature review is made. The central concept of the case study is Circular Economy. It is defined as a new economic paradigm inspired by the natural living systems and where the economic value of the activities arises from the increase of resource efficiency.

A Circular economy cycle is composed of two closed materials loops, one that represents the forward supply chain and another that represents reverse logistics activities that allow recapture value in EOL products. Several strategies can be used to achieve those closed materials loops, like Retain Product Ownership, Extend Product Lifetime and Designing for recyclability.

Introducing Circularity also leads to modifications at the supply chain management level as companies rely heavily on the integration of both upstream and downstream branches of their supply chain, creating what is called adaptive supply chains. In those structures, knowledge is shared between different stakeholders, enabling the focal company to use Collaborative planning and forecasting replenishment events.

The circular economy is also known to augment innovation as it promotes eco-innovations and collaboration between different stakeholders, namely in the form of open innovations or co-creation programs.

The Case Study questions solution follows the literature review. It is essential to highlight that Signify complies with the laws in force in the European Union, namely the WEEE directive, as the company surpasses the established recyclability target of 80% and must be eligible for the Ecolabel recognition.

The corporation uses all three strategies that a manufacturing business can use to achieve Circularity in its activity: Retain Product ownership (in the form of Light as a service), Design for Recyclability (with 3D printed luminaires and modular products) and Extend Product Lifetime (with connected lighting solutions and designs that are easy to maintain and repair).

The firm also promotes all the innovations recognised as being crucial to the development of CE-based environments as it presents multiple examples of eco-innovations. It is essential to highlight the ones that arose from the collaborations and partnerships the company performed, like the systemic innovation that culminated in the carbon-neutral vessels with Maersk. Furthermore, the co-creation platform Pioneers of Lighting results from the collaboration with professional Customers like designers and architects.

For all the reasons mentioned, Signify can be considered a role model for all companies that would like to transition to a CE-based model.

References

Adibi, N., Lafhaj, Z., Yehya, M., & Payet, J. (2017). Global Resource Indicator for life cycle impact assessment: Applied in wind turbine case study. *Journal of Cleaner Production*, 165 1517-1528. http://dx.doi.org/10.1016/j.jclepro.2017.07.226

Akcil, A., Agcasulu, I., & Swain, B. (2019). Valorisation of waste LCD and recovery of critical raw material for circular economy: A review. Resources, *Conservation and Recycling*, 149, 622-637. https://doi.org/10.1016/j.resconrec.2019.06.031

Alamerew, Y. A., & Brissaud, D. (2019). Circular economy assessment tool for end-of-life product recovery strategies. Journal of Remanufacturing, 9(3), 169–185. https://doi.org/10.1007/s13243-018-0064-8

Andersen, T. (2022). A comparative study of national variations of the European WEEE directive: manufacturer's view. Environmental Science and Pollution Research, 29, 19920–19939. https://doi.org/10.1007/s11356-021-13206-z

Antikainen, M., &; Valkokari, K. (2016). A Framework for Sustainable Circular Business Model Innovation. Technology Innovation Management Review, 6 (7), 5-10. http://timreview.ca/article/1000

Atasu, A., Guide, V.D.R. Jr & Van Wassenhove, L.N. (2010).So what if remanufacturing cannibalises my new product sales? California Management Review, 52 (2), 56-76. https://doi.org/10.1525/cmr.2010.52.2.56

Barney, J. B., & Hesterly, W. S. (2014). Strategic Management and Competitive Advantage: Concepts and Cases.

Barratt, M. (2004). Understanding the meaning of collaboration in the supply chain. Supply Chain Management: An international journal, 1 (9), 30-42. https://doi.org/10.1108/13598540410517566

Belk, R. (2014). You are what you can access: Sharing and collaborative consumption online. Journal of Business Research, 67(8), 1595–1600. https://doi.org/10.1016/j.jbusres.2013.10.001

Bocken, N. (2021). Circular business models–Mapping experimentation in multinational firms. Circular economy: Challenges and opportunities for ethical and sustainable business. Routledge.

Bonciu, F. (2014). The European economy: From a linear to a circular economy. *Romanian Journal of European,* 14 (4), 78-91. https://www.researchgate.net/profile/Florin-Bonciu/publication/289891523_The_European_Economy_From_a_Linear_to_a_Circular_Economy/links/57876d9b08aea8b0f0c2bcb4/The-European-Economy-From-a-Linear-to-a-Circular-Economy.pdf

Caetano, A., & Tavares, S. (2000). Tendências na mudança organizacional e tensões na gestão de pessoas in A. Gomes, A. Caetano, J. Keating e M. Cunha (1th ed.). Organizações em transição. Coimbra: Imprensa da Universidade.

De Jesus, A., Lammi, M., Domenech, T., Vanhuyse, F., & Mendonça, S. (2021). Eco-innovation diversity in a circular economy: Towards circular innovation studies. *Sustainability,* 13(19), 1-22. https://doi.org/10.3390/su131910974

De Jesus, A., & Mendonça, S. (2018). Lost in transition? Drivers and barriers in the eco-innovation road to the circular economy. *Ecological economics,* 145, 75-89. https://doi.org/10.1016/j.ecolecon.2017.08.001

Dermatini, S., Bass, F., Scholand, M., (2022). Refurbishing Europe´s Fluorescent Lamp Manufacturing Facilities. CLASP

Di Maio, F., Rem, P.C., (2015). A robust indicator for promoting circular economy through recycling. *Journal of Environmental Protection* 6, 1095-1104. http://dx.doi.org/10.4236/jep.2015.610096

Donmaz, A., Sayil, E., Havayolları, A., & Bölümü, B. (2017). The Growth & Importance of Middle-Class Consumers in Emerging Markets. In *IBANESS Conference Series: Kırklareli, Turkey*.

Dubey, R., Gunasekaran, A., Childe, S. J., Papadopoulos, T., & Helo, P. (2019). Supplier relationship management for circular economy: Influence of external pressures and top management commitment. *Management Decision,* 57(4), 767–790. https://doi.org/10.1108/MD-04-2018-0396

Elhossade, S. S., Abdo, H., & Mas' ud, A. (2021). Impact of institutional and contingent factors on adopting environmental management accounting systems: the case of manufacturing companies in Libya. *Journal of Financial Reporting and Accounting, 19*(4), 497-539 https://doi.org/10.1108/JFRA-08-2020-0224

Elia, V., Gnoni, M. G., & Tornese, F. (2017). Measuring circular economy strategies through index methods: A critical analysis. *Journal of cleaner production,* 142, 2741-2751. https://doi.org/10.1016/j.jclepro.2016.10.196

Ellen Macarthur Foundation, 2023 https://ellenmacarthurfoundation.org/circular-examples/why-buy-light-bulbs-when-you-can-buy-light-signify

Ernst & Young (2013). Hitting the sweet spot: The growth of the middle class in emerging markets. http://www.ey.com/gl/en/issues/driving-growth/middle-class-growth-in-emerging-markets.

Ernst & Young (2013b). Rapid-Growth Markets Forecast. http://www.ey.com/Publication/vwLUAssets/EY_RapidGrowth_Markets_Forecast/$FILE/EY-Rapid-Growth-Markets-Forecast-July-2013.pdf

European Commission, (2012). WEEE directive https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R0699&from=EN

European Commission, (2014). Study on collection rates of waste electrical and electronic equipment (weee) https://ec.europa.eu/environment/pdf/waste/weee/Final_Report_Art7_publication.pdf

European Commission, (2020a). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A new Circular Economy Action Plan for a Cleaner and More Competitive Europe https://eur-lex.europa.eu/legalcontent/EN/TXT/HTML/?uri=CELEX:52020DC0098

European Commission (2020b). Shaping Europe's digital future: Eurobarometer survey shows support for sustainability and data sharing. https://ec.europa.eu/commission/presscorner/detail/en/ip_20_383

European Commission, (2020c). https://ec.europa.eu/environment/topics/waste-and-recycling/waste-electrical-and-electronic-equipment-weee_en

European Commission, (2020d) Ecolabel https://environment.ec.europa.eu/topics/circular-economy/eu-ecolabel-home/about-eu-ecolabel_en

European Commission, (2020e) Right to repair https://ec.europa.eu/commission/presscorner/detail/en/ip_23_1794.

European Commission, (2021). Insights about the EU Circular Electronics Initiative And take-back study. https://circulareconomy.europa.eu/platform/sites/default/files/cei_260521bl_002.pdf

European Environmental Agency, (2018). Mercury in Europe’s environment A priority for European and global action. Luxembourg: Publications Office of the European Union. https://doi.org/10.2800/558803

European Parliament, (2020a) Right to repair https://www.europarl.europa.eu/news/en/headlines/society/20220331STO26410/why-is-the-eu-s-right-to-repair-legislation-important

European Parliament (2023a). Circular Economy Importance and Benefits. (https://www.europarl.europa.eu/news/en/headlines/economy/20151201STO05603/circular-economy-definition-importance-and-benefits?&at_campaign=20234-Economy&at_medium=Google_Ads&at_platform=Search&at_creation=RSA&at_goal=TR_G&at_audience=circular%20economy&at_topic=Circular_Economy&at_location=PT&gclid=CjwKCAjw36GjBhAkEiwAKwIWybonNcoGGqo1OsnPxSn2VdzYIwymLKWA56uJdpAjo-l48u2ZGJHILxoCb54QAvD_BwE

European Parliament, (2023b). Circular Economy Infographics. https://www.europarl.europa.eu/thinktank/infographics/circulareconomy/public/index.html

Eurostat, (2020). WEEE statistics in Europe. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics_-_electrical_and_electronic_equipment&oldid=552555

Eurostat, (2023) https://ec.europa.eu/eurostat/databrowser/view/ENV_WASELEEOS__custom_7464622/default/table?lang=en

Felix, C. B., Ubando, A. T., Chen, W. H., Goodarzi, V., &; Ashokkumar, V. (2022). COVID-19 and industrial waste mitigation via thermochemical technologies towards a circular economy: A state-of-the-art review. *Journal of Hazardous Materials*, 423. https://doi.org/10.1016/j.jhazmat.2021.127215</div>~

Fliedner, G. (2003). CPFR: an emerging supply chain tool. *Industrial Management & Data Systems* 103, 1(2), 14-21. https://doi.org/10.1108/02635570310456850

Forti V., Baldé C. P., Kuehr R., Bel G. (2020). *The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential*. United Nations University (UNU)/United Nations Institute for Training and Research (UNITAR) – co-hosted SCYCLE Programme. International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Rotterdam

Frankenberger, K., Takacs, F., & Stechow, R. (2021). A Step Toward Making Your Company More Sustainable. *Harvard Business Review*. https://scholar.google.com/scholar_lookup?title=A%20Step%20toward%20Making%20

Your%20Company%20More%20Sustainable&publication_year=2021&author=K.%20Frankenberger&author=F.%20Takacs&author=R.%20Stechow

Franklin-Johnson, E., Figge, F., & Canning, L. (2016). Resource duration as a managerial indicator for Circular Economy performance. *Journal of Cleaner Production*, *133*, 589-598. https://doi.org/10.1016/j.jclepro.2016.05.023

Gaur, J., Amini, M. and Rao, A.K. (2017). Closed-loop supply chain configuration for new and reconditioned products: an integrated optimisation model. *Omega*, 66(B), 212-223. http://dx.doi.org/10.1016/j.omega.2015.11.008

Gaur, J., Mani, V., Banerjee, P., Amini, M.; Gupta, R. (2019). Towards building circular economy: A cross-cultural study of consumers' purchase intentions for reconstructed products. *Management Decision*, 57(4), 886-903. https://doi.org/10.1108/MD-07-2018-0728</div>~

Geissdoerfer M., Savaget P., Bocken N.M.P, Hultink EJ. (2017). The circular economy – a new sustainability paradigm?. Journal of Cleaner Production 143, 757-768. https://doi.org/10.1016/j.jclepro.2016.12.048

Gradziuk, P., Gradziuk, P., Jończyk, K., Gradziuk, B., Wojciechowska, A., Trocewicz, A., & Wysokiński, M. (2021). An Economic Assessment of the Impact on Agriculture of the Proposed Changes in EU Biofuel Policy Mechanisms. Energies, 14(21), 6982. https://doi.org/10.3390/en14216982

Graedel, T. E.; Allwood, J.; Birat, J.; Buchert, M.; Hagelűken, C.; Reck, B. K.; Sibley, S. F. & Sonnemann, G., (2011). What Do We Know About Metal Recycling Rates?. USGS Staff Published Research 596. https://digitalcommons.unl.edu/usgsstaffpub/596

GSI-Alliance, 2020 https://www.gsi-alliance.org/wp-content/uploads/2021/08/GSIR-20201.pdf

Granstrand, O., & Holgersson, M. (2020). Innovation ecosystems: A conceptual review and a new definition. *Technovation*, 90, 102098. https://doi.org/10.1016/j.technovation.2019.102098

Grant, R. M., (2016). *Contemporary Strategy Analysis: Text and Cases*. (9th ed.). United States of America: Wiley

Hazen, B.T., Mollenkopf, D.A. & Wang, Y. (2017). Remanufacturing for the circular economy: an examination of consumer switching behaviour. *Business Strategy and the Environment*, 26 (4), 451-464. https://doi.org/10.1002/bse.1929

Homrich, A. S., Galvão, G., Abadia, L. G., & Carvalho, M. M. (2018). The circular economy umbrella: Trends and gaps on integrating pathways. *Journal of Cleaner Production*, 175, 525-543. https://doi.org/10.1016/j.jclepro.2017.11.064~

Huizingh, E. K. (2011). Open innovation: State of the art and future perspectives. *Technovation*, 31(1), 2-9. https://doi.org/10.1016/j.technovation.2010.10.002

Koberg, C. S., Detienne, D. R., & Heppard, K. A. (2003). An empirical test of environmental, organisational, and process factors affecting incremental and radical innovation. *The Journal of High Technology Management Research*, 14(1), 21-45. https://doi.org/10.1016/S1047-8310(03)00003-8

Lahti, T., Wincent, J., & Parida, V. (2018). A definition and theoretical review of the circular economy, value creation, and sustainable business models: Where are we now and where should research move in the future?. *Sustainability* 10(8), 2799. https://doi.org/10.3390/su10082799

Laubscher, M., & Marinelli, T. (2014, November). Integration of circular economy in business. In *Proceedings of the Conference: Going Green—CARE INNOVATION*.

Lee, B. & Saunders, M.N.K. (2017). *Conducting Case Study Research*. London: Sage.

Linder, M., Sarasini, S., & van Loon, P. (2017). A metric for quantifying product-level circularity. *Journal of Industrial Ecology*, *21*(3), 545-558. https://doi.org/10.1111/jiec.12552

Lindgreen, A., & Swaen, V. (2010). Corporate social responsibility. *International journal of management reviews*, 12(1), 1-7. (ISSN 1460-8545)

Morseletto, P. (2020). Targets for a circular economy. *Resources, Conservation and Recycling*, 153, 1-12. https://doi.org/10.1016/j.resconrec.2019.104553

Nascimento, D. L. M., Alencastro, V., Quelhas, O. L. G., Caiado, R. G. G., Garza-Reyes, J. A., Lona, L. R., & Tortorella, G. (2019). Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: A business model proposal. *Journal of Manufacturing Technology Management*, 30, (3), 607–627. https://doi.org/10.1108/JMTM-03-2018-0071

Norman, W., & MacDonald, C. (2004). Getting to the bottom of "triple bottom line". *Business Ethics Quarterly*, 14(2), 243-262. https://doi.org/10.5840/beq200414211

OECD (2003). Glossary of Environment Statistics, Studies in Methods, Series F, No. 67, United Nations, New York https://stats.oecd.org/glossary/detail.asp?ID=2626

Oliveira, M. C., Machado, M. C., Chiappetta Jabbour, C. J., & Lopes de Sousa Jabbour, A. B. (2019). Paving the way for the circular economy and more sustainable supply chains: Shedding light on formal and informal governance instruments used to induce green networks. *Management of Environmental Quality: An International Journal*, 30(5), 1095–1113. https://doi.org/10.1108/MEQ-01-2019-0005

O'Reilly III, C. A., & Tushman, M. L. (2013). Organisational ambidexterity: Past, present, and future. *Academy of Management Perspectives*, 27(4), 324–338. https://journals.aom.org/doi/abs/10.5465/amp.2013.0025

Park J. P., Chertow, M. R., (2014). Establishing and testing the "reuse potential" indicator for managing wastes as resources. *Journal of Environmental Management*,137, 45-53 https://doi.org/10.1016/j.jenvman.2013.11.053

Peattie, K. & Charter, M. (2003). Green marketing. In: Baker, M., (5th ed.) The Marketing Book. Burlington: Butterworth-Heinemann, 726-756.

Philips, (2015). Closing the materials loop. Towards a circular economy https://www.assets.signify.com/is/content/PhilipsConsumer/PDFDownloads/Global/ODLI20160406_001-UPD-en_AA-Collection-Collection-and-Recycling-brochure.pdf

Philips, (2023a) https://pro.mycreation.lighting.philips.com/sustainability

Philips, (2023b) https://www.usa.lighting.philips.com/application-areas/specialist-applications/uv-disinfection

Philips, (2023c) UV lamps for water purification | Philips lighting. https://www.usa.lighting.philips.com/products/uv-disinfection/water

Philips, (2023d). https://www.lighting.philips.com/application-areas/specialist-applications/horticulture/vertical-farming

Philips hue (2023) | i4Things – Smart home as a Service. https://spark.i4things.eu/integration/philips-hue/

Ranjan, K. R., & Read, S. (2016). Value co-creation: concept and measurement. *Journal of the academy of marketing science*, 44, 290-315. https://doi.org/10.1007/s11747-014-0397-2

Remenyi, D., Money, A., Price, D., & Bannister, F. (2002). The creation of knowledge through case study research. *Irish Journal of Management*, 23(2), 1-17. https://www.proquest.com/openview/1b2cd274086da783e88a42735df4640c/1?pq-origsite=gscholar&cbl=10069

Rodríguez, R. W., Pomponi, F., Webster, K., & D'Amico, B. (2020). The future of the circular economy and the circular economy of the future. *Built Environment Project and Asset Management*, 10(4), 529-546. https://doi.org/10.1108/BEPAM-07-2019-0063

Samuelson, P. A., & Nordhaus, W. D. (2010). (19th ed.) *Economics*. United Kingdom: McGraw Hill.

Signify, (2017). Minimising environmental footprint and creating instant savings. https://www.assets.signify.com/is/content/Signify/Assets/signify/global/20220325-minimize-environmental-footprint-create-instant-savings.pdf

Signify, (2021a). Packaging requirements. https://www.assets.signify.com/is/content/Signify/Assets/signify/global/20210322-packaging-policy-requirement.pdf

Signify, (2021b). Climate Action Report 2021. https://www.assets.signify.com/is/content/Signify/Assets/signify/global/20220422-climate-action-report-2021.pdf

Signify, (2023a). Brands portfolio| Signify Company Website. https://www.signify.com/en-gb/brands

Signify, (2023b). Innovation page | Signify Company Website. https://www.signify.com/global/innovation/trulifi/what-is-trulifi

Signify (2023c). Annual Report 2022| Signify Company Website. https://www.signify.com/global/our-company/investors/financial-reports/annual-report

Signify, (2023d). Circularity – Lighting solutions | Signify Company Website. https://www.signify.com/global/our-company/blog/sustainability/circularity-preserves-value

Signify, (2023e). Light as a Service | Signify Company Website. https://www.signify.com/en-za/lighting-services/managed-services/light-as-a-service

Signify, (2023f). Secure, wireless high-speed data with ultra-low latency | Signify Company Website. https://www.signify.com/it-it/innovation/trulifi/devices

Signify, (2023g). What is LiFi? Learn more about LiFi technology | Signify Company Website. https://www.signify.com/it-it/innovation/trulifi/what-is-trulifi

Signify, (2023h). Supplements to Annual Report 2022. https://www.assets.signify.com/is/content/Signify/Assets/signify/global/20230228-supplements-to-the-annual-report-2022-sustainability-statements.pdf

Signify, 2023i. Innovation | Signify Company Website. https://www.signify.com/en-gb/innovation

Signify, (2023j). Welcome to Pioneers of Light | Signify Company Website. https://www.signify.com/global/specifier

Signify, (2023l). External Recognition| Signify Company Website. https://www.signify.com/global/sustainability/external-recognition

Stank, T. P., Keller, S. B., & Daugherty, P. J. (2001). Supply chain collaboration and logistical service performance. *Journal of Business Logistics*, 22(1), 29–48. https://doi.org/10.1002/j.2158-1592.2001.tb00158.x

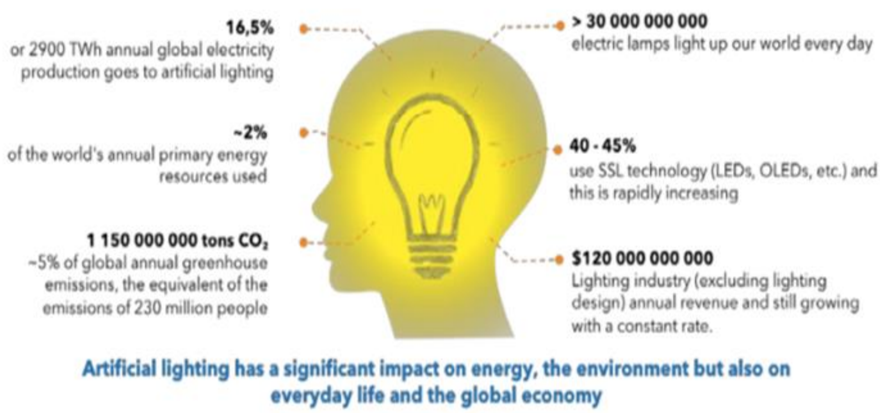
Ünal, E., Urbinati, A., & Chiaroni, D. (2018). Managerial practices for designing circular economy business models: The case of an Italian SME in the office supply industry. *Journal of Manufacturing Technology Management*, 30(3), 561–589. https://doi.org/10.1108/JMTM-02-2018-0061

Vanegas Pena, P., Peeters, J., Cattrysse, D., Duflou, J., Tecchio, P., Mathieux, F., & Ardente, F. (2016). Study for a method to assess the ease of disassembly of electrical and electronic equipment. Method development and application to a flat panel display case study. Publications Office of the European Union. https://doi.org/10.2788/489828

World Bank, 2018. https://www.worldbank.org/en/news/press-release/2018/09/20/global-waste-to-grow-by-70-percent-by-2050-unless-urgent-action-is-taken-world-bank-report

Yin, R.K. (2009) Case Study Research and Applications: Design and Methods. 4th edition. California: Sage

Zissis, G., Bertoldi, P., & Serrenho, T. (2021). Update on the Status of LED-Lighting world market since 2018. Publications Office of the European Union: Luxembourg.



Annexe A: Artificial lighting industry in Numbers Source: Zissis et al., 2021:3

Annexe B: Signify Goals to create long-term values Source: Signify, 2023c:11

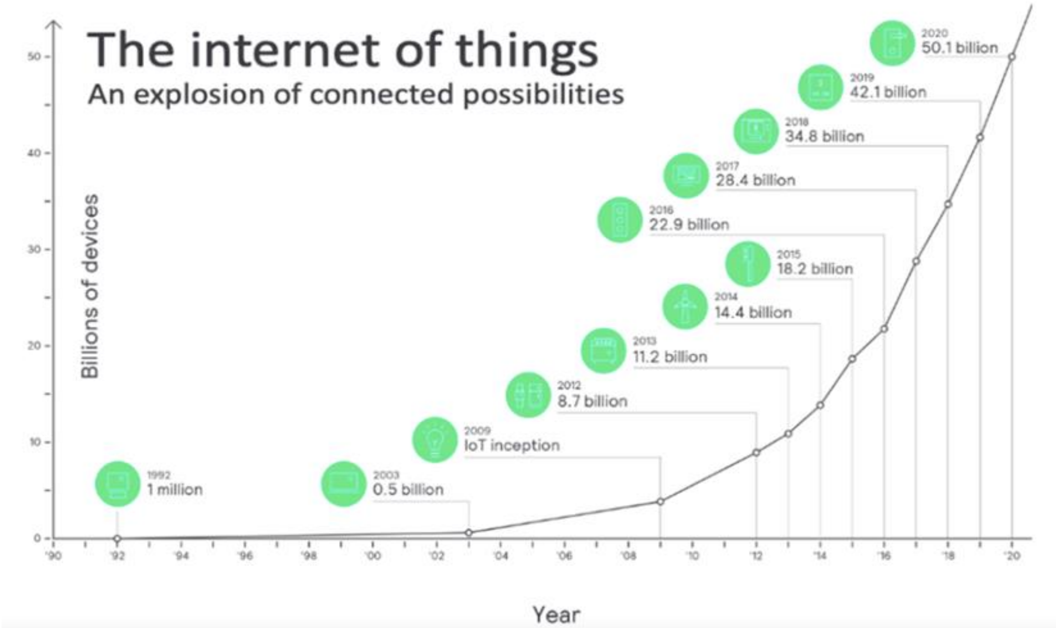
Annexe C: Signify Circularity application thresholds Source: Signify 2023d

Annexe D: The LAAS loop Source: Signify 2017:11

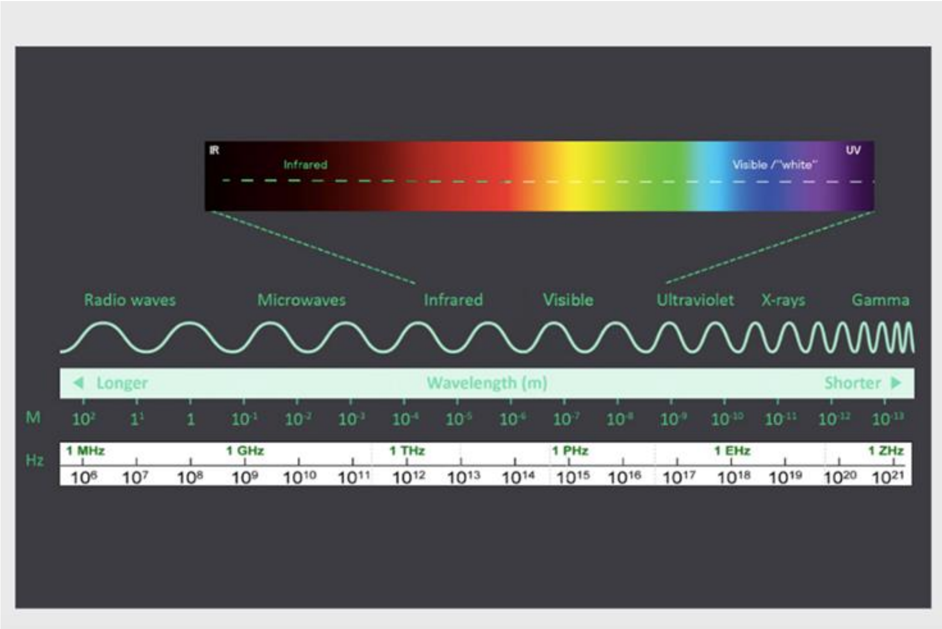
Annexe E: Example of Circular ready product Source: Signify 2017:13

Annexe F: 3D printing luminaires design examples Source: Signify, 2023d

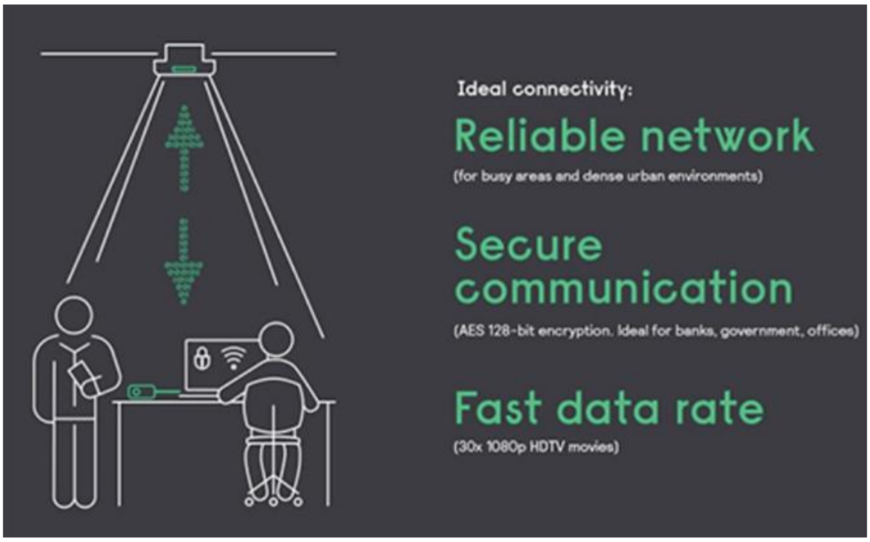
Annexe G: Example of solar lighting street product Source: Signify, 2021b



Annexe H: Evolution of the number of devices connected to the Internet
Source: Signify 2023f



Annexe I: Lightwave spectrum Source: Signify, 2023g



Annexe J: Illustration of how Lifi works Source: Signify, 2023g

How we did it*

46% lower emissions

Energy efficiency measures, such as:

- LED lighting & optimized HVAC
- Industrial process optimization
- 100% renewable electricity

92% lower emissions

Same as industrial sites, and:

- 100% renewable electricity
- Increased office space utilization
- Automated building processes

52% lower emissions

Shift to sustainable transport modes:

- Shift to sea freight
- Improved logistics operational efficiency

80% lower emissions

Changed business travel:

- Travel less
- Travel cleaner

Annexe K: How the company achieved carbon neutrality Source: Signify 2021b:15

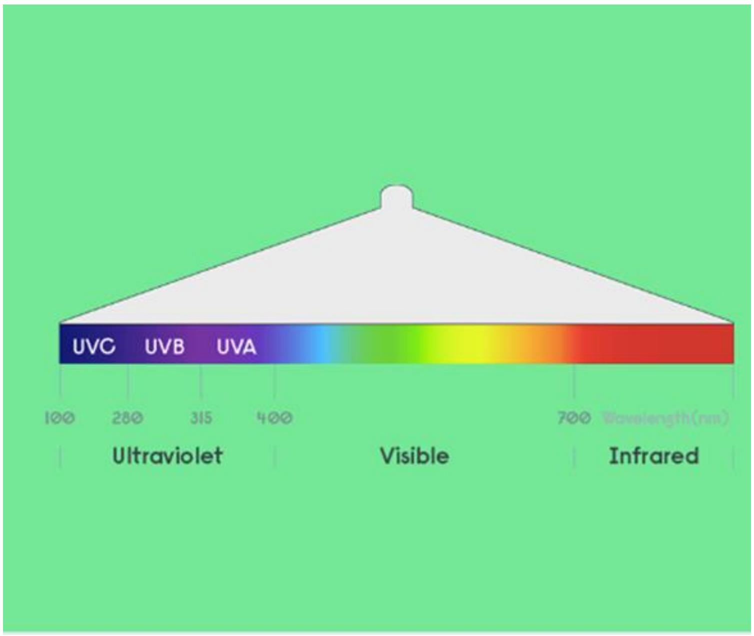
Recycling rate per waste category

	2020	2021	2022
Canteen waste	43%	66%	72%
Chemical Waste	29%	36%	45%
Electrical and Electronic Waste	99%	100%	99%
Glass (line rejects)	100%	100%	100%
Metal scrap	100%	100%	100%
Paper/cardboard	99%	99%	97%
Plastic waste	79%	81%	84%

Manufacturing waste in kilotonnes

	2020	2021	2022
Recycled	30 (91%)	38.7 (89%)	37.7 (89%)
Incinerated	1.9 (6%)	3.8 (9%)	3.8 (9%)
Landfilled	0.9 (3%)	0.9 (2%)	0.6 (1.5%)
In scope of commitment	0 (0%)	0.4 (0.88%)	0.2 (0.49%)
Total waste	**32.8**	**43.8**	**42.2**

Annexe L: Total waste and recycling rate Source: Signify 2023c:163



Annexe M: UVC location in the Light Spectrum Source: Philips, 2023b

Output Fraction	Purpose	Recipient
Glass	Glass	Glass industry Lamp industry
	Glazing	Ceramic industry
	Fusion agent within black copper foundry	Metal industry
	Abrasive sand for cleaning	Cleaning
	Clinker	Building/cement industry
	Sand replacement	
	Under layer for asphalt road	
	Glass wool	
	Silicon substitute	Incinerators
Caps and metallic components	Metal foundries	Metal industry
Plastics	(Mix of) plastic	Plastic industry
	Plastic waste	Energy recovery Controlled incineration Controlled landfill
Fluorescent powders	Recycling	Rare earth industry
	Recycling	Lamp industry
	Waste	Controlled landfill
Mercury	Cathode	Chlorine and caustic soda industry
	Mercury	Lamp industry
	Waste	Controlled landfill

Annexe N:: Types of waste produced by Signify, second-life purposes and potential buyers Source: Philips 2015: 6

Appendix A: Indicators to evaluate CE Inspired by Elia et al., 2016

Authors/Year	Article title	Objectives	Methodology used	Indicators
Joo Young Park **Marian R. Chertow** **2014**	Establishing and testing the "reuse potential" indicator for managing wastes as resources	Quantitatively measure how Coal Combustion by-products (CCBs) in the United States can be reused in the composition of concrete, agricultural and other industries products.	Quantitative- First, the authors identified the different kinds of CCBs produced (fly ash, bottom ash, etc.) and their current usefulness for concrete, agriculture and other industries based on the classification system used in the 2009 CCB utilisation survey conducted by the American Coal Ash Association (ACAA). After they calculated the reuse potential indicator for each one of those by-product categories. The indicator depends on the technologies available to extract	**Potential reuse indicator** Scale- 0 to 1 (0 meaning that the material is 100 % waste-like and one that the material is 100 % resource-like) The expression gives the calculation. CCB category production on that year/ (Quantity produced of a specific material that can contain CCBs in its composition+ CCB´s quantity used on it)

			those by-products (for example, in the case of fly washes, the particular extractor) safely. Per the reuse category, only the most widely applied technology was selected and considered in the calculation. They also considered the existing legislation that limits the CCB´s use in certain activities due to the presence of hazardous elements such as arsenic and mercury.	Example: Quantity of Concrete produced in 2009 + Quantity of fly ash present on the Concrete produced/Quantity of Fly ash produced in that year
Elizabeth Franklin-Johnson*, Frank Figge, Louise Canning 2016	Resource duration as a managerial indicator for Circular Economy performance	Quantitatively measure how much time is added to a product if it is reintroduced in the material flow cycle by being refurbished and/or recycled instead of being discarded at the end of its life cycle.	Quantitative The application of the longevity indicator measures the contribution to material retention based on the time a resource is kept in use. The measure comprises three generic components: initial lifetime, earned refurbished lifetime and earned recycled lifetime. The last two are	**Longevity indicator** Scale in months The expression gives the calculation (Initial new product use+ Refurbishing process time added+ Recycling process time added)

			conditioned by the collection rate of equipment reintroduced in the supply chain and also by the efficiency of the recycling technology since there are always some material losses within the process (unrecovered materials).	Example: Initial mobile phones lifetime average + Added time to the refurbishing process + Added time by the recycling
Valerio Elia, Maria Grazia Gnoni, Fabiana Tornese 2016	Measuring circular economy strategies through index methods: A critical analysis	Consider qualitatively the prospect of satisfying the present gap in the environmental assessment of CE approaches on the micro level through some of the numerous methodologies already existing and applied in the industrial and service segments.	Qualitative: The authors aggregated the existing methodologies in the literature to evaluate the CE approach impact in four categories: material flow, energy flow, land use and consumption, and other lifecycle-based. Each one of those categories was divided into two other subcategories depending on the number of indicators (s) used by the authors. Regarding that parameter,	Not applicable

			the methodologies were grouped into one single indicator methodology and multiple indicator ones.	
Francesco Di Maio, Peter Carlo Rem **2015**	A Robust Indicator for Promoting Circular Economy through Recycling	Replace the recycling rate indicator with a more accurate one that takes into account not the quantity of materials entering the recycling facilities but instead the monetary value that arises from the components and materials that compose each End-of-life (EOL) product that enters those facilities.	Quantitative: After accessing the market value (€ per kg) of four different materials used for producing cars- Steel, plastic, Aluminium(Al) and Copper (Cu) they calculated the Circular economy index for each one of those materials. Although the current technology available only allows the recovery of steel from cars, due to the high CEI from the other three components evaluated, the authors concluded that it would probably be a good investment to develop new technologies that enable the	**Circular Economy Index (CEI)**. The indicator proposed in this paper is the ratio of the material value produced by the recycler (market value) to the material value entering the recycling facility. In other words: CEI = Material value recycled from EOL product(s)/ Material value needed for (re −)producing EOL product (s)

			recovery of other materials recovery, too.	That indicator measures the economic value (i In €)
Paul Vanegas, Jef R. Peeters, Dirk Cattrysse, Joost R. Duflou (KU Leuven) Paolo Tecchio, Fabrice Mathieux, Fulvio Ardente (JRC) **2016**	Study for a method to assess the ease of disassembly of electrical and electronic equipment	The paper focuses on developing a standardisable method with a verifiable metric to assess the reversible disassembly of electrical and electronic equipment (EEE). The primary motivation of this study was the need for a robust method to evaluate the ability to access or remove specific components from products to facilitate their repair, reuse or recycling. Such a method is developed for different purposes, such as	Quantitative: After a literature assessment of prevailing procedures and accurate tests to access the key elements affecting disassembly acts, a computation process was created using a catalogue containing disassembly intervals grounded on the MOST logic (relating the product and connectors characteristics mutually). An LCD monitor was employed to illustrate the feasibility of the suggested system, and the times needed to complete each task involved in the disassembly were accounted for by direct observation.	**Ease of disassembly (eDim):** The indicator expresses the time (in seconds) needed to disassemble a product completely. It follows the MOST methodology, so the time needed to complete the disassembling process is decomposed into six main tasks, and it is given by the summation of the time needed to finish each task individually $eDiM = \sum_{i=1} (Tool\ Change + Identifying + Manipulation + Positioning + Disconnection_i + Removing_i)$ Example:

		optimising product design, compliance with policies and improving end-of-life treatment.	The range of the method used extends only to non-destructive operations, intending to raise product lifetime through policies such as reparation and recycling.	
Linder, Sarasini and van Loon, 2017	A Metric for Quantifying Product-Level Circularity	This paper aims to overlap the absence of a standardised process for computing circularity at the micro (product-level) level. Based on the metric developed (Product-Level Circularity), authors contend to enable stakeholder decisions since only measurable things can be managed.	Quantitative: After reviewing the existing methods to calculate circularity at the micro level as well as its respective advantages and disadvantages, the authors defined their metric, the Product Level Circularity Metric (PLCM or simply C), and defined the unit more suitable to measure that metric, based on the market fluctuation aspects, in this case, the economic value of an item. They also tested the indicator feasibility by applying it in two	**Product-Level Circularity Metric (PLCM):** The circularity metric ranges between 0 and 1 (or 0% to 100% recirculated parts). Circularity is defined by the fraction of a product that comes from used products, more specifically, the price of reused materials in relation to the total economic value of the good (market price). This is expressed in the equation to obtain *c, which* denotes product-level circularity:

			theoretical examples (a simple and complex one).	*C= economic value of recirculated parts/ economic value of all parts* Whenever there is no established market price for the good, the economic value of the product must be given by a cost-based estimation; in other words, the economic value must be above the costs inherent to asset production since companies are mostly profit-seeking entities. In that case, the product circularity is given by the expression where r_i denotes the economic value of recirculated parts of the new product part, and n_i denotes the economic value of no recirculated parts (i.e., virgin

				materials for the relevant product part i): $c_i = r_i / (r_i + n_i)$ The economic value (r) of recirculated parts obtained by the firm is computed by adding all the costs involved in the sourcing transaction for those types of materials (including the direct ones and the **opportunity cost**): r = max[cost of parts including handling costs such as procurement and logistics costs; sum of market prices for virgin materials contained in the product; second-hand market price for used material or component]

N. Adibi [a] [b], Z. Lafhaj [b], M. Yehya [b], J. Pay et [c] [d] 2017	Global Resource Indicator for life cycle impact assessment: Applied in wind turbine case study	Creating a complete indicator to access the availability of global resources by inserting new dimensions that other indicators did not consider.	Quantitative: After reviewing the existing indicators for calculating resource availability under the Life Cycle Assessment(LCA) framework, the authors defined their metric, Global Resource Scarcity. This new metric considers two factors that the previous ones did not: material recyclability and geopolitical availability. Recyclability is a critical factor because even if a particular resource is considered scarce because of the lack of natural reserves, the possibility of recycling it and the efficiency rate of the process may alter the	**Global Resource Indicator (**GRI): GRI= X/(Y*Z) X-Scarcity Y-Recyclability Z-Geopolitical Availability

			resource availability considerably. At the end of the study, they also tested the indicator feasibility by applying it to a wind turbine case.	
T. E. Graedel **Julian Allwood** **Jean-Pierre Birat** **Matthias Buchert** **Christian Hagelűken** **Barbara Reck** **Scott Sibley** **Guido Sonneman**	What Do We Know About Metal Recycling Rates?	Review the existing types of metal scraps that enter recycling facilities (home, new and old scraps, respectively) and recycling-related concepts associated with the metal recycling industry, such as functional and non-functional recycling. Based on the explored notions and the metal life cycle (see Figure W), the authors try to access some values that allow evaluation of the efficiency of	Quantitative: Analyze the metal life cycle and evaluate the efficiency of End-of-life metals (EOL metals) usage through the lenses of four proposed indicators. In order to access the indicators, a model was created (see Figure Y) based on the different stages a metal passes (production, fabrication, manufacturing, use, collection and recycling) and 12 variables t were identified. The relationships and interactions between the identified variables are responsible for the indicators.	Four different indicators are used: 1. Recycling process efficiency Rate (RR): Compares the total amount of EOL metal collected with the quantity that is made available for reuse through the recycling process RR= g/e 2. End-of-Life Recycling Rate (EOL-RR): It is the ratio between the EOL metals collected and the actual input

2011		the processes associated with the metal recycling procedure.		that arises from the recycling process (recycled EOL metals) EOL-RR= g/d (functional recycling) or f/d (non-functional recycling) 3. Recycling Input Rate (RIR): Describes the fraction of secondary (scrap) metal in the total metal input of metal production RIR=(j+m)/ (a+j+m) 4. **Old Scrap Ratio (OSR):** Quantifies the EOL metal contained in various discarded products that is collected and enters the recycling chain (as

				opposed to landfilled metal). In other words, it reveals the quantity/fraction of old scrap metal that is reused for metal production and product manufacturing OSR= (g) / (g+h) Primary metal input End of life (EOL) products (metal content) e. EOL metal collected for recycling f. EOl metal separated for non-functional recycling g. recycled EOL metal (old scrap) j. scrap used in fabrication (new and old) m. scrap used in production (new and old)