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CALCULATION OF THE CARBON FOOTPRINT OF BOOKS AND E-READERS THROUGH THE STAGES OF THE PRODUCT LIFE CYCLE

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Abstract: *In this research, the carbon footprint for the book and e-reader was calculated for all phases of the product's life cycle. The scientific paper also compares the amount of CO_2 equivalents by stages of the life cycle analysis of the listed products, identifies possible places in production or individual habits that can be responsible for reducing the carbon footprint, and suggests ways to reduce the carbon footprint. The CO_2 equivalent was used in the carbon footprint calculations because other greenhouse gases such as methane, N_2O and fluorinated gases are also emitted during the life cycle of books and e-readers. Calculating the carbon footprint is essential for understanding, monitoring and reducing greenhouse gas emissions. The calculation can contribute to raising people's awareness of issues important for reducing the negative impact on the environment, can be a driver of necessary changes in lifestyle with the aim of more sustainable business and lifestyle, and contributes to global efforts in the fight against climate change. The importance of the obtained indicative numbers lies in the fact that individuals and organizations can use the obtained values to make informed decisions that positively affect the environment, society and the economy.*

Key words: carbon footprint, product life cycle stages, book, e-reader

1. INTRODUCTION

When calculating the impact on the environment, the CO_2 equivalent is most often used, which is a measure used to convert the amounts of different greenhouse gases into an equivalent amount of carbon dioxide (CO_2) (Çelekli & Zariç, 2023; East, 2008). The calculation is based on their global warming potential (GWP), which shows how many times more (or less) heat a particular gas retains in the atmosphere compared to CO_2 over a certain period, usually 100 years (Pandey, Agrawal & Pandey, 2008). When studying the carbon footprint balance for books, other greenhouse gases should be taken into account in addition to carbon dioxide (CO_2). Different greenhouse gases have different global warming potentials (GWP), so it is important to consider all relevant gases to get a complete picture of the overall environmental impact (Courchene & Allan, 2008; Edgar & Peters, 2009). When the life cycle of a book is divided into the stages of paper production, printing, transport and disposal, it can be concluded that CO_2 is present as the main pollutant. In addition to the aforementioned gas, methane emissions (CH_4) are present at landfills where paper waste is decomposed anaerobically, and nitrogen oxide emissions (N_2O) from the production and use of fertilizers for growing trees that are used for paper and transport processes.
Electronic equipment has a significant impact on the environment throughout its life cycle, including production, use and disposal (Gard & Keoleian, 2008). Electronic devices require the extraction and processing of various metals and rare earth elements, which can cause environmental devastation, including habitat loss, water pollution and soil degradation (Oladipo et al., 2023). The product design phase should be based on the development of products with a smaller carbon footprint, increased energy efficiency and the use of sustainable materials. CO_2 emissions are related to energy consumption during the production, transportation and use of electronic devices. Fossil fuels emit significant amounts of CO_2 in the mentioned phases of the product's life cycle. In addition to CO_2, other greenhouse gases such as methane, N_2O, and fluorinated gases are also emitted. Electronic production can indirectly contribute to methane emissions, particularly through energy consumption from fossil fuels such as natural gas and coal. Industrial processes, including the manufacture of electronic components, can emit N_2O as a by-product (Lee, Ryu & Moon, 2012; U.S. Environmental Protection Agency Office of Resource Conservation and Recovery, 2020). Fluorinated gases are used in manufacturing processes to clean semiconductor devices. They have a very high global warming potential (GWP) and are long-lived in the atmosphere. PFCs (perfluorocarbons) are used in the production of semiconductors (Tsai, 2002). SF_6 (sulfur hexafluoride) is used in electrical equipment as an insulating gas due to its excellent dielectric properties (Dervos & Vassilou, 2000; Badrul, 2021; Zhou, Teng & Tong, 2018). The last phase of the product's life

cycle should be delayed as much as possible with responsible device maintenance, because e-waste often contains toxic materials (e.g. lead, mercury, cadmium) that can contaminate soil and water if not properly disposed of. Recycling electronic equipment can reduce the need to extract new raw materials but requires specialized processes to safely extract useful materials and dispose of hazardous components. Responsible practices include developing more efficient methods to extract and reuse valuable materials from e-waste. The aforementioned implements the circular economy model, which has become imperative in all production branches (Zhou, S., Teng, F. & Tong, 2018; Geissdoerfer et al., 2020).
Carbon footprint is an important factor in understanding environmental impact. Calculating the carbon footprint helps identify the largest sources of greenhouse gas emissions within an organization, process or product (Yang & Meng, 2020). The obtained data have a qualitative and quantitative dimension of reporting on emissions and thus can contribute to easier achievement of sustainability (Durojaye, Laseinde & Oluwafemi, 2019; Kumar, Sharm & Vashista, 2014). Organizations can use carbon footprint data to set emission reduction targets and track progress towards those targets. Often, the calculation of the carbon footprint can contribute to improving efficiency by identifying places to optimize resources, which can lead to reduced emissions and costs. In addition to reducing costs, carbon footprint monitoring can lead to new investments as investors increasingly seek information on sustainability and greenhouse gas emissions before deciding to invest. Organizations that monitor and reduce their carbon footprint may have easier access to funding. Consumers are becoming increasingly aware of the environmental impact of their purchasing decisions. Products with a smaller carbon footprint can have a market advantage. In addition to the aforementioned, many legislative bodies impose reporting requirements on greenhouse gas emissions (Hertwich & Peters, 2009; Hawkins, Ma, Schilizzi & Zhang et al., 2016). Calculating the carbon footprint helps organizations comply with regulations. Some companies have introduced transparent carbon footprint reporting to improve the organization's reputation and the desire to present themselves as companies that are committed to sustainable business and production. It can be noted that as regulations have been tightening for many years, organizations that already monitor their carbon footprint are better prepared to adapt to the new requirements. Requirements for reducing global greenhouse gas emissions are reflected in various national and international goals, such as the goals of the Paris Agreement and the Sustainable Development Goals (SDGs) set by the United Nations, which relate to climate action and sustainable production (Jones et al., 2017; Ordonez-Ponce, 2023; Rei, Goncalves & de Souza, 2017; Streck, Keenlyside & von Unger, 2016). Awareness of one's carbon footprint can motivate individuals and organizations to adopt more sustainable practices. In this paper, a carbon footprint for a book and an e-reader will be presented. The stages of life cycle analysis of the listed products will be compared and possible places in production or individual habits that can contribute to reducing the carbon footprint will be defined.

2. METHODS

To define the product life cycle, all phases of the product life cycle are identified: procurement of raw materials, production, distribution, use, and disposal or recycling. Research papers related to greenhouse gas emissions and carbon footprints of various materials and processes were searched in the scientific databases ScienceDirect, Google Scholar, and PubMed. In addition to the above, reports from industrial organizations were also used, such as those dealing with production, transport and recycling, which can provide data on energy needs and emissions. Literature published by environmental protection agencies and NGOs, manufacturers' specifications and declarations, and websites offering carbon footprint calculators (e.g. Carbon Footprint Calculator) for preliminary estimates were studied. The collection and analysis of data for the calculation of the product's carbon footprint required a systematic approach and the use of a large number of enumerated data sources.
Various greenhouse gases such as methane (CH_4), nitrogen oxide (N_2O), and fluorinated gases (HFCs, PFCs, SF_6), which significantly contribute to global warming, are integrated into the calculation. Each of these gases has a different GWP, the GWP of methane (CH_4) is 28-36 times greater than CO_2 over 100 years, while the GWP of nitrous oxide (N_2O) is about 298 times greater. CO_2 equivalent enables simpler communication and comparison of total emissions of different gases because it converts all emissions into one common measure. This makes it easier to calculate the overall impact of activities and products on climate change. The use of CO_2 equivalents standardizes the data, allowing for consistency and comparability between different studies.
To calculate the CO_2 equivalent, you need to multiply the amount of each gas by its GWP (Equation 1):

$$CO_2\text{-}eq=(M_{CO2}\times 1)+(M_{CH4}\times GWP_{CH4})+(M_{N2O}\times GWP_{N2O})+... \quad (1)$$

Where is:

M_{CO2}: Mass of emitted CO_2
M_{CH4}: Mass of emitted CH_4
GWP_{CH4}: Global Warming Potential of Methane (CH_4)
M_{N2O}: Mass of emitted N_2O
GWP_{N2O}: Global warming potential of nitrogen oxide (N_2O)

By including all relevant greenhouse gases in the calculation of CO_2 equivalents, a more comprehensive assessment of the real impact of climate change is obtained.
To verify the accuracy of certain parts of the phases of the product life cycle, the results were validated by comparing the obtained results with other studies or reference values to ensure credibility. By combining quantitative and qualitative data from reliable sources, accurate and detailed insight into the total carbon footprint of the product throughout its entire life cycle can be achieved. This data can help identify key areas to reduce emissions and improve product sustainability.

3. CALCULATION OF CARBON FOOTPRINT

The carbon footprint of physical books and e-readers has been calculated, which includes an assessment of the CO_2 emissions associated with their life cycles to make a judgment about their environmental burden.

3.1 Calculation of carbon footprint for book

The life cycle of a physical book includes paper production (growing raw material or using recycled raw material, paper production), printing and binding, distribution (transport to bookstores and/or end users, use (generally no additional emissions) and disposal (recycling or disposal) (Figure 1) (Borggren, Moberg & Finnveden, 2011). Paper production includes processes such as the extraction of wood and other raw materials needed for paper production. CO_2-eq emissions include emissions from logging machines, transportation of raw materials to paper mills, etc. During the paper pulp production process, wood chips are cooked and washed, as white and dry paper pulp. These processes are energy-intensive and often use fossil fuels. If we assume that the average book has about 200 to 300 pages, it is evident that 1 kg of paper, emits 1,2-1,5 kg of CO_2-eq (Gower et al., 2006; Moberg & Borggren, 2010).
According to CEPI (Confederation of European Paper Industries), average CO_2-eq emissions for paper production in Europe are around 0.78-1.32 kg CO_2-eq per kilogram of paper, depending on the type of paper and the efficiency of the production process. The Environmental Paper Network (EPN) reports that CO_2-eq emissions for the production of recycled paper can be lower, around 0.7-1.0 kg CO_2-eq per kilogram, while emissions for raw fibre paper can be higher, around 1.3-1, 5 kg of CO_2-eq per kilogram. Ecoinvent Database like GaBi and SimaPro, contains data showing that CO_2-eq emissions for different types of paper can vary between 0.9 and 1.5 kg CO_2-eq per kilogram. Printing processes include the use of ink, printing machines and materials in finishing processes such as glue, and covers. All processes use energy for production. Emissions related to the printing and binding process emit approximately 1-2 kg of CO_2-eq. In total, to produce one book of 1 kg of paper, approximately 2,2-3,5 kg of CO_2-eq is emitted (Toffel, M. W. & Horvath, 2004; Wells et al., 2012).

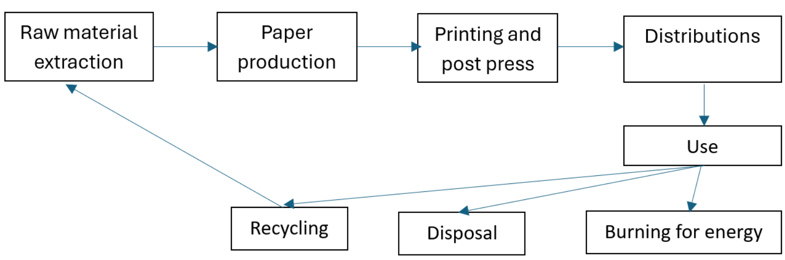

Figure 1: The life cycle of a book

The distribution estimate includes various stages of transportation, such as the transportation of books by trucks, ships, aeroplanes, and delivery vehicles. Different modes of transport (truck, ship, plane) have different emission profiles. Trucks and planes tend to have higher CO_2-eq emissions per kilogram of cargo than ships (Ferrer & Thomé, 2003; Yoon, Y., Yang, M. & Kim, 2008). The estimation of the amount of CO_2-eq emissions is influenced by the distance from the printing press to the warehouse and from the warehouse to bookstores or end users, as well as the size of the load. Larger loads distributed over longer distances result in higher emissions. When studying international transport according to data from Carbonfund.org, the CO_2-eq emissions for transporting one ton of cargo over 1,609 km by truck are about 63 kg of CO_2-eq. For a ship, the same distance amounts to about 6 kg of CO_2-eq. According to the European Environment Agency (EEA) average emissions for heavy truck transport (HGV) are around 62-105 g CO_2-eq per ton-kilometre (g CO_2e/Tkm). Data from the IPCC (Intergovernmental Panel on Climate Change) are similar, where emissions range from 60 to 150 g CO_2-eq per ton-kilometre, as well as from DEFRA (UK Department for Environment, Food & Rural Affairs), where approx. 80-120 g CO_2-eq per ton-kilometre. For transport within the country, the amounts are quite different, depending on the mode of transport and the size of the country, i.e. the length of the journey. Estimates of emissions for distribution vary around 0.1-0.5 kg CO_2-eq per book.

Transport from the printing house to the warehouse (by truck):
Distance: 1000 km
Emissions: about 0.063 kg CO_2-eq T/km
For 1 kg of books: (0.063 kg CO_2-eq / 1000 kg) * 1000 km = 0.063 kg CO_2-eq

Transport from warehouse to bookstore or user (local delivery by truck or van):
Distance: 100 km
Emissions: about 0.2 kg CO_2-eq T/km for local delivery
For 1 kg of books: (0.2 kg CO_2-eq / 1000 kg) * 100 km = 0.02 kg CO_2-eq

Delivery to the end user (delivery vehicle or car):
Distance: 10 km
Emissions: about 0.1 kg CO_2-eq T/km
For 1 kg of books: (0.1 kg CO_2-eq / 1000 kg) * 10 km = 0.001 kg CO_2-eq

The total emission in the transport phase is about 0.084 kg CO_2-eq due to large variations in the parameters for further calculation the amount of approximately 0.5-1 kg CO_2-eq per book will be used.
It was mentioned earlier that the phase of use does not affect CO_2 emissions. In the disposal phase, different methods can be used, such as recycling, incineration and landfilling (Shang et al., 2021; Laurijssen et al., 2010). The paper recycling process includes collection, transport to a recycling facility, and an energy-consuming recycling process. Recycling reduces the need for new raw materials but still consumes energy that generates CO_2-eq emissions. According to the Environmental Paper Network (EPN), paper recycling can reduce CO_2-eq emissions by about 1.4 kg CO_2-eq per kilogram of recycled paper compared to the production of paper from raw fibres. IPCC (Intergovernmental Panel on Climate Change) research estimates that CO2-eq emissions for paper recycling are around 0.3-0.6 kg CO_2-eq per kilogram of paper, including all collection, transport and processing processes Burning books can generate energy, but it also emits CO_2. Emissions depend on the efficiency of the incineration plant and the energy value of the burned material. Paper should not be disposed of in landfills, but some paper still ends up there (Guo et al., 2020). Paper in a landfill can be decomposed anaerobically, emitting methane (CH_4), a powerful greenhouse gas. Modern landfills often have methane capture systems, which can reduce emissions. A study on the life cycle of paper estimates that CO_2-eq emissions from recycling one kilogram of paper amount to about 0.0007-0.001 kg CO_2-eq. The amount indicates a very high efficiency of the recycling process. When studying landfilling, the EPA (United States Environmental Protection Agency) claims that CO_2-eq emissions are about 0.3 kg CO_2-eq per kilogram of paper, but this number can be higher due to methane (CH_4) emissions from landfills. The IPCC estimates that emissions from paper disposal can be between 0.5-1.0 kg CO_2-eq per kilogram of paper, taking methane emissions into account. Incineration with energy valorization has a smaller impact on the environment, so the European Environment Agency (EEA) estimates emissions of about 0.7-1.2 kg CO_2-eq per kilogram of paper, while the EPA at about 0.8 kg CO_2-eq per kilogram of paper. When paper is burned without energy valorization, the IPCC estimates the emission at around 1.0-1.5 kg CO_2-eq per kilogram of paper. The estimate that book disposal emits approximately 0.1-0.5 kg of CO_2-eq per book is based on analyses of different disposal methods and their emission profiles.

When the average impact for all phases of the book's life cycle is added up and when all contributions are considered, the total carbon footprint per book is about 3.6-7.5 kg CO_2-eq.

3.2 Calculation of carbon footprint for e-reader

The life cycle of an e-reader includes production (extraction of raw materials, production of components, assembly), transport (transport to the end use), use (energy consumption during use) and disposal (recycling or disposal) (Figure 2).

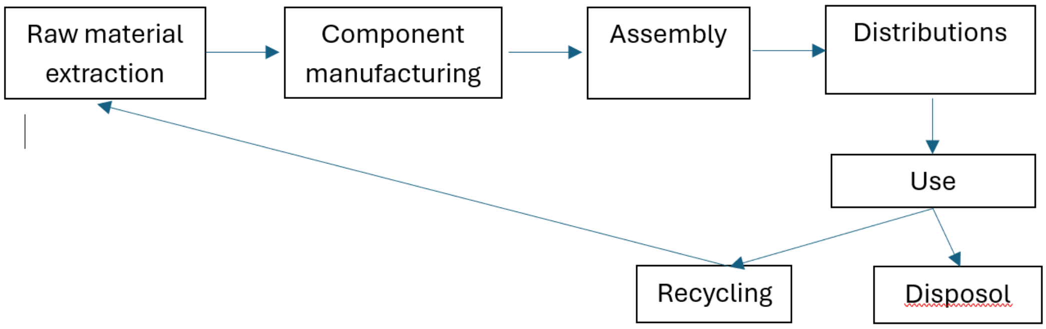

Figure 2: The life cycle of a e-reader

In the production phase of e-readers, CO_2 is emitted through the extraction, transportation and refining of raw materials, i.e. metals (e.g. lithium, cobalt) for batteries, rare earths for electronic components, and other raw materials such as plastic, which is energy intensive (Moberg, 2010). Emissions from metal extraction and refining: about 30 kg CO_2-eq. In e-readers, many metals are used to make housings and other structural parts, so for example copper is used in printed circuit boards (PCBs) for electrical connections and wiring due to its excellent conductivity (Chancerel, 2015). Gold and silver are used for plating contacts and connectors because of their exceptional resistance to corrosion and good conductivity (Vats & Singh, 2015). Along with plating, nickel is used in alloys to increase resistance to corrosion and wear. Lithium is used in batteries due to its high energy density and long service life, and cobalt is used in lithium-ion batteries as well as in cathode materials due to its electrochemical properties (Park & Fray, 2009). Tin is used for soldering components on printed boards, and palladium is used in capacitors and contacts for its exceptional conductive and chemical properties (Gorewoda et al., 2020). Steel is characterized by strength and resistance to mechanical stress, so it is used in screws and internal structures. The next step is to manufacture the components including the screen, battery, processor and other electronic components. Production of screens (e-ink or LCD) emits about 40 kg of CO2-eq, batteries about 20 kg of CO_2-eq, and other electronic components about 30 kg of CO_2-eq. Energy consumption and emissions in this phase depend on the production technology and the energy used in the factories (Kozak et al., 2021; Majeau-Bettez, Hawkins & Strømman, 2011; Williams, 2004). Assembling the components into the finished device includes the energy costs of the assembly lines and auxiliary processes, which amount to about 10 kg of CO_2-eq. Emissions in the transportation phase include the transportation of raw materials to factories and finished components to assembly plants, which amounts to about 38 kg of CO_2-eq. Emissions depend on the distance of transport and the means of transport used. The Life Cycle Assessment of Electronic Devices study provides estimates of CO_2-eq emissions for the life cycle of e-readers that vary between 150-200 kg CO_2-eq, depending on the model and technology. Some manufacturers publish environmental reports detailing the CO_2-eq emissions associated with their products, for example, Amazon publishes CO_2-eq emissions for different models of Kindle devices. The calculated value in this study coincides with the study and manufacturer's reports and is approximately 168 kg CO_2-eq per device.

The calculation of the carbon footprint for the transport phase is based on the same settings as for the calculation for the book, with the difference that here, for international transport, the data is given for transport by ship, because raw materials and parts of the reader can come from overseas countries, so such transport is more favourable by ship. CO_2-eq emissions for ship transport, according to the European Environment Agency (EEA) are about 3-15 g CO_2-eq per T/km, according to the IPCC they are about 5-15 g CO_2-eq per T/km and according to the IMO (International Maritime Organization are around 8-18 g CO_2-eq per T/km.

The emissions of transport by ship:

The emissions of transport by ship are about 6 g CO_2-eq per ton per kilometre, so for a distance of 10,000 km, it would amount to 0.012 kg CO_2-eq with a reader weight of 0.2 kg.

(6 g CO_2-eq / 1000 kg) * 10,000 km * 0.2 kg = 0.012 kg CO_2-eq

Transport from the port to the warehouse (by truck):

When the distance from the port to the warehouse, from the warehouse to the user, which we estimated at 1000 km, is combined with the transport by ship, the CO_2-eq emission is 0.0126 kg, i.e. a total of 0.0246 kg.

Emissions: about 63 g CO_2-eq T/km

For 0.2 kg e-reader: (63 g CO_2-eq / 1000 kg) * 1000 km * 0.2 kg = 0.0126 kg CO_2-eq

Combining the stages of transport (Ship transport + truck transport): 0.0246 kg CO_2-eq

More realistic scenarios often include air transport, which significantly increases emissions, and additional local transport is also required. Air transport by plane has an average emission of about 500 g CO_2-eq per ton per kilometre travelled. Emissions related to the aforementioned transport depend on many factors, so conservative emission calculations of around 500 g CO_2-eq per ton of product per kilometre are used here.

Air transport:

The calculation for a distance of 10,000 km would be:

For 0.2 kg e-reader: (500 g CO_2-eq / 1000 kg) * 10,000 km * 0.2 kg = 1 kg CO2-eq

Local transport:

With an additional local transport of 500 km with emissions of about 63 g CO2-eq per ton per kilometre for a 0.2 kg e-reader were 0.0063 kg, i.e. a total of 1.0063 kg.

63 g CO_2-eq / 1000 kg) * 500 km * 0.2 kg = 0.0063 kg CO_2-eq

Combining the stages of transport (Transport by plane + transport by truck): 1.0063 kg CO_2-eq

The average power consumption of a book reader (e-reader) may vary depending on several factors such as screen size, screen type (e.g. E Ink vs. LCD), screen brightness, frequency of use of wireless functions (Wi-Fi, 3G/4G) and page-turning frequency. But in general, e-readers with E Ink screens, which are the most common among devices specialized in reading books, are known for very low energy consumption. The reasons for the low energy consumption are, among others, the fact that E Ink screens consume energy only when refreshing the page, which means that a static display does not consume energy. This technology is very energy efficient, resulting in a long battery life. Some e-readers have a built-in front light that can increase power consumption if used at higher brightness. In addition to the aforementioned use of Wi-Fi or mobile data can significantly increase energy consumption. A larger battery capacity enables a longer duration between charges but does not directly affect energy consumption per hour of use.

Calculating the carbon footprint of e-book readers by product life stage involves estimating CO_2 emissions during the different stages of the device's life cycle. These phases include production, transport, use and disposal. The carbon footprint of e-reader manufacturing includes extraction of raw materials, manufacturing of components and assembly of the device. Emissions estimates can vary, but data from life cycle analysis (LCA) studies are often used (Hischier & Wäger, 2005; Gatti, Basseau & Bourely, 2011; Moberg et al, 2010; Teehan & Kandlikar, 2013). According to a study from 2012, it is estimated that the production of e-readers (e.g. Kindle) emits about 168 kg of CO_2-eq. Transport includes emissions associated with moving the device from the place of production to the end user. These emissions depend on the distance and mode of transport (aeroplane, ship, truck). Transport emissions can vary, but the average value is around 10 kg CO_2-eq. Usage includes emissions associated with electricity consumption over the lifetime of the device. Unfortunately, e-reader manufacturers rarely directly mention the exact amount of energy consumed in watts or watt-hours but often provide estimates of battery life under typical usage conditions. However, there is information that can be used to approximate energy consumption. For example, the Amazon Kindle Paperwhite can do up to 28 hours of continuous reading with Wi-Fi off and low brightness, which can be estimated at around 2-3 weeks of use per charge, with a typical usage of around 30 minutes per day. The Kindle Paperwhite has a battery with a capacity of about 1500 mAh at 3.7V, which gives a total of about 5.55 Wh (1500 mAh * 3.7V). In this case, a calculation was made to estimate the consumed energy as follows:

Battery life in hours of use: 6 weeks x 7 days/week x 0.5 hours/day = 21 hours of total use.
Energy consumption per hour: 5.55 Wh / 21 hours ≈ 0.26 Wh per hour of use.
For the calculation, let's assume 2 hours of daily use over 3 years (typical service life):
Total hours of use: 2 hours/day * 365 days/year * 3 years = 2190 hours
Total energy consumption: 2190 hours * 0.26 Wh/hour = 569.4 Wh = 0.5694 kWh
Carbon emissions for use: 0.5694 kWh * 0.475 kg CO2/kWh ≈ 0.27 kg CO_2-eq

Similar figures are for the Kindle, the Clara HD can also last several weeks on a single charge under similar conditions of use. E-readers consume very little power, often between 1-2 W, which allows long-term use without frequent charging. Kobo quotes similar figures to Amazon, up to 6 weeks with an average of 30 minutes of daily use, Wi-Fi off and low brightness. Clara HD has a battery with a capacity of 1500 mAh at 3.7V, which gives a total of about 5.55 Wh. It was already mentioned earlier that energy consumption depends on the specific model and method of use, but it is clear that e-readers are designed for maximum energy efficiency. To calculate for a certain device, reviews by technology portals like CNET, TechRadar, or The Verge can be used, which often include battery life tests: such tests can often provide additional information about the energy efficiency of the device and mention the conditions of use of the device and energy consumption (Wang et al., 2011; Keil & Jossen, 2016; Birkl et al., 2017; Peters et al., 2017; Xu et al., 2016).

Disposal includes emissions associated with recycling, incineration or end-of-life disposal of devices. Factors that affect CO_2-eq emissions in the recycling of e-readers are the collection and transport of the device to recycling facilities and the possibility of separating, processing and recycling different materials (plastics, metals, glass). It is necessary to emphasize that in the calculation it is necessary to consider the energy required for the breakdown of the device and the recovery of the material. According to life cycle studies, recycling of electronic devices can result in emissions of around 2-4 kg of CO_2-eq per device, depending on the type and size of the device and the efficiency of the recycling processes (Dias, Bernardes & Huda, 2018; Peiró, Méndez & Ayres, 2013; Chancerel & Rotter, 2009; Hischier, Wäger & Gauglhofer, 2005; Kissling et al., 2013). When incineration (with energy recovery) is planned at the end of the life cycle, it should be considered whether the mentioned item can generate energy by incineration and whether incineration will emit CO_2 and other greenhouse gases, as would be the case with e-readers. CO_2-eq emissions from incineration of electronic devices vary but can be between 1-3 kg CO_2-eq per device, considering the energy generated during incineration (Oguchi, Sakanakura & Terazono, 2013; Ciacci et al., 2010; Niu & Li, 2007; Li et al., 2007; Jiang, Chen & Liu, 2012). The amount of energy generated will not be crucial, how important is the raw material that can be reused by recycling. E-readers in landfills can emit greenhouse gases during decomposition. CO_2-eq emissions from the disposal of electronic devices in landfills can amount to about 1-2 kg of CO_2-eq per device, depending on the conditions of the landfill and the presence of a gas collection system (Gamberini et al., 2011; Kiddee, Naidu & Wong, 2013; Nixon et al., 2013; Chung & Zhang, 2011; Song, Li & Zeng, 2015). As with the incineration process, it should be noted that the disposal of e-readers in landfills is not sustainable management because the raw material can be reused in the cyclical economy process. Disposal emissions can vary, but the average value is around 3 kg CO_2-eq.

By adding up all the contributions in the individual phases of the life cycle of the e-reader, the total carbon footprint of the e-reader is approximately 183.27 kg CO_2-eq.

Total carbon footprint: 168 + 10 + 0.27 + 3 ≈ 181.27 kg CO_2-eq.

It should be emphasized that carbon emissions depend on the energy source. Each country has a different mix of energy sources, which affects carbon emissions per kWh. According to data from the International Energy Agency (IEA), the global average of CO_2 emissions from electricity production is around 0.475 kg CO_2/kWh.

4. DISCUSSION

When studying the products book and e-reader both involve production processes that require extraction of raw materials, production, assembly and distribution. Although both products have a carbon footprint related to transport to the end user, the specific emissions of transport are different due to the weight of the product, the supply of raw materials over different distances and the transport of finished products over different distances. The raw material for the book can be produced at a shorter distance due to the greater availability of the raw material, i.e. cellulose, than the metals that are needed to make e-readers. Chip production is also tied to fewer locations in the world, so there are often higher emissions when

transporting parts or semi-finished products. Both options have emissions associated with disposal, although the methods and amounts of emissions vary (recycling paper vs. electronic components). The book has no additional shows during reading. The e-reader consumes energy during use. Average consumption is low, but long-term use generates additional emissions due to electricity consumption.
If the e-reader is used to read a large number of books, the emissions per book decrease with the increase in the number of books read.

100 books read on an e-reader: 183.27 kg CO_2-eq / 100 books = 1.83 kg CO_2-eq per book

200 books read on an e-reader: 183.27 kg CO_2-eq / 200 books = 0.92 kg CO_2-eq per book

The carbon footprint of a physical book is approximately 3.6-7.5 kg CO_2-eq per book, while that of an e-reader is initially high (183.27 kg CO_2-eq) but decreases as the number of books read increases. This analysis shows that e-readers become more environmentally friendly as the number of books read increases, while physical books have a constant carbon footprint per book.
Reducing the carbon footprint can be further influenced by lifestyle. Using an e-reader for a longer period reduces the overall carbon footprint because emissions from production are distributed over a larger number of books read. The life of an e-reader can be extended by regular maintenance and repairs of the device instead of replacing it with a new device. Creating good habits when optimizing the combination of reading books and e-readers can further contribute to reducing the carbon footprint. E-readers can be used by those who read often, while physical books are better to use if you rarely read them. Borrowing books from libraries or from acquaintances reduces the need to produce new books and e-readers.
The e-reader should be charged as much as possible using renewable energy sources (solar energy, green energy from the grid) to reduce the emissions associated with electricity consumption. If you reduce the time of using the device when it is not necessary (using sleep mode), a lot of energy will be saved. In addition to the aforementioned, it is important to dispose of the e-reader by recycling to reduce emissions from disposal in landfills. If available, it is recommended to use the device recovery program offered by the manufacturers.

5. CONCLUSIONS

The carbon footprint of books and e-readers varies significantly due to differences in production, use and disposal. E-readers have a larger initial carbon footprint due to complex manufacturing processes but may be more sustainable in the long run if used to read many books. By changing lifestyles, such as extending the life of devices, using renewable energy sources, optimizing reading and responsible disposal, their overall carbon footprint can be significantly reduced.
When reading habits are studied, one can greatly influence the reduction of the carbon footprint. People who read a lot of books may have a larger carbon footprint if they only use printed books. Their carbon footprint could be reduced if people used public libraries or e-readers. The environmental impact of an e-reader is greatly reduced as the number of books read increases, so it is a good option for avid readers. In addition to the active recycling of paper and electronic devices and the use of renewable energy sources for charging e-readers and supporting servers should be encouraged. Buying and selling used books extends their lifespan and reduces the need to produce new books.
At the beginning of product design, the use of recycled or biodegradable materials for e-reader components should be maximized. Recycled plastics can be used to make the case, while recycled metals can be used for internal components. In addition to this, attention should be paid to the easy disassembly of the device for more successful recycling, which supports the zero-waste policy. To reduce the CO_2-eq of transport, logistics should be simplified to reduce the distance and frequency of sending shipments. Such solutions should be combined with the use of low-emission transport such as electric trucks for local deliveries and maritime transport instead of air transport for international transport. E-readers should be designed to be more durable and resistant to damage, which extends their lifespan, and should allow for regular software updates to keep older devices functional and secure, reducing the need for frequent replacements. Optimizing device hardware and software to consume less energy, such as installing energy-efficient displays and processors, can contribute to reducing eCO_2. Customer service can ask users how to use their e-readers more efficiently, such as adjusting screen brightness and using power-saving modes. Return programs for the collection of old devices and proper recycling of e-readers and cooperation with certified e-waste recycling services will contribute to the increase in the recycling of e-reader components. Increasing the availability and variety of digital books will make e-readers a more

attractive option for consumers and reduce their carbon footprint per book copy. Addressing areas of product lifecycle stages that have proven problematic can significantly improve the productivity of e-readers while reducing their carbon footprint.

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