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Does the digitalization of the book industry reduce its environmental impact?

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ABSTRACT

Digitalization has transformed the book market with significant environmental consequences. Various life cycle assessments (LCAs) compare the per-unit greenhouse gas (GHG) impacts of reading paper books and e-books. However, they do not capture the net GHG effects of digitalization, which also depend on changes in production and consumption volumes in both formats. This article assesses whether digitalization has increased or decreased the GHG footprint of the book market by combining evidence from LCAs with economic insights on how digitalization affects book supply and demand. Our results show that e-books can lower emissions for heavy readers, while paper books may be more climate-friendly when they are widely shared. While e-books offer advantages such as accessibility and portability that support substitution, many digitalization-driven supply and demand effects expand the overall book market by improving discoverability, lowering costs and prices, and accelerating publication and distribution. Our quantitative analysis indicates that e-books reduce emissions only if they substantially displace print, yet evidence suggests substitution rates are low and emissions may therefore increase. This shows that treating e-books as simple substitutes for paper books is overly simplistic, and that integrated environmental and economic perspectives are needed to assess their net sustainability impact.

1. Introduction

The continued digitalization[1] of the media industry is accompanied by a profound impact on our ecology. Its causes and results are complex, and there is an urgent need to develop a more sophisticated understanding of the current and future states of sustainable digital and physical media. In this article, we focus on books, which stand among the earliest digital innovations in media as they were converted from paper to e-books. Today, over 1 billion people worldwide access e-books (Statista, 2024b) and further growth is expected (Statista, 2024a).

The digitization of books appears to be environmentally friendly, as it eliminates the need for paper, printing, and transportation—commonly referred to as dematerialization. However, reading e-books also contributes to environmental pollution because it is not an immaterial process. The production of digital reading devices can be resource- and energy-intensive, and unlike paper books, reading books on these devices (e.g., laptops or e-book readers) requires electricity (Moberg et al., 2011). Over the past two decades, several studies

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[1] Please note that we use the term digitalization to refer to the broader change process enabled by digital technologies and the term digitization to describe the technical process of transforming paper books to e-books (based on Brennen and Kreiss (2016)).

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have been conducted to compare the environmental impact of reading paper books versus e-books. These studies rely on life cycle assessment (LCA), a method to analyze the environmental effects of products and services across their entire lifespan, from production and usage to disposal (ISO, 2025). These LCAs vary in the functional units they use as their basis of analysis. A functional unit is a quantified description of a product or service delivered, which allows the comparison of different alternatives for delivering this product or service, such as physical paper or a digital file. For instance, some studies assess the environmental impact of reading a single book, while others consider the impact of reading multiple books annually or other scenarios (Moberg et al., 2011; Tahara et al., 2018; Enroth, 2009). Additionally, the analyses differ in their system boundaries (i.e., the process steps considered), the countries and time periods in which they were conducted, and the types of reading devices evaluated for e-books. To draw meaningful conclusions, it is essential to compare the results of these studies, accounting for their diverse contexts and methodologies.

Moreover, LCAs primarily focus on assessing the environmental impact of paper and e-books on a per-unit basis (e.g., per book or per book-read). However, these comparisons do not provide a final answer as to whether the overall environmental impact of the book industry has decreased through digitalization. The overall environmental impact of producing and reading books also depends on the total quantities produced and consumed in both formats. From an environmental standpoint, the ideal scenario might be for the production and reading of an e-book to entirely replace its paper counterpart, achieving a 100% substitution rate.[2] However, this is not always the case, as various market dynamics influence the supply and demand for paper and e-books. For instance, e-books are often offered alongside paper books as complementary products, and their availability can even stimulate demand for paper books (Nagaraj and Reimers, 2023; Bergström and Höglund, 2020). Additionally, the digitalization of the book market has further impacts on book supply and demand, driven by factors such as new distribution channels through online platforms or newer pricing strategies like e-book subscriptions.

In the digitalization and sustainability community, such impacts are usually discussed in the context of (digital) rebound effects (Coroama and Mattern, 2019).[3] In the broadest sense, these describe mechanisms due to which the reduction in environmental impact from a digital application is not as high as expected or even completely canceled out (Sorrell, 2009; Coroama and Mattern, 2019). These effects are also present in the book market and understanding them is essential to determine whether the digitalization of the book market has contributed to a reduction in environmental pollution.

Commonly, literature distinguishes three types of digital rebound effects (Bieser et al., 2023).

- Direct rebound: Digitally-induced cost (and price) reductions of a service (or good) leading to an increase in consumption of the service (or good).
- Indirect rebound: Digitally-induced cost (and price) reductions of a service (or good) leading to an increase in consumption of another service (or good).
- Economy-wide rebound effects: Digitalization leading to macroeconomic adjustments across sectors.

Here, costs are understood broadly and go beyond consumer prices or monetary production costs. The discussion around digital rebound effects also encompasses other factors that impact supply and demand such as easier discoverability or 24/7 accessibility (Bieser et al., 2022). From a transaction cost perspective, digitalization reduces search, distribution, and coordination costs for both producers and consumers, thereby lowering barriers to market participation and access. In creative industries, these reductions have been shown to expand supply, increase product variety, and facilitate discovery, as digitalization substantially lowers the costs of bringing creative works to market and matching them with consumers (Waldfogel, 2017). While these reductions can increase welfare, they may also stimulate additional consumption, which is central to understanding rebound effects in the environmental assessment of digital media. While it is acknowledged that all three types of rebound effects are challenging to measure, economy-wide effects are particularly difficult to predict. This is because they depend on complex dynamics that collectively shape market behavior, which is why some researchers have called economy-wide rebound effects the aggregation or sum of all direct and indirect effects (Metic and Pigosso, 2022; Sorrell et al., 2007).

The aim of this article is to discuss whether the advent of e-books and the digitalization of the book market overall has resulted in an increase or decrease in its environmental impact. We aim to consider both the environmental impact at the product level (per functional unit) but unlike previous studies also synthesize results from across the literature to address the broader market effects of digitalization at a sectorial level while considering the rebound effects of digitalization. Knowledge at both the product level and sectorial level is required for bottom-line assessments of the environmental effects of digitalization in the book industry. Therefore, we will examine.

- The environmental impacts of producing and reading paper books versus e-books.
- The mechanisms through which e-books and the digitalization of the book (and media) market have affected the supply and demand for both paper and e-books.

By examining both dimensions, we shed light on the direct and indirect rebound effects of digitalization in the book market — such as price-driven demand increases and market expansion through improved discoverability — and assess whether these offset the per-unit emission advantages of e-books.

Our analysis focuses solely on the environmental indicator of greenhouse gas (GHG) emissions (even though some studies considered further indicators), as it is the most commonly used metric in these studies and facilitates cross-study comparisons. To demonstrate the relevance of the identified supply-demand relations of paper and e-books for the GHG impacts of digitalization, we calculate the GHG footprint of the book market based on actual sales figures, the results of the examined LCA studies, and stylized assumptions about the substitution rate of paper books by e-books.

While our primary focus is on the book market, the findings can also be partially applied to other types of media, such as magazines, newspapers, and music. Additionally, this work aims to help uncover the mechanisms that contribute to economy-wide rebound effects, which, as just noted, are challenging to measure. This should also encourage the exploration of the supply-demand relationships in other industries that are reshaped by digital technologies. Identifying such mechanisms is crucial to identify targeted measures to reduce environmental loads and to inform and prevent premature conclusions about the environmental benefits of digital applications, which are often made without considering potential rebound effects.

The remainder of this article is structured as follows: Section 2 describes the methodology employed, Section 3 provides a comparison of the results of LCAs comparing paper and e-books, Section 4 examines literature on the supply and demand dynamics in the book industry, Section 5 presents quantitative estimates for substitution scenarios, taking into account whether e-books function as substitutes or

[2] Throughout the paper, we define the substitution rate as the share of e-book sales that displace paper book sales, a concept sometimes referred to as cannibalization in the literature.

[3] Rebound effects describe situations in which efficiency improvements or technological changes reduce the environmental impact per unit of a service but lead to higher overall consumption, partly or fully offsetting the initial savings.

complements to paper books, and Section 6 integrates these findings into a discussion and concludes.

2. Method

This article was developed through a three-step process.

First, we conducted a literature search on GoogleScholar, Scopus or Web of Science to identify existing environmental LCAs comparing paper books and e-books (Section 3). We reviewed the identified studies and categorized them based on their study location, publication year, and the functional units they addressed. For each study, we extracted the key findings on the GHG impact of paper books and e-books, and their comparison. From this analysis, we identified the most robust conclusions that could be drawn across studies, as well as the most significant measures to reduce the GHG impact of books. Each of the reviewed environmental LCA studies assessed GHG emissions in kilograms of carbon-dioxide equivalent (kgCO_2e) based on *Intergovernmental Panel on Climate Change (IPCC)* specified equivalence factors for comparing the *Global Warming Potential* of different gas emissions over a 100-year time frame (Huijbregts et al., 2016).

In the second step (Section 4), we identified and contextualized literature on the supply and demand changes in the book market driven by digitalization. Our focus was mainly on (empirical) economic literature that had already examined the supply and demand dynamics for paper and e-books but had received limited attention in the literature on digitalization and sustainability. In some cases, we also refer to studies on other media types (e.g., art), which allow conclusions to be drawn. We also consider the impacts of digital technologies that go beyond the digitization of paper books, such as the shift from local to online retail, automation in book production, or broader changes in the media landscape. From the literature, we identified and outlined the key mechanisms through which e-books and the digitalization of the book market as a whole affect the supply and demand for both paper and e-books.

In the third step (Section 5), we quantitatively illustrate the relevance of the supply-demand relationship of paper books and e-books for digitalization's impacts on the GHG footprint of the book market. Therefore, we estimated and compared the book market GHG footprint in two scenarios: In the first scenario, we estimate the emissions of the book market based on actually observed unit sales figures for paper and e-books between 2010 and 2020. The second scenario outlines the potential development of the GHG footprint of the book market, assuming e-books had never been introduced (counterfactual scenario). Since demand in the absence of e-books is inherently unobservable — as highlighted for instance by Chen et al. (2019), who require a natural experiment to approximate it — we instead rely on stylized assumptions about the substitution rate, which we vary across scenarios to transparently reflect this uncertainty. By comparing both scenarios and accounting for the uncertainty, we can also determine the break-even substitution rate—the rate at which the introduction of e-books does not result in any change to the GHG footprint of the book market. For comprehensibility, we provide a detailed explanation of the calculations and assumptions made in both scenarios in Section 5.

3. GHG impacts of paper books and e-books

We have identified seven studies that compared the GHG emissions caused by paper books and e-books (see Table 1). The studies were conducted between 2003 and 2021 in Japan, Norway, South Africa, Sweden, Netherlands and the USA. In the following section and in Table 1, we discuss the main results of the studies with regard to the GHG impacts caused by paper books, e-books and their comparison and derive key measures to reduce GHG emissions. While these studies allow us to draw some broad conclusions about the GHG emissions caused by paper books and e-books, direct comparison across these studies is difficult as the assumptions underpinning each study and the conditions in country where each study is focused are different. For example, the GHG intensity of electricity production varying significant between countries.

3.1. GHG impacts of paper books

The key stages in the life cycle of a paper book include content creation (writing, editing, and designing), material production (such as paper, ink and binding materials), printing and binding, distribution through warehouses, bookstores or mail order, reading, and the final disposal of the book (Tahara et al., 2018). The studies indicate that pulp and paper production account for the largest share of GHG emissions along the life cycle. In addition, the electricity consumption for printing and the consumer's shopping trip to the bookstore (specifically by car) can account for a significant part of GHG emissions. An older study shows that online shipping is more climate-friendly than brick and mortar retail and the consumer's shopping trip, mainly due to the emissions from the operation of the bookstore (Moberg et al., 2011). A more recent study suggests that the delivery method, including the type of transportation used, plays a more significant role than bookstore operations. The study shows that online delivery is more climate-friendly than self-pickup, assuming an average modal split across transport modes (Tahara et al., 2018).

Two studies considered paper recycling and concluded that it reduces emissions by avoiding the production of virgin paper (Tahara et al., 2018; Campisano et al., 2021). However, it is important to note that paper cannot be recycled indefinitely and is often downcycled into products such as toilet paper or cardboard. Additionally, the recycling also involves transportation to recycling facilities and energy consumption, both of which generate GHG emissions. Taking this into account, both studies still concluded that recycling offers a net reduction in emissions compared to the direct disposal of paper in incinerators or landfills and virgin pulp production. In addition, the extent of the book (number of pages) and the weight of the paper are decisive factors (Naicker and Cohen, 2016; Tahara et al., 2018). According to the results of these studies, the most important measures to reduce emissions along the life cycle of books are.

- Use of recycled, lightweight paper and recycling of the materials at the end of the book lifecycle.
- Use of GHG-efficient electricity sources in printing production.
- Use of GHG-efficient means of transport to collect the book or for its delivery.
- Shared use of books (multiple readers) to decrease demand for new books.

3.2. GHG impacts of e-books

The most important steps of the e-book life cycle are the content production, the production of the reading device (e.g., e-book reader, tablet), the distribution of the reading device to consumers, the operation of the device during reading, the production and distribution of e-books (e.g., via Internet downloads), and the disposal of the reading devices (Tahara et al., 2018). All studies show that the production of the reading device accounts for the largest or a very high share of the GHG emissions from reading e-books. Some studies also show that electricity consumption during use is very relevant (Kozak and Keoleian, 2003; Naicker and Cohen, 2016; Tahara et al., 2018; Enroth, 2009), which depends on two factors: First, the *GHG intensity of the electricity mix* varies greatly across regions. For example, a kWh of electricity generated in the USA causes over 100 times more GHG emissions than a kWh generated in Norway (Our World in Data, 2023). Second, the *energy efficiency of the reading device* varies across device types. Tahara et al. (2018) have shown that e-ink readers, smartphones, and tablets use significantly less electricity when reading than laptop and desktop computers. This is not surprising as these devices are designed for mobile use with little space for batteries.

Table 1
Categorized overview of the results of LCA studies comparing the GHG emissions caused by paper books and e-books.

Author(s)	Year	Location	Functional units	Key assumptions	System boundaries	Main Results		
						Paper Book	E-Book	Key conclusions
Kozak and Ke-olelan (2003)	2003	USA	American college student reading 40 scholarly textbooks on paper or on an e-book reader over four year period	• Each book is assumed to be 500 pages long and 178 × 254 mm in size (if printed) or 1,372 kB (if digital) and read on a REB 1100 dedicated e-book reader weighing 510 g powered by a rechargeable lithium battery. It is assumed that each printed book is read by one student only. • Geographic location of manufacturing of paper books or e-readers not specified, limiting the robustness of conclusions.	Material production, manufacturing, product distribution, use, and end-of-life management included.	• Paper production, electricity consumption for printing, and travel of users to bookstores cause most GHG emissions.	• Electricity required for powering the e-book reader causes most GHG emissions.	• Reading textbooks on paper causes roughly four times more GHG emissions per book. • Comparison depends on the number of users per book and the electricity mix used.
Enroth (2009)	2009	Norway	Use of paper textbooks or web-based teaching aids with desktop or laptop computers by 5000 students per year over five years	• Each student uses the web-based teaching aid or textbook for 2 h per week, 40 weeks per year in Norway. • Textbooks are manufactured in Norway from paper produced in Sweden. GHG emissions of computers based on generic global data. • After five years the textbooks are disposed of, with 80% of the paper recycled and 20% incinerated. 3.7% of the impact of the production and disposal of the computer is allocated to the functional unit based on the proportion of its active use used for accessing teaching aids.	Material production, manufacturing, product distribution, use, and end-of-life management included. Forestry work and editorial work on books are explicitly excluded.	• Pulp and paper production dominate life cycle emissions of paper books.	• Electricity for powering and producing computers dominates web-based teaching aid emissions.	• Web-based teaching aids with laptops cause 10 times more emissions than printed textbooks, and with desktop computers, 30 times more. • Assuming that each printed text book was used for many hours by many users meant the GHG emissions were much lower for printed text books compared to web-based teaching aids.
Moberg et al. (2011) Borggren et al. (2011)	2011	Sweden	One book (paper or e-book) read by one user in Sweden.	• Each paper book is assumed to be a hardcover novel weighing 600 g, 360 pages long and 151 × 228 mm in size and produced, bought and disposed of in Sweden. The paper book is either bought from an online retailer or a traditional bookshop. • Each e-book is a 1.5 MB PDF file equivalent of a 360 page novel, downloaded to a desktop computer and read on an e-reader produced in China.	Material production, manufacturing, product distribution, use, and end-of-life management included. Work of the book author explicitly excluded.	• Paper production and travel to bookstores cause most emissions for paper books. • Delivery methods impact results significantly; postal delivery causes least emissions.	• E-book reader production causes most emissions in the e-book life cycle.	• If an e-book reader replaces 30-40 paper books, e-books cause less emissions per book read. • If the paper book is read by two people, the break-even increases to 60-70 books.
Naicker and Cohen (2016)	2016	South Africa	Reading 21textbooks by a single user in South Africa for 2 h/day over four years on either paper or an iPad tablet	• Each paper textbook weighs 1210g and is produced in South Africa from locally harvested plupwood. End of life disposal is to municipal landfill.	Material production, manufacturing, product distribution, use, and end-of-life management included	• Pulp and paper production dominate life cycle emissions for paper books. • Coal-based electricity contributes	• iPad production and usage dominate e-book GHG emissions; travel to bookstores also impacts emissions.	• Reading on paper causes roughly 2.5 times more emissions than reading on the iPad.

(*continued on next page*)

Table 1 (*continued*)

Author(s)	Year	Location	Functional units	Key assumptions	System boundaries	Main Results		
						Paper Book	E-Book	Key conclusions
				• IPads are assumed to be made in China and disposed to municipal landfill at the of life. 64.5% of the iPad's total use is for reading the text books. • Four two-way 10 km trips in a personal vehicle were assumed to be required to purchase the paper books. A single trip of the same length was assumed for purchase of the iPad.		significantly to production GHG emissions.	• Coal-based electricity contributes significantly to production and use phase GHG emissions.	
Amasawa et al. (2018)	2017	USA	Book reading activities of a person over one year, and book reading activities per person per book.	• Each paper book is assumed to be a hardcover novel weighing 600 g, 360 pages long; each e-book is a 1.5 MB PDF file equivalent of a 360 page novel. • 43.8% of paper books were assumed to be purchased online an 56.2% in physical book stores, with a 2 km round trip in a car required for purchase. • Books are assumed to be purchased new and not shared. • E-books are assumed to be read on an Amazon Kindle or an Apple iPad, both with a lifetime of 3 years and used exclusively for book reading. • A web survey was used to create consumer segments of paper book and e-book users and their consumption patterns.	Material production, manufacturing, product distribution and use included. End-of-life management included for paper book but not e-reader. Internet infrastructure and lighting excluded.	• Paper book consumers purchase an average of 5.36 books per year	• E-book consumers purchase more books per year in total and typically purchase more paper books each year compared to consumers who only purchase paper books. Kindle users purchase an average of 20.5 books per year, approximately half of which are e-books, while iPad users purchase 10.6 books per year, again split between e-books and paper books.	• E-book readers cause fewer emissions if more than 4.7 books are read annually. • Tablets cause fewer emissions if more than 9 books are read annually. • iPad users who read books when out had the highest GHG emissions of 16.6kgCO2e per year from their book reading activities. Consumers who only read paper books at home has lowest GHG emissions of 3.64kgCO2e per year from their book reading activities.
Tahara et al. (2018)	2018	Japan	The provision and reading one book of 224 pages on either paper or an ebook (2.4 MB digital file) using different types of devices	• A web survey was used to quantify consumer behavior and develop book usage scenarios. • Print run in Japan of 5000 copies assumed for paper book, of which 3000 are sold to consumers. GHG emissions associated with retail process calculated based on survey results. Assumed that 22% of books incinerated or landfilled and 78% recycled at end of life • Primary data for the production of e-ink tablets was collected; secondary data used for other e-reader devices.	Material production, manufacturing, product distribution, use, and end-of-life management included. Infrastructure such as factories, roads, routers and the telecommunication system excluded but the operation of the network transmission system is included.	• Paper production and travel dominate GHG emissions. • Recycling reduces paper book emissions significantly.	• Reading on e-ink readers or smartphones causes less emissions than reading on desktop or laptop computers.	• E-books are more climate-friendly if users read more than 30 min/day for tablets, 15 min/day for smartphones, and 75 min/day for laptops and desktop computers. • Considering reading habits, reading on e-ink tablets or smartphones is very likely more climate-friendly than reading on paper books; however, this is not necessarily the case for laptop and desktop computers. • GHG emissions are 1.11 kgCO2e per paper book; under average use conditions, the GHG emissions of e-books range from 0.25 to 0.91 kgCO2e per book, with e-ink

(*continued on next page*)

Table 1 (*continued*)

Author(s)	Year	Location	Functional units	Key assumptions	System boundaries	Main Results		Key conclusions
						Paper Book	E-Book	
								tablets the lowest and desktop computers the highest.
Campisano et al. (2021)	2021	Netherlands	Reading 120 physical books of 300 pages length or reading 120 books of same length on an e-reader over the course of five years	- E-reader is assumed to be manufactured in China, weighs 322g and shipped to the Netherlands. Its battery is recharged twice per month during use. It assumed that 75% of e-readers are recycled and 25% incinerated with energy recovery. - Paper books weigh 440 g in A5 format and are manufactured in the Netherlands. Books are delivered to users by light commercial vehicle in 200 g cardboard boxes. After reading each book is disposed of, with 90% recycled and 10% to incineration with energy recovery.	Material production, manufacturing, product distribution, use, and end-of-life management included.	• Paper production and printing dominate GHG emissions. • Recycling the physical book avoids future woodchip production, reducing the overall environmental impact.	• Production and use phases approximately equal in terms of the GHG emissions for e-readers.	• Reading 120 books on paper causes roughly three times more GHG emissions than reading on an e-book reader. • If less than 25 books are read over five years, paper books cause less GHG emissions.

A similar pattern can be observed for the production impacts of the reading devices. These are highest for tablets, laptops, and desktop computers and smaller for smartphones or specialized e-book readers. However, it should be noted that smartphones, tablets, laptops, and desktop computers—in contrast to e-book readers—can be used for many other purposes and are, therefore, not necessarily produced and purchased just for reading e-books.

The studies that have considered the distribution of e-books over the Internet and telecommunication networks have come to the conclusion that this step is not very significant in terms of GHG emissions (Borggren et al., 2011; Tahara et al., 2018; Naicker and Cohen, 2016). No study has fully considered the emissions from digitally storing and preserving e-books. In the case of libraries, for example, this includes redundant long-term archiving on servers, regular checks of data integrity, update and conversion of file formats and more (Tallman, 2021).

Overall, the most important measures to reduce emissions from e-books are.

- Use of existing devices for reading e-books and extending their life-time (e.g., through protective cases or repairs) to reduce demand for new devices.
- Increasing material efficiency, energy efficiency, and use of GHG-efficient electricity mixes in device production.
- When purchasing new devices, considering multi-use devices to reduce demand for new devices (e.g., owning one tablet instead of a laptop, tablet, and e-reader).
- If devices are purchased for reading only, choosing compact e-book readers and second-hand devices.
- Use of GHG-efficient electricity for powering reading devices.
- Use of energy-efficient digital infrastructures for distributing and storing e-books.

3.3. GHG impacts of paper books vs. e-books

The studies reviewed here suggest that it is not possible to draw a universal conclusion about whether reading paper or e-books produces fewer GHG emissions in part because behavioral variability has a very significant impact. For example, cultural practices such as the extent of book sharing or preferred mode of shopping very significantly influence the relative impact of paper books versus e-books. The comparison largely depends on the following factors.

- Reader behavior, including preferred book purchase method and length of time spent reading each book.
- The number of readers per paper book (the more readers per book, the fewer emissions per book-read).
- Whether a new device is purchased for reading e-books and the GHG emissions caused by its production.
- The energy efficiency of the device when reading and the GHG-intensity of the electricity used.
- The lifespan of the reading device and the number of e-books read with it.
- Changes in reading behavior due to switching to e-books (e.g., buying more books).
- Transport modes used by consumers to pick up the book or to deliver it, which affect paper books but are largely absent for e-books.

Although universal claims remain elusive, we can, with some degree of certainty, identify specific contexts where physical or e-books appear preferable from a climate standpoint. Based on the studies reviewed, we hypothesize that for heavy readers, switching to e-books is likely to lead to a reduction in GHG emissions. This is because studies allocate the relatively high production emissions of reading devices across the total number of book-reads on the device. As more books are read on the device, the emissions per book-read decrease, making e-books increasingly advantageous compared to paper books. Some studies have also identified a break-even point, i.e., the number of readings beyond which e-books become more climate-friendly. Amasawa et al. (2018) identify the break-even point at approximately five books per year, Moberg et al. (2011) estimate it to be 30–40 books over the lifetime of the device, while Campisano et al. (2021) estimated the break-even point to be 25 books over the lifetime of the device that is assumed to be five years. However, assuming that paper books are read by two users, thereby halving the emissions per book-read, the break-even point shifts to 50–70 books in the study by Moberg et al. (2011). These diverging break-even points reflect differences in functional units, assumed device lifetimes, and study contexts, and are therefore not straightforward to compare directly (see Table 1 for details on key assumptions and system boundaries). Thus, there can also be situations where the paper book is more advantageous. This is especially the case when paper books are shared by many people (e.g., library books) or when e-books are read on devices that are particularly energy-intensive (e.g., desktop computers).

Only one study concluded that reading on paper is significantly more climate-friendly than reading digitally (Enroth, 2009). However, this study examined a distinct scenario involving 5000 students using either paper books or web-based teaching aids over five years. The study assumed that each physical book was used by five students over its lifetime, with each student using the book 80 h over the course of a year before passing it on to another student for reuse. Additionally, the paper books analyzed were lighter than those in other studies, resulting in lower production emissions (Naicker and Cohen, 2016). Overall, the study is not entirely comparable to others but does suggest that extensively shared books (e.g., through libraries) are likely to have a climate advantage over e-books. In principle, paper books can endure for centuries and be widely shared, as seen in national libraries holding copies over 1000 years old (National Library of the Netherlands (KB)). The longevity of e-books or e-book readers have not yet been observed over comparable time periods. However, their lifespan is likely shorter due to rapid technological shifts and frequent changes in file formats and devices.

Another important factor to consider is reading behavior and the difference in reading habits between users of paper books and e-books, such as the time spent reading and the number of books purchased. For example, once a paper-book reader buys an e-book reader, he or she might alter the daily reading time, and the number of books purchased. Changes to reading practices were only addressed in two studies (Tahara et al., 2018; Amasawa et al., 2018). Amasawa et al. (2018) [p. 1874] found that the "overall book reading volume remains unchanged upon e-reader adoption" using a web survey and social experiment. However, the study relied on a small sample size, and further research is required to draw more definitive conclusions. Tahara et al. (2018) found that respondents purchased on average 27.1 books in the year prior to the survey and that respondents who also bought e-books read 9.3 e-books. They also found that e-book reading speed is fastest on smartphones (0.84 min/page), followed by e-ink tablets (1.11 min/page), tablets (1.20 min/page), portable music players (1.31 min/page; the study used an iPod Touch with a screen comparable to an iPhone's, thus enabling reading), desktop or laptop computers (1.33 min/page) and conventional ("nonsmart") cell phones (1.57 min/page). However, they did not examine how reading behavior differs between paper and e-book users. In the following, we partly address this gap by exploring relevant economic literature on the impact of digitalization on book supply and demand, and the interaction between both.

4. Impacts of digitalization on supply and demand of paper and E-books

The studies mentioned so far have assessed GHG impacts associated with the production and use of paper books and e-books. Beyond these factors, digitalization exerts systemic influence on demand and supply patterns in creative industries (Waldfogel, 2020), which is challenging to identify and measure. Here, we attempt to clarify these complex dynamics within the book market, highlighting mechanisms through which digitalization impacts demand and supply of both paper and e-books. Importantly, these mechanisms are interrelated and not always straightforward to separate empirically — for instance, lower e-book prices both stimulate overall consumption volumes and drive substitution away from paper books. We nevertheless structure them by their primary locus of impact on demand and supply, and synthesize their directional environmental implications at the end of this section.

4.1. Mechanisms impacting demand of paper and E-books

4.1.1. Substitution of paper books with E-books

Availability of e-books alongside paper counterparts may lead to a decline in paper book demand, but existing evidence points to substantial heterogeneity in substitution patterns. Using survey data for the German book market, Prostka et al. (2018) find little realized substitution in the early stages of e-book diffusion. In contrast, Li (2021) simulates a market without e-books and finds that 71.5% of e-book sales come from substituting print books, with the remainder representing market expansion, while documenting strong variation across genres and local market conditions. One of the few quasi-experimental studies in this context, Chen et al. (2019) finds that temporarily delaying e-book releases does not lead to a significant increase in print book sales, indicating that substitution between formats is often incomplete. Taken together, these findings suggest that substitution between paper books and e-books is highly context-dependent. Moreover, substitution is constrained by the fact that not all titles are available in electronic format, particularly books with complex layouts or illustrations, such as many textbooks, for which digital versions may be unavailable or perceived as inferior substitutes.

E-book availability can also stimulate paper book sales through discovery effects. Nagaraj and Reimers (2023) provide causal evidence for this channel using the Google Books project, finding sales gains particularly for less popular titles and through independent publishers introducing new editions.

4.1.2. Simplified access to paper and E-books

Digital media is easier to obtain, with e-books readily available via online platforms like Amazon's Kindle shop. However, access and availability also depend on consumers' adoption of reading devices. By 2013, 43% of US households owned an e-reader (Waldfogel and Reimers, 2015), and 40% of US adults owned a tablet in 2014 (Peukert and Reimers, 2022). Today, many readers also use other devices for e-reading (World Intellectual Property Organization WIPO, 2021).

Paper books can also be easily obtained via online retail, with improved delivery speed and convenience. Internet platforms have enhanced access and discoverability of both e-books and paper books. Survey data from 17 international markets shows more respondents prefer buying books online than in physical stores (YouGov, 2024).

4.1.3. Changing consumer prices

Falling retail prices have been observed for books, with e-book prices decreasing more drastically. An analysis of Top 10 bestsellers on Amazon in 2016 showed e-books were available for 22% less in the US and 19% less in Germany compared to paper books (Statista, 2016). One reason is that e-books carry no costs associated with paper production and physical delivery.

New pricing models like subscriptions have been established for e-books, allowing consumers to access multiple titles for a fixed fee. Such models can reduce the marginal cost of additional reading and may increase consumption volumes, implying that book digitization can affect not only format choice (paper versus e-book) but also the scale of overall book consumption.

However, digitalization has not uniformly reduced book prices. College textbook prices have increased significantly faster than average consumer prices in the past 20 years, whereas prices for recreational literature have decreased (American Enterprise Institute (AEI), 2016). Additionally, consumer demand does not always increase with lower prices, even when free or cheaper alternatives exist, consumers may continue to purchase higher-priced editions (Reimers, 2019). Book markets are also subject to strict price regulations in countries like Germany or France (Van der Ploeg, 2004).

4.1.4. Increase in auxiliary information related to paper and E-books

Digitalization has lowered barriers to the production, dissemination, and use of auxiliary information about books, such as reviews, ratings, and summaries. Access to crowd-sourced reviews can shift demand in the consumer market by improving consumers' ability to assess product quality prior to purchase (Chevalier and Mayzlin, 2006). Reimers and Waldfogel (2021) show that book reviews play an important role in product discovery, with reviewed titles experiencing substantial increases in visibility and sales. In addition, they discuss Amazon reviews and star ratings as part of emerging product discovery institutions that add value by improving pre-purchase information and helping consumers identify appealing titles, particularly in the context of the growing number of available books.

4.1.5. Quality, media and lifestyle shifts in reading behavior

Digitalization has fundamentally altered the media landscape, with reading increasingly competing with other digital activities such as video streaming, social media, and gaming. In Germany, leisure activity data show a decline in traditional media use and a rise in digital media. While e-book reading has slightly increased, overall book reading frequency remains largely stable (Freizeitmonitor, 2024).

In the news market, electronic formats have largely displaced print newspapers, reflecting the substantially higher utility of digital news, including constant updates, real-time access, and low tolerance for delays (Bhuller et al., 2024). These features make electronic news a close substitute for print. In contrast, the utility gains from digitalization are more limited for books, whose content is typically static and for which physical formats retain advantages related to readability, ownership, and sensory experience. As a result, substitution rates from paper books to e-books appear considerably lower and more context-dependent.

Thus, paper and e-books differ significantly in product quality, impacting demand. Quality encompasses characteristics influencing the value consumers attribute to books, varying across consumer groups. Paper books are valued for sensory qualities, aesthetic appeal, durability, and uniqueness. E-books are valued for accessibility, portability, and additional features like embedded links (Muthu, 2012; Spence, 2020). Lastly, Hsiao and Chen (2017) indicate that digital media is perceived to be "greener" by book buyers.

4.2. Mechanisms impacting supply of paper and E-books

4.2.1. Lower production costs and reuse of creative works

Digitalization has transformed the supply side of cultural goods by lowering production and distribution costs and enabling reuse. E-books, for example, can be self-published without traditional publishers (Waldfogel and Reimers, 2015), and distribution costs have fallen sharply (Peukert and Reimers, 2022). Cost reductions have also stemmed from automation, offshoring to low-wage countries, and consolidation in the publishing industry. In particular for e-books, these developments have lowered marginal costs and retail prices by 10–15% in some cases (Waldfogel and Reimers, 2015). Digitization also makes published content easily reusable and adaptable, allowing new versions and derivative works to be created (Nagaraj, 2018;Cuntz et al., 2023; Cuntz and Sahli, 2023). With generative AI on the rise, reuse as a driver of new supply is becoming even more relevant.

4.2.2. Faster publication cycles

The number of books published has increased in recent years. One main driver is self-publishing, where authors bypass lengthy discussions and checks by publishers. Nagaraj and Reimers (2023) find that digitization allows independent publishers to easily introduce new editions for existing books, increasing sales. The breakthrough of AI, especially large language models, is likely to accelerate writing and publication speed, as AI-generated books started flooding the market (SonntagsZeitung, 2025).

4.2.3. Differences and changes in product quality

Digitalization has also impacted content quality, particularly through self-publishing, which bypasses traditional gatekeepers like publishers. This removes certain quality assurance processes, potentially resulting in a decline in content quality. However, publishers are not always perfect judges of quality (Waldfogel, 2017). Self-publishing has likely enabled a broader range of quality works to reach the market.

4.2.4. Personalized consumer information

Recommendation systems on digital platforms facilitate marketing of books tailored to individual preferences, enhancing user engagement and influencing purchasing decisions. These tools also enable precise monitoring of consumer preferences, informing the production process. As more data becomes available, firms can make accurate predictions, increasing investments in promising ideas (Peukert and Reimers, 2022).

4.2.5. New distribution channels and revenue opportunities

Digitalization has opened new distribution channels and revenue opportunities in publishing by lowering entry barriers and enabling disintermediation. Self-publishing platforms like Amazon, Smashwords, Apple, and Lulu allow authors to make books available directly to consumers without traditional publishers (Waldfogel and Reimers, 2015). Whether self-published or released through a publisher, books can also be sold directly by authors or publishers to consumers, bypassing intermediaries.

4.3. Environmental implications of key mechanisms

Digitalization impacts demand through reduced transaction costs, such as improved access and discoverability, increased availability of auxiliary information (e.g., reviews and ratings), changes in pricing and business models, and differences in product quality and consumer perception that influence which format consumers choose and how many books they consume. On the supply side, digitalization lowers production and distribution costs, enables self-publishing, accelerates publication cycles, and opens new distribution channels and revenue opportunities, thereby expanding the range and diversity of available titles.

From an environmental perspective, these mechanisms can be broadly organized by their directional implications. Mechanisms that primarily promote substitution of paper books by e-books — such as the accessibility, portability, and perceived environmental friendliness of e-books, as well as personalized recommendation systems that facilitate discovery of e-book titles — tend to reduce emissions, since e-books generally have a lower per-unit GHG footprint for frequent readers. In contrast, many mechanisms act to expand the overall size of the book market, which tends to increase total emissions: discovery effects that stimulate paper book demand (Nagaraj and Reimers, 2023), lower prices and subscription models that encourage higher consumption volumes, faster publication cycles, and new distribution channels that lower barriers to market entry and increase the total number of titles produced and read. The direction of some mechanisms is ambiguous and context-dependent — for instance, lower consumer prices may promote substitution toward e-books but can equally stimulate additional consumption of both formats. Similarly, lifestyle and media shifts may reduce overall reading in favour of competing digital activities, or increase it through greater accessibility.

The relative magnitude of these effects cannot be determined with available data. We therefore illustrate how the net GHG impact depends on the balance between substitution and market expansion using stylized assumptions in the following chapter.

5. Empirical data: E-book substitution rates and GHG implications

An important implication arising from our discussion on the mechanisms affecting the demand and supply of paper and e-books—and their implications for sustainability-related research—is the underlying assumption that paper and e-books can act as either complements or substitutes. Some consumers have shifted entirely to digital reading since the introduction of e-books, others use both formats interchangeably, while some perceive print books as fundamentally different goods. From a climate perspective, however, it is crucial to understand the extent to which e-books displace the market for physical books (substitution rates). Unfortunately, we cannot observe a counterfactual world with only print books, which makes it necessary to rely on quasi-experimental settings or modeling approaches to estimate effects and contrast findings. We therefore construct counterfactual scenarios that rely on stylized assumptions about paper book sales in the absence of e-books and explore a range of substitution scenarios to assess how sensitive the resulting GHG estimates are to these assumptions. Thus, we examine how GHG emission effects depend on whether e-books complement or substitute paper books by comparing two scenarios.

- Observed (real-world) scenario: The actual emissions caused by paper and e-books based on observed sales figures.
- Counterfactual scenario: The emissions that would have been caused by paper books in the absence of e-books.

The difference between the two scenarios yields the emissions impact of e-books. Below, we describe both scenarios and our estimation approach.

5.1. Observed (real-world) scenario

For the real-world scenario, we require actual sales figures for paper and e-books. The most suitable data we found describes the book market in the US between 2004 and 2020 and comes from TonerBuzz (2023) and Statista. The data provides a uniquely long and granular split between paper and e-book unit sales. Fig. 1 shows that since the introduction of e-books in 2010, demand for e-books increased significantly until 2013/2014, declined slightly in 2015, and then remained relatively stable. The demand for paper books initially declined after the introduction of e-books, but it has steadily increased since 2013. However, until 2020, it remained at a lower level than before the introduction of e-books. This indicates a substitution effect of paper books with e-books. However, the overall market (paper books + e-books) has continued to grow. It should be noted that no sales figures for e-books prior to 2010 are available from the source, and we assumed these to be zero.

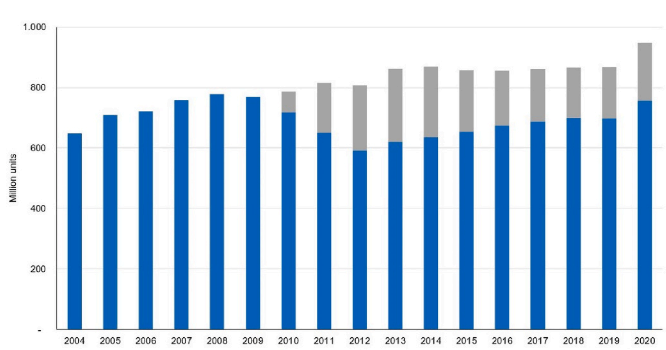

Fig. 1. Unit sales of printed books and e-books from 2004 until 2020.
Note: Based on TonerBuzz (2023) and Statista. E-book sales data before 2010 is not available and we assumed it to be zero.

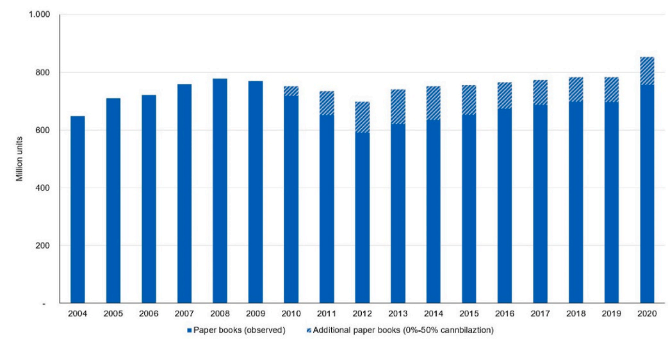

Fig. 2. Unit sales of paper books from 2004 until 2020 in the counterfactual scenario assuming a 0% and 50% substitution rate.
Note: Based on TonerBuzz (2023), Statista and own calculations.

Several limitations of this data should be noted. The figures cover the US market only, which may not be representative of other contexts. The data is aggregated from secondary industry sources, and market coverage is not fully transparent — in particular, self-published titles, which represent a significant share of e-book sales, may not be fully captured. Furthermore, assuming zero e-book sales before 2010 likely understates early e-book adoption. Given these limitations, results should be interpreted as illustrative rather than precise estimates.

5.2. Counterfactual scenario

This scenario represents the unit sales of paper books in a world where e-books were never introduced. This is a hypothetical scenario, as such a world no longer exists and cannot be observed. To address this uncertainty, we calculate several counterfactual scenarios using the data from Fig. 1, assuming different rates of substitution of paper books by e-books. We vary the substitution rate in 10% increments, ranging from 0% to 50%. This range is broadly consistent with empirical estimates from the literature, which suggest substitution rates vary widely across contexts (Prostka et al., 2018; Li, 2021). The 0% scenario assumes that all e-books sold in a given year were entirely additional and did not replace any paper books, while the 50% scenario assumes that half of the e-books would have been sold as paper books had e-books never been introduced. Fig. 2 shows the observed sales figures of paper books (blue shading) and the hypothetical scenario of additional papers sales that would have occurred assuming a 0% substitution rate (blue-grey shading, lower bound) and a 50% substitution rate (blue-grey shading, upper bound). This approach enables us to estimate the emissions impact of e-books while accounting for uncertainty and to compare the

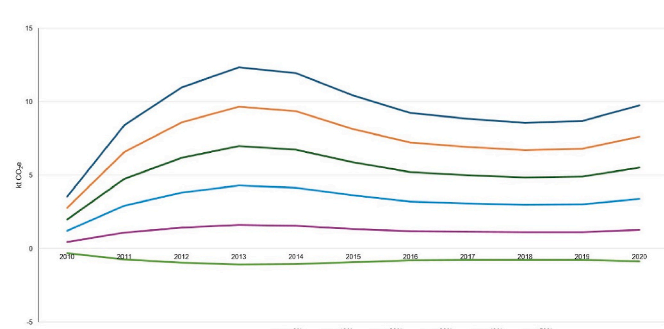

Fig. 3. Emission difference between the real-world and the counterfactual scenario assuming different substitution rates.
Source: Own calculations.

assumed substitution rates with actual rates of substitution reported in the literature.

5.3. Comparison of emissions in real-world and counterfactual scenario

We now estimate the emissions of the book market for both the real-world and counterfactual scenarios, as well as the difference between them. Drawing on Tahara et al. (2018), the following values for emissions per book read were assumed.

- Paper book: 1.1 $kgCO_2e$/book read
- E-Book: 0.51 $kgCO_2e$/book read

The first value represents the full life cycle of a paper book, assuming each paper book is read by one person. The same applies to the e-book value, which includes the emissions from the production of the reading device, factoring in the device's lifetime. Given that the emissions of different reading devices vary, we used an average value for e-books, weighted according to the frequency of use as reported by Tahara et al. (2018), which is 32% for desktop computers, 31% or smartphones, 17% for tablets, 9% for cell phones and 7% for e-ink tablets. Device usage patterns also vary over time, across regions and age groups; therefore, we later conduct a sensitivity analysis by varying book-reading emissions from their minimum to their maximum values according to Tahara et al. (2018). Fig. 3 illustrates the annual emissions difference between the two scenarios at different substitution rates. In the 0%- 40% scenarios, emissions increased with the introduction of e-books, as 100% to 60% of the e-books sold did not replace paper books but instead expanded the overall book market. In the 50% scenario, emissions from the book market decreased due to e-books, as a substantial portion of paper books were replaced by e-books, resulting in fewer emissions per book read. The greater the substitution rate, the higher the emission-reducing effect of e-books. Still, in this scenario, the overall market also grows between 2012 and 2020; however, the emissions savings due to substitution effects are greater than the emissions increase resulting from market growth. The break-even substitution rate, i.e. the rate at which both effects cancel each other out, is 46%.

To exemplify the significance of these differences, we calculated the cumulative emissions changes between 2010 and 2020 according to Fig. 3 and compared them to the cumulative emissions of the entire book market in the counterfactual scenario over the same period, summarized in Table 2. This demonstrates that with a 0% substitution rate, e-books resulted in a cumulative 13% increase in emissions over the entire period; showing how quickly cumulative emissions can accumulate. With a 50% substitution rate, this value drops to −1%, indicating that e-books would have led to a 1% reduction in emissions compared to the counterfactual scenario; showing that cumulative emission changes accumulate rapidly.

The results of our analysis are highly sensitive to the assumed difference in emissions between reading paper books and e-books, as well as to the types of devices used for reading, which vary in their emission intensity. To account for this, we conducted a sensitivity analysis by recalculating the break-even substitution rate using the highest e-book emission factor reported by Tahara et al. (2018) (desktop computer: 0.91 kg CO_2e per book read) and the lowest (e-ink tablet: 0.25 kg CO_2e per book read). When e-book emissions are high, the break-even substitution rate rises to 82%, meaning that emissions only decrease if most paper books are replaced by e-books. Conversely, with low e-book emissions, the break-even substitution rate falls to 23%, meaning that replacing roughly a quarter of paper books with e-books is sufficient to achieve an emissions reduction.

Table 2
Comparison of cumulative emission changes assuming different substitution rates.

A: Substitution rate	0%	10%	20%	30%	40%	50%
B: Cumulative emissions [kt CO_2e] *[counterfactual sc., 2010–2020]*	819	842	864	886	909	931
C: Cumulative emission diff. [kt CO_2e] *[real-world sc. – counterfactual sc., 2010–2020]*	103	81	59	36	14	−8
D: Share [C/B]	13%	10%	7%	4%	2%	−1%

Comparing our calculated break-even substitution rates with the available evidence in the literature, studies on books generally report no strong evidence of substantial substitution (Chen et al., 2019). This suggests that, in practice, we may be observing a scenario in which emissions cumulatively increase. While Li (2021) also notes that e-book channels do not always harm print channels, they report substitution rates exceeding 70% in specific contexts. However, the existing evidence is primarily based on small-scale case studies, and there is a lack of comprehensive long-term research on this topic.

Due to limited data availability, we used sales data from the US and emission data per book read from Japan, despite differences in the CO_2e intensity of electricity used for reading devices between those countries. However, since emissions from device production dominate across the life cycle (see Section 3.2), this data is adequate for our analysis. Still, the results should be seen as illustrative, emphasizing how emissions depend on the substitution rate—i.e., the extent to which e-books substitute or complement paper books. More generally, the quantitative results in this section depend on key LCA assumptions, including the emission intensity of electricity used for device operation and data transmission, as well as assumptions on device lifetimes and usage patterns. Different assumptions would shift the estimated break-even substitution rates, but the qualitative insight that the net GHG impact of e-books depends jointly on substitution rates and energy intensities remains robust.

6. Discussion and conclusion

Our comparison of LCA results on GHG emissions from paper books and e-books is limited by several factors. First, rapid technological changes quickly render older studies outdated and regional differences in energy mixes make comparisons across contexts difficult. These factors affect both the electricity-related emissions of reading devices and the production emissions of paper books. For example, Naicker and Cohen (2016) find that in South Africa, coal-based electricity production drives up paper production emissions. Emissions from manufacturing reading devices are likely less variable, as production is concentrated in a few countries globally. Results also depend heavily on underlying assumptions, particularly whether the e-reading device is purchased and used exclusively for reading. This is typically true for dedicated e-readers. Desktop and laptop computers, which have much higher production emissions, are usually used for multiple purposes, with book reading representing only a small share. For paper books, distribution to the consumer is another key factor. Car trips to bookstores generate the highest emissions, while online delivery or collection by walking, cycling, or public transport is more climate-friendly. Despite these differences across studies, the literature points at conditions where e-books are more climate-friendly. They generally have a lower GHG footprint for frequent readers but can be more carbon-intensive for infrequent readers, especially if new devices are purchased solely for reading. To reduce emissions, readers should use existing devices rather than buying new ones for e-books. If a new device is needed, paper book purchases should be minimized (or library services used), and when buying paper books, combining deliveries with other goods or using slow or public transport for collection helps lower GHG emissions. Overall, GHG outcomes depend not only on reading frequency, but also on device choice, sharing practices, and distribution channels, as discussed above.

Further, we described that GHG impacts depend on changes to both demand and supply. The net impact of digitalization on the book market appears to be a structural transformation rather than a simple expansion. Digitalization has increased the diversity of available titles, lowered barriers to entry for authors, and shifted consumption toward digital formats, while total reading frequency and overall book demand appear relatively stable in many contexts.

The analysis underscores the critical role of substitution rates between paper books and e-books. While e-books generally have lower emissions per unit, their climate advantage materializes only if they displace, rather than add to, paper book use. Without sufficient substitution, e-books can increase the overall GHG footprint. In this regard, it is important to distinguish between market-driven dynamics and targeted policy levers. Several mechanisms identified in Section 4 — such as discovery effects that stimulate paper book demand, supply expansion through self-publishing, and faster publication cycles — are largely market-driven and not easily influenced by policy. Policy leverage is therefore more targeted but nonetheless important. Our analysis points to several specific instruments. First, differential VAT on paper versus e-books — already implemented in some countries — strengthens price incentives for format substitution and could be more widely adopted. Second, copyright frameworks governing library e-lending in many countries restrict simultaneous borrowers or require per-lend fees, directly limiting substitution toward shared digital reading; reforming these rules would lower barriers to e-lending at scale and push substitution rates closer to the break-even point discussed in Section 5. Third, extended producer responsibility and right-to-repair legislation for reading devices would directly target the dominant emission source in the e-book life cycle — device production. Finally, public procurement policies in education and government could favour e-formats where substitution is most feasible, reducing paper book consumption in institutional contexts.

Our study also discusses that economic analysis of supply-demand relationships can complement LCAs and prevent overly optimistic assumptions about the environmental benefits of digitalization. This is essential to avoid reinforcing a simplistic dematerialization narrative that ignores systemic rebound effects. Future assessments must integrate both unit-level impacts and systemic market effects to provide a realistic picture of sustainable digitalization.

Our calculations rely on several assumptions. Emissions per e-book vary by device type; we used a weighted average based on the device usage distribution (Tahara et al., 2018). If all e-books were read on desktop computers, the emissions and break-even substitution rate would be higher (82%), because reading on desktops is more CO_2e-intensive than other devices. If read only on smartphones, the impact would be lower (23%). In addition, other factors such as population growth or unrelated supply shifts may have influenced demand.

Future research on the environmental sustainability of book publishing should address both near-term and systemic challenges. Immediate priorities include greening the production of paper books and reading devices and promoting sustainable reading practices. In practical terms, sustainable reading practices involve sharing or reusing paper books, or, for e-book readers, concentrating reading on a single device and avoiding parallel consumption of paper books. At the same time, there is a need to examine the expanding network of products, services, and behaviors linked to digital book media. Digital platforms such as Amazon and Archive.org play a central role not only in emissions but also in shaping reading and publishing practices. Sustainable physical bookstores (e.g., with a focus on second-hand sales or book sharing) and industry-related services like Goodreads must also be considered as sites for intervention and consumer awareness. A further important avenue for future research concerns audiobooks (and podcasts), which represent a rapidly growing segment of the book market (Cameron, 2022). Audiobooks differ from both paper books and e-books in their production, distribution, and consumption patterns, and may therefore have distinct environmental implications, for example due to streaming, data transmission, and listening behavior. While there is existing literature on the GHG impacts of music streaming, to our knowledge this has not yet been extended to audiobooks or to their net GHG impacts as substitutes or complements to paper books and e-books. Other underexplored factors—such as piracy via platforms like LibGen, AI-based automation and recommendation systems, and opaque backend infrastructures—may also contribute significantly to the sector's GHG footprint and warrant scrutiny. Finally, the field lacks forward-looking sustainability guidelines.

CRediT authorship contribution statement

Matthias Sahli: Conceptualization, Data curation, Formal analysis, Methodology, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing. **Jan Bieser:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Jonathan Chenoweth:** Funding acquisition, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Jeff Love:** Methodology, Validation, Writing – original draft, Writing – review & editing. **Mi Lin:** Validation, Writing – original draft, Writing – review & editing. **Marco Martens:** Funding acquisition, Writing – original draft, Writing – review & editing. **Maureen Pennock:** Funding acquisition, Writing – original draft, Writing – review & editing. **Uta Pottgiesser:** Funding acquisition, Validation, Writing – review & editing.

Declaration of competing interest

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Data availability

Data will be made available on request.

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