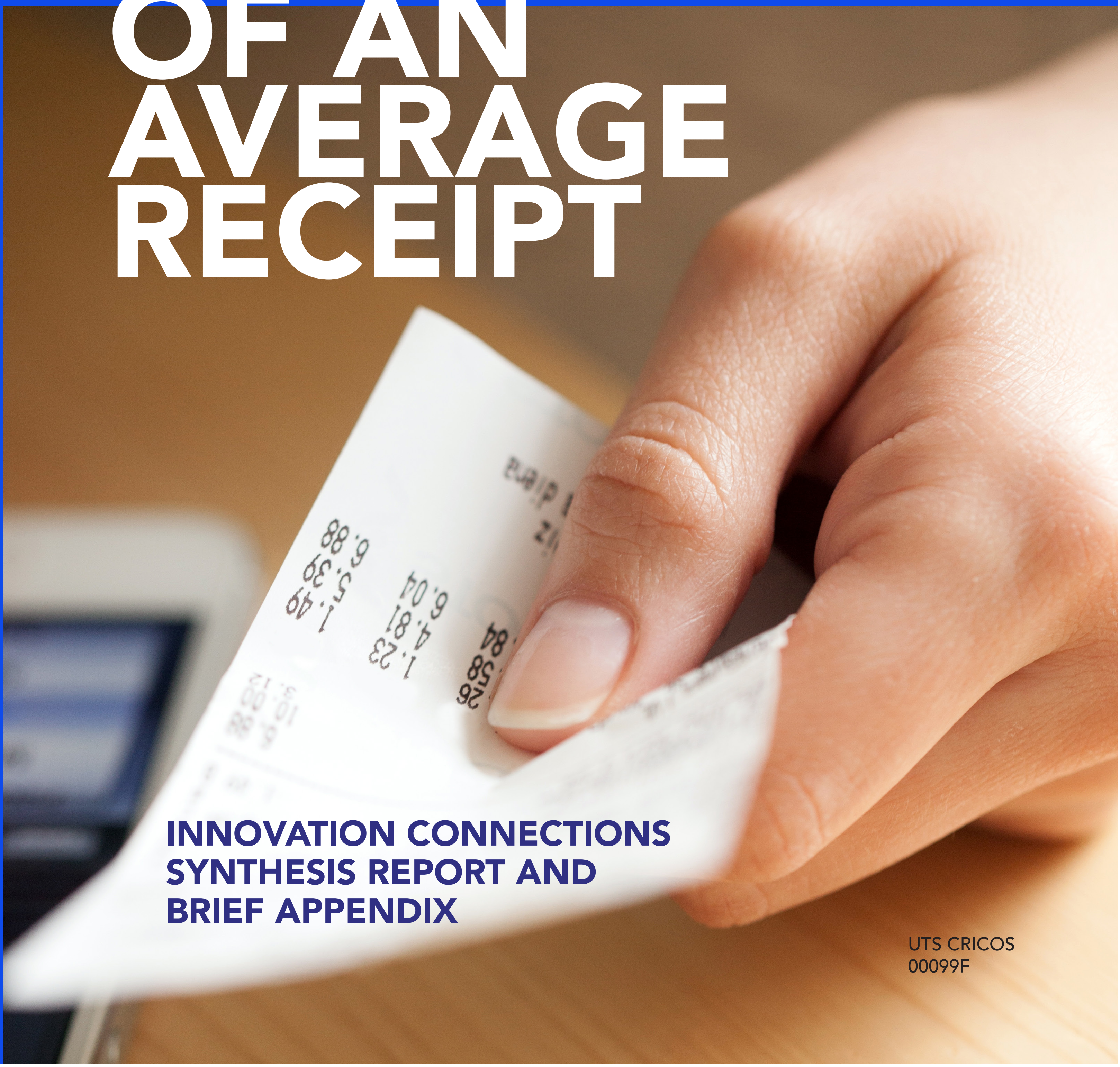
THE LIFE JOURNEY OF AN AVERAGE RECEIPT



INNOVATION CONNECTIONS SYNTHESIS REPORT AND BRIEF APPENDIX

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1. RESEARCH BACKGROUND

This research was made possible due to the Australian Government Innovation Connections scheme and in partnership with Slyp. The study's overarching aim was to identify the social, environmental, and economic impacts of an average thermal and digital receipt and to quantify the direct environmental impacts of those average receipts.

The overall mixed methods study involved:

- Academic and grey literature reviews on the social and ecological impacts of payments systems and sustainable supply chain
- Mapping the supply chains for a paper and digital receipt, deriving sustainability impacts from literature review, and seeking validation through expert and stakeholder interviews (n= 14).
- Quantification of an average thermal paper receipt (n=708) and average digital receipt and environmental input-output analysis and scenarios
- Scientific literature review (n=38) and microcosm experiment for determining interactive impacts of thermal receipts at the end of life (disposal in ecosystems) sampling four ecosystems (Freshwater aquatic, oceanic, bushland and landfill).

A consumer analysis study formed the final component of the UTS/Slyp study. This was a consumer survey on point-of-sale and post-consumer preferences for digital and paper receipts (n=1000), and some insights from this study have informed the quantification of the average receipt.

2. RESEARCH SYNTHESIS

This short report and short appendices provide a synthesis of key findings from the mixed methods research. The complete scientific research outputs can be found in extended supporting appendices available on request.

2.1 CONTEXT: DIGITAL TRANSFORMATION IN THE PAYMENTS ECOSYSTEM

Transactions within payment systems provide the foundation for a functioning economy and society by facilitating payments for exchanges of material, energy, and information in production and consumption systems.

Receipts transmit information to facilitate payment transactions and exchanges and provide a record of their occurrence. This service fulfils many needs at the point of purchase and beyond. While payment systems are complex and undergoing large-scale changes, and basic transactions remain enduring features, the payment, exchange, and receipting services are undergoing digital transformation.

Receipts have predominantly been transmitted through paper-based materials, most recently using thermal paper. Thermal paper is a special kind of fine paper that is coated with a chemical that changes colour when exposed to heat, instead of using ink for printing. A thermal paper roll is used to make paper receipts in thermal printers, which are very cheap or light devices like machines, cash registers, and credit card terminals. Recently, the health and ecological impacts of thermal paper receipts have been called into question because the paper contained Bisphenol A (BPA) or like substances, which had been found to have an interactive effect on human hormones. Further, paper consumption is resource intensive, and paper receipts become a waste stream when disposed of after use.

At the same time, digital transactions and electronic or digital receipt services have grown in popularity and have started to layer over or replace the service once exclusively offered by paper receipts. For instance, pre-pandemic studies demonstrated that around half of the Australian population made payments using their mobile phone and engaged in the digital economy somehow.

Digital services provide eco-efficiencies at the point of purchase, by removing the reliance on paper in the receipt service. However, environmental impacts are associated with the upstream infrastructures that allow access to the service, such as those associated with smartphone manufacturing and cloud storage.

While research has focussed on the digital transformation of payments systems, there is minimal research on:

- The ecological and social impacts of paper or digital receipt services. This study was the first attempt to outline the positive and negative social, ecological, and economic impacts and quantify the immediate ecological impacts of an average digital and paper receipt.

- The critical gap in direct analysis between thermal paper pollution and environmental health. Scientific studies have examined social impacts - the interactive effect of human exposure to the substances contained in some thermal paper (BPA and common BPA substitutes) - and found negative health impacts *(see summary in Appendix A)*. Since regulation has come into effect in the EU to ban these known chemicals, very little is known about the toxicity of chemical substitutes used in thermal paper. Furthermore, limited studies have examined the interactive effects of thermal paper waste on environmental ecosystems.
- The microcosm scientific study was a world first to examine the interaction between thermal receipt waste and the environment. It was designed to test key chemical changes in four different types of Australian environments when exposed to a standardised impact of thermal receipt pollution.

2.2 SUMMARY OF KEY FINDINGS

2.2.1 BACKGROUND

Provision of all products and services involves the coordination of activities across a complex value chain to transform materials, information, and capital from the extraction of raw materials to the end of life. Each organisation (we refer to these as stakeholders) and every activity involved in service provisions adds value to the process and generates some form of social, ecological, and economic impacts. Impacts are often evaluated to make assessments of the relative benefits of different services, make productivity gains and optimise resource efficiencies.

There are several key stages in the supply of receipt services and how impacts could be further evaluated. Receipt services, at the point of in-store sales transactions, have relied on material (paper product) and digital (data) processes and complex supply chains for each. The digital or paper receipt supply chain is a network of organisations connected through upstream (i.e. supply) and downstream (i.e. distribution) linkages, where each organisation involves different business processes and activities that produce value in the form of receipt services delivered to the ultimate customer.

Both value chains aim to fulfil the basic service value of a receipt to: (1) provide information to facilitate a transaction; (2) provide a record and information about the transaction that occurred. Our quantification of the environmental impacts of digital and paper receipts drew a boundary on the provision of the service at the point of purchase and is not a direct comparison method.

Our study revealed a variety of social, ecological, and economic indicators across each stage of the supply chain (upstream) and post-purchase (downstream) for both digital and paper receipt services.

Interviews validated the complexity of the supply chain, the different upstream arrangements for paper receipts and the emerging upstream infrastructures for digital receipts. We found that both digital and paper receipt stakeholders had strategies in place to mitigate negative social and environmental impacts and that each highlighted advantages of their services for customers and merchants during and post the point of purchase Given the complexity, the interviews reinforced that direct comparison of sustainability impacts is not possible or desirable, so the environmental Input-output analysis for an average receipt is appropriate.

2.2.2 SUMMARY OF KEY FINDINGS AND INSIGHTS

1. THE PAPER RECEIPT SUPPLY CHAIN IS COMPLEX AND LACKS TRANSPARENCY REGARDING PRODUCT ORIGIN OR CONTENTS

Interviews revealed the difficulties in accessing data and information about the ecological impacts in the paper receipt supply chain and the lack of regulation of this industry.

The thermal paper supply chain analysis revealed the different channels for thermal paper rolls to reach the end consumer. Thermal paper production from pulp occurs offshore and there are various upstream import processes including bulk import and processing, wholesale bundling and direct.

The paper industry in Australia provides value add services to manufacture thermal paper rolls from bulk import and is currently focussed on improving the eco-efficiencies of the paper production process, especially where they procure bulk from suppliers in European markets.

Bulk paper imported from European markets has sustainability certifications on responsible forestry, sourcing of pulp materials and paper manufacturing (for eg. PEFC and FSC Certifications) and have banned the use of inputs such as Bisphenol A (BPA). Other markets of origin require further investigation.

It is noteworthy that health concerns were specifically cited as an influencing factor in amendment 2016 / 2235 2016 (EU) restricting BPA content of thermal paper and noting BPS as a potentially hazardous substitute with similar effects.

While it is common practice to label certifications, there is no requirement for labelling of the product contents or its origin. It is therefore difficult for a merchant or consumer to know from which market paper rolls originate and what the product contains.

KEY INSIGHT:
Regulation would enable more transparency in the supply chain and inform business procurement about thermal paper roll decisions. In addition, the certification of imported thermal paper could be mandated and include product content labelling and the disclosure of GHG emissions in the supply chain.

2. AN AVERAGE DIGITAL RECEIPT HAS LESS DIRECT ENVIRONMENTAL IMPACT

Given the complexity and variation in each value chain, we sought to quantify the 'average thermal paper receipt' and the 'average digital receipt' to make some point of comparison of the ecological impacts (trees, water and energy usage, CO2 emissions and waste). *Appendix B provides a brief overview of this study.*

There is much variation in the dimensions of the average paper receipt by retail category and size of purchasing spend (i.e. the number of items printed on the receipt)[1]. Based on a randomly collected sample of receipts (n=708) we estimated the average paper receipt size derived from an average across industry segments as indicated in the table below.

TABLE 1. SUMMARY OF THE DIMENSIONS OF SAMPLE RECEIPTS

PRODUCT CATEGORY	SAMPLE	AVERAGE LENGTH (CM)	AVERAGE WIDTH (CM)
GROCERY	188	28.08	7.67
TRANSPORTATION	185	18.42	7.91
HOUSEHOLD	101	31.64	7.81
CLOTH	82	29.35	8.05
RECREATION	51	6.00	5.50
RESTAURANT	51	25.31	8.09
CHEMIST	50	34.62	8.00
TOTAL SAMPLE	708		
OVERALL AVERAGE		27.85	7.692

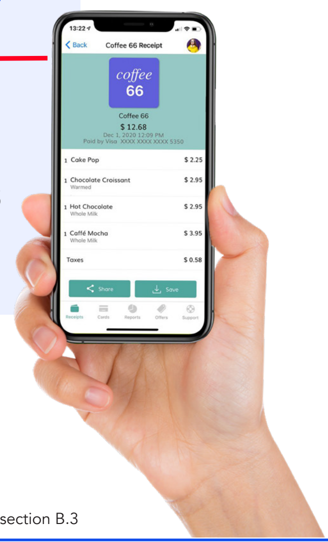
Likewise, there are variations in the dimensions of a digital receipt including size, number of data storage points/access and type of energy input. Despite this we obtained the average size of a printed receipt and digital receipt as follows:

AVERAGE THERMAL PAPER RECEIPT

LENGTH: 24.8cm
WIDTH: 7.7cm
WEIGHT: 57gsm (gram per sq metre)

AVERAGE SLYP DIGITAL RECEIPT

SIZE: 5KB
NUMBER OF DATA STORAGE POINT: 3



[1] Complete analysis of the average receipt can be found in the Supplementary Appendix B in section B.3

It is important to note this comparison draws the boundary around the direct material composition of an average receipt. It does not include the entire material inventory analysis across the supply chain or life cycle of a receipt.

Considering the analysis of the average receipt, a bounded Environmental Input-Output and scenario analysis was conducted.

THE CALCULATION OF THE DIRECT ENVIRONMENTAL INPUTS & OUTPUT REVEALS THAT PRODUCTION OF

100 MILLION PAPER RECIEPTS ACCOUNTS FOR:

1412 TREES
14664379 LITRES OF WATER
903.03 MT OF CO_2
982984.3 KWH OF ELECTRICITY
58.06 MT OF WASTE

TO PRODUCE/STORE 100M DIGITAL RECEIPTS, ENVIRONMENTAL INPUTS/IMPACTS ARE BETWEEN:

9.5 MT & 228 MT OF CO_2
(BASED ON THE DATA SIZE)
22500 KWH & 540,000 KWH ENERGY
(BASED ON THE DATA SIZE)

The only direct comparison of environmental impacts is made between CO_2 and energy. It should be noted that the input data for emissions is based on historical standards information and would be subject to change over time.

Next scenarios are considered to estimate the impact of the average paper receipts for Australia in one year. One scenario analysis which draws on secondary data and considering the UTS consumer research study - which found consumer receipt preferences (74%) - shows that in Australia, during 2019-2020, total Point of Sales (POS) printed receipt was around 10.656 billion which is likely to account for an estimated:

- 150, 462 trees
- 1.562 billion litres of water
- 96, 227 MT Carbon emission
- 104.746 million KWH Energy use.

The table below shows a range of different scenarios that vary by number of purchase/ transactions/year and chance of taking a receipt.

TABLE 2.
SCENARIO ANALYSIS

PURCHASE TRANSACTION/ YEAR	CHANCE OF TAKING RECEIPT	TOTAL RECEIPT/YEAR	ONPUT PRINTED RECEIPT	ONPUT DIGITAL RECEIPT
14.4 BILLION [a]	0.74 [b]	10.656 BILLION	150,462 TREES	0 TREES
			1,562,636,189 LITRES WATER	0 LITRES WATER
			96,227 MT CARBON	3,037 MT CARBON
			104,746,755 KWH ENERGY	7,192,800 KWH ENERGY
14.4 BILLION	0.50	7.2 BILLION	101,664 TREES	0 TREES
			1,055,835,262 LITRES WATER	0 LITRES WATER
			65,018 MT CARBON	2,052 CARBON
			70,774,848 KWH ENERGY	4,860,000 KWH ENERGY
15.84 BILLION [c]	0.50	8.8 BILLION	111,830 TREES	0 TREES
			1,161,418,788 LITRES WATER	0 LITRES WATER
			71,519 MT CARBON	2,257 MT CARBON
			77,852,333 KWH ENERGY	5,346,000 KWH ENERGY

a - According to Reserve Bank of Australia (RBA) during financial year 2019-20 total purchase transaction (card-10.7 billion and cash -5.4 billion) is around 16 billion. According to Australian Bureau of Statistics (ABS 2022) around 10% online retail purchase transactions are online. Hence, Cash and card purchase transaction/year excluding online purchase transactions is 14.4 billion.
b - According to consumer survey 74% of the respondents are often/always issue printed receipt following in-store purchase.
c - Assuming a 10% increase in the number of purchase transactions

Finally, we can estimate the paper receipt impacts for a typical Australian consumer over one year:

Paper receipt input for average Australian (average Australian prints 485 receipts/year which is equivalent to 0.000528424 MT paper receipts)

0.0068 trees

71.14 litres of water

0.00438 MT CO2

4.7685 KWH of electricity

0.000282 MT of waste

It should be noted that these results are a best estimation as consumer preference for no receipt does not equate with a paperless receipting system and duplication occurs. For instance, as consumers adopt alternates such as digital receipts the preference for no receipt would increase and therefore the resource consumption would be lowered. Even despite consumer preferences for no receipt, some retailers may print receipts for each transaction for their own operational purposes, therefore the resource consumption could be much higher than in the scenario above. Further, the input data for emissions is based on historical standards information and would be subject to change over time. For instance, the qualitative research revealed one company uses a 1:1 ratio as opposed to the 1:9 ratio from the calculator. It is changing over time as companies adopt more efficient technologies to reduce their carbon footprint.

KEY INSIGHT:
An average Slyp digital receipt has a smaller direct material impact than an average paper receipt. According to the Environmental Input-Output model - paper receipt production is less environmentally efficient compared to digital receipts.

3. EVEN IN A POST-BPA ERA THE TOXICITY OF THERMAL PAPER HAS ECOLOGICAL IMPACTS

The literature review (see Appendix A) highlighted key findings of chemicals involved with thermal paper, including traditional coatings of Bisphenol A (BPA), Bisphenol S (BPS), and other related products. It is clear there are a wide range of chemicals involved in the manufacture of these products, although specific chemical composition data for most brands are lacking due to the nature of these materials and regulatory landscape more broadly. Together, the scoping exercise and pilot experiment identified key environmental and human health related issues that arise from exposure to chemicals released when thermal receipts break down in different environments.

Previous studies have highlighted the potential toxicity impacts on human health of certain forms of thermal paper receipt which contain Bisphenol A (BPA), however our study was the first to consider how thermal paper receipt waste streams interact in landfill and within typical local ecologies. This study assumed thermal paper currently terminates in landfill at its end of life as it does not have a separate diversion collection stream.

Interviews with the paper industry claimed that their supply chain is BPA-free and that most Australian manufacturers of thermal paper do not produce from pulp with their predominant supply channel of bulk thermal paper being sourced from Europe, where there is a ban on BPA. Other direct supply chains identified in this study include, direct from overseas paper roll manufacturer, wholesale intermediary and wholesale bundled with other packaging supplies. Our study is inconclusive about which thermal paper roll supply chains contain BPA (or other phenol components such as BPS) due to a lack of regulation and poor labelling on thermal paper roll products.

The science experiment sourced two thermal paper samples from a major wholesaler which had no obvious product labelling about composition. The unique results typify receipting in the 'post-BPA era', where despite there being no obvious concentration of BPA, there were observed changes in the environment, and especially in the chemistry of the aquatic environment. These signal thermal paper waste has an impact on natural ecologies which could be explored in further research.

New discoveries were made in the scientific study even despite BPA not being detected in any microcosm environment at the end of the 3-month experiment.

For instance, the qualitative research revealed one company uses a 1:1 ratio as opposed to the 1:9 ratio from the calculator. It is changing over time as companies adopt more efficient technologies to reduce their carbon footprint.

KEY INSIGHT:

A new discovery in the experimental work shows that regardless of BPA content, which is often the focus of stakeholder conversation, there were significant changes in environmental pH when thermal receipt waste was deposited in aquatic environments, at levels which may lead to harm for aquatic biota. The scale of this impact and therefore risks in real world scenarios is likely dependent on:

- i) the volume of waste material,
- ii) the receipt chemical composition (i.e., different receipt products may use different binding agents comprising of stronger or weaker acids, or stronger or weaker alkali salts) and,
- iii) the size of the water body. Smaller bodies of water with low flow, or self-contained ponds and dams are at higher risk of this than larger bodies due to natural dilution which occurs in large, continually flowing water systems.

4. A HYBRID RECEIPT SYSTEM IN TRANSITION AND MANY OPPORTUNITIES FOR POSITIVE SUSTAINABILITY IMPACTS

There is much variation within and between the digital and paper supply chains, so a direct comparison of social, ecological, and economic impacts across the entire value chain would be highly complicated and, in our view, is not recommended. However, the analysis of impacts across the value chains allows a comprehensive way of communicating the negative and positive impacts of each service.

On balance, participants in both the paper and digital receipt value streams cited strategies that were being undertaken or targeted for improvements in eco-efficiencies and creating positive social impacts. For instance, the paper industry representatives cited adherence to new environmental standards in manufacturing and procurement of paper receipts, and those in the digital industry highlighted carbon reduction strategies in data storage and usage. Therefore, the impact indicators are dynamic and expected to change over time.

Notably, the digital receipt industry is focussed on ensuring responsible data governance, data integrity and privacy, and improving the consumer experience through data. Sound governance forms the foundation for their future strategy to amplify the positive impacts of their service through further integration of services and enabling the technology to be utilised to inform sustainable consumption decisions and enhance a circular economy. They claim upstream strategies include selecting eco-efficient data storage service providers and setting targets to power services through renewable energy.

While our study has raised further questions regarding the toxicity of thermal paper receipts, the paper receipt industry focusses on upstream strategies for eco-efficiencies in paper manufacturing and responsible procurement through PEFC and FSC Certifications. They claim their service provides a tactile and trusted method, especially for those who do not have access to, or are unwilling to engage with digital technologies and devices.

Overall, we find a system in transition that is best conceptualised as a hybrid of digital and paper receipting services. The receipting service system would be improved overall if circular solutions were in place to close the loop on waste (e-waste and paper), eliminate the toxicity of paper receipts, and improve eco-efficiencies across all processes. Stakeholders could cooperate to deliver optimal receipting services by different consumer segment preferences and to ensure responsible material consumption, emissions reductions, circularity and equitable service accessibility.

KEY INSIGHT:

The transition in receipting services should be best positioned as ‘hybrid’, combining paper and digital services in the short term. Longer term, however, digital could provide an eco-efficient alternative to paper in instances where the social and ecological benefits are enhanced. These instances would be when:

i) Renewable energy sources power digital receipt services.

ii) Users have equitable access to smart technologies and data.

iii) End-of-life solutions are provided for e-waste

2.2.3. LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The research in this study was conducted during a short timeframe and so there are various limitations which have been identified in supplementary appendices to this report.

As this research was a first of its kind, it has provided the basis for more comprehensive analysis of receipting systems. The following future research is recommended by the UTS research team:

1. Conduct full life cycle analysis for a digital/smart receipt and potential to seek climate active certification for digital receipt product - the paper industry claims they have conducted a full lifecycle assessment of paper receipts. We were not able to cite this work. A full lifecycle analysis considers the material inventory of each stage of the lifecycle using data provided directly form the service providers. The broad aims of this current study and short timeframe restricted a complete lifecycles analysis of digital receipts. Such analysis would provide a more comprehensive empirical validation of the impacts. Further, longitudinal data regarding resource consumption and carbon emission can be collected to test the model.
2. Scientific study of the composition of paper receipts and the health impacts of thermal paper receipts – lab testing of a broader sample of receipts for their composition and toxicity would provide more insight into the potential health and ecological impacts of paper receipts in a post-BPA market. Given the timeframe required to secure human research ethics we were not able to explore the interactive effects of receipts on human health. More analysis of the composition of different forms of receipts and their interactive effects with human health would inform policy and regulation or could provide guidance to the industry on product safety and labelling
3. Economic impact study on paper and digital receipts – this would involve identification of the impact indicators that could be quantified and where relative comparison is possible with modelling and scenarios like those presented in this study, but including more factors.
4. Policy and strategic analysis of the digital and sustainability transformation of the receipting services - digital receipts further integrate the transaction process between financial service providers, retailers, and customers through smart devices and offer augmented services to enhance the value of the receipt service. It is anticipated that the growth in the digital economy and consumer acceptance of digital technology-enhanced payments would increase the market for digital receipt services.

An opportunity exists for enhancing receipting services and to become more sustainable and responsible by eliminating negative and enhancing positive impacts. Both the digital and paper receipt services have linear value streams and so there is great potential for both or in hybrid to develop more circularity and eliminate unnecessary waste.

BRIEF APPENDIX

APPENDIX A:
A BRIEF SUMMARY OF ENVIRONMENTAL AND HUMAN HEALTH RISKS

1.1 OVERVIEW

Thermal paper is a multi-layered type of paper that carries solid ink on its surface, providing a logistically simple method of printing where the only consumable is the paper itself. The print head is a row of resistive heating elements that the paper is pressed against by a rolling rubber drum. This roller drum is the only moving part, lowering its associated costs, and improving reliability leading to this technology's widespread adoption. Thermal paper is composed of a few basic elements: the paper substrate, and the print coating. This coating includes layers of inks (e.g., leuco dyes), solid acid or alkali bases (i.e., developers) and solid solvents (i.e., sensitizers).

The colour of the ink is activated by the developer (Björnsdotter et al. 2017a). The heating elements on the print head melts the solid solvent is melted in specific spots, which dissolve and mixes the dye and developer together, darkening the ink and creating a printed pixel (Collura 2014; Mendum et al. 2011).

Both the digital and paper receipt services have linear value streams and so there is great potential for both or in hybrid to develop more circularity and eliminate unnecessary waste.

1.1.1 BISPHENOL A (BPA)

Studies into the general risks and effects of the chemicals present in thermal paper generally focus on the developer component BPA (i.e., bisphenol A) and common BPA substitutes. This is due to two factors: one, BPA is an essential building block for materials in polycarbonates, epoxies, and coatings (Minnesota Pollution Control Agency, n.d.). Consequently, it has a large presence as a pollutant with close and widespread human interaction (Research and Markets, 2021; Rubin, 2011). Two, its ability to mimic estrogenic hormone effects at very low concentrations. This has been observed in vertebrates, algae, and plants as the subject of many experiments concerned with BPA's impact on the environment.

1.1.2 ENVIRONMENTAL RISKS

The presence of BPA has been measured in various pollution control studies. While not much BPA can dissolve in water, levels needed to cause hormonal disruptions in live fish are on the scale of a thousandth of this limit or less (Crain et al. 2007). The biological impacts of BPA concentrations measured in nature have been observed in algae, sheep, rat, and fish cell cultures (Leusch et al. 2006b; Viñas & Watson 2013), and in live fish, mice, monkeys, and algae (Kurian et al. 2015). Multiple studies on zebrafish involving BPA and its commonly used alternatives BPS, BPSIP, have shown that each have similar effects including premature hatching, neuron development, and interruption of sex hormone signaling pathways. Reductions in overall growth and reproductive health are observed in either sex (Crain et al. 2007; Lee et al. 2018; Naderi et al. 2014; Qiu et al. 2016). Studies involving BPA and BPS exposure in mice have found similar signs of hormonal disruption leading to impacts on health and fertility (Horan et al. 2018).

Beyond animal effects, studies also exist involving crop studies of various fruits, leafy greens, and beans. Plants were irrigated with BPA-laced water and found BPA accumulation highest in roots and fruit with only partial metabolism in certain species, showing reduced growth in areas that accumulated BPA (Xiao et al. 2020). Tobacco plants were also found to be effective in metabolizing BPA into less harmful forms (Nakajima et al. 2004). Large variations in metabolism efficiency were also found amongst vegetable cell cultures, supplementing the possibility of plant-based remediation (Schmidt & Schuphan 2002).

1.1.3 BISPHENOL TREATMENTS AND FATES

Water treatment techniques used in Australia have been found to be effective in significantly reducing BPA content, but studies involving treated wastewater discharge wetlands have found localized BPA-induced effects on fish and algae populations (Leusch et al. 2006a). While the localized effects suggested well-lit and warm wetlands were a vital part of BPA breakdown as part of the water treatment process, the results of these studies have implications in the possible knock-on effects of hormonally active pollutants (Leusch et al. 2006b).

Regardless of waste streams implemented, BPA, and its substitutes BPS and BPF have been detected in dust collected from offices, homes, and outdoor environments (Dueñas-Mas et al. 2019). Other studies involving recycled paper have also found traces of BPA in the pulp, presumably from thermal paper put through the recycling waste stream (Björnsdotter et al. 2017a; Pivnenko et al. 2015).

1.1.4 LEACHATE FROM LANDFILL CELLS

Thermal paper, amongst other wastes containing BPA, is typically sent to landfill depending on each country's disposal policies. The Australian Bureau of Statistics show that 35% of paper and cardboard wastes and 80% of plastic wastes are sent to landfill in 2020. Landfill containment may not always be reliable for mitigating environmental risk (McCabe & Clarke, 2017), with BPA having been detected in landfill leachate in several international regions (Crain et al. 2007). Leachate contamination can spread to groundwater and eventually emerge into other aquatic environments without the aerobic environmental conditions needed to break down BPA (Crain et al. 2007; EPA Victoria, 2020).

1.1.5 HUMAN HEALTH RISKS

A particular focus on thermal paper exists due to the unpolymerized ("free") BPA content. When BPA is turned into plastic, as in the examples previously publicized with infant bottles, reusable plastic food containers, or protective canned food liners, they are formed into large molecules with any actual BPA being remnants from incomplete polymerization and breakdown associated with age and heating. These large, assembled molecules do not have the same hormonal effect as "free" BPA. In contrast, the BPA in thermal paper is unpolymerized, as the process of turning it into plastic removes the acidic element needed to activate the paper dyes (Björnsdotter et al. 2017a; Mendum et al. 2011). This free form of BPA is found to have the same hormonal strength as natural estradiol (Bittner et al 2014; Rubin, 2011).

I. FOOD SERVICE INDUSTRIES

The use of thermal paper in proximity to food handling scenarios (Pivnenko et al. 2015), and point-of-sale jobs where frequent handling of receipts occur, has inspired research focusing on human exposure from everyday use. Dermal transfer and absorption from human contact was shown via blood and urine samples (Bernier & Vandenberg, 2017; Environmental Defense Canada, 2019; Gerona et al. 2016). There is also interaction with skin cream which often includes derma penetrating additives (Biedermann et al. 2010), as well as emerging interest in how hand sanitizer carries BPA, as the active ingredients in alcohol-based sanitizers are found to be an ideal solvent for BPA (Environmental Defense Canada, 2019; Hormann et al. 2014). Amongst these results and more, the European Food Safety Authority has recognized thermal paper exposure to represent 75% of human absorption of BPA.

II. PREGNANT WOMEN

Callan et al.'s 2013 study of pregnant women conducted in Western Australia found that 85% of participants have detectable levels of blood BPA and finding no correlation between canned food consumption and BPA levels. Genius et al's 2011 study summarizes that 91 - 99% of the population has detectable levels of BPA. Gerona et al's 2016 study involving pregnant women have detected BPA in almost all participants and shows that exposure to thermal paper is the determining factor to BPA levels in urine. A review paper has found a correlation between blood BPA levels and infertility rates, plus found additional problems in those undergoing IVF treatment (Ziv-Gal & Flaws, 2016). A review article by Nesan et al. in 2018 finds agreeing studies that BPA can cross the human placental barrier and is found in human fetus serum and breast milk. This is especially concerning when extrapolating the multi-generational impacts of zebrafish exposed to BPA as embryos (Hao et al. 2022; Naderi et al. 2014).

III. DETOXIFICATION

Fortunately, the control stage of Environmental Defense Canada's 2019 thermal paper touch transfer study shows that a BPA and BPS 'detox' is possible by avoiding exposure to bisphenol containing food containers and thermal papers, with levels falling below detectable levels after two weeks. This is a significant finding worth consideration regarding longer-term strategies.

1.1.6 CURRENT AND EMERGING GOVERNMENT POLICIES

As awareness of BPA's possible health effects became more widespread, governing bodies and public pressure led to the initial adoption of BPS as a substitute for BPA in many consumer products. Unfortunately, BPS was soon found to have similar hormonal activity and potency to BPA (Horan et al. 2018), along with other bisphenol compounds such as BPF (Bittner et al. 2014; Rochester & Bolden, 2015) and BPSIP (also known as D-8 and WinCon-8) (Lee et al. 2018). Health concerns were specifically cited as an influencing factor in amendment 2016 / 2235 2016 (EU) restricting BPA content of thermal paper and noting BPS as a potentially hazardous substitute with similar effects (Aschberger et al., 2010; ESFA 2021). Non-phenol substitute 'Pergafast 201' recently gained more market share as the EU's strict BPA limitations came into effect in 2020, but still represents a minority compared to BPA and BPS (Biedermann et al. 2010; Björnsdotter et al. 2017b; European Chemicals Agency, 2020; Goldinger et al. 2015; Pivnenko, 2015; Vervliet et al. 2019). Furthermore, Pergafast 201 and any other alternatives currently lack research on their environmental and health safety, in line with the considerations raised in this short review. To stop the chain of unsuitable chemical substitutions, Environmental Defense Canada and the Minnesota Pollution Control Agency currently recommends avoiding printed receipts and only printing upon consumer request, especially for low value purchases. This is a simple solution with numerous benefits, including decreasing the chemical burden of thermal receipts. Further review of thermal receipts for Australian contexts are also worth deep consideration in light of this scientific evidence.

1.2 SCIENTIFIC EVIDENCE CHALLENGING THE SERVICE VALUE OF THERMAL RECEIPTS

An exhaustive scientific literature review formed the basis of the Science experiment.

The following provides a snapshot of the high-level findings of the scientific desk research.

Thermal paper carries solid ink on its surface, providing a method of printing where the only consumable is the paper itself. The print head is a long row of microscopic resistive heating elements that the paper is pressed against by the roller drum. This roller drum is the only moving part, further lowering its costs and improving reliability leading to this technology's widespread adoption.

‘Thermal printing’ is different from ‘thermal transfer printing’, whereby a black plastic coating is melted from a separate ribbon onto paper, or plastic “paper” in specific applications.

The structural and chemical composition of thermal papers are generally as follows: paper substrate, printing coating (acid-activated ink, solid acid, and a solid solvent). The solid solvent is melted by heat, which dissolves the acid and ink which darkens the ink colour. While plastic coated thermal paper exists, it seems to be less common.

While there appear to be relatively few trials into health impacts of these two-stage dyes and almost all are currently indicated as “safe” on their MSDS. Most of the scientific research to date is on the solid acid due to two factors:

1. BPA materials constitute a multi-billion dollar global industry as an essential building block for many polycarbonate materials (e.g., reusable food and drink containers), sealants, and chemical coatings, and also used as an additive in other plastics which results a relatively large presence, domestically and globally.

2. BPA’s ability to chemically mimic hormone function in mammals, and the levels of its persistence in nature is worth consideration. Examples include scientific studies of its accumulation in edible plants and its presence in natural water sources. Because BPA is detectable at microgram per litre scales, combined with its large production volume, the effects on mammal health especially developing young in the wild is of interest.

Thermal paper contains a notable chemical mass of BPA, figures reaching 1% of total mass. A Ricoh MSDS quotes “2 - 5% phenol derivative”. These “phenol derivatives”, along with “BPA free” without indicating “BPA / BPS”, “phenol free”, etc. may be BPS instead, which is supported by chemical analysis of thermal paper samples. BPS, along with other similar bisphenol compounds, can have similar levels of EA as found in more recent European studies.

Studies specific to Australian contexts are far less common. This is a critical knowledge gap which should be addressed with future research investigations. The few Australian studies which do exist have found that most of the thermal paper in Australia (> 80%) use BPA, with BPS and other phenol derivatives accounting for the rest of the market.

In direct human exposure, receipts are handled by customer service and the majority of the public, including applications where it directly contacts or is handled alongside food. Coating can be aggravated with mechanical action of tearing and crumpling, and carried by fats in food or skin. While not much BPA can dissolve in water (0.3g / L), levels found to induce hormonal responses and wildlife studies are on the scale of micrograms/L. There is also emerging interest in hand sanitizer interaction, as the active ingredients in alcohol-based sanitizers is found to be an ideal solvent for BPA and are used to extract BPA as a standard method in studies.

There has been preliminary research involving human touch tests, in vitro studies with algae and animal cultures, crop studies of various fruits, vegetables, beans, and some field studies of plants and fish. Research on leaching from food containers, especially microwaving oily foods, has been conducted and consistently indicate that low levels of BPA are leached from polymer materials.

Additionally, it is worth noting many brands like Nalgene have moved away from the use of any bisphenol type chemicals, aspiring to use environmentally safer alternatives. State legislation in California, USA moved to regulate BPA in food packaging in 2005. Since that time, more than 30 US states and localities have introduced policies to ban or restrict BPA in consumer products.

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APPENDIX B :
SUMMARY OF THE QUANTIFICATION OF THE AVERAGE RECEIPT STUDY

2.1 BACKGROUND

Increasingly, companies want or are required to monitor and report on their social, ecological, and economic performance and impacts of their operations. In response a variety of evaluation and reporting frameworks, standards and certifications have been created, which are commonly known as sustainability or ESG (Environmental, Social and Governance). In applying these frameworks businesses have mostly been concerned with the direct efficiencies and impacts of their own performance (which is referred to as their Scope One). In recent times there has been a shift in expectations for companies to be accountable for the direct (Scope Two) and indirect (Scope Three) impacts of their activities both upstream and downstream in the value chains of their service offerings. It is important for businesses to know how delivering service value through their operations can have broader impacts.

In this context, the following two objectives have been explored for both thermal and digital receipts as the basis of developing some form of comparison between the two regarding their supply chain impacts:

Quantify average thermal receipt

Quantify sustainability impacts (where secondary data available) of an average thermal receipt versus a smart receipt

Through the development of an environmental input-output analysis, this report provides a quantification of the average thermal and smart receipt using available secondary data related to certain environmental indicators. The formula for this analysis could be further expanded if data were available to include more of the social, environmental, and economic indicators (such as those identified in the previous section). Such quantification would provide a more comprehensive evaluation of the broad sustainability impacts of each type of receipt.

2.2 METHODOLOGY FOR QUANTITATIVE ANALYSIS

This section quantifies the sustainability impact of both printed and smart receipts. Then a comparative analysis of the environmental impact of both receipt types has been conducted. We used environmental input-output analysis for quantifying environmental impact of both receipts, then a scenario analysis technique was used to compare impacts for different quantities of receipts. Notably, because of the varied nature of the products and having different sets of parameters for environmental impact assessment, exact comparison of the impacts of the two products (printed and smart receipts) is difficult.

2.2.1 ENVIRONMENTAL INPUT-OUTPUT ANALYSIS

Environmental input-output analysis is rooted in the classical input-output (IO) model, which was first developed by U.S. economist Leontief who constructed a linear model of the relationship between production inputs and outputs in an economic system (Camara and Llop, 2021; Kjaer, Høst-Madsen, Schmidt and McAloone, 2015). At the core of IO analysis is an input-output mathematical framework that enables a modeler to capture the direct and indirect relationships among conserved flows that may include material or energy flow within a system (Piluso, Huang, and Lou, 2008). Brown and Blanchard (2015) note that input-output analysis is not an accounting tool rather this method offers an estimation of an entity's energy and environmental impact, and the method is widely adopted in studies of environmental impacts and energy consumption of international trade, global cities, national economies, health systems and individual firms. However, apart from economic systems, the IO model has been adapted to explain the input-output relationships in other systems, such as environmental input and output (EIO) analysis to understand the relationship between environmental input and output (Piluso, Huang, and Lou, 2008; Tan, Aviso and Foo, 2018). For example, in EIO analysis inputs can be considered as the environmental resources (e.g. raw material, water and energy etc.) used for producing outputs (e.g. a physical product or a service).

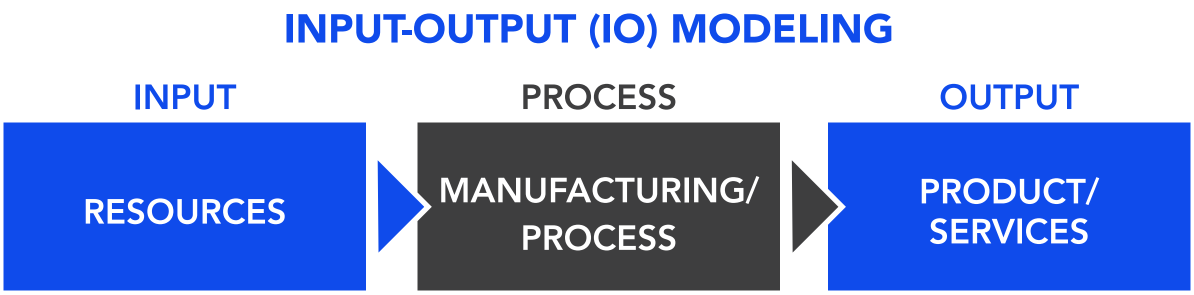

FIGURE B.1:
INPUT-OUTPUT MODEL

2.2.2 SUSTAINABILITY IMPACT ASSESSMENT

Sustainability is a multi-dimensional construct that can be assessed based on the triple bottom line of social, environmental and economic aspects. In this section, according to research objective 2, sustainability impact will be quantified based on the environmental aspect. One of the popular approaches for environmental impact assessment is EIO analysis which is adapted from the generic IO analysis (Kjaer, Høst-Madsen, Schmidt and McAloone, 2015). In this research the generic IO model (Figure 1) is extended and contextualised to analyse environmental input-output as presented in Figure 2. In our EIO model (Figure 2) the inputs are environmental resources and impacts (e.g. trees, water, energy use and carbon emission) of the process and output is the quantity of physical product. Notably, carbon emission has been considered as output in some studies but many previous studies (e.g. Egilmez et al., 2013) also considered it as input in EIO analysis. In this research, in line with Egilmez et al., (2013) all environmental impacts including carbon emission have been considered as environmental input.

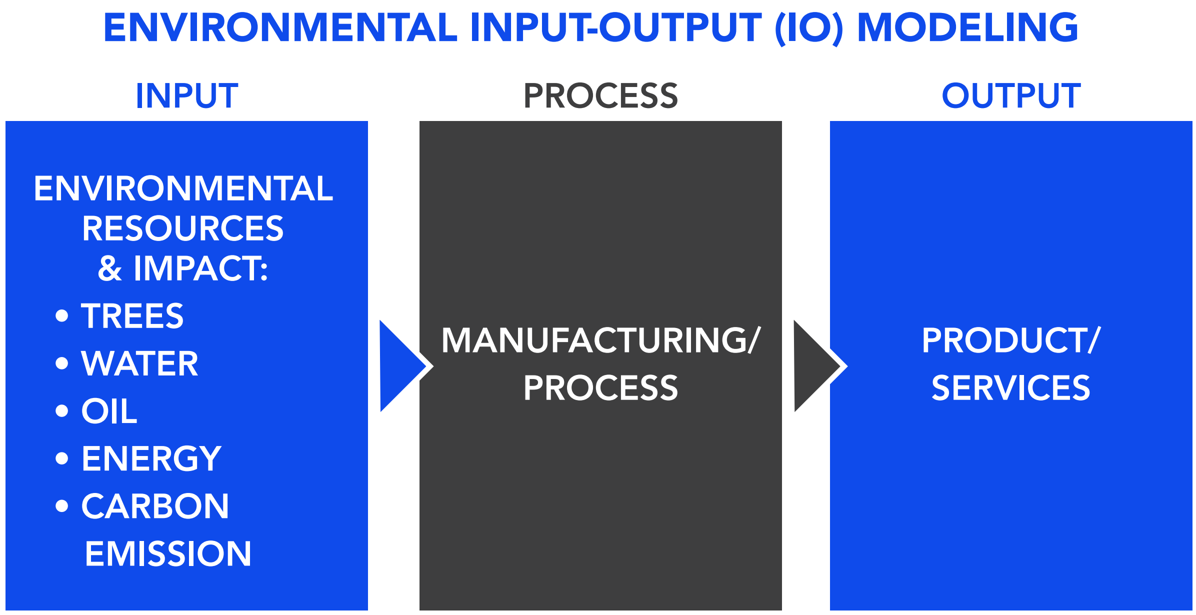

FIGURE B.2:
ENVIRONMENTAL INPUT-OUTPUT (EIO) MODEL (ADAPTED FROM GENERIC INPUT-OUTPUT MODEL)

This research aims to quantify the uses of trees, water, energy and carbon emission for the printed receipt and compare them against smart/digital receipts. Corresponding to the research objective we adopt the EIO analysis to measure the environmental impact in terms of quantity of physical input (e.g. amount of tree, water, oil, energy and carbon emission) used for a particular unit of physical output- both printed and smart receipts. The EIO analysis is also used for life cycle assessment (LCA) (Onat et al., 2020; Kjaer, Høst-Madsen, Schmidt and McAloone, 2015). In LCA, impacts are assessed either based on "top down approach" where the transactions between the activities are measured in monetary units or "traditional process-based LCA" where flow of activities/ transactions are measured in terms of physical units (e.g. such as kilograms or kWh) (Camara and Llop, 2021). Both methods have their limitations. For example, to conduct a comprehensive process-based LCA of a product requires both direct and indirect operational (administration, R&D, marketing, etc.) data and it is a difficult task to collate this (Manderson & Considine, 2018; Malik et al. 2021). On the other hand, in a top-down approach (transactions measured in monetary terms) one of the main weaknesses is sector aggregation, as sectors may be too heterogeneous to reflect a particular product (Camara and Llop, 2021).

Notably, the approach to quantify the environmental impact in this research is not LCA based, and we are not considering the physical flow of goods at different stages of the value chain; instead, we are considering the aggregate level input and output of the value chain. Our EIO approach quantifies the environmental impact of the unit of output and will enable the decision-makers to analyse the environmental efficiency of alternative products and processes to select the best alternative option. For example, if alternative A needs x unit of input and alternative B requires 2x units of input, in that case alternative A is more resource efficient as it deploys less input.

2.2.3 MODEL SPECIFICATION FOR SUSTAINABILITY IMPACT ASSESSMENT

We know from the input-output relationship model that, output = f (inputs)

which in our context has been modified as output Y= f (environmental inputs/impacts)

Here, the output is the total units of product (e.g., thermal receipt or smart receipts) produced by a system/process, and the inputs are environmental impacts of the process to produce a particular quantity of output. We considered quantity of trees, water, energy use and carbon emission as inputs because all of those inputs have environmental impacts.

The input-output relationship can be determined by the following equation.

$$Y = \sum_{i=1}^{n} \alpha_i x_i$$

The above equation can be written in the extended form as follows:

$$Y \;=\; \alpha_1 x_1 + \; \alpha_2 x_2 + \; \alpha_3 x_3 + \cdots \ldots \ldots \ldots \ldots \ldots \ldots . \alpha_n x_n$$

Notations:

Y = Quantity of output (measured in 100 mil)

x_i = total environmental input from source i (e.g., quantity of trees, water, energy and carbon emission) (known from the secondary data)

α_i =Input output multiplier/coefficient representing efficiency of inputs,

for example, α_1 reflects efficiency of environmental input x_1

and α_2 presents efficiency of environmental input x_2 and so on;…………………………

n = number of sources that create environmental impact

2.3 CASE STUDY FOR ENVIRONMENTAL IMPACT ASSESSMENT

In this section, we developed a case study (for printed and smart receipts in Australia) and applied our EIO model to quantify the environmental efficiency of both alternative products (printed and smart/digital receipts).

2.3.1 CASE STUDY: ENVIRONMENTAL IMPACT OF PAPER AND DIGITAL RECEIPT IN AUSTRALIA

To apply our EIO model into real life, it is important to prepare data that is compatible with the model specification.

For this case study, the following information was requested:

1. Quantity of tree, water, energy and carbon emission corresponding to output Y.

Quantity of tree, water, energy and carbon emission corresponding to paper receipt output Y (e.g., 100 million receipt) was determined from the data available to secondary sources (e.g. Green America report) and the collected data is comparable with paper calculator of Environmental Paper Network (EPN) which is a coalition of over 140 not-for-profit organizations across the world working together toward the sustainability of paper production and use (https://environmentalpaper.org/epn-projects/).

Relating to digital receipt the direct impacts are mainly the energy consumption and carbon emission while there are indirect impacts as well (e.g. use of plastic, metal, energy etc relating to the production of devices used for storing and generating digital receipt data). In this study due to the lack of available published data on the indirect impacts of digital receipt we have considered direct impacts (i.e. energy consumption and carbon emission) of digital receipt for our EIO analysis. The energy consumption in generating and storing digital data depends on many factors (e.g., power usage efficiency, type of devices used in data centres, data retrieval rate etc.). Because of multiple factors involved in the power consumption of data, extant studies provide mixed findings. For example, Coroama et al., (2013) found that an estimated power consumption of data transmission is 0.2KW/GB data (excluding end device) on the other hand, Weber et al., (2010) claimed that is 7 KWH/GB (including end device). Considering an average estimated power consumption of 4.5KWH/GB (including end device), in line with United States Environmental Protection Agency (EPA) calculator, we find an estimated carbon emission of 1.9 Metric ton/TB data. This estimation is also consistent with the findings of Adamson (2017). However, it noteworthy that energy intensity of internet and data centres are substantially decreasing overtime (Coroama and Hilty 2014).

2.3.2 MEASUREMENT OF AVERAGE RECEIPT FROM COLLECTED SAMPLES

The measurement of average receipt (i.e., length and width) was determined from collected samples. The UTS team collected 708 sample receipts across various categories (e.g., supermarket and grocery shops, pharmacies, transportation, household appliances, café/restaurants, hardware shops, fashion clothing and footwear stores) with at least 50 samples from each category were collected. Based on the samples, an average receipt length and width were determined (*see Appendix B.1 for average length and width of receipts by different categories*). This average receipt length and width is instrumental in quantifying output and corresponding environmental impact/ input.

The input-output table (see table 1) derived from secondary data is presented below and the information from Table 1 is used for populating our EIO model. It is noteworthy to mention that, where required, industry expert opinion was also incorporated in quantifying the input-output data.

TABLE B.1:
INPUT-OUTPUT TABLE FOR PAPER AND DIGITAL RECEIPTS

INPUT OUTPUT CATEGORIES	THERMAL RECEIPT	DIGITAL RECEIPT
OUTPUT - TOTAL QUANTITY OF THERMAL PAPER RECEIPT/DIGITAL RECEIPT	OUTPUT - 1 METRIC TON (MT) PAPER	OUTPUT -1 TERA BYTE (TB) OF CLOUD STORAGE
INPUT - ENVIRONMENTAL IMPACT	INPUT FOR 1 MT OF THERMAL PAPER	INPUT FOR 1 TB OF DATA STORAGE IN CLOUD
TREE USE	12.96 TREES	
WATER CONSUMPTION	134621 LITRES OF WATER	
CARBON EMISSION	8.29 METRIC TON OF CO2	1.9 MT OF CO2/TB/YEAR
ENERGY USE	9024 KWH OF ELECTRICITY	4500 KWH/TB/YEAR
SOLID WASTE FROM PRODUCTION AND DISPOSAL	0.533 MT OF WASTE	*

* To quantify solid waste corresponding to the devices used for digital receipt need further research as published data is not available in this aspect.

TABLE B.1 shows input-output analysis of paper receipts and digital/smart receipts. The calculation of input quantities for paper receipt is based on the Green America environmental impact (for paper receipt) quantification and the input quantities for digital receipt is based on the Stanford Magazine cloud storage environmental impact calculation. Paper receipts input was calculated corresponding to 1 metric ton of output while digital receipt input was calculated corresponding to 1 TB of digital receipt data. The calculation results reveal that production of 1 metric ton paper receipt accounts for 12.96 Trees, 134621 litres of water, 8.29 MT of CO2, 9024 KWH of electricity and 0.533 MT of waste. On the other hand to produce/store 1TB digital receipt environmental inputs/impacts are 1.9 MT of CO2 and 4500 kwh energy. Notably the impact of digital receipt relating to tree and water consumption is null as tree and water is not required directly as input for generating digital receipt. The LCA data for digital receipt is not available in extant studies to quantify direct and indirect impacts. A thorough LCA based study, which include both direct and indirect impacts, may provide a better understanding on the impact relating to water and other input usage (e.g. plastic, metal etc.) required for producing digital devices. Therefore, future research, using LCA based approach, is recommended to quantify the environmental impact of both paper and digital receipt with high precision.

TABLE B.2:
INPUT-OUTPUT TABLE FOR PAPER RECEIPTS

PAPER RECEIPT INPUT FOR 100 MIL RECEIPT (100 MIL RECEIPT = 108.93 MT [a])		PAPER RECEIPT INPUT FOR AVERAGE AUSTRALIAN (AVERAGE AUSTRALIAN PRINTS 485 RECEIPTS/YEAR [b] WHICH IS EQUIVALENT TO 0.000528424 MT PAPER RECEIPTS)
TREE	12.96*108.93= 1412 TREES	12.96*0.000528424= 0.0037 TREES
WATER	134622.04*108.93= 14664379 LITRES OF WATER	134622.04*0.000528424= 71.14 LITRES OF WATER
CARBON EMISSION	8.29 *108.93= 903.03 MT OF CO2	8.29*0.000528424= 0.004381 MT OF CO2
ENERGY	9024*108.93= 982984.3 KWH OF ELECTRICITY	9024*0.000528424= 4.7685 KWH OF ELECTRICITY
WASTE	0.533*108.93= 58.06 MT OF WASTE	0.533*0.000528424= 0.000282 MT OF WASTE

MT- metric ton, kwh- kilowatt-hour, a. see Appendix B.2 for calculation, b. see Appendix B.3 for calculation

TABLE B.3:
INPUT-OUTPUT TABLE FOR 100 MIL DIGITAL RECEIPTS

DIGITAL RECEIPT OUTPUT IN TB (ASSUMING SINGLE DATA POINT)	DIGITAL RECEIPT OUTPUT IN TB ASSUMING THREE DATA POINTS)**	DIGITAL RECEIPT OUTPUT IN TB (ASSUMING THREE DATA POINTS)
100 MILLION DIGITAL RECEIPT = 5 TB DATA (ASSUMING THAT AVERAGE DIGITAL DATA SIZE= 5KB)	100 MILLION DIGITAL RECEIPT = 15 TB DATA (ASSUMING THAT AVERAGE DIGITAL DATA SIZE= 5KB)	100 MILLION DIGITAL RECEIPT = 120 TB DATA (ASSUMING THAT AVERAGE DIGITAL DATA SIZE= 40 KB***)
DIGITAL RECEIPT INPUT	DIGITAL RECEIPT INPUT	DIGITAL RECEIPT INPUT
9.5 MT OF CO2/YEAR	28.5 MT OF CO2/YEAR	228 MT OF CO2/YEAR
22500 KWH/YEAR	67500 KWH/YEAR	540,000 KWH/YEAR
xxx*	xxx*	xxx*

xxx*= digital waste which needs to be considered
* according to an IT expert from a digital receipt service provider (Slyp) average size of digital receipts data is 5KB
** according to interview findings there are three data points that store digital receipts data
*** according to our experiment average digital data size= 40 KB which is found from the estimation of size of data for email receipts

TABLE B.2 & B.3 presents Input-Output quantities for 100 million paper and digital receipts which help us to understand the environmental input efficiency of both alternatives- paper and digital receipt. In this study we considered output quantity 100 million for ease of calculation, but it can be calculated for any units required for analysis. The calculation results in Table 2 show that 100 paper receipt is equivalent to 108.93 MT of receipts (*see appendix B.1 for the detailed calculation of the weight of paper receipt*). Every paper receipt has length and width. In this regard, corresponding 708 sample receipts, average length and width of paper receipts are 0.2485m and 0.07692m. Each paper receipt has a weight which can be calculated based on gram per square meter (GSM) specification. Relying on the standard gsm of thermal paper average gsm of thermal paper is 57. Therefore, the estimated weight of 100 million paper receipt is equivalent to 108.93 MT. Corresponding to 100 million paper receipt, input estimation results show that paper receipt requires 1412 trees, 14664379 litres of water, 903.03 MT of CO2, 982984.3 KWH of electricity.

On the other hand, considering 3 data point (according to expert opinion data is kept by cloud service provider, merchant/bank and digital receipt platform service provider), 100 million digital receipt data size is 15 TB (assuming that 1 digital receipt requires 5KB data derived from expert opinion). In this regard 100 million digital receipt is directly responsible for 0 unit of tree, 0 litres of water, 28.5 MT of CO2 and 67500 KWH of energy. However, according to our experiment average digital data size= 40 KB which is estimated from the size of data relating to email attached receipts. Along this line considering average digital data size= 40 KB and three data points 100 million digital receipt is responsible for 0 unit of tree, 0 litter of water, 228 MT of CO2/year and 540,000 KWH of energy/year. Therefore, it appears that, for a particular output (100 mil receipt) environmental input for paper receipt is significantly higher than the digital receipt. As a result, according to our EIO model paper receipt production is less environmentally efficient compared to digital receipt. However, this comparison shall be used with some precaution due to the following limitations in the quantification process- the input calculations for both products are mainly based on secondary data sources instead of a thorough life cycle analysis of both products; the indirect input for digital receipt such as water usage, electronic waste from data storage devices could not be included in calculation because of lack of available published data and lifecycle analysis of digital receipts. Therefore, LCA based future research is required to derive a precise and more comparable estimation of input for both alternatives- paper and digital receipts.

2.3.3 EIO MODEL AFTER POPULATING DATA

Our input-output equation for paper receipt based on the above data is below:

Output Y *(in 100 mil paper receipts)* = $1412x_1 + 14664379x_2 + 903.03x_2 + 982984.3x_4 + 58.06x_5$

Where, x_1 represents TREE

x_2 represents WATER

x_3 represents CO2

x_4 represents ENERGY

x_5 represents WASTE

Our input-output equation for digital/smart receipt based on the above data is below:
Output Y *(in 100 mil digital receipts)* = $0x_1 + 0x_2 + 28.5x_3 + 67500x_4 + 0x_5$

Output Y *(in 100 mil digital receipts with 40KB/receipt)* = $0x_1 + 0x_2 + 228x_3 + 540{,}000x_4 + 0x_5$

Comparing the EIO model/equation for paper and digital receipt it appears that coefficient of input (tree, water, carbon, energy and waste) for paper receipt is higher and therefore, paper receipt production is less environmentally efficient compared to digital receipt.

2.3.4 SCENARIO ANALYSIS:

In the scenario analysis we analysed what are the input quantities if K amount of paper and digital receipts are used in Australia. Where the value of K is dependent on various factors such as purchase transactions/year and chance of taking printed receipts. The results of scenario analysis are presented in **TABLE B.4**.

TABLE B.4:
SCENARIO ANALYSIS

CASH & CARD PURCHASE TRANSACTION/ YEAR EXCLUDING ONLINE PURCHASE TRANSACTIONS	CHANCE OF TAKING RECEIPT	TOTAL RECEIPT/ YEAR	INPUT PRINTED RECEIPT	INPUT DIGITAL RECEIPT (AVERAGE RECEIPT DATA SIZE 5 KB)	INPUT DIGITAL RECEIPT (AVERAGE RECEIPT DATA SIZE 40 KB)
14.4 BILLION [a]	0.74 [b]	10.656 BILLION	150,462 TREES	0 TREES	0 TREES
			1,562,636,189 LITRES WATER	0 LITRES WATER	0 LITRES WATER
			96,227 MT CARBON	3,037 MT CARBON	24,293 MT CARBON
			104,746,775 KWH ENERGY	7,192,800 KWH ENERGY	57,542,400 KWH ENERGY
14.4 BILLION	0.50	7.2 BILLION	101,664 TREES	0 TREES	0 TREES
			1,055,835,262 LITRES WATER	0 LITRES WATER	0 LITRES WATER
			65,018 MT CARBON	2,052 MT CARBON	16,416 MT CARBON
			70,774,848 KWH ENERGY	4,860,000 KWH ENERGY	38,880,000 KWH ENERGY
15.84 BILLION [c]	0.50	8.8 BILLION	111,830 TREES	0 TREES	0 TREES
			1,161,418,788 LITRES WATER	0 LITRES WATER	0 LITRES WATER
			71,519 MT CARBON	2,257 MT CARBON	18,058 MT CARBON
			77,852,333 KWH ENERGY	5,346,000 KWH ENERGY	42,768,000 KWH ENERGY

a - According to Reserve Bank of Australia (RBA) during financial year 2019-20 total purchase transaction (card-10.7 billion and cash -5.4 billion) is around 16 billion. According to Australian Bureau of Statistics (ABS 2022) around 10% online retail purchase transactions are online. Hence, Cash and card purchase transaction/year excluding online purchase transactions is 14.4 billion.
b - According to consumer survey 74% of the respondents are often/always issue printed receipt following in-store purchase.
c - Assuming a 10% increase in the number of purchase transactions

IN TABLE B.4 three scenarios were considered.

THE 1ST SCENARIO is to analyse the input and output if total purchase transaction (Card and cash transactions excluding online purchase) is 14.4 billion/year with 74% chance of taking receipt for each transaction. In the base scenario we considered 74% chance of printing paper receipt corresponding to transactions as our consumer survey result reveals that almost 74% of the customers often take printed receipts after instore purchase.

THE 2ND SCENARIO is to analyse what is the input-output if total purchase transaction is 14.4 billion and chance of printing receipts is 50%. As many of the purchase transactions may take online, we assume that in the case of the online purchases the chances of printing receipts are low. Therefore, in the 2nd scenario we considered a conservative estimate of printing receipt. The 3rd scenario is to analyse what is the input-output if total purchase transaction is increased to 15.84 billion (10% increase) and chance of printing receipts is 50%.

Using a conservative estimate our scenario analysis shows that in Australia, during 2019-2020, total POS printed receipt was around 7.2 billion which is likely to account for an estimated 101,664 trees, 1.056 billion litres of water, 65,018 MT Carbon emission and 70.775 million KWH Energy use. The impact of any increase in transactions will result in printing more receipts. From all scenario analyses we find that printed receipt has significantly higher environmental impact than digital receipt. Therefore, to reduce the environmental impact of point of sales receipts technology enabled digital/smart receipt solution may play a significant role.

2.4 LIMITATIONS AND FUTURE RESEARCH

Every research has some limitations. Likewise, this research also has some limitations. This research, for quantification purpose, has considered only environmental impact, while the social and economic impact may also be considered for quantifying the sustainability impact. Future research may be conducted to quantify social, environmental and economic aspects holistically. Further, this research did not include lifecycle assessment of receipt supply chain. Future research can be conducted to include LCA of paper and digital receipt supply chain by using both primary and secondary sources of data which will provide a better understanding on the impacts (direct and indirect impacts) of both receipts. Further, in this research, the input calculations for both receipts are mainly based on secondary data sources instead of a thorough life cycle analysis of both products to include both direct and indirect impacts. Therefore, the impacts presented in the tables shall be used with some precaution. An LCA based study is highly recommended to be able to draw a precise comparison of the environmental impacts of printed and digital receipts. Further, longitudinal data regarding resource consumption and carbon emission can be collected to test the model.

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APPENDIX B.1:
SUMMARY OF THE DIMENSIONS OF SAMPLE RECEIPTS

PRODUCT CATEGORY	SAMPLE	AVERAGE LENGTH (CM)	AVERAGE WIDTH (CM)
GROCERY	188	28.08	7.67
TRANSPORTATION	185	18.42	7.91
HOUSEHOLD	101	31.64	7.81
CLOTH	82	29.35	8.05
RECREATION	51	6.00	5.50
RESTAURANT	51	25.31	8.09
CHEMIST	50	34.62	8.00
TOTAL SAMPLE	708		

APPENDIX B.2:
CALCULATION FOR PAPER AND DIGITAL RECEIPTS

FOR PAPER RECEIPT:
Average length of one Printed money receipt is X meter
Average width of one Printed money receipt is Y meter
Average weight of per square meter of paper is Z gram.
Average Area of one Printed money receipt = XY Square meter
Total area of 100 Million Printed Money receipt = 100 million * XY square meter
If z is the weight of gram per square meter, then

Total weight of 1 money receipt is:
= XY *Z gram

Or,
= (XY*Z/1000) Kilo Gram
= (XY*Z/1000000) Metric Ton paper/per money receipt

Total weight of 100 million money receipt is:
= {(XY*Z/1000000) * 100 million} Metric Ton paper
= 100 XY*Z Metric ton.
Formula for calculating the Weight = Width(W) x Length(L) x GSM(g/m^2)
The standard gsm of thermal paper is 48gsm, 55gsm, 60gsm, 65gsm, etc.

Average weight in gsm= (48+55+60+65)/4= 57 gsm

Based on an average money receipt length of 0.2485 m (24.85 cm) width 0.07692 m (7.692 cm), average gsm 57:
Weight of 100 mil receipt= 100*0.2485*0.07692*57 MT = 108.93 MT

Which is equivalent to
0.2485*100 million meter, where 0.2485 meter is the average length of a receipt in meter = 24.85 million Meter or 24850 KM/100 million receipt

FOR DIGITAL RECEIPT:
As par IT expert from a digital receipt service provider 1 digital receipt data size in cloud storage is 5KB.
Therefore, 100 mil digital receipt = 5 TB data storage (considering one data point)
However, according to our experiment average digital data size= 40 KB which is found from the the estimation of size of data for email receipts.

APPENDIX B.3:
CALCULATION OF TOTAL RECEIPTS OF AN AVERAGE AUSTRALIAN/YEAR

According to Reserve bank of Australia statistics (2021-22 financial year) total non-cash/electronic transaction is 650/year while cash transaction accounts for 27% of total transaction and 75% of the electronic transactions are made by card (credit and debit card).

Based on these statistics the total transaction per year (which includes card transaction 488 and cash transactions 240) = 728.

SOURCE: https://www.rba.gov.au/publications/annual-reports/psb/2022/the-evolving-retail-payments-landscape.html

According to Australian Bureau of Statistics (ABS) The average monthly proportion of online sales to total retailing for 2022 is 10.6 per cent which is significantly above the pre-Covid level in October 2019 of 6.6 per cent. Considering the ABS data, in our calculation we have estimated the online retail sales is around 10% in the recent years.

As an average proportion of online sales is 10%, around 90% transactions can be considered instore/physical transactions. Thus, out of 728 total transactions (cash and card) around 655 transactions are instore/physical transactions which may have printed transaction receipts. According to our consumer survey on an average 74% of the cases consumers take printed receipt followed by instore purchase. This leads us to assume that total number of receipts printed by an average Australian in a year is 485.

SOURCE: https://www.abs.gov.au/statistics/industry/retail-and-wholesale-trade/retail-trade-australia/latest-release#online-retailing

The scientific reports include: interpretative analysis of secondary data from peer-reviewed sources (see Appendix A); quantification of an 'average' digital and paper receipt and their direct ecological impacts (see Appendix B); interviews with stakeholders in the paper and digital receipt value chains (see Appendix C); results of the scientific microcosm experiment (see Appendix D).

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