THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Washing with (con)science

Combining psychology and life cycle assessment to better understand the environmental impacts from domestic laundering

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Cover by Erik Klint:

A man toiling with the conflicting emotions of reducing the amount of laundry at the expense of appearing unclean. Even though he understands the necessity of reducing environmental impacts, he fears the imagined social repercussions. Conflicting psychological goals like these are seldom addressed in life cycle assessments, although they often undermine willingness to change.

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Abstract

Technological aids often allow us to trade resources for time. Having taken away the tedious work of laundering clothes by hand, the washing machine has allowed people to spend more time on increasing household productivity, leisure activities and education. Today, people in Europe own more clothes and wash them more frequently than at any other time in history. This extensive consumption also means that the environmental impacts from domestic laundering are higher than at any other time in history. One way to estimate these impacts is through life cycle assessment (LCA). The results from such LCAs can help prioritise interventions and policies that aim to reduce pressures on the environment. Unfortunately, many such initiatives have failed again and again. These failures indicate an incomplete understanding of what motivates consumer behaviours and present a challenge regarding how to appropriately address these issues in LCAs. This thesis shows what motivates domestic laundering behaviours psychologically speaking, highlights the uncertainties associated with contemporary LCAs of domestic laundering, and presents a way to expand the LCA methodology. The main message is that laundering our clothes is socially motivated. Therefore, a proper assessment of the environmental impacts must be based on a social perspective rather than a contemporary technical one.

Since behaviours are adaptive, they need to be treated as systemic components in LCAs rather than as static values. Failing to do so might otherwise result in compensatory behaviours and burden shifting. By using insights from psychology and sociology as a starting point for the analysis, LCAs can offer a more nuanced assessment of the environmental impacts of consumer products and services. A social perspective also permits a more comprehensive assessment of societal trends, such as the rebound effect. With a more holistic understanding of why people engage in certain behaviours, LCAs can better guide interventions and policies towards targeting *motivations* rather than focusing on the *consequences* of behaviours. As such, a social perspective in an LCA is critical for the success of any policy or initiative aimed at reducing environmental impacts where the use phase is a significant contributor.

Keywords: domestic laundering, LCA, environmental psychology, behaviour

List of publications

This thesis is based on the work contained in the following papers and publications:

Academic articles

Paper I

Klint, E., & Peters, G. (2021). Sharing is caring – the importance of capital goods when assessing environmental impacts from private and shared laundry systems in Sweden. Int J Life Cycle Assess, 26(6), 1085-1099. https://doi.org/10.1007/s11367-021-01890-5

Paper II

Klint, E., Johansson, L.-O., & Peters, G. (2022). No stain, no pain – A multidisciplinary review of factors underlying domestic laundering. Energy Research & Social Science, 84, 102442. https://doi.org/10.1016/j.erss.2021.102442

Paper III

Klint, E., Johansson, L. O., & Peters, G. (2023). Mind the (reporting) gap – a scoping study comparing measured laundry decisions with self-reported laundry behaviour. Int J Life Cycle Assess, 28(9), 1211-1222. https://doi.org/10.1007/s11367-023-02189-3

Paper IV

Klint, E., Peters, G., & Johansson, L.-O. (2024). Pro-environmental behaviour is undermined by disgust sensitivity: The case of excessive laundering. PLOS ONE, 19(6). https://doi.org/10.1371/journal.pone.0302625

Paper V

Klint, E., Peters, G., & Ekvall, T. (2024). Loads of trouble – Assessing the rebound effect of domestic laundering using LCA [manuscript].

Additional published material

Data Set I

Klint, E., Peters, G., & Johansson, L.-O. (2024). Domestic laundering behaviours in Sweden (Dataset version 1). https://doi.org/10.5878/cnaf-v548

Contribution report

Paper I
EK conducted the LCA and wrote the first draft of the article. GP proposed initial research questions, assisted with the software implementation and suggested editorial changes to the text.

Paper II
EK was the main contributor to formulating the research question and conducting the literature review, including writing the initial draft. GP and LOJ reviewed and suggested revisions to the text.

Paper III
EK was the main contributor to formulating the research question, conducting the data collection, and writing the initial draft. GP helped with equipment installation and data collection. GP and LOJ reviewed and suggested revisions to the text.

Paper IV
EK formulated the research question, planned the data collection, and performed the analysis under the supervision of LOJ. EK wrote the initial draft. GP and LOJ reviewed and suggested revisions to the text.

Paper V
EK was the main contributor to formulating the research question, carrying out the LCA, and writing the initial draft. GP helped with data collection and TE with methodological considerations. GP and TE reviewed and suggested revisions to the text.

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While professional support at work is important, it is hard to get anything done in life when you have young children if you do not get support in your private life as well. This thesis would not have been possible without the

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Gothenburg, 2024
Erik Klint

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1 Introduction

Technological aids often allow us to trade resources for time. With this in mind, some people argue that one of the greatest inventions of the Industrial Revolution was the washing machine (Rosling, 2010). Having been relieved of the tedious work of laundering clothes by hand, people could spend more time on increasing household productivity, leisure activities, and education. Pakula and Stamminger (2010) estimated that roughly 30% of the world's households owned a washing machine in 2010. This percentage seems to be growing rapidly, and in 2015, handwashing clothes or having someone else do it for you was only reported as the main laundering method by 20% – 25% of the respondents of a global consumer survey (The Nielsen Company, 2016). Recent data on global ownership of washing machines support this trend (Statista, 2024). Unfortunately, replacing manual labour with an automatic machine often leads to an increase in direct resource and energy consumption and, by extension, an increase in environmental impacts. Higher availability and lower cost (either in time or monetary value) also have the potential to increase consumption. This means that the environmental impacts from domestic laundering have increased and might continue to increase further with improved living standards. Understanding the magnitude of this increase and, by extension, the consequences will be dependent on the answers to two questions: how certain are current assessments of the environmental impacts from laundering? And to what extent do people alter their laundering behaviours once they have access to a washing machine?

1.1 How certain are current impact assessments of laundry?

Determinations of the environmental impacts of consumer products and services such as washing machines and laundering often rely on the results from life cycle assessments (LCA). LCA is a systematic process for evaluating the environmental impacts of a product, process or service throughout its entire life cycle, from raw material extraction to disposal. Since LCA model emissions are based on quantitative calculations, any proper analysis requires good and reliable data. Unfortunately, many published LCAs describe estimating the environmental impacts from domestic laundering as

a challenging undertaking. These challenges are important to recognise since the results from many LCAs guide initiatives for the reduction of environmental impacts. The more uncertain the underlying data is, the less well informed the planned initiatives will be. This is especially true when comparing the results from one LCA with another. Domestic laundering is directly connected to textile consumption, and the relationship between the production of clothes and clothing care (i.e., laundering) is often highlighted. For example, a common claim is that laundering is one of the most detrimental life cycle phases with regard to the environmental impacts from clothing consumption (Muthu, 2015). However, other authors reject this conclusion and claim that the impacts associated with the production phase of textiles are the most detrimental ones (Sandin et al., 2019; van der Velden et al., 2013). Some of these contradictory results come from different assumptions regarding the amount of renewables included in the electricity mix when laundering. Uncertainties connected to consumer behaviours also contribute to these diverse conclusions. Depending on the assumptions regarding energy and consumer behaviour, final estimations of climate impact from laundering seem to vary as much as by a factor of 6.5 between European countries, and by a factor of 3.5–5 within each country (Shahmohammadi et al., 2017). Thankfully, there is seldom a lack of good data concerning the national electricity supply (IEA, 2024; Swedish Energy Agency, 2024). However, information about consumer behaviours with regard to domestic laundering is sparse.

Behavioural data for domestic laundering is usually based on self-reported data. This data is mainly collected through surveys (Arild & Brusdal, 2003), although diaries (Conrady et al., 2013; Laitala et al., 2020) and interviews (Pink & Postill, 2019) are also used. For example, self-reporting is most often used to estimate how much laundry is being washed each week, how often a washing machine is run, or to what extent the machine is loaded to its capacity (Alborzi et al., 2017; Laitala et al., 2020; Miilunpalo & Räisänen, 2018; Morgan et al., 2018). Self-reported data is also used to understand the contextual factors shaping the requirements for labelling energy-using products (EuP) in the EU, a regulatory framework that aims to inform consumers about the energy efficiency of products (Faberi et al., 2007a, 2007b; Graulich et al., 2011). When LCA models are constructed, these data greatly influence their results. Take, for example, the load level. When

calculating the environmental impacts from laundering, the results are often expressed in relation to how much textile is being washed. Let us say that running a wash program is associated with approximately 1 kg of CO_2-eq. In this fictive example, a regular washing machine (6 kg) was used and loaded using Europe's most common self-reported loading rate (67%). In such a scenario, the associated levels of global warming potential (GWP) per kg of laundry would be around 0.25kg CO2-eq. This conclusion might be misleading since the choice of using average values excludes any variability and uncertainty in the data. This is important as the impacts *per kg laundry* increase non-linearly as the amount of laundry being washed decreases (Koerner et al., 2010). In this example, washing a single pair of jeans (which corresponds to a load level of approximately 7%) would increase emissions *per kg of laundry* by a factor of 10.

It is currently unclear how uncertain the behavioural data is, mostly because of methodological challenges in verification. These challenges exist both for data describing previous behaviours (i.e., can people accurately remember past behaviours?) and for stated preferences in the future (i.e., accurate predictions of future behaviours when given a choice). For example, if people state they are willing to switch from one alternative to another, will they follow through? Understanding this is crucial because these types of strategies are already being deployed to reduce the climate impacts from domestic laundering (Morgan et al., 2018). The fact that behaviour is not a static property but is constantly evolving with individual circumstances further exacerbates these types of challenges. This aspect becomes especially important to consider for laundering, where access to cheap laundering options has been consistently growing in the last decades.

1.2 Do people change their laundering behaviour with increased availability and lower cost?

For many types of products and services, a decrease in cost is often associated with increased consumption. This dynamic is so prevalent that it has been given a specific term: the rebound effect. Originally, the rebound effect was used to describe an observation regarding historical coal consumption. Improved efficiency of use did not lead to a reduction in national coal consumption but rather an increase (Alcott, 2005). The same

situation still applies to much of the energy use today, and policies that promote energy efficiency are often not the best way to save energy or reduce environmental impacts (Herring, 2006; Herring & Roy, 2007). However, rebound effects are not limited to energy consumption. The same dynamic can be observed for the use of materials (Gutowski et al., 2017), household expenditure (Girod & De Haan, 2010), and even for circular economy strategies aiming to reduce the need for products and virgin materials (Lowe et al., 2024). Regarding domestic laundering, Bittman et al. (2004) have shown that purchasing a clothes dryer often increased the amount of time spent on doing the laundry, even though the machine was marketed as a time-saving investment. In the same spirit, Khazzoom (1980) and Wörsdorfer (2010) argue that continuous technical improvements in washing appliances will lead to more household laundering. However, whether this growth can be observed in real life is unclear since historical data is mostly limited to reports of household expenditures or national time surveys.

A common perception is that the time spent on domestic laundering increased between 1925 and 1968. Industrialisation, improved living standards, and greater participation in the workforce by women meant that people could afford to own more clothes and wash them more often (Cowan, 1983; Mokyr, 2000; Vanek, 1974). These claims have recently been criticised for lacking sufficient empirical evidence. New estimations have instead shown that the time spent on laundering *decreased* between the early 1920s and mid-1970s (Gershuny & Harms, 2016). Similar findings have been presented by Bianchi et al. (2000), who showed that the average time spent on laundering decreased from 6.7 hours per week in 1965 to 2.4 hours per week in 1995. Analysis of time-use diary data in the United Kingdom suggests that less time was spent on laundering in 2005 compared to 1985 (Anderson, 2016). This type of data might illustrate what happens when people get access to washing machines. However, it does not indicate if the *amount* of laundering was reduced rather than just the time spent on the activity. Nor does it show if laundering behaviour stabilises after the initial change from manual labour to using a washing machine. For this picture to emerge, we must focus on more recent data for countries that have had high access to washing machines for a longer time, e.g., Sweden.

Public access to shared laundries was introduced in Sweden during the early 1920s, and access to washing machines (both shared and private) has been high since the 1950s (Lund, 2009). Statistical data from Sweden show that the weekly time spent on laundering and ironing fell from approximately three hours to two hours between 1990 and 2010 (Statistics Sweden, 1992, 2003, 2012)[1]. This decrease might suggest a reduction in laundering or ironing activity amongst the Swedish population. Such a trend would be beneficial from an environmental perspective since less activity often means less resource consumption and environmental impacts. Unfortunately, as argued at the beginning of this chapter, a reduction in time could also indicate that more resources are being used when laundering clothing. More thorough investigations into the behaviours behind the data reveal a clearer picture. Older people in Sweden are much more likely to air clothes or remove stains by hand to avoid running the washing machine (Carlsson-Kanyama et al., 2005). Young people are much more prone to clean their clothes using a washing machine, running it more frequently with larger loads (Carlsson-Kanyama et al., 2005; Lindén, 2008). Removing stains by hand rather than putting the clothes into the washing machine often takes longer but uses less energy and fewer resources. This means that the observed Swedish trend is better understood as an indicator of Swedish people consistently increasing their resource consumption to save time. That being said, the question remains: Does the change from manual labour to automatic machines lead to more frequent washing? Looking at the technical improvements in the energy efficiency of washing machines suggests that it does.

A great amount of effort is invested into making domestic laundering cheaper and more energy efficient. In just the period 2000–2010, the amount of energy needed to wash a specific amount of clothing using a

[1]A Swedish time-use survey from 2021 exists, although the method of data collection in this report differs (i.e., self-reported behaviour rather than diary logs). As such, the results in this report should not be compared with previous results (Statistics Sweden, 2021).

washing machine sold in Europe was reduced by 34% (Boyano et al., 2017). However, this relative efficiency improvement was mainly a function of washing machines growing in size: from an average rated capacity of 4.86 kg in 2000 to an average rated capacity of 6.5 kg in 2010. To fully realise this potential reduced need for electricity, people would need to adjust how often they washed due to having access to larger machines. This does not seem to be the case. Instead, how frequently people choose to wash is not dependent on the load capacity of their washing machine (Schmitz et al., 2016), and cycles per week seem to have remained rather stable between 2000 and 2010 (Laitala et al., 2012). This could mean that the machines are consistently underutilised or that people adapt their behaviour by washing more laundry. Since the self-reported loading rate has been rather consistent in Europe throughout the 21st century (Alborzi et al., 2017; Faberi et al., 2007b; Schmitz & Stamminger, 2014), it is not unreasonable to assume that larger washing machines prompt people to wash more laundry. Some researchers do argue that people wash their clothes more frequently than during any other period in history (Klepp, 2003), which begs the question: can this trend be expected to continue? And if so, how can we estimate the associated environmental impacts?

Accurate forecasting of societal developments is inherently hard. It is human nature to revere believable (rather than relevant) evidence, and we are all overconfident in the future scenarios we predict (Tetlock, 1994; Tetlock & Gardner, 2015). In other words, it is unclear if the trend towards more laundering can be predicted to continue or not. The best we can do is pinpoint and describe the forces that encourage or discourage such a development, e.g. the observed mechanisms behind a potential rebound effect. Unfortunately, there is currently no theoretical consensus on what governs rebound effects in LCA and how to address them properly in the analysis (Font Vivanco & van der Voet, 2014). This often means that rebound effects are excluded or overlooked in LCA or treated arbitrarily in the discussion as an area for future research. Some authors have stressed the need to properly account for rebound effect mechanisms and come up with some suggestions on how to account for this phenomenon in LCA models. For example, Hicks (2022) suggests an integration of Agent-Based Modelling (ABM) with LCA to properly address variations in behaviour during the use phase. Other authors argue that the functional unit needs to become more

dynamic (Kim et al., 2017) or that insights from behavioural science should be included in all parts of the LCA (Polizzi di Sorrentino et al., 2016). This thesis is partly an answer to these calls.

1.3 Thesis and Research Questions

The starting point for this thesis is the understanding that most human decisions and behaviours are socially motivated. How this principle affects LCA must be explored further within the field. In practice, this means that a proper understanding of the technical system is not enough if the main contributor to the impacts is the use phase. *This thesis underscores the need for a social perspective when using LCA to understand the environmental impacts of individual behaviour.* In the following sections, I will use domestic laundering as an example of why it is important to acknowledge this principle. More specifically, three consecutive research questions illustrate the necessity of this perspective. The first question comes from the recognition that a proper understanding of the use phase is critical when assessing the impacts of consumer goods and services. Unfortunately, the use phase is often also the hardest to assess. Real-life behaviour typically deviates from the intended use of a product or a service. For instance, people might not use the full capacity of the machines or wash clean clothes out of habit. Observing a behaviour or a potential trend, such as a rebound effect, in society is one thing. It is quite another to pinpoint the mechanisms contributing to its existence.

Numerous sociological studies illustrate the meanings people ascribe to laundering. Yet these insights are seldom translated into modelling choices in LCAs. Furthermore, psychological aspects that could influence laundering behaviour are generally missing. In this case, sociology and psychology could be seen as two sides of the same coin. The lack of psychological investigations means that while the explicit reasons for behaviours may be known, the underlying mechanisms that shape real decisions are not. It could be argued that these different aspects are somewhat irrelevant to LCA methodology. Modelling environmental impacts based on scenarios is solely dependent on data that describes the behaviours, rather than their underlying motivation. For this type of setup, average values suffice. However, understanding the potential trajectories of behavioural change

over time is not possible if the underlying motivation is unclear. Too generic data will in this case increase the challenges in, for example, understanding and addressing the rebound effects of domestic laundering. Approaching the behavioural aspects from a psychological perspective might also help shed light on the reasons for the low success rate of previous behavioural interventions. The first research question (RQ) for this thesis is therefore:

RQ1: ***What are the main drivers of domestic laundering behaviour?***

While identification of behavioural drivers is a critical first step, it is also important to understand how these might vary with contextual factors and between individuals. Such a more nuanced view is dependent on good data. Unfortunately, while previous LCAs focusing on domestic laundering might rely on large datasets, these are often narrow in terms of data variability. This limitation is especially true for measurements of behaviour. Rich individual variation in this type of data is often simplified to an average value that is assumed to represent a specific consumer group in the LCA model. This simplification of data has two implications. The first is that any uncertainty or variability in the data is lost. This means that the final impacts in the LCA model appear more certain than they are. Such a false sense of certainty is especially troublesome since the use phase is the most important part of the life cycle of laundering. The second implication is that average values do not allow for any deeper analysis of what the numbers might represent. As such, it is hard to properly understand the nuances in the data, including any clues to the potential motivations for or barriers to a willingness to change. This means that average data makes it harder to understand the mechanisms in the use phase that underpin specific behaviours and trends. This leads to the second research question:

RQ2: ***To what extent does behavioural data for domestic laundering vary?***

Contemporary LCAs of domestic laundering are not only narrow in data variability, these investigations are often also narrow in scope. The analysis is mainly limited to resource consumption when producing and later running a washing machine or a tumble dryer. These direct impacts are essential to include, but the LCAs might underestimate the additional

indirect effects connected to the activity. In LCA terms, this challenge can be described as uncertainty regarding the system boundaries. One such example is the environmental impacts associated with the use of the building space needed for the laundry or the machines (Borg & Högberg, 2014). Another example is that using a washing machine damages textile fibres. A high frequency of washing therefore suggests a higher turnover rate for specific garments due to wear and tear. Someone who chooses to wash more frequently will need to buy more clothes, all else being equal. This type of additional consumption further exacerbates the environmental impacts from laundering. In other words, the final environmental impacts from domestic laundering can be considered a consequence of a complex interaction between a technical system (e.g., the resource consumption of the machines and textiles) and a social system (e.g., the specific decisions and behaviours of the user). To create an LCA of domestic laundering, both systems need to be properly understood. Of special interest is the relative influence of each system on the results, including any associated uncertainties. The third research question for this thesis is therefore:

RQ3: How can the LCA perspective be expanded to enhance assessments of the environmental impacts from laundering?

Answering this final research question will provide a more holistic view of the environmental impacts connected to laundering. In practice, this would mean a better integration of psychological insights with LCA methodology. Since implicit psychological goals might differ from the explicit reasons for behaviours, the hope is that this new information will complement current sociological knowledge. The results presented in this thesis have implications for how LCA practitioners should assess the environmental impacts from laundering and, in a more general sense, consumer products and services. I hope this work will facilitate a more general discussion about the relevance of the social perspective when conducting LCAs for consumer products and services. For a visual representation of the relationship between the three research questions, see Figure 1.

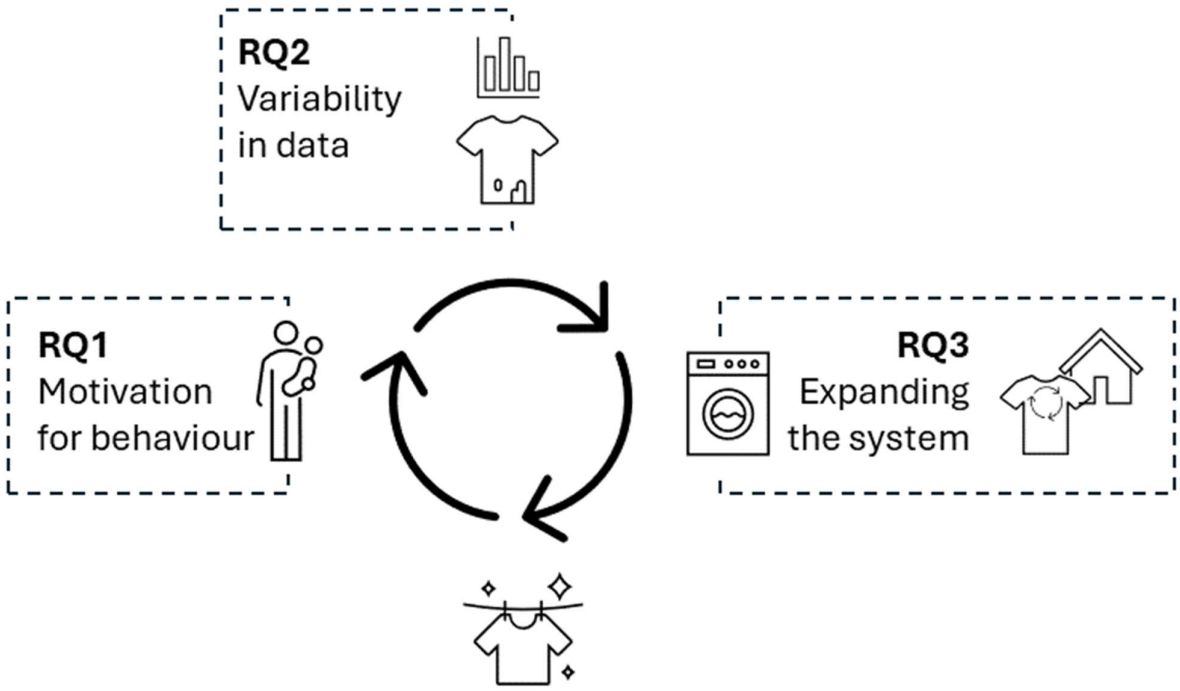


Figure 1. A visual representation of the research questions.

1.4 Contextual factors relevant to the thesis

The research presented in this thesis was made possible through base funding from Formas and Chalmers Energy Area of Advance, with additional support from HSB Levande Lab AB and Electrolux Professional. Part of the empirical data in this thesis was collected at HSB Living Lab (HSBLL), a combined multi-family building and research facility in Gothenburg. Here, tenants can rent a small apartment or a room in a student dorm. What is unique is that the tenants agree to have data passively collected throughout their stay, e.g., water use and energy use. In addition, researchers collaborating with HSBLL can also collect data through surveys and voluntary interviews. The operational data collected at the shared laundry facility is relevant to this thesis. This data includes logs from the tumble dryers and washing machines such as the choice of programs, energy consumption, and weight of the laundry washed. Electrolux Professional facilitated access to this data. Both HSBLL and Electrolux Professional provided valuable insights into the possibilities and limits of data collection at the facility but did not influence the general research design.

The interdisciplinary aspiration of combining psychological insights with LCAs was already included in the larger grant application submitted to Formas. Initially, the focus was mainly on exploring psychological strategies that policymakers and designers could apply to steer decisions pertaining directly to machine operation. As the research project progressed, however, it became obvious that the scope had to be changed. Instead of focusing on immediate decisions (such as loading rate and temperature choice), the psychological explorations had to be extended further. This meant focusing more on the abstract influences of social norms and perceptions of cleanliness. The findings from this change in focus might not be as directly applicable as the original purpose, although I believe that the general insights from this type of work are much more important. Hopefully, the discussion provided in the last chapters will convince more LCA practitioners of the urgency of including a social perspective when investigating the environmental impacts associated with consumer products and services.

1.5 The relationship between the papers

This thesis focuses on the intersection between the environmental impacts of technology and psychological motivations for behaviour. Figure 2 provides a visual representation of the relationship between the papers. Paper I presents a classical life cycle assessment for domestic laundering in a Swedish context. The paper's main aim was to investigate the relative influence of capital goods (i.e., machines and buildings) in assessments of the environmental impacts from domestic laundering. This aspect has traditionally been excluded in LCAs of laundering, even though private and shared laundry rooms differ in room size and are equipped with different types of machines. While the findings from Paper I were interesting, it became apparent that few LCA studies accounted for uncertainties connected to behaviour. This limitation was even more remarkable since individual behaviour during the use phase is arguably one of the most significant factors affecting overall impacts.

The realisation that psychological motivations for laundering were largely unexplored prompted a shift in research focus towards the behavioural side of domestic laundering. For practical reasons, this new focus was limited to

two critical questions: What factors motivate our laundering decisions (Paper II), and to what extent can self-reported behavioural data used in LCA be trusted (Paper III). The results from Paper II and Paper III then guided a more in-depth investigation of the psychology underlying laundering, i.e. how psychological aspects affect laundering frequencies (Paper IV).

The initial motivation for investigating the behavioural aspects of laundering was to enhance the quality of technical assessments. The aim was to reduce uncertainties in the data, leading to improved LCA models and, consequently, more effective recommendations for initiatives to mitigate environmental impacts. The findings from Paper II-IV, however, revealed that the initial questions posed in Paper I were too narrow and too technical. This realisation led to exploring a different functional unit when modelling the environmental impacts from laundering (Paper V). As such, this final paper represents an effort to synthesise all previous findings, combining psychological motivations for behaviour with LCA for domestic laundering.

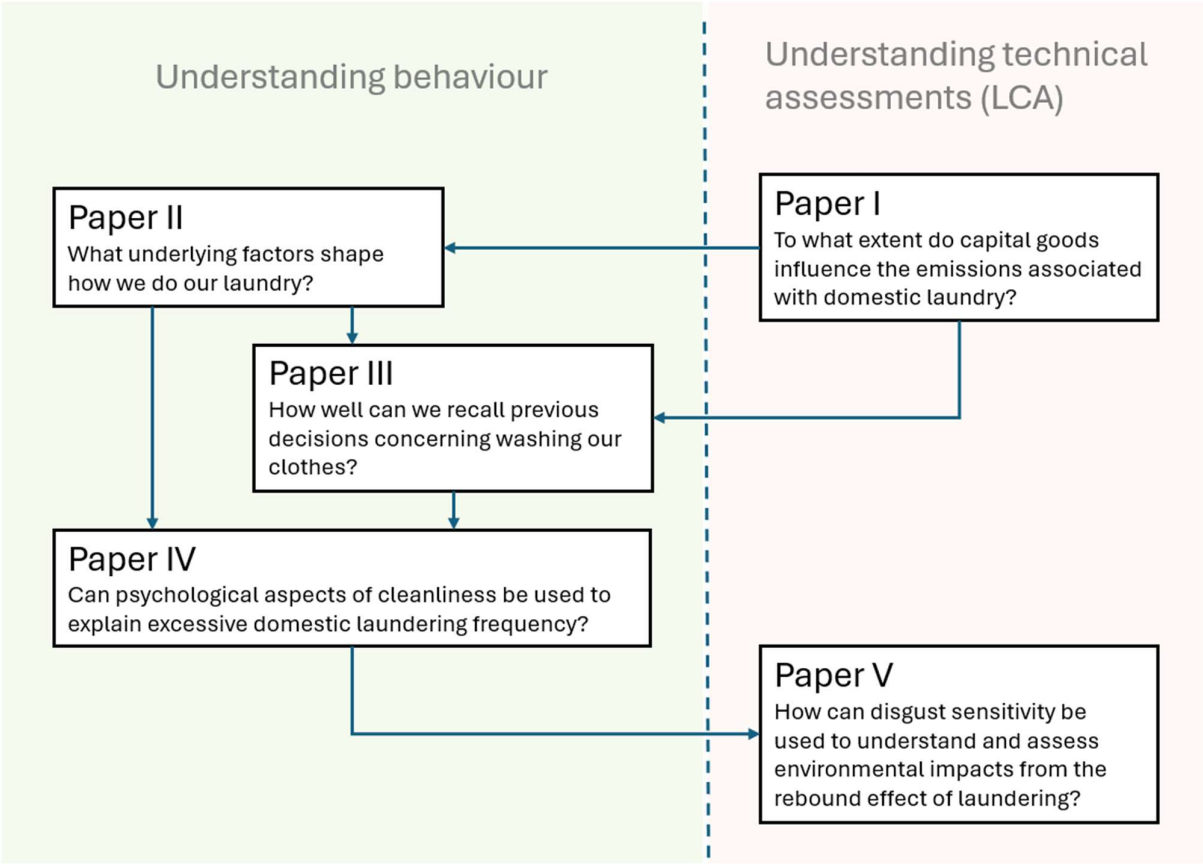


Figure 2. The relationships between the papers in this thesis. Arrows indicate the main influences of ideas between the publications.

The remainder of this thesis is structured as follows. Chapter 2 introduces the primary theoretical considerations. Chapter 3 then summarises the main conclusions and reasoning behind each amended paper. Chapter 4 discusses the papers' findings in relation to the overarching research questions, including implications for the thesis. Chapter 5 includes concluding remarks, and Chapter 6 reflects upon future research directions that aim to further combine psychological explorations with LCA.

2 Theory

2.1 Life cycle assessment

Life cycle assessment (LCA) is one of many analytical tools available for assessing environmental impacts (Finnveden & Moberg, 2005). The general idea of LCA is to map and evaluate the relevant flows of resources, energy, and emissions through the processes involved in providing a specific product or service. The scope captured is often the complete "life" of the product: from the initial extraction of raw materials needed for production to the final stages of disposal and waste management (JRC, 2010). In LCA terms, such a scope is called a cradle-to-grave analysis. Flows interacting with the general environment (e.g., the atmosphere, soil, and bodies of water) are of special interest since these flows are the basis for estimating the resulting impacts in nature.

From a historical point of view, the development of LCA methodology took off during the early 1990s and has grown considerably since then (Finnveden et al., 2009). To facilitate the reporting of results and increase the public's trust, LCA procedures and methods were consolidated into two current ISO standards: 14040 and 14044. According to these standards, conducting an LCA entails four stages (ISO, 2006a, 2006b):

- **Goal and scope definition**. The first step towards any LCA is to clearly define the technical system under assessment and the impacts to be assessed. Contextual factors that need to be addressed include, for example, the geographical location of the system, the intended application of the results, limitations of the analysis (e.g. temporal and spatial), and the target audience. A key aspect of this step is to properly define the functional unit, the system boundaries, and the reference flow used in the model.
- **Life cycle inventory (LCI) analysis**. After the system has been clearly defined, the actual data collection and modelling can be performed. Typically, this step is the most time-consuming due to data availability and quality limitations. For example, while generic data for many elementary flows and processes can be found in commercial databases,

this information is not always applicable due to the specific scope of the study.

- **Life cycle impact assessment (LCIA) phase.** During the final modelling step, the inputs and outputs of elementary flows quantified in the LCI are translated into an environmental impact assessment. The final result is often illustrated as a summary of all the emissions that can potentially act on the natural environment and humans. Depending on the study's goal and scope, these estimations are often presented for one or more impact categories, either as a midpoint indicator (i.e. aggregated environmental pressure) or as an endpoint indicator (i.e. estimated damage to human health, natural resources, or biodiversity).
- **Interpretation phase**. Interpretation is needed throughout the analysis. Examples include identifying significant issues with the initial assumptions, assessing model sensitivity and data uncertainties, assessing the soundness of modelling choices, and determining what conclusions can be drawn from the results.

Although these four stages are often listed sequentially, in practice the process of conducting an LCA is more iterative (Bauman & Tillman, 2004). This means that most of the steps are revisited as the analysis progresses. To highlight this dynamic, the relationships between the stages are often illustrated as shown in Figure 3.

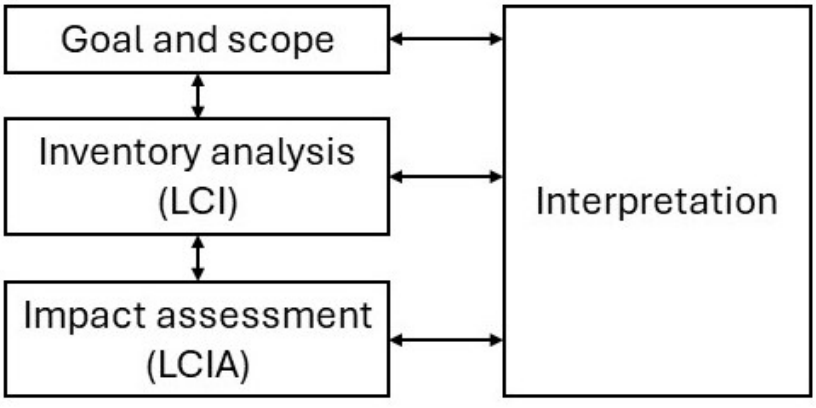


Figure 3. The iterative steps when conducting an LCA in accordance with ISO 14040 and 14044 (ISO, 2006a, 2006b).

To continue this thesis, two specific aspects regarding the definition of goal and scope need to be further explained: the functional unit and the system boundary.

The functional unit can be described as the denominator of the type of value the analysed system aims to provide. This is often chosen as a quantity of the goods or services under scrutiny. Its quantitative description facilitates calculations since modelling variables and final results can be numerically compared and adjusted. The preference for a quantitative description can also be seen in the ISO standard:

"The scope of an LCA shall clearly specify the functions (performance characteristics) of the system being studied. The functional unit shall be consistent with the goal and scope of the study. One of the primary purposes of a functional unit is to provide a reference to which the input and output data are normalised (in a mathematical sense). Therefore, the functional unit shall be clearly defined and measurable." (ISO, 2006b)

A key term in the ISO definition is "performance characteristics" or, in other words, the main reasons why the product or service exists in the first place. However, what constitutes these performance characteristics (i.e. the definition of a function) is left for the practitioner to identify. In the early LCA literature and handbooks, the term *function* was more clearly defined as follows:

- *"[…] the products must fulfil the same purpose or need, but standard methods to identify and classify these needs have not been identified."* (Nordic Council of Ministers, 1992)
- *"One has moved from the washing machine to its function. The amount of clothes can therefore be called "the functional unit of product". Thus, one should consider the desired function of the product, i.e. its use."* (UETP-EE, 1993)
- *"The function is thus the benefit or the service provided, and it is an important restriction in LCAs that the basis for the study in most cases can only be a function."* (Lindfors et al., 1995)
- *"A function can be defined as something that fulfils a need."* (Rydh et al., 2002)

In other words, the functional unit is concerned with measuring the value provided by a product or service. Evidently, what function is deemed relevant will have consequences for how the analysed system is structured. This type of delimitation is called the system boundary.

In LCA, the term **system boundary** describes the set of criteria that guides which processes should be included in a system (ISO, 2006a). This type of delimitation aims to exclude activities that have a negligible impact on the result, i.e. reducing the complexity of the real world to a manageable LCA model. Several dimensions need to be considered, such as the boundaries between the technological system and nature, geographical area, time horizon, inclusion of capital goods, and the life cycle of other products (Tillman et al., 1994). Defining the system boundary might initially seem straightforward. However, this work is highly dependent on the methodological choice between attributional or consequential LCA.

The focus of an attributional LCA (ALCA) is to estimate the *share* of global emissions that can be associated with an analysed product or service. The main idea is to map and describe all the relevant physical flows to and from the environment, given a life cycle and its subsystem. Each of these flows can then be attributed (i.e. connected) to the relevant processes and, by extension, the functional unit. On the other hand, a consequential LCA (CLCA) aims to describe how the relevant physical flows change given a decision, including the potential *changes* in emissions (Curran et al., 2005; Ekvall, 2020). While both methodological approaches have their challenges and benefits, the choice between ALCA and CLCA must ultimately depend on the question being asked. Since many LCAs exhibit both attributional and consequential characteristics, not reflecting on the implications of this methodological choice might lead to misleading conclusions (Plevin et al., 2013).

2.2 Psychology

Many aspects of psychology could influence our relationship with laundering. This thesis focuses on how people relate to environmental issues and social perspectives on cleanliness.

2.2.1 Environmental psychology

When trying to understand how psychological aspects steer or limit sustainable behaviour, a usual point of departure is to focus on environmental psychology. Environmental psychology is a small sub-field often divided into two viewpoints (Nilsson Hed, 2009). The first viewpoint concerns how we are affected by our surroundings, for example, the therapeutic effects of nature. The second viewpoint concerns how we understand and respond to direct and indirect environmental impacts, often in relation to our own decisions (Gifford, 2014). This subsection focuses on the latter and, more specifically, on pro-environmental behaviour (PEB).

One of the more widely used theories when targeting PEB is the theory of planned behaviour (TPB). The main idea of TPB is that individuals make logical and reasoned decisions by evaluating any available information (Ajzen, 1991). Behaviour is thought to be decided by our intentions to perform it, which in turn is shaped by our attitudes, subjective norms, and perceived behavioural control. TPB has been gaining popularity for a wide variety of PEBs (Rozenkowska, 2023), including purchasing intentions for eco-friendly apparel (Kumar et al., 2022) and willingness to try alternative recycling options for textiles in China (Zhang et al., 2020). A challenge is that TPB often fails to properly account for pre-existing habits and conflicting interests and intentions (Abraham & Sheeran, 2003). In these situations, past actions are often a much better predictor of future actions (Aarts et al., 1998).

A theory better suited to addressing conflicting interests regarding PEB is the Goal-framing theory. Initially developed by Lindenberg and Steg (2007), the theory postulates that conscious or unconscious goals can frame people's decisions and behaviours. These goals, in turn, are categorised into three separate groups: hedonistic, gain, and normative goal-frames. Since motivations are rarely homogeneous, multiple goals are often active at any

given time. This means that the chosen behaviour is a result of the individual strengths of each goal. By understanding which goals are activated, the motives driving behaviour can be better understood. Such knowledge can then be used to support interventions for PEB and hopefully lead to a reduction in environmental impacts (Steg & Vlek, 2009). For example, Goal-framing theory has been used to explain why people respond differently to sustainability communications in fashion stores. Depending on which of their goals were activated, some consumers were susceptible to the information. Others viewed this type of information as an attempt to shift responsibility for environmental issues onto the consumer (Vlasenko & Grubbström, 2023). However, a problem arises when the goals and (potential) conflicts related to PEB are unknown. For example, few people associate washing clothes with environmental impacts (Arild & Brusdal, 2003; Miilunpalo & Räisänen, 2018). Exploring goal conflicts regarding PEB for washing clothes might therefore be difficult, since environmental concerns are not necessarily recognised as a goal to begin with. In this situation, blindly applying contemporary strategies for PEB (Steg et al., 2014) would be pointless. A more fruitful starting point for understanding the motivations driving laundering would instead be the more general idea of pro-environmental identity.

2.2.2 Social identities and norms

We are all formed by the social groups we belong to and whose values we share. These groups and the social identities they signal affect our behaviour (Ellemers et al., 2002; Turner & Oakes, 2011) and our personal opinions (Klucharev et al., 2009), so that over time, we align ourselves with our peers. This means that normative messages often have the power to steer decisions and behaviour more effectively than objective information (Nolan et al., 2008; Schultz, 2002). The same dynamic can be seen for sustainability issues; personal norms are a strong predictor of PEB (Bamberg & Möser, 2007; De Groot & Steg, 2009; Helferich et al., 2023).

Identifying yourself as an environmentalist will shape how you relate to environmental issues and the type of policies you prefer, as well as increase your levels of self-reported PEB (Brick & Lai, 2018; Fielding & Hornsey, 2016; Fritsche et al., 2018). This is especially true if those behaviours are

visible to others (Brick et al., 2017). Unfortunately, higher levels of PEB do not equate to lower levels of emissions. Even if you identify as "super green", the sum of your annual greenhouse emissions might still be the same as someone who does not report any level of PEB (Tabi, 2013). Likewise, while many consumers argue that they buy *less but better* clothing (i.e. longer lifetime and reduced total emissions), specific garment use periods are fairly consistent between customer segments (Gwozdz et al., 2017). These findings can be disheartening at first, but they do indicate a missing link between behaviour and motivations. In line with this reasoning, Griskevicius et al. (2010) tested the extent to which costly signalling theory (Miller, 2001; Zahavi, 1975) could be used to explain consumer preferences for pro-environmental products. The main finding was that the 'green' products offered an important status-enhancing effect, increasing the owner's perceived reputation and pro-social appearance. A key aspect of these findings was that, once more, the consumption needed to be displayed publicly for the effect to occur (Griskevicius et al., 2010). More recent studies have shown that this dynamic works in both directions: anti-environmentalists do less, and environmentalists do more of PEB when being watched (Brick & Lai, 2018). In other words, public PEB is a way for individuals to signal that they share certain pro-environmental values and adhere to certain pro-environmental norms with their peers (van der Werff et al., 2014). All of this contributes to the case that social norms are an effective way to promote PEB (Bergquist et al., 2019).

While many PEBs are performed in public, laundering is not. Nor is it common to talk about how laundry should be done, at least not outside the immediate family. All of this suggests a weak potential for using pro-environmental norms to steer behaviour. However, *the result* from laundering is clearly displayed publicly once you put on your clothes. This suggests that social norms that are more directly tied to the notion of cleanliness are important to consider. For example, people generally agree that limiting environmental impacts from cleaning our clothes is the right thing to do. At the same time, the prevailing norm in many societies is that it is important to have clean clothes in public or at work. Since many people do not trust the cleaning capabilities of the ECO-setting on the washing machine (Visser & Schoormans, 2023), there exists an obvious conflict between PEB and the social norm of cleanliness. This means that if we want

to understand motivations for laundering, we need to be conscious of the consequences of failing to do it properly.

2.2.3 Shame

Let's say you are presenting something at work. As your presentation draws to an end, a member of the audience raises their hand. The person points out that you have a large stain on your chest, presumably from the previous lunch. How would you react? Disregard the comment and carry on like nothing happened? Or put on a sweatshirt, finish up as quickly as possible, and consider hiding under the nearest rock? While many of us would like to be unaffected by such a comment, most of us would feel embarrassed and ashamed.

Shame is most often treated as a self-conscious emotion (Sedighimornani, 2018; Tangney, 1999). The emotion of shame contains largely social properties and is experienced when we see ourselves through the eyes of others, with the understanding that others judge, evaluate and form opinions about our person (Leary, 2007). Shame is mostly experienced in public settings and is often the consequence of negative self-evaluations in relationship to peers (e.g. "I am less attractive", "I am less intelligent", "I have lower social standing"). This distinction separates the feeling of shame from similar emotions. Shame focuses on the person (I *am* bad) instead of the action (I *did something* bad), which instead would be classified as guilt (Niedenthal et al., 1994). The only difference between shame and embarrassment is the level of intensity, where embarrassment is the least intense feeling of the two (Crozier, 2014).

Shame is often regarded as a regulator of social interactions between groups and within hierarchies. In this sense, shame shares some properties with disgust, and previous studies have found similar evolutionary paths for the two emotions (Terrizzi & Shook, 2020). It is not hard to imagine that shame (or rather the fear of experiencing it) can guide our relationship to clothes in general and laundering more specifically. For example, few would take offence if someone wore the wrong or improper clothing at a social event, e.g. training attire at a job interview or pyjamas when walking in the woods. The presence of certain types of stains or odours, however, might be seen as a moral transgression regardless of the type of clothing, e.g. wearing a jacket

that smells of sweat on a first date, wearing pants with a chocolate stain on your crotch, or showing up to a wedding with yellow-stained underarms on your shirt. In this sense, laundering could be viewed as an insurance towards shame. Not only does laundering minimise the risk of shameful situations, but it can also be used as a disarming excuse: *"I just realised that the washing machine was unable to remove this stain; what stain remover would you use?"*. However, for shame to be an effective motivator for laundry, each potentially dirty garment under consideration must be imagined in a social context. This is both time-consuming and mentally exhausting. A more efficient way to evaluate cleanliness would be either using a rule of thumb or basing the judgment on a more direct, reactive feeling. The most obvious candidate for this task is the feeling of disgust.

2.2.4 Disgust

Imagine stepping on a bus on a warm summer day. As the bus accelerates, a nearby passenger is caught off-guard and bumps into your arm. Courtesy phrases and apologies are exchanged, but you also realise that your shirt now has a large, slightly damp stain from the other person's sweat. How comfortable are you continuing to wear that same shirt for the rest of the day? What is the probability that you will throw it in the laundry basket the moment you get home?

Feelings of disgust are universally shared by humans (Ekman et al., 1987). Although its main function is to protect us from diseases (Curtis & Biran, 2001; Oaten et al., 2009), recent findings suggest more general functions for disgust, such as protecting the self from offensive objects and social groups (Hodson & Costello, 2007). Furthermore, what triggers a response has been shown to vary between cultures and throughout history (Miller, 1997). Therefore, a more nuanced interpretation of its function is that it warns us about a possible reduction in our evolutionary fitness, be it physiological or reputational. Triggers of disgust can be sorted into a limited number of categories (Rozin et al., 2008). These categories are thought to have evolved gradually over time in stages as society changed, see Table 1.

Table 1. The prevailing model of disgust and its elicitors.

Stage	Function	Elicitor(s)
Distaste	Protect the body from poison	Bad tastes
Core disgust	Protect the body from disease/infection	Food, body products, animals
Animal nature disgust	Protect body and soul; deny mortality	Sex, death, hygiene, envelope violations
Interpersonal disgust	Protect body, soul, and social order	Direct and indirect contact with strangers
Moral disgust	Protect social order	Moral offences

Source: Rozin et al. (2008)

While the model presented in Table 1 has proven useful in explaining a number of behaviours, it has recently begun to receive criticism from an evolutionary perspective. For example, while there is no doubt that disgust serves as protection towards pathogens, it is still unclear why the emotion is also evoked by acts not related to direct contamination (Tybur et al., 2013). Because of this, an alternative model of disgust better rooted in selection pressures has been suggested by Tybur et al. (2009), see Table 2. This updated model aims to explain how disgust has been used as a solution for a number of adaptive problems throughout evolution: avoiding diseases, minimising the risk of choosing the wrong mating partner, and avoiding socially costly individuals, either for oneself or within one's social network (Tybur et al., 2013).

Table 2. The functional domains of disgust and its cues.

Type of disgust	Adaptive problem	Cues
Pathogen	Avoid physical contact with sources of infectious disease-causing organisms.	Bodily fluids and products, animals, poor hygiene, decomposing or rotting organic matter
Sexual	Avoiding sexual contact with individuals jeopardising fitness	Sexual interest from individuals with poor genetic compatibility (kin) and with low mate value
Moral	Communication and coordinating condemnation with other people	Behaviours likely to be condemned by others (lying, cheating, stealing, rule violations)

Source: Tybur et al. (2013)

Regardless of the theoretical foundation, it is obvious that feelings of disgust are relevant when trying to understand laundry practices. Since stains and odours are associated with a suspicion of pathogens, merely suggesting that something might be dirty can give rise to aversive behaviour (Oaten et al., 2009). Interestingly, these tendencies are not limited to objects with high levels of bacteria or viruses (e.g. soiled children's clothing). Feelings of contamination can also be experienced by mere association, e.g. standing close to a person who has a strong and unpleasant body odour (Tybur et al., 2009) or socialising with a friend that you discover only changes their underwear once a week (Haidt et al. (1994); modified by Olatunji et al. (2007)). The influence of disgust on laundering is also highlighted by the fieldwork done by Curtis and Biran (2001). The authors explored the motivations for hygiene behaviours in different countries. They found that common sources of disgust included worn clothes (India), dirty clothes (Burkina Faso, West Africa), dust and sweat (Netherlands), and sweaty persons (United Kingdom).

3 Summary of the publications

3.1 Paper I – The importance of capital goods

Paper I explores the relative importance of capital goods, i.e. the machines and building space needed for domestic laundering. The goal of this paper was to examine the differences in the contributions of private and shared systems to environmental impacts in Sweden, since both of these types of installations are common in multi-family housing. To facilitate comparison with previous studies, the functional unit chosen was the washing and drying of 1 kg of clothing. Data for the production and use of the machines (e.g. bill of materials) was taken from the European Commission reports on preparatory studies for Eco-design requirements (Faberi et al., 2007a, 2007b; Lefèvre, 2009). This data was then combined with estimations of the impacts from the floor use in a multi-family concrete building in Sweden (Liljenström et al., 2015).

The results show that capital goods contribute substantially to the greenhouse gas (GHG) emissions from domestic laundering. The machines and building space for the private system contributed approximately 38% of the estimated GHG emissions. For the shared system, the relative contribution was lower, at around 11–16%. Looking at capital goods in more detail, building use was at least as important as the machines themselves.

Although the results are interesting in themselves, uncertainties remain in how to deal with the large uncertainties that exist connected to machine operation. For example, the machine's full capacity is seldom used when loading it for a wash program (Miilunpalo & Räisänen, 2018), and few people follow the recommendations on how much detergent should be used when washing (Alborzi et al., 2017; Laitala et al., 2012). These insights prompted a more targeted approach to understanding behaviours, since operational decisions have the potential to increase the emissions per kg of laundry.

3.2 Paper II – Laundering is socially motivated

Trying to understand motivational reasons for domestic laundering is not a new endeavour. However, many explorations have been rather narrow in

their scope, prompting authors to call for broader interdisciplinary collaborations (Conrady et al., 2013; Yates & Evans, 2016). In Paper II, a large literature review was performed to aid such collaborations while at the same time creating a common starting point for understanding laundering motivations. The goal was not to capture all the available research related to laundry. Instead, this paper tries to identify gaps and overlaps between different fields of knowledge that are attempting to answer the question: *What underlying factors shape how we do our laundry?* Initially, 2591 articles were screened and assessed. The final result was a synthesis of 80 articles that more explicitly targeted the initial research question. Three general principles could be identified:

Technology changes conventions, while social context dictates market acceptance of new cleaning technology. The introduction of new technology will, over time, change how people do their laundry and, by extension, how they define cleanliness. Historical reductions in the amount of labour and resources needed for washing (e.g. using an automatic washing machine) have led to fewer excuses for wearing clothes that have stains and odours. This meant an increased expectation to wear clean clothes (Shove, 2003) while at the same time shifting the definition of clean from *sanitised* towards *"whiteness"*. However, the potential introduction of new technology is sometimes hampered by prevailing societal expectations. For example, people from cultures that do not associate heat with cleanliness are more reluctant to buy washing machines that wash using warm water (Spencer et al., 2015). Similarly, people whose strict family values advocate washing by hand will (understandably) avoid using a washing machine to begin with (Meintjes, 2001).

Technological interventions are often suggested to influence consumers, but individual concerns seem to override the effects of these interventions. From an environmental perspective, it is generally easy to focus on the point sources when trying to limit emissions. For domestic laundering, this often manifests as proposals for efficiency measures for washing and drying machines: the machines should be made more efficient (Laitala et al., 2011), and people need to be informed about how to operate them properly (Harris et al., 2016). Unfortunately, such measures only change the *optimal* scenario when washing clothes. In practice, individual habits, concerns, and fears about the result steer how

each activity is performed (Labrecque et al., 2016). For example, many consumers mistakenly believe that eco-programs have lower cleaning capabilities and that quick programs consume fewer resources.

Consumers are guided by social conventions rooted in underlying psychological dynamics (e.g. moral dimensions of cleanliness). Most of us have been taught how to do the laundry by our parents, predominantly by our mothers (Hecht & Plato, 2016). These lessons are not limited to how to operate the machine but often also include how to sort and pre-treat textiles. This means that social conventions and norms are partly inherited and will, over time, influence the decisions we make in the laundry (Mylan & Southerton, 2017). Few would disagree that different cultures evaluate cleanliness differently, but the root cause of this variation is still unclear. It is not unreasonable to assume that part of this variation can be tied to variations in psychological aspects, e.g. disgust sensitivity (Neves, 2016; Reicher et al., 2016) and moral judgement (Liuzza et al., 2019). However, such a connection for laundry is yet to be properly investigated.

3.3 Paper III – Self-reported data underestimate behaviour

Access to good consumer data is crucial to properly assess the environmental impacts from domestic laundering. Diaries recorded while laundering provide this data, yet it is unclear whether the respondents would remember that same behaviour later. Data collected by surveys and interviews might be less certain since these data only describe recalled behaviour rather than actual behaviour in real life. In Paper III, self-reported behaviour was compared to passively collected data from the washing machines at HSBLL in Gothenburg. The main results showed that the tenants, as a group, underestimated how many times they washed each month and vastly underestimated how much laundry (in kg) they filled the machines with. Most of the tenants stated that they were interested in changing to the new wash programs, although few did when presented with the choice in real life. However, a change in attitude towards the new programs could be observed after they were installed in the machines. This meant that more tenants were positive about a potential change after being exposed to the option before answering the survey. The findings indicate that there is a high risk that people fail to accurately recall how often and how much laundry

they wash each month. Likewise, any statements regarding preferences for future choices (e.g., new types of wash programs) should not be taken as a guarantee for future action. When it comes to cleaning our clothes, people might believe that they will act in a certain way, although records of previous actions would be a much better predictor of future choices. In other words, habits trump intentions. To properly estimate the environmental impacts of laundry specifically and textile consumption in general, psychological aspects need to be better understood and accounted for.

3.4 Paper IV – Conflicting goals of laundering

Few, if any, previous research studies have investigated how psychological aspects of cleanliness could affect domestic laundering. This fourth paper aimed to explain how psychology could be used to understand how often we run a washing machine. More importantly, this article tried to pinpoint some of the underlying reasons for excessive laundering behaviour. The point of departure was related to the findings from Paper II. Specifically, Paper IV targeted how the constructs of disgust, shame, cleanliness norms, environmental identity, and habitual behaviours shape laundry decisions and practices. Data collection was performed in collaboration with NOVUS (a Swedish professional analysis and research company) to ensure that the results would be representative of the general population in Sweden. Data was collected through two large online surveys (N = 1116, N = 1136) and in-depth interviews with new participants (N = 39). The analysis showed that all of the psychological constructs and self-reported behaviours except environmental identity were correlated with washing frequency, see Table 3. These results suggest that how often we wash is determined by several psychological and behavioural considerations, even though they do not establish a causal relationship. However, the correlations in Table 3 do not take into account any potential overlaps between each construct and behaviour. Nor do these correlations account for the potential effects of background variables.

Table 3. Correlations between washing frequency and psychological constructs/self-reported behaviours.

Construct/behaviour	Correlation	Meaning
Disgust	+	People with higher sensitivity to disgust wash more often.
Shame	+	People who are more prone to shame wash more often.
Cleanliness norm	+	People who express stronger cleanliness norms wash more often.
Environmental identity	0	There is no influence over how often people wash.
Evaluation sensitivity	+	People with stricter criteria for stains and odour wash more often.
The mean number of wears (clothes)	−	People who wear clothes for longer periods wash less often.
Inadequate laundry loads	+	People who do not use the full capacity of the washing machine wash more often.
The mean number of nights (bed linen)	−	People who use their bed linen for longer periods wash less often.

More detailed statistical analysis revealed that the effects of disgust, cleanliness norms, and environmental identity were mediated by the behaviours preceding running a washing machine. The main mediators were how many times people were willing to use their clothes before throwing them into the laundry basket and whether they loaded the machine to its capacity. The analysis also showed that the construct of shame lacked sufficient internal consistency to be used as an independent variable; the different questions that we had developed to measure shame were perhaps not good enough. More importantly, the results revealed a strong goal

conflict between disgust and environmental identity. Higher levels of disgust sensitivity indirectly led to higher washing frequencies, while higher levels of environmental identity indirectly led to lower washing frequencies.

These findings have implications for understanding the lack of successful behavioural interventions and for how we should adapt our LCA models when assessing the environmental impacts from domestic laundering. For example, reflecting upon the results, it is not surprising that previous pro-environmental interventions have failed. In many cases, the only rationale offered for changing one's behaviour has been environmental concerns, without any regard for other psychological aspects. Since feelings of disgust seem to be a more prominent motivator for laundering, in many cases pro-environmental arguments are toothless, especially since many people (falsely) believe that washing in a pro-environmental manner leads to less clean clothes.

It is also clear that contemporary LCAs of laundering are too narrow in their scope to properly assess the environmental implications of behavioural change. These findings suggest that laundering is the end-product of a series of preceding behaviours, not the motivator. Therefore, a reduction in wash frequency would imply that the preceding behaviours and motivations have changed. Since these behaviours have additional environmental impacts that are not necessarily connected to laundering per se, the scope and the system boundary must be expanded accordingly. For example, how often we wash is partly motivated by our disgust sensitivity. A reduced wash frequency would thus suggest that the individual has become less sensitive to cleanliness evaluations. Such desensitisation would also affect their relationship to and consumption pattern of textiles in a more general sense. For example, how many times clothes are worn before washing them, or how inclined we are to throw away clothes due to insufficient stain removal. These aspects of wear-and-tear and the turnover rate of clothes have large environmental implications since they both affect the lifetime of each garment. In other words, a more systemic approach for the use phase is needed to properly assess the environmental consequences of domestic laundering.

3.5 Paper V – Treating behaviours systemically in LCA

The final paper explored the implications for LCA when changing the perspective from a linear relationship between consumption and environmental impacts to a more systemic approach. In practice, this meant changing the functional unit from a technical quantification of the behaviour (i.e. *1 kg laundry washed and dried*) to the underlying motivation to perform the behaviour (i.e. *feeling confident in social situations regarding clothing cleanliness*). This change in perspective was needed to understand better why the amount of time and energy spent on laundering activities is growing despite the historical technical improvements in efficiency. The main interactions are illustrated in Figure 4.

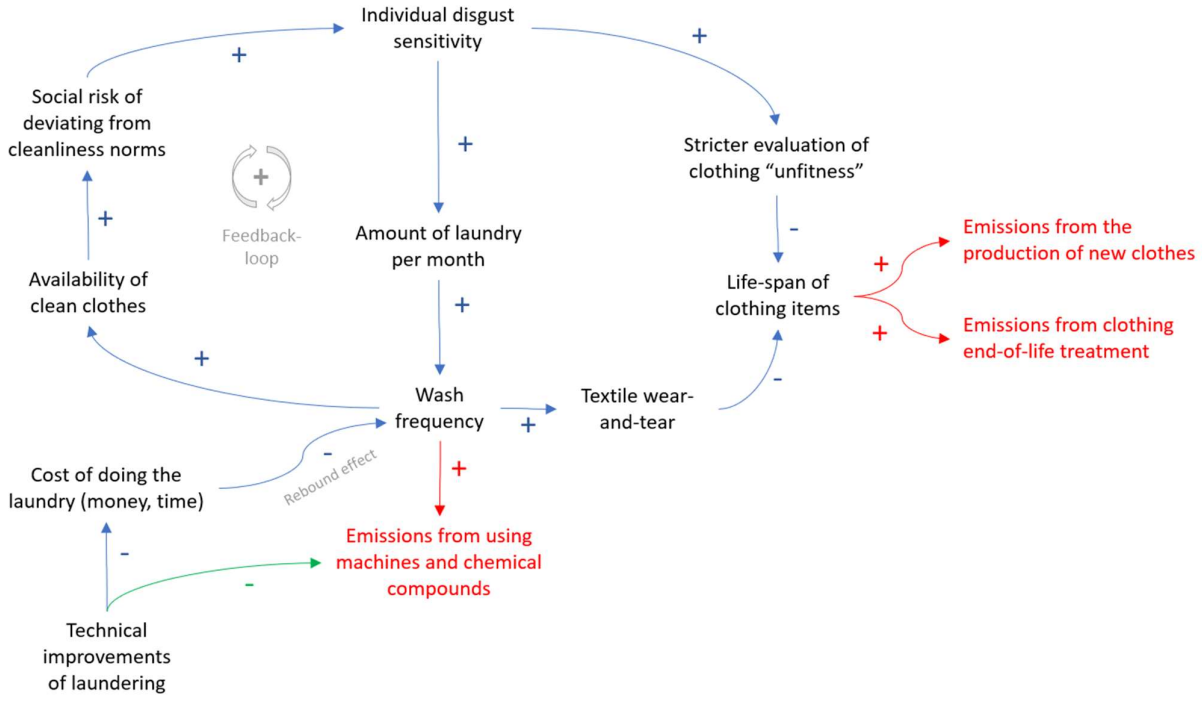


Figure 4. A casual loop diagram showing domestic laundering is understood from a systemic perspective with a focus on psychological motivation.

The LCA presented in the article illustrates how our growing sensitivity to disgust will affect how much time and money is spent on clothing cleanliness. The model also quantifies how much higher environmental impacts we can expect from just maintaining the status quo due to the

ongoing trend towards higher levels of clothing cleanliness in society. Currently, the most disgust-sensitive people contribute approximately 20% more to GWP and freshwater eutrophication than the average Swede. This can be compared to the least disgust-sensitive people, who only contribute approximately 2/3 of what an average Swede contributes, see Figure 5. If the trend towards more laundering continues, it is reasonable to assume that the average Swede will start to wash more like the current disgust-sensitive Swedes. Likewise, the least disgust-sensitive people will start to wash more like the average Swede, both accordingly increasing the environmental impacts from laundering.

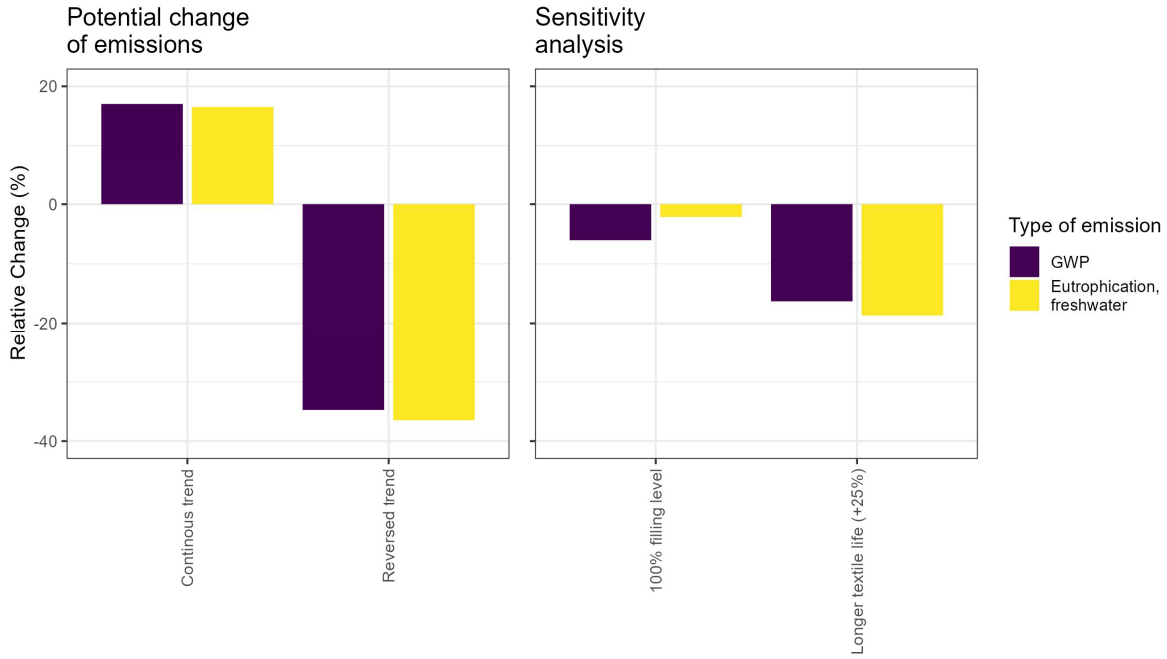


Figure 5. Relative changes in future emissions if the current trend for clothing cleanliness and consumption is allowed to progress or is reversed.

3.6 Data Set I – Domestic laundering behaviours in Sweden

The data set collected for Paper IV was more extensive than what was ultimately included in the final publication. To aid future research on domestic laundering and consumer behaviours, the complete data set was published separately through the Swedish National Data Service (SND). SND's primary function is to support the accessibility, preservation, and reuse of research data and related materials. This publication is relevant since the data contains more information than has been used and published in Paper IV.

For example, how we relate to laundering relies on the implicit meanings of expressions, which vary between individuals. As such, the technical definition of what is considered an adequately loaded machine is not the same as what is experienced as "a full machine". One way to illustrate this discrepancy is to ask how the machine usually looks after being loaded with laundry (regardless of whether this is a "full machine") and compare it with a self-reported quantitative estimation of fullness. Three different ways were recorded in the data that can be used for this purpose:

- Individual estimations of the percentage of a full machine (i.e., a single value ranging from 1–100%).
- How well did the respondents agree with the statement *"In my household, we usually wash full machines"?*
- The choice between five pictures illustrating and describing different load levels.

Comparing the answers to the various types of questions reveals a significant variation between what is considered a full machine and the numerical representation, see Figure 6. According to one manufacturer of automatic washing machines, Picture D is the technical definition of a full machine.

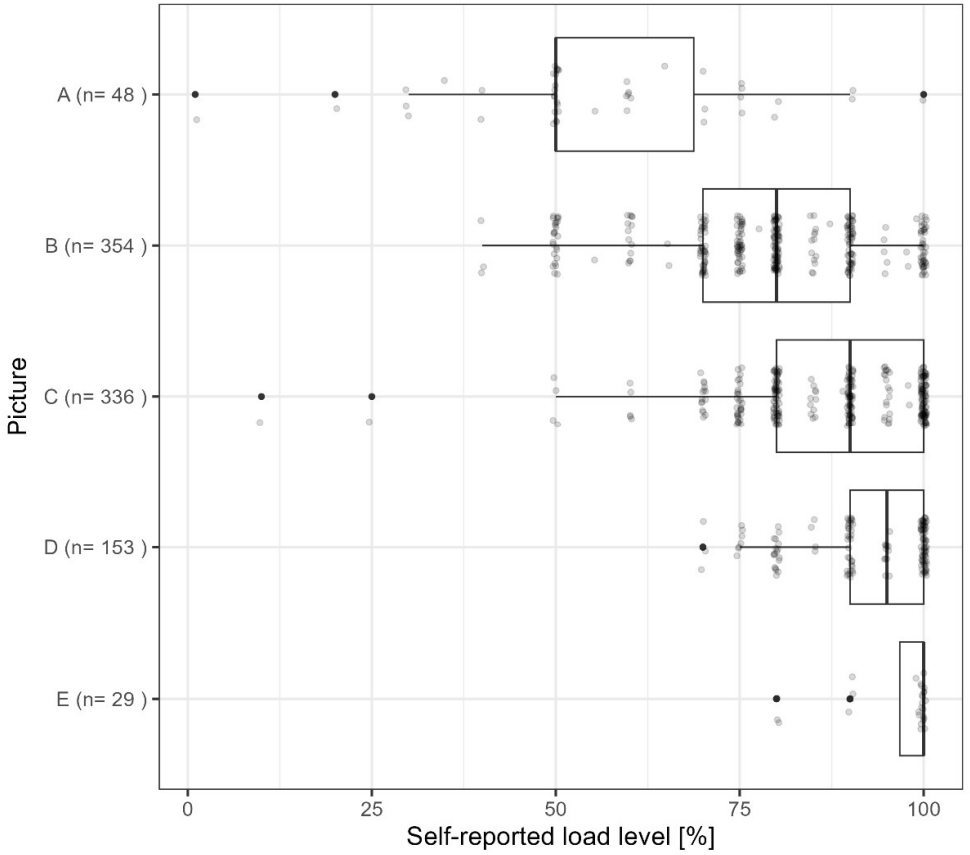
Picture	Letter	Description of picture	Corresponding answers to load level as a percentage
	**A**	A little less than half of the drum is filled with laundry.	
	**B**	Almost the entire drum is filled with laundry.	
	**C**	The complete drum is filled with laundry and has been slightly compressed.	
	**D**	The amount of laundry makes it just possible to fit a clenched fist at the top of the drum.	
	**E**	The amount of laundry forces you to use a bit of force when closing the door	

Figure 6. An illustration of the variations in self-reported data concerning load level reported in Data Set I. The respondents chose a visual load level (pictures A-E) and also stated a load level as a percentage of a full machine.

4 Discussion

This section discusses the findings in Paper I-V in relationship to the three research questions. Each subsection focuses on one specific research question, although some overlaps are unavoidable. A short summary of the relevancy of each paper is shown in Table 4 to facilitate an overview of the most relevant contributions from each paper.

Table 4. A short summary of the relevance of each publication.

	RQ1: What are the main drivers of domestic laundering behaviour?	***RQ2: To what extent does behavioural data for domestic laundering vary?***	***RQ3: How can the LCA perspective be expanded to enhance assessments of the environmental impacts from laundering?***
Paper I			The technical system needs to be expanded to include also the indirect impacts of capital goods.
Paper II	Social conventions generally guide people. Psychological aspects guide specific decisions (e.g. moral dimensions of cleanliness).		The goal and scope of LCA need to properly address any cultural variations relevant to the analysis.
Paper III		Self-reported data underestimates past behaviour in real life. Stated preferences do not equate to future behaviour.	Variations and uncertainties in behavioural data must be measured and included in the LCA model.
Paper IV	Pro-environmental laundering is undermined by disgust sensitivity. Domestic laundering is mainly socially motivated.	Behavioural data varies extensively with lifestyle choices and household constellations. The way behavioural data is collected affects the results from the LCA modelling.	Laundering is a means to an end. The preceding behaviours that generate laundry should also be included in the LCA rather than just the consequences of action (e.g., measurements of frequency, load level, etc.).
Paper V			The functional unit must capture the underlying (social) motivation for behaviour rather than limiting it to a technical description. Behaviour needs to be treated systemically in the LCA model rather than as a static and isolated variable.
Data Set I		Laundering frequency varies greatly depending on lifestyle choices, age, family constellation, etc. How questions are asked influences the reliability of each answer.	

4.1 Drivers for laundering behaviour and the relevance for LCA

"Genom sig själv känner man andra." (Through ourselves, we know others)

- Swedish proverb

Drivers for laundering behaviour are mainly investigated in Paper II and Paper IV. Paper II maps the current state of knowledge regarding general motivations for behaviour from the sociological, technological, and psychological perspectives. The results illustrate that individual laundering behaviour is mainly socially motivated. Social norms guide individuals regarding when and how things are to be cleaned, including how cleanliness is defined. Many of these "rules" are often invisible, since laundering and cleanliness are seldom discussed outside of the immediate family. As a side note, a consequence of this invisibility is that many people tend to assume that others relate to laundering and cleanliness in a similar way to themselves. This could be seen for example, during the qualitative interviews for Paper IV, where some participants expressed surprise that others thought differently. These different norms and expectations regarding cleanliness become visible only after being questioned or when compared with the laundering behaviours of people from other cultures. Some more direct examples of this can be found in Paper II:

- In Brazil, the following sorting categories are common: laundry containing pollution from outside the home (i.e. clothes), pollution from inside the home (i.e. tablecloths, towels etc.), baby clothes, and women's underwear (Neves, 2016).
- In Norway, it does not seem to be uncommon to wash underwear separately from kitchen towels (Laitala et al., 2012).
- Not changing clothes regularly might unintentionally signal a questionable character amongst Danish teens (Gram-Hanssen, 2017).

- In Soweto, using a washing machine might inadvertently signal laziness, undermining a woman's image as '*a good wife*' and, by extension, the credibility of the household (Meintjes, 2001).

Cultural nuances and social norms are important to recognise since they are strong drivers of or barriers to laundering behaviours. With respect to LCA methodology, it is important that these aspects are covered in the goal and scope.

Paper IV is a more detailed investigation of the extent to which psychological aspects affect domestic laundering frequency in Sweden. The analysis highlights an indirect goal conflict between environmental identity and disgust sensitivity. The statistical model also shows that laundering is a means to an end, i.e. the activity is not the main motivator for the behaviour. While it might seem self-evident, how often we choose to wash our clothes is influenced by how much laundry we generate and how much laundry we clean with each machine program. This is important to understand since conflicting goals can undermine willingness to change. Failing to address these issues in LCA work might lead to proposals for policies that look reasonable on paper but are difficult to implement in real life. In order to understand how to expand LCA methodology in practice, the first step is to understand how contemporary assessments of laundering are constructed.

A clear pattern can be seen in Paper II when reviewing the current literature on LCAs of domestic laundering; most articles find that the largest contributor to its environmental impacts is the use phase. This seems to be true regardless of whether the analysis focuses solely on laundering per se (e.g. Cortez et al. (2024), Laitala et al. (2011), and Moon D. (2020)), or more on general aspects of clothing consumption (e.g. Laitala et al. (2020), and McQueen (2017)). A common conclusion is that understanding and managing consumer behaviour is crucial to limiting environmental impacts. However, what is seldom addressed is that all of these conclusions derive from a strong technological perspective. The first clue to this can be seen in how the functional unit is defined. A common functional unit for LCAs of domestic laundering is often something like "1 kg of clothes washed and dried". The question to be answered then becomes how to increase the amount of laundry that can be done while reducing emissions from the life

cycle stages that contribute the most emissions. Policy recommendations often follow suit. Examples include higher efficiency requirements for the appliances, information campaigns to modify laundering practices, or technical solutions that compensate for sub-optimal consumer behaviour (e.g. automatic dosing of detergent or adjustable water levels in the machines). These are all relevant suggestions, but largely rely on the proper choice of functional unit.

What is the function of laundry? Based on the definitions of a function presented in Section 2, the function of *a washing machine* is to clean a certain amount of clothing. However, the findings in Paper II and Paper IV strongly suggest that the true motivation is the need for proper clothing, i.e. to fit in. In other words, the function of *doing the laundry* must be seen as the same function as having access to proper clothing, i.e., to feel confident about the cleanliness levels of our clothes[2] in social situations. Things are washed when they fail to perform their task in relationship to contextual factors (Mylan & Southerton, 2017). While this might once again seem self-evident, this function should be used as a basis for analysis regarding laundering instead of "1 kg washed and dried".

As a thought experiment, let us come back to the traditional recommendations for reducing the environmental impacts from laundering. Take, for example, the suggestion to install automatic detergent dosing in

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[2] As a side note, similar challenges exist for how to properly define the functional unit when conducting LCAs of clothing. A systematic review performed by Munasinghe et al. (2021) found that the most common functional units were either a certain amount of material (e.g. 1 kg of cotton) or a certain number of uses of a generic garment (e.g. daily use of a cotton T-shirt for a year). However, if you ***ask*** people why they wear clothes, few would say "to consume cotton or polyester". Nor would the answers be a simple case of "the daily use of a T-shirt". Instead, many would talk about the function of protection, modesty, and communication of the individual self (Fowles, 1974).

washing machines. This makes sense from a technical perspective since many mostly go “by feel” when estimating the amount of detergent needed for a wash program. The environmental impacts per kg of laundry would be better optimised by letting the machine automatically adjust the amount of detergent required. However, this analysis only optimises the “1 kg laundry washed and dried” function. Notice how the analysis and conclusions change if we assume that the functional unit is used instead to maximise the chance of feeling confident in social situations. Over-dosing detergent could then be seen as a behavioural margin of safety. For example, imagine that I want to run a wash program but am nervous about whether the machine is working properly. In this situation, it is possible that I would overdose the detergent to ensure I have done everything I can to clean my clothes properly. Installing automatic dosing could make me feel less confident (i.e., unsure if the clothes have been cleaned properly) since I have given up operational control.

Furthermore, trust in technical solutions can erode quickly. This means that while I might accept automatic dosing at first, this acceptance hinges on every wash meeting my cleanliness expectations. Suppose the clothes are not as clean as I expected after washing them. In that case, chances are high that I would introduce additional compensatory measures regardless of whether the failure has anything to do with the automatic dosing. This dynamic is not only theoretical but has been observed repeatedly at HSB Living Lab, where the machines are fitted with automatic dosing systems. Many tenants have repeatedly stated that they knowingly introduce some extra detergent when loading the machines. When asked why, they often say they want to ensure the laundry is properly cleaned since they do not trust the automatic dosing system. Rationalising this behaviour is hard based on an analysis with the functional unit of “1 kg washed and dried”. It is, however, relatively straightforward if the function of cleaning our clothes is to “feel confident in social situations”.

4.2 Variability and uncertainty in behavioural data

"Declarations of high confidence mainly tell you that an individual has constructed a coherent story in his mind, not necessarily that the story is true."

- Daniel Kahneman

The findings in Paper III illustrate the considerable uncertainty and variance in load rate. Most participants in the study stated that they "washed full machines" and reported a load level of around 65–70%. If these self-reported estimations were taken at face value, it would mean that the tenants washed approximately 5–5.5 kg of laundry each time since the capacity of the machines was 8 kg. However, the passive measurements showed that the machines were seldom loaded with more than 2 kg of clothing in each wash. The findings in Paper III also illustrated that stated preferences do not, by default, equate to future behaviours regarding the choice of wash programs, i.e. habit trumps intentions. These discrepancies between self-reported data and reality mean the final impacts *per kg laundry* in many LCA are vastly underestimated. Furthermore, designing wash programs based solely on consumers' stated preferences might be ineffective. For example, although many people said they would like a wash program that minimises the environmental impacts, few choose this option. From a psychological perspective, this type of behaviour is not surprising.

A vast pool of knowledge already exists and could be utilised when collecting data for LCAs of consumer products and services. It is, however, well-known within psychology that self-reported data can be problematic (Podsakoff et al., 2003). For example, several biases and psychological factors have been identified that affect how we perceive reality and ourselves. Remembering past actions, such as decisions related to laundering, is no exception. Some of the more obvious ones that might affect self-reported data for washing clothes include the following.

Recall bias. Some things are easier to remember than others. Information and experiences that we perceive to be important or of a more vivid/sensational/explicit nature are easier to remember (Knowlton &

Castel, 2022). Mental recollections of laundering are neither. How we choose to launder is often habitual and experienced as tedious. Since laundering activities are generally difficult to recall, the risk for recall bias consequently increases (Coughlin, 1990). When reporting past behaviours connected to laundering, it is easy to be guided by simple rules of thumb. For example, rather than answering the question *"How many times have you washed clothing in the last month?"*, many of us might be more inclined to unconsciously answer instead the question *"How many times is it reasonable for you to have washed clothing in the last month?"*. This suggests that much of the current self-reported data consists of stylised versions of real life rather than actual accounts of how people actually launder. Additionally, a particular type of recall bias called the *peak-end-effect* exists (Fredrickson & Kahneman, 1993). This type of bias means that we are disproportionately affected by the most recent and the most intense situation within the recall period. It is related not only to specific behaviours but can also be affected by relevant odours (Scheibehenne & Coppin, 2020). Similarly, future predictions of behaviour are often guided by atypical situations that have occurred previously (Morewedge et al., 2005). The peak-end-effect suggests that people with high disgust sensitivity might overestimate how much laundry they do. Likewise, people living with toddlers might overestimate the amount of laundering done in the household due to their higher exposure to soiled clothing.

Social desirability bias. Many people report a different type of behaviour than how they behave in real life. The social desirability bias means that respondents tend to comply with what they think is the social norm (i.e. the "right answer") or in line with their preferred self-image (Bogner & Landrock, 2016). This tendency becomes more pronounced for sensitive questions (Kreuter et al., 2009). Clothing consumption concerning cleanliness evaluations is an intimate subject, and asking about laundering could be perceived as sensitive information. Social desirability can also be implied mistakenly by how some questions are framed. For example, asking respondents whether they agree with the statement "I wash with full machines" might be considered benign, but the statement does imply that a full machine is preferable. In this case, people with higher sensitivity to

social norms might be inclined to agree with the statement rather than provide a more accurate estimate.

Challenges with qualitative expressions. It is common to use qualitative expressions when collecting self-reported laundering data. Unfortunately, qualitative expressions might instil a sense of understanding but are often highly ambiguous, as shown by the published Data Set I. This is especially true if the answers are used without a proper understanding of how the respondents interpreted the question (Einola & Alvesson, 2020). For example, let us once more consider the common question of whether the respondent usually washes *"full machines"*? Since no universal definition of a full machine exists, how the question is interpreted varies from person to person. For some, a full machine could be when no more room is left in the drum. For others, a full machine would mean that no more laundry is left in the laundry basket or no more garments from a specific laundry category (e.g. light/dark, household textiles/clothes). A related challenge occurs if respondents are asked to clarify what they mean by the expression "a full machine", especially if they are expected to express this in a certain weight of clothing. In this scenario, respondents may once more be inclined to rely on rules of thumb when answering questions. For example, if you know that your washing machine has a capacity of 6 kg and you believe that you wash with "almost" full machines, you probably state that 5 kg of laundry was washed. These challenges with interpreting qualitative statements suggest that the current self-reported data constitute stylised versions of real life.

Access to behavioural data of higher quality will most likely lead to more precise LCAs for domestic laundering. This increase in quality, however, is only valuable if the analysis targets the right question to begin with. As it turns out, the psychological insights provided in this thesis also have more general methodological implications for LCAs of consumer products and services.

4.3 Expanding LCA through the lens of psychology

"I suppose it is tempting, if the only tool you have is a hammer, to treat everything as if it were a nail."

- Abraham Maslow

LCA was initially developed as a tool to understand material and energy consumption for industrial processes and supply chains (Bjørn et al., 2018). Since its initial proposal in the early 1960s, LCA methodology has grown considerably, and today, it includes various methods such as prospective LCA and social LCA (SLCA). However, the implicit technological perspective is a common denominator for most LCAs, regardless of their application. Products and services are reduced to quantitative measures that are analysed for their energy and material flows and engineered processes. This analytical framework is beneficial and sometimes crucial when investigating complex production routes or modelling cumulative resource consumption. However, this technological perspective often fails to properly account for disruptions to environmental outcomes due to human behaviour, e.g., rebound effects (Gutowski, 2018). This thesis argues that an additional point should be added to the methodological challenges when addressing the rebound effect: the strong tendency within the LCA community to rely on the technological perspective when assessing environmental impacts.

LCAs are always a simplification of reality. To paraphrase Box and Draper (1987), this means that all LCA models are wrong, although some are useful. While most of these simplifications are necessary for practical reasons, this thesis highlights the need to separate how we treat behavioural data from how we treat technical data. This necessity becomes especially important when conducting LCAs for consumer products and services, i.e., where the use phase greatly influences the final results.

Technical data are often additive. If one machine uses 3 kWh and another 2 kWh, they can be combined into a 'two-machine summary' that consumes 5 kWh. Contemporary LCAs for laundering treat behavioural data similarly. Specific decisions are reduced to quantitative measurements that, together

with contextual facts, become stylised versions of consumer groups. Few, if any, studies try to include the nuanced results from sociological investigations into describing the explicit reasons for behaviour. If this perspective is included, it is often placed in the introduction as a general description of which contextual factors could influence certain decisions. Moreover, contemporary LCAs of domestic laundering seldom account for conflicting goals regarding behaviour. The main focus of an LCA is on assessing emissions, which makes it logical to investigate the chosen product or service from an environmental perspective. However, it can be argued that human behaviour is seldom motivated by environmental intentions, and domestic laundering is no exception. Therefore, addressing the environmental impacts of domestic laundering behaviour means addressing conflicting behavioural goals.

Some conflicting laundering goals are highlighted in Paper IV. This psychological investigation shows that people are often forced to prioritise between disgust sensitivity and pro-environmental identity regarding their cleanliness behaviours. However, no *direct* influence of pro-environmental identity on laundry frequency could be found. As argued in the paper, this is not surprising. The main motivation for doing laundry is to have clean clothes, not to reduce environmental impacts. However, laundering is still often analysed from the perspective of pro-environmentalism (i.e. how do we reduce the environmental impacts from domestic laundering?). The findings in Paper IV imply that this might not make any sense regarding user behaviours. Just because we assess the environmental impacts of a product or service does not automatically make pro-environmental behaviour relevant for the user or consumer. I believe this type of logical fallacy is partly a consequence of drafting the analysis from a technical perspective, starting out from the problem (i.e., the environmental impacts).

In LCA terms, resource consumption and emissions occur at the intersection between the environment and the technosphere. These types of exchanges are called elementary flows and include all the materials, energy, or space used from or released back into the environment (Edelen et al., 2017). Concerning domestic laundering, elementary flows occur, for example, when raw materials are extracted to produce the machines, buildings, and

chemicals needed to do laundry. Elementary flows can also be seen when energy is consumed to run the machines, treat the wastewater, or in all the end-of-life processes. This technological perspective inevitably reduces laundry behaviour to machine operation that needs to be optimised. This narrow focus regarding environmental impacts further limits the analysis to those technical variables and decisions that, by extension, affect the elementary flows. In practical terms, the LCA often becomes an evaluation of a set of scenarios to determine the most preferable outcome (e.g. the scenario with the lowest environmental impacts). This type of analytical approach is illustrated in Figure 7.

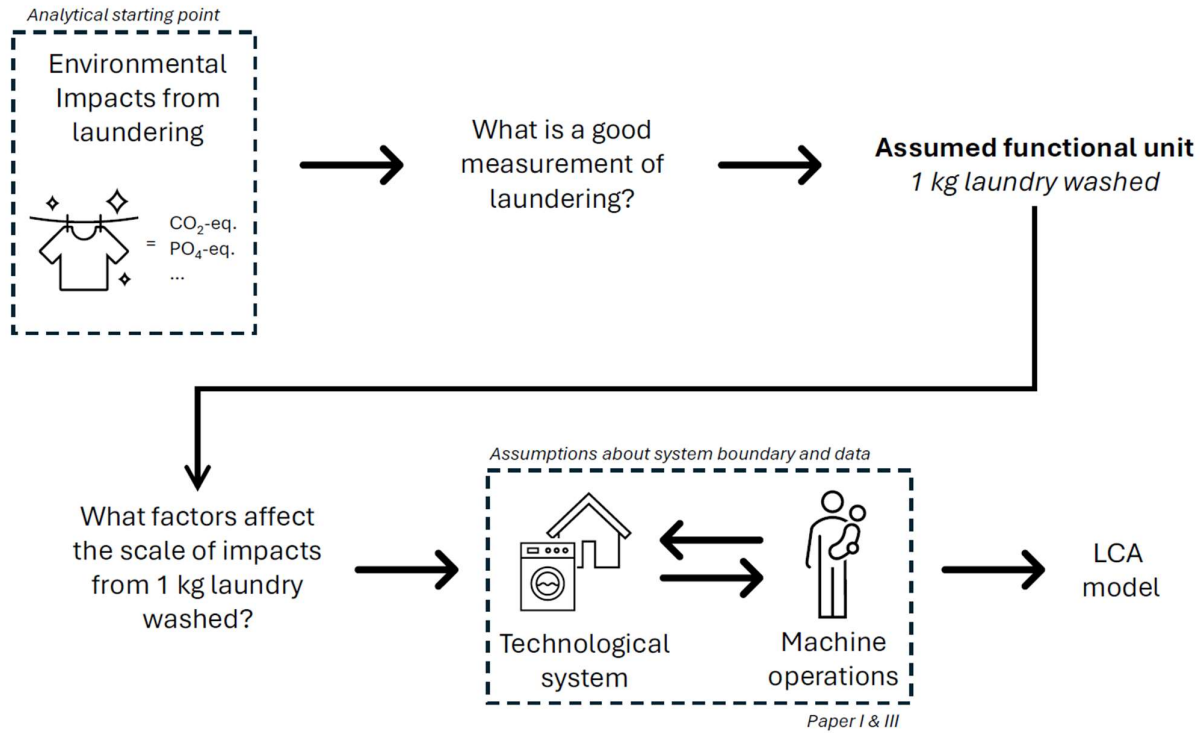

Figure 7. The analytical line of reasoning with a starting point in the environmental impacts from laundering. Arrows indicate the logical next step in creating an LCA model.

While the workflow presented in Figure 7 is not wrong, notice how quickly the analytical system narrows down. A logical consequence of starting with the environmental impacts is that the final LCA model becomes a linear relationship between the technological system and the machine operator.

Individual behaviour is reduced to variables that can and should be optimised to limit resource consumption and environmental impact. This type of analytical framework can be noticed in Paper I and Paper III. Paper I describes an optimisation of the technological system (i.e. using a private or shared laundry room), and Paper III describes the uncertainties regarding behavioural data. This might be interesting for some, but what would happen if we chose to start at the specific behaviour rather than at the consequences of that behaviour? What motivates people to wash their clothes at all? What are the dreams (or fears), aspirations and values each person attributes to laundering?

While the technological system can be described using technological data, these new questions require new information and insights. This alternative starting point allows for a broader set of behaviours that are not necessarily limited to machine operation. As indicated by the proposed thesis, people's relationship with domestic laundering can be understood from two perspectives. The first perspective is the explicit meanings that laundry and laundering represent amongst people. The second perspective is the underlying personality traits and psychological states that influence how we interpret and react to specific situations. In other words, to better understand our relationship with laundry, the technological assessments must be complemented with data from sociology and psychology. At first glance, this might seem like a reversed version of Figure 7. However, this interdisciplinary approach makes a key difference when performing the LCA—namely, the consequences of defining the functional unit.

In the approach illustrated in Figure 7, the resource consumption and environmental impacts are linked directly to specific operations of a washing machine. A natural choice of the functional unit then becomes the outcome of running such a wash, e.g. 1 kg of laundry washed (and dried). The alternative perspective of starting with individual behaviours forces us to think more. As argued in this discussion, sociological investigations of laundering show several explicit reasons for washing clothes. These aspects are discussed in more detail in Paper III, including following social conventions, conforming to religious and moral practices, and feeling confident in social settings. In turn, Paper IV digs deeper into the

psychological aspects of laundering behaviour. Here, the motivational properties of disgust sensitivity, environmental identity, shame and norms are investigated in more detail. Capturing all these nuances and perspectives into a single functional unit is no easy task.

This thesis argues that laundering has a safeguarding function in social situations. By cleaning our clothes, we proactively address our fear of embarrassment and minimise the risk of offending others with foul odours or stains. How can this type of function be expressed in a unit? Moreover, how can it be measured? Paper V offers an initial proposal. Here, psychological experiences of cleanliness are linked to reported behaviours in the laundry room. These scenarios are then used in the LCA model to better illustrate the synergistic effects of decisions over time and their associated environmental impacts. Notice how this change in analytical starting point also affects the LCA's system boundary. If the functional unit is *"to be presentable in social situations",* cleaning one's clothes is just one part of the puzzle. Other types of behaviour that extend outside the laundry room are also needed. Presentability is not only jeopardised by cleanliness violations. For example, damaged clothing or improper clothes (with respect to both type, material, and fit) must also be addressed. Would it be acceptable to show up at work in a clean shirt riddled with holes? Hardly. Can a newly washed T-shirt be considered clean if it has shrunk or contains persistent stains? Probably not. Is it appropriate to wear shorts to work? Depends. Therefore, the system boundary for LCA of consumer products and services based on a social perspective must be broader than the technical one. This suggestion of expanding the system boundary should not be confused with the LCA term *system expansion*. The term *system expansion* refers to a type of solution for managing multi-functionality when conducting an LCA (Heijungs et al., 2021; Nguyen & Hermansen, 2012; Weidema, 2000). This thesis argues for *expanding the system boundary* so that behaviours are viewed systemically and not as singular actions. This means that more diverse decisions and coupled behaviours related to the functional unit must be included. If the function of laundering is to be presentable, an LCA of laundering must also, for example, include the turnover rate for specific clothing items and the wardrobe size. This more holistic approach also allows for a more useful identification of potentially

compensatory behaviours. One such example could be a higher consumption of new clothes as a consequence of lower wash temperature. This alternative workflow for an LCA of domestic laundering is illustrated in Figure 8.

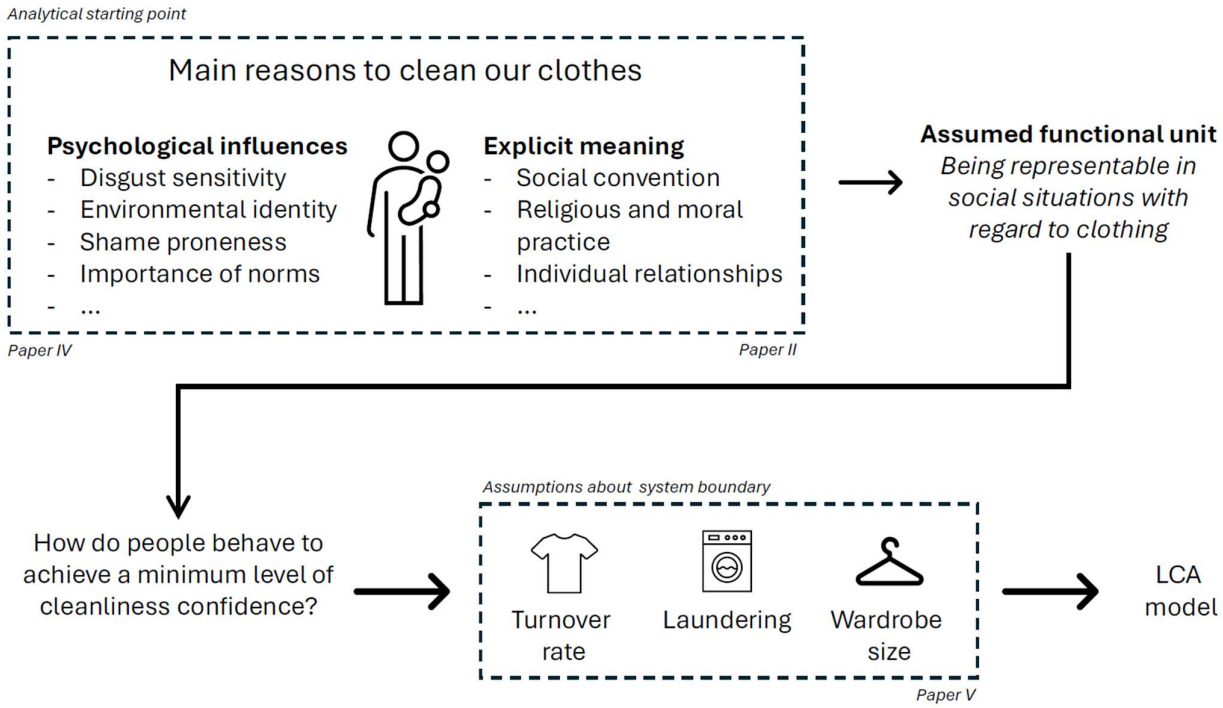

Figure 8. The analytical line of reasoning with a starting point in the behavioural motivations for domestic laundering. Arrows indicate the logical next step in creating an LCA model.

It is questionable whether the resulting LCA model from Figure 8 can be used to assess the environmental impacts of laundering properly. After all, the initial goal and scope of the LCA might have been to capture environmental impacts solely from the operations of machines and not aspects related to additional clothing consumption. Constructing an LCA using this behavioural perspective might also become unnecessarily complex and time-consuming. That being said, I argue that this type of LCA is necessary in order to capture the function of clean clothes (i.e. the motivation for doing laundry) and not just laundering (i.e. the outcome of the technical system). This type of perspective also allows for a better comparison between environmental impacts attributed to laundering and impacts attributed to buying and discarding clothes. This can often be challenging since clothing

consumption is motivated by factors other than just having proper garments. For example, many consumers change wardrobes due to an interest in fashion, changed lifestyles or family constellations, or simply when feeling the need for something new. Comparing clothing consumption with laundering might, therefore, risk comparing apples with oranges. However, the findings presented in Paper V show that this approach is both feasible and offers new insights. However, it does require another type of data for the analysis to be feasible.

I believe that the analytical approach in Paper V is more suitable for suggesting initiatives that try to limit the environmental impacts from laundering. In a way, this is quite logical. If we want to target the behavioural aspects of consumption, it is useful if the analyses are rooted in motivations for behaviour. In comparison, the technical perspective in Figure 7 inevitably gives rise to a small set of technical interventions that are believed to reduce emissions: the installation of automatic dosing of the detergent, requiring electricity from non-fossil energy sources, replacing old machines with more efficient ones, or requiring shared laundry rooms in newly built multi-family apartment buildings. These are not bad suggestions. That being said, the behavioural perspective in Figure 8 gives rise to a more nuanced set of recommendations, where the subjective experience of cleanliness and representativity is better illuminated. Such initiatives could be better clothing design for useability, alternative cleaning practices (e.g. airing or manual spot removal), campaigns that challenge the social norms regarding cleanliness or garment variations, or strategies for clothing rotation (without cleaning them). Interestingly, some of these initiatives have previously been tested with promising results (Jack, 2013; Sahakian, 2019). Taken as a whole, this thesis strongly supports the idea that LCAs focusing on consumer products and services have a lot to gain by including behavioural motivations as a systemic part of the analysis. More interdisciplinary collaboration is needed to bring insights from sociology and psychology into the field of LCA.

Basing the LCA on behavioural motivations allows for a better understanding of a potential rebound effect regarding domestic laundering. As highlighted above, cleanliness is a state of mind evaluated in relation to

peers and surroundings. This means that the functional unit of feeling representable in social settings varies with contextual factors. The relative cost of being clean is implicitly evaluated in relation to the fear of being judged. Imagine a society where exposure to pollution is high. If laundering is costly (in time or money), there will be greater societal acceptance of being dirty. This explains the historical inclination to use cleanliness as a marker of social class; the poor would stink while the elites sought out clean and non-smelly places (Corbin, 1986). Technical improvements have reduced the cost of doing laundry, either in terms of monetary value or in time spent doing it. This means that acceptance of having dirty clothes is continuously falling. Consequently, many people likely feel the need to wash more frequently (Davis, 2008; Mizobuchi & Yamagami, 2022; Sorrell et al., 2009). Interestingly, the functional unit illustrated in Figure 8 suggests that the demand for laundering might also increase because of *clothes* becoming cheaper. Since cleanliness is relative, what is considered a basic level of cleanliness increases the more people use clean clothes. The rise of fast fashion might, therefore, have led to a higher frequency of laundering since there is no way to know whether the cleanliness of your peers comes from washing their clothes or increased consumption of new (and therefore clean) garments. However, this claim is speculative, and more research is needed to establish if such a relationship can be expected.

5 Conclusions

Understanding human behaviour is crucial when trying to assess the environmental impacts of domestic laundering. Not only is the use phase a significant contributor to its environmental impacts, but people also adapt their behaviour to the relative cost of washing. The gains associated with more energy-efficient washing machines, for example, are offset by increased consumption. Functional units used in contemporary LCAs tend to be purely technical. As such, the function of laundering is more about quantitative outcomes related to the technical systems used rather than underlying motivations for laundering. This thesis shows how such an approach limits the LCA's applicability when making policy recommendations or taking initiatives that target the environmental impacts from laundering. Cleaning our clothes is socially motivated, which also means that LCAs must start out from a social perspective rather than a technical one.

Furthermore, LCA practitioners must treat behaviour as a systemic component rather than a static value. Failing to do so might otherwise result in compensatory behaviours and burden-shifting. By using psychological and sociological insights as a starting point for the analysis, LCAs can offer a more nuanced assessment of consumer products and services. A social perspective also permits a more comprehensive assessment of societal trends, such as the rebound effect. With a more holistic understanding of why people engage in certain behaviours, LCAs can better guide interventions and policies towards targeting motivations for behaviours rather than focusing on the consequences of those behaviours. As such, a social perspective in an LCA is critical for the success of any policy or initiative derived from it which aims to reduce environmental impacts where the use phase is the most significant contributor to these impacts.

6 Future Research

Synthesising several perspectives is crucial when trying to understand the reasons behind human behaviour. Most products and services are purchased and used not just for their technical capabilities but also for a variety of personal, social, and cultural reasons. Interdisciplinary research can help unravel these complexities, linking a more comprehensive understanding of consumer behaviours with their environmental impacts. The following aspects are of special interest.

Systematically map the broader social and cultural factors shaping consumer behaviours! This knowledge can then be used as input to LCA models to provide a more nuanced and accurate picture of environmental impacts stemming from consumer behaviours.

Develop and refine alternative approaches to functional units in LCAs! Alternative functional units should be able to better capture the realities of consumer behaviour and usage patterns, rather than just the outcome of a technical system. By moving beyond purely technical descriptions, we can create functional units that more accurately represent how products are used in real life, leading to more realistic and applicable LCA results.

Emphasise the importance of measuring the right data in the right way! Accurate data and data analysis are fundamental to improving the reliability and validity of LCAs. This includes not only technical data but also data on user behaviours and motivations. Better data collection practices can enhance the overall quality and applicability of LCA findings.

Investigate the impact of different laundering choices on fabric wear and tear! This aspect is often overlooked but is crucial for understanding the full environmental impact from domestic laundering. Laundering affects the lifespan of clothing, both directly through wear and tear and indirectly through insufficient stain removal and loss of fit. The relationships between laundering choices, fabric durability, and consumer evaluations of cleanliness are thus critical for a better understanding of the final environmental impacts of clothing consumption and domestic laundering.

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