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OPINION PAPER

# From Simplistic to Systemic Sustainability in the Textile and Fashion Industry

**Olli Sahimaa[1] · Elizabeth M. Miller[2] · Minna Halme[1] · Kirsi Niinimäki[3] · Hannu Tanner[4] · Mikko Mäkelä[5] · Marja Rissanen[6] · Anna Härri[7] · Michael Hummel[8]**

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**Abstract**
The fast fashion industry is notorious for wicked environmental and social problems, such as exploitative resource use, high amounts of waste, excessive pollution, below-living wages and unsafe working conditions. Addressing these problems calls for a systemic view on the industry with the goal of minimising the intake of natural resources into the system as well as the output of waste. However, thus far, most solution attempts have turned out simplistic and insufficient to nudge the industry to more sustainable practices at scale. We examine the textile and fashion system at the three different levels—the product, industry and socio-ecological system levels—and show the inadequacy of the current sustainability-driven practices in the field. As an alternative, we propose systemic solutions, geared toward long material and product lifetimes, that have the potential to trigger adaptive responses throughout different actors in the system and across all three levels. These systemic solutions operationalise a circular value retention hierarchy coupled with a sufficiency-based consumption philosophy.

**Keywords** Textile and fashion industry · Fast fashion · Systemic sustainability · Sufficiency-based circular economy · Circular transition · Circular value retention

## Introduction

Every day, we dress ourselves in clothes that traversed long, complicated supply chains to reach us. Clothes are one of our basic needs, providing warmth and protection and often also a means of individual expression. The ubiquity and simplicity of these seemingly innocent products, however, mask a wide array of environmental and social problems. The current textile and fashion industry (referred to simply as 'textile industry' going forward) over-uses natural resources and produces immense amounts of waste. With the expansion of so-called fast fashion, through their lifecycles, clothing globally contributes up to 10% of total carbon dioxide ($CO_2$) emissions [1, uses 4% of freshwater [2] and produces over 20% of industrial waste water [3]. Textiles are the estimated source of over 35% of microfibres

Extended author information available on the last page of the article

released into waterways [4], and cotton cultivation is responsible for 16% of pesticide use globally [5].

On the social side, the textile industry is a significant sector in the global economy, providing employment for hundreds of millions around the world [6]. At the same time, workers in garment supply chains often face human rights violations [7], unsafe working conditions [8], precarious work [9] and wage theft [10]. A prime example of notoriously exploitative working conditions and practices is the 2013 Rana Plaza building collapse, which killed at least 1135 garment workers and injured approximately 2500 others [11], mostly from its young, female labour force.

In just a few decades, the textile industry has gone through dramatic changes that have led to alarmingly short material and product lifetimes [1, 12]. Clothes once were durable, long-lasting goods but have now become disposables that are soon discarded as waste. Many garments are not manufactured to last and may only endure a mere 10 wash cycles [13]. Fast fashion originates from the West, but the growing middle class in emerging economies is increasing consumption. In 2019, China surpassed the USA as the world's biggest fashion market [14].

To tackle these problems, the industry has introduced a number of solutions, such as the use of organic materials and eco-labels. However, these conventional solutions have been increasingly criticised for their superficiality and failure to address the root causes of problems in the textile system [15]. This article argues for more systemic solutions, aimed at maximizing the value of materials throughout their lifecycles to reduce resource use and waste (Fig. 1). The study provides an interdisciplinary examination of the textile industry at the product, industry, and socio-ecological system levels. Moreover, it critically assesses the existing solutions and presents potential systemic solutions to replace the unsustainable practices in the industry. The findings contribute to the growing body of interdisciplinary sustainability research on the systemic transition to life within the planetary boundaries.

## What Are 'Systemic Solutions'?

In complex adaptive systems theory, autonomous actors organise their activities based on the constraints of the existing system while also co-creating those systemic conditions. Actors respond to one another and adapt accordingly, leading to new patterns of behaviour [16]. Without those new patterns of behaviour, there is no systems change.

At the root of the many seemingly separate problems in the textile industry are the cheapness and speed of fast fashion operating model, which has pushed down clothing lifetimes and contributed to the social challenges of the industry. The material conditions at the product level, the organisational choices at the industry level and the dominant paradigm at the socio-ecological system level together set the conditions for short textile use lives. Actors adapt to these conditions in an attempt to become successful, and in so doing, entrench them further. 'Systemic solutions' are those with the potential to trigger adaptive responses in other actors, from which new patterns of behaviour may emerge—ultimately forming co-evolution between actors. In contrast, 'simplistic solutions' are those that are not likely to trigger such co-evolution, either by design or due to problems in their implementation. By triggering adaptation in other actors, systemic solutions have the potential to serve as system attractors that can lead to a change in the system state.

What could such systemic solutions resulting in a radical decrease in the textile sector's environmental and social sustainability impacts look like? How could the textile sector

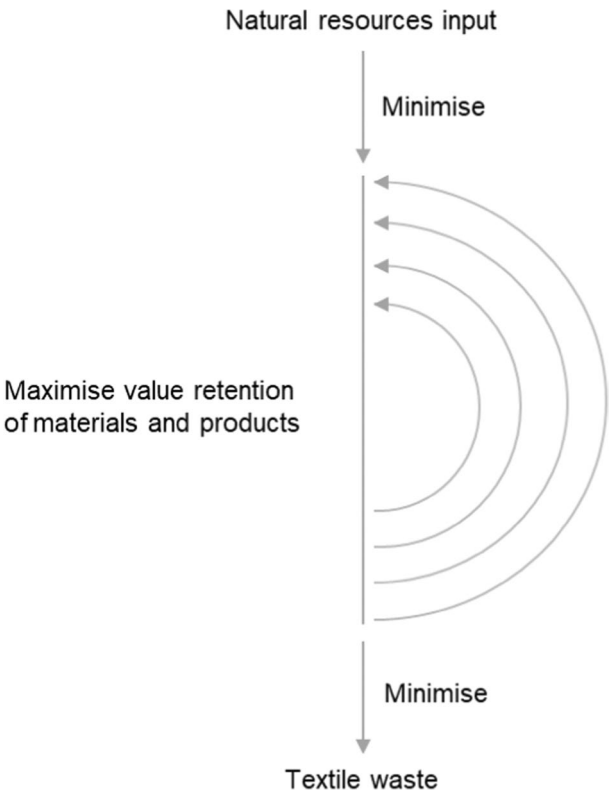


**Fig. 1** The operation principle of the aspired sustainable textile system

move away from simplistic sustainability attempts and instead aim for long material lifetimes and maximal value retention?

## Product Level: from Simplistic to Systemic Solutions that Maintain Long Material and Product Lifetimes

### Barriers to Long Material Lifetimes at the Product Level

Over the past few decades, the quality of textiles has decreased, making them fall apart faster [17, 18]. The low quality of clothing is embedded in the fast fashion business logic, where high quality is compromised for rapid fashion cycles and low prices, often intentionally following the planned obsolescence philosophy. Today, flaws in the quality of garments, along with wear and tear, are significant reasons for clothing disposal [18].

The materials themselves are not the only product-level barrier to long lifetimes. Quickly changing fashion cycles and a large number of new collections each year also contribute to short material lifetimes and loss of value. Fast fashion is fuelled by a continual stream of new styles that fall out of fashion as quickly as they fall in. This design for obsolescence is a critical barrier to longevity. Until the late twentieth century, fashion brands only introduced new styles seasonally, either two or four times per year. Fast fashion brand Zara famously broke the mould by offering new styles every 2 weeks, and now ultra-fast

fashion brands like Shein, Boohoo and Asos release new styles continuously. This has led to consumers adopting a 'throwaway mentality' [19] that pushes down the use rate and lifetimes of clothing.

Along with turning into waste ever more rapidly, textiles have also become less recyclable by being more frequently made of cotton-synthetic blends. If you check the label of the garment you are wearing, there is a high likelihood that the fabric is woven or knit with a blend of different fibres, such as a mix of cotton and polyester. In traditional mechanical recycling processes, these blended fibres cannot be separated into their component parts to be re-spun as pure cotton, polyester and so on, leaving them often landfilled, incinerated or, at best, downcycled to purposes other than clothing.

## Simplistic Product Solutions and Why They Do not Work

As one response to criticism, the fashion industry has introduced supposedly less harmful textile materials. Simply swapping out materials will, however, not trigger beneficial systems change. With some alternative materials, the problem is one of trade-offs and unintended consequences. Organic cotton, for example, requires more arable land than traditional cotton due to lower yields [20]. Fabrics made from recycled PET bottles shed microplastics when washed [21] and require a continuous stream of plastic waste to produce at scale. Additionally, even new materials that have several ecological benefits, like wood-based textile fibres, do not inherently lead to textile materials being in use longer. Also, these new materials might not lead to improved working conditions or enhanced social sustainability.

On the design side, responsive design that produces limited batches based on specific consumer trends may seem like a solution to the 'push' of new styles that shortens the use lives of each garment. This is Zara's approach. The Spain-based company has extensive consumer analysis capabilities, as well as production capacities near Europe to quickly identify and produce highly specific trend pieces. Giving consumers what they want should lead them to value and maintain those items for longer, right? Unfortunately, no. While this kind of responsive design does limit waste from deadstock, it simply perpetuates the view of fashion as fast and disposable. Perhaps because this design is responsive but not bespoke, there is no evidence that consumers wear mass-market responsive designs longer. To sum up, these solutions have not radically cut down the industry's environmental impacts.

## Systemic Solutions for the Product Level

To improve product longevity, we need solutions that will trigger co-evolution with other actors and new patterns of behaviour, like forming new business ecosystem partnerships and creating new modes of fashion consumption. New practices need to be adopted in particular at the design and end-of-life phases.

In the design phase, the first important element of design for longevity is a focus on the physical aspects of longevity: durable materials and high-quality assembly work. Physical durability enables the extended use time of the garment and also enhances the re-wear opportunities. High-quality assembly work might not automatically lead to more ethical work, but coupled with less time pressure and higher prices, it can enable better working conditions.

The second element of design for longevity is the psychological aspect. Considering psychological aspects of consumers' garment use is essential when aiming for longevity of use, because garments are not only disposed of when they are worn out and broken [22]. Only by understanding the multidimensional decision making of consumers' clothing-related choices is it possible to design timeless products that do not end up at the bottom of the wardrobe or in the waste bin. Modular garments—ones that can be disassembled into different parts and reassembled at the wearer's will—could be one answer to the consumer's need for change and self-expression. Consumers, on the other hand, should adopt new approaches to acquiring and using clothing by modifying, customizing, and repairing clothing and adopting these as normal practices aimed at extending product lifespans.

In the end-of-life phase—as even long-lasting garments will eventually reach the end of their use lives—product circularity requires the rise of new actors who can sort and re-process textiles. However, textile recycling is still in its infancy for two main reasons. The first, and most critical, reason is the ubiquity of cotton-synthetic blends or other composite materials that cannot be separated. The other reason is that recyclers need to use a great deal of effort to evaluate the composition of textiles, which is not always accurately reflected on the tags.

The obvious solution to the first recycling challenge is to increase the use of mono-materials, like pure cotton, wool or synthetic mono-materials. However, that would not address the massive amounts of blended textiles already in use. It is also unlikely to happen because mono-materials cannot compete with blends in certain technical garments, such as sports apparel. Therefore, new technologies are needed to enable the separation and subsequent recycling of blended textiles. Chemical recycling technologies make it possible to produce high-quality virgin manufactured cellulose fibres using textile waste as feedstock.

For instance, Ioncell is a technology in which cellulose is dissolved in ionic liquids and spun into fibres by dry-jet-wet spinning technology [22, 23]. It can also utilise cotton waste fabric [24], cotton/polyester blend fabrics [25], cardboard [26] and old newsprint [27] to produce long-lasting fabrics and garments. Recent studies showed that Ioncell fibres can be recycled at least twice without significant decrease in fibre quality [28, 29]. Although the chemical recycling technologies to produce recycled manufactured cellulose fibres are in their relatively early days, there are already a variety of commercialised technologies in the area—such as the Infinited Fiber Company's Infinna and Re:newcell's Circulose® pulp. Chemical recycling does not have the disadvantages of mechanically grinding down textiles, which causes fibres to become shorter and requires virgin fibres to be added to make new fabric. Thus, it extends material lifetimes without increasing natural resource use in the process.

The solution to the second recycling challenge is the use of optical measurement technologies to identify material components without destroying the fabric. Before any recycling process, textile waste must be sorted according to the materials they contain. This is a key function, as the actual recycling process needs to be adapted to different materials. If chemical recycling or other recycling technologies are to be applied at scale, solving the large-scale reliable sorting of the textile waste flows is a crucial question. Current rapid and non-destructive methods for fibre identification are mostly based on optical measurements in the near infrared (NIR) range [30]. Modern imaging and machine vision methods have the potential to complement traditional and portable NIR sensors in the future and offer clear benefits for high-throughput applications. Imaging and machine vision methods provide spatial information on material properties and reduce the need to control the position of an object on a measurement or transport line.

The chemical information provided by an NIR spectrum enables distinguishing the most common synthetic and natural fibres, such as polyester, cotton, viscose and wool [30–36]. Promising fibre identification studies have recently been reported for classifying different synthetic and natural fibres and for estimating the properties of fibre blends under laboratory and pilot conditions [34–37]. Thick and layered textiles, however, pose challenges for reliable identification due to the limited penetration depth of NIR wavelengths.

The systemic solutions presented above require the rise of new actors who can design long-lasting textiles, as well as actors to sort and re-process textiles at scale at the end of their use lives.

## Industry Level: Circular Business Models with Value Retention and Digital Tracing to Replace Fast Fashion

### Barriers to Long Material and Product Lifetimes at the Industry Level

Product-level limitations are not the only causes of short material lifetimes. Industry practices, like short fashion cycles and complex global supply chains, also contribute to the web of problems in the sector.

Until the 1980s, the textile and fashion industry was organised to respond to customer demands by forecasting their expectations for two seasons, a much slower market speed than today [12]. Since the 1980s, fast fashion started to gain dominance, which meant that the speed-to-market increased tremendously.

Today, brands are able to offer a rapidly changing selection of cheap clothes because of the structural changes that have enabled offshoring production and the power brands wield in global supply chains. Garment manufacturers are easy to set up, requiring relatively little start-up capital and mostly low-skilled labour. The ease of establishment has led to an explosion of garment suppliers, creating cutthroat competition and giving brands significant leverage over their suppliers [12]. This competition transcends geographical boundaries. As wages rise, infrastructure improves and trade agreements change, production tends to move to lower-wage countries. This ‘caravan capitalism’ [38] has seen textile production march from western industrial centres to China, Bangladesh, Vietnam, Ethiopia and others. The leverage over suppliers allows brands to push down both prices and lead times. Textile and garment workers tend to come from vulnerable populations—such as women and migrants—that allow factory owners to force short turn-around times, low wages and (often unpaid) overtime. According to a sample covering 60 employees, the monthly average salaries of women garment workers in Bangladesh ranged from 45 USD to 60 USD, depending on the role [39]. All of this enables a continuous, quickly changing stream of cheap clothes.

These complex supply chains are connected to problems at the product level. Because there are so many different sub-suppliers involved, it is almost impossible for brands to know every company that is involved in production and every ingredient put into their textile materials. A recent study on optical identification of cellulose textile fibres found that 14% of the sampled consumer textiles contained fibres or fibre blends that were different from those reported on the textile labels [40]. This makes proper recycling of textiles more difficult.

### Simplistic Solutions at the Industry Level and Why They Do not Work

Right now, the dominant fast fashion business models push companies to sell as much as possible as frequently and cheaply as possible. Yet, with rising consumer demand for sustainability, brands have begun to 'green' their garments. One of the most common tools for doing this is eco-labelling.

Unfortunately, eco-labels and certifications of social sustainability, on the whole, do not lead to co-evolution of new practices with other actors. The growing criticism of third-party audits indicates they can be unreliable [41]. Auditors can be corrupt, and suppliers that are given sustainability mandates without any financial support may be additionally incentivised to fake audit results [42–44]. This all, of course, assumes companies pursue third-party labels and certifications in the first place, as the process of gaining and using verified labels and certificates involves cumbersome bureaucracy and requires extensive documentation and manpower [45]. Some brands instead use their own in-house certifications of social sustainability or eco-labels, such as 'Conscious choice' by H&M. These labels tend to be less trustworthy than those with third-party verification [46].

What about the labels' impact on consumer habits? Even when the information on labels is trustworthy, it can be difficult for consumers to understand. Consumers can thus be slow to translate awareness into action [47], rendering eco-labels' leverage for change limited in this sense as well.

### Systemic Solutions for the Industry Level

Companies need to change their core business models to enable product longevity and circularity, which can be supported by new data management approaches. In addition to obvious environmental improvements, the resulting effects—like lower volumes, higher purchasing prices and slower cycles—can also enable social improvements in supply chains [48]. New types of business models may encourage sufficiency [49] (like the US company Buy Me Once), help extend garment lifetimes or enable multiple use phases of the garment. For example, the Finnish brand Anna Ruohonen produces most garments on-demand only, and thus, no surplus is formed. Additionally, the business model features collections of timeless, well-cut, everyday clothing and a second-hand service, where customers can return used Anna Ruohonen clothing to the stores in exchange for a gift card. The brand itself then takes care of the resale.

Given the higher price points, business models for longevity and sufficiency are likely to cater to higher-income consumers. In the best-case scenario, sustainability-minded affluent consumers may shift their purchasing habits to prioritise longevity and sufficiency. In many places, second-hand and vintage garments have become very trendy [50, 51], enabling the success of business models like Emmy, a Nordic online store for second-hand brand apparel. Second-hand garments make it possible for lower-income consumers to extend material and product lifetimes without relying on fast fashion. The online peer-to-peer marketplace Poshmark—known primarily for its fashion exchange—was valued at $3 billion US dollars at the time of its initial public offering [52], illustrating that there is money to be made in facilitating reuse.

Companies can also shift their business logic by monetising end-of-life or maintenance activities. Various forms of repair services—either through guarantees, contracted separate services provided through the brand or stand-alone repair services—enable consumers to

extend the use lives of their own garments. Patagonia, for example, instructs their customers to repair their Patagonia clothing, offers repair services and sells used Patagonia clothing in their Worn Wear program. Joutsen, a Finnish outdoor coat brand, provides repair and washing services for its garments.

There is also significant market potential in business models that allow consumers to rent instead of buy. Through their rental service, MUD Jeans charges their customers a monthly fee. This allows consumers to replace or return their pair of jeans for no extra cost. Once a pair of jeans is damaged or reaches the end of its life, the consumer sends the jeans back. The jeans are then recycled, and the material is used to create another high-quality garment [53, 54]. Rent the Runway and Vaaterekki are examples of larger 'clothing libraries' where you have access to a certain number of changing garments according to your chosen membership plan.

In the long run, these new, circularity-oriented business models can trigger co-evolution because they often need new partners, ecosystems and customer segments to survive. For example, business models that involve sorting textiles may need new kinds of actors to emerge, such as those with NIR measurement capabilities. Others, like Rent the Runway and Vaaterekki, can change patterns of behaviour, like switching to renting garments for special events or testing new styles rather than buying them. For any of these business models to reach their full potential, it is critical to acknowledge the associated changes and potential difficulties in cash flows, customer base and market dynamics. Transitioning to product longevity and sufficiency requires targeting a more conscious and sustainability-driven consumer base, deviating from traditional trend-focused, impulsive buying behaviours. Companies need to identify and engage with these new segments effectively, and consumers across various income brackets must increasingly recognise the value of longevity, sufficiency and reuse over the allure of fast fashion. Circular business models often also lead to a reconfiguration of financial flows, where revenue generation is spread over extended product lifetimes rather than frequent sales cycles, urging companies to rethink production, inventory and distribution strategies to maintain profitability.

Data is critical for the success of these new kinds of circular business models [55]. For example, resale and rentals require detailed data on the content, condition and location of the product. Visibility of products' lifecycles would require equipping materials, components and end products with data carriers that contain identifying data and tracking their journey through the different stages of the production and use life. Depending on the need, this identification could be used to provide access to information aimed at producers or consumers. Within the supply chain, the information could be, for example, detailed process and manufacturing data, which could be used to manage material flows and supply chain orchestration. For the consumer, reading the garment's data carrier with a mobile device, for example, could provide information on materials and treatments, or the environmental and social impacts of the manufacturing process. Data carriers could also establish a channel for brands to interact with consumers after the purchase, which has typically been difficult to arrange. Information on garment care, repair services or resale and take-back programmes could be offered. At the end-of-life phase of the garment, recyclers could use the data to automatically disassemble the garment and sort the materials to appropriate segments.

From a technological perspective, radiofrequency identification (RFID and NFC) tags and 2D optical codes—for example, bar codes or QR codes—have the most potential to serve as data carriers in the textile industry. RFID and NFC tags are flexible and efficient, but they are more expensive than QR codes and need to be removed before recycling processes. They hold more data and can be updated during the product lifecycle. RFID tags

are already widely used in manufacturing, inventory control, warehousing, distribution, logistics, and supply chain management. Along with embedding data, RFID tags can also be used for advanced functions such as measuring the duration or frequency of clothing use or laundering [56], which can be useful information in determining what comes next at the end of the garment's current use life.

Two-dimensional optical codes are simpler and cheaper than RFID tags, and they can be printed onto packaging or the product itself. They are cost-effective, accurate and reliable, and can be integrated into existing processes. However, the code cannot be updated along the supply chain, but a replacement code must be created.

Imagine how the material lifetime of a blouse could be extended through circular business models enabled by identification data: When the fabric is woven, it is labelled with a QR code listing all of the component materials and where it was made. The fabric is cut and sewn into a blouse with a timeless design. The blouse manufacturer extends the fabric data with information on the materials added, like buttons or embellishments, and stores all the data in an RFID tag sewn into a seam of the blouse. The blouse is then bought by a customer who has an RFID-enabled washing machine (which already exist) to track its washes. At the end of the blouse's life, the recycling processor scans the tag to see the component materials and details of its use life. Few washes and seldom used? Send it for resale. Mono-material in good condition? Send it to be re-spun into new thread. Mixed materials heavily worn and washed? Send it to the Ioncell process or other chemical recycling to be made into new fibres.

In addition to trustworthy technological solutions, successful implementation of the data-assisted circular economy requires unprecedented, industry-wide collaboration between stakeholders as well as common data standards and guidelines [57]. Basically, legislators should demand transparency to level the playing field. At the time of writing, the European Union is planning regulation on the use of digital product passports, which could support circular material use and provide consumers a better understanding of the materials used in the products, as well as their embodied environmental impacts.

## Socio-ecological System Level: Paradigm Shift to the Sufficiency-Oriented Circular Textile System

### Barriers to Long Material and Product Lifetimes at the Socio-ecological System Level

A societal paradigm is 'the shared idea in the minds of society, the great big unstated assumptions, or deepest set of beliefs about how the world works' [58]. The underlying paradigm of contemporary society rests on the fundamental assumptions of economic growth as a primary national policy goal and shareholder profit maximisation as the organising principle for international business systems [59].

In the textile sector, short-term profit maximisation has firmly entrenched the system in unsustainable practices. The dominant fast fashion paradigm is locked into a model based on ever-lowering costs, low profit margins per item of clothing and constantly increasing sales of garments. The constant demand for new collections and styles at low prices has led the industry to prioritise speed and efficiency over quality and sustainability. Production methods have become increasingly focused on cost-cutting, leading to the use of cheap and hazardous materials, labour exploitation and reduced product lifespans. The combination

of low prices, speed to market and significant marketing budgets of fast fashion companies have made it difficult for sustainability-oriented companies to gain significant market share.

### Simplistic Solutions at the Socio-ecological System Level and Why They Do not Work

Ecological modernisation is a school of thought that tries to resolve the ecological crisis through radical improvements in resource efficiency and the substitution of environmentally harmful industrial processes for less harmful ones, without undermining economic growth and other capitalist imperatives [60]. The ecological modernisation view relies on a green growth standpoint on the growth dilemma: modern societies may 'grow beyond' social and environmental problems with the right kind of economic growth compatible with environmental sustainability.

Ecological modernisation cannot fully solve the problems associated with fast fashion for several reasons. Ecological modernisation primarily focuses on improving the efficiency of production processes and reducing waste, but it does not address the root causes of fast fashion, such as overconsumption and the pressure to continuously produce new collections. The ecological modernisation approach relies on market-based solutions, such as eco-labels and certifications. As mentioned earlier, 'ecological collections' or certification and labelling systems, which seek at best to green but at worst greenwash existing practices, have not fundamentally overhauled the existing unsustainable development at the socio-ecological system level. Globally, the majority of textiles end up in incinerators and landfills [6], and the average prices of different treatment options reflect that adequate incentives for textile circularity have not been achieved. The costs for waste disposal in landfills globally vary from 20 to 70 USD/tonne. For waste incineration, the price ranges from 20 to 130 USD/tonne [61]. The cost and labour intensity of collecting and sorting post-consumer textile waste garments make it economically unfeasible for companies to establish mechanical recycling operations, thus impeding widespread industrial adoption [62]. Finally, the ecological modernisation approach does not provide adequate incentives for companies to make significant changes to their production methods and business models. Consequently, a more systemic approach is needed to address the interrelated social and ecological issues associated with fast fashion.

### Systemic Solutions at the Socio-ecological System Level

A range of alternative economic paradigms for the current growth-at-all-costs model have been suggested. Circular economy is one of those. Regardless of the relatively strong focus on economic growth, the organising principle of circular economy holds potential as it aims to eliminate waste, keep products and materials at their highest value in biological and technical cycles and move from extensive extraction of natural resources to the regeneration of nature. However, to reduce natural resource extraction and avoid perpetuating green-growth approaches to circular economy that focus only on end-of-life solutions [63], we suggest a *sufficiency-based circular economy* as the systemic solution at the socio-ecological system level.

From the environmental sustainability perspective, successful implementation of circular economy in the textile and fashion system requires the goal of minimised intake of natural resources into the system and minimised output of waste from the system. Taking a sufficiency-based orientation means 'being satisfied with less new material goods than usually consumed today, while enjoying the existing ones' [64]. As an operationalisation

principle, this would mean prioritising reduce, resell/reuse and repair value retention forms over material recycling and incineration [65, 66]. In that scenario, after their original use, textile products and materials should be at best reused or upcycled into new fibres, or less optimally downcycled to retain the best possible value of the material. We have operationalised these principles in the sections covering the systemic solutions at the product and industry level.

The risk is that due to the complexity of socio-ecological system change, any kind of material circulation might pass as an acceptable circular solution. In that scenario, recycling used textiles into road filling would be seen equal to reuse of garments in their original function. From an environmental impact perspective, however, the former loses much of the material value taken from nature, while the latter keeps it. Thus, it is imperative to discern and promote genuine circular practices that have true benefits from climate, biodiversity and resource scarcity perspectives.

To change the paradigm of the textile system, a comprehensive transformation must be carried out, involving changes in product qualities, business models, recycling processes, regulation and consumer behaviour. This change can be achieved through design for longevity and circularity, a shift in consumer mindsets to value sufficiency and product longevity and new business models that encourage circularity and monetise end-of-life or maintenance activities. The sufficiency orientation is particularly important, as in the textile industry, there is a risk that circular products will only add to overall consumption rather than displace primary production [66, 67]. The industry also needs to prioritise efficient recycling and upcycling, and it should be re-organised through regulation and policy measures that incentivise circular practices and internalise environmental and social costs in product prices. Additionally, the transition requires changes to the operating environment, such as policies to level the playing field for innovators [68] and new cross-sectoral collaborations [69]. All of these changes must work together to fundamentally change the textile and fashion industry as a whole and move towards a more sufficiency-based circular economy.

Figure 2 pulls together key concepts of this paper and paints a picture of how the sufficiency-based circular economy paradigm could trigger adaptive responses in different industry actors – ultimately forming co-evolution towards a sustainable textile system.

## Discussion: the Transition to a New Kind of Sustainable Textile Industry

In this paper, we explored the problematic system dynamics of the textile industry through a multi-level look at the sector. Table 1 summarises the key elements driving down material and product lifetimes in the textile system, some of the currently applied simplistic solutions and more impactful systemic solutions that we suggest.

The product, industry and socio-ecological system levels are presented in separate columns, but they all relate to one another. For example, even the most durable fabrics that could last without wear and tear for decades will not solve the problem of short material lifetimes without industry and paradigm changes, since well-made clothes can still go out of style. In the same vein, new industry practices, like innovative business models and ways of using data, are not alone enough to fundamentally extend material and product lifetimes. Even the most innovative business models and intricate traceability data system will do nothing to extend longevity without materials that are durable to begin with. On the

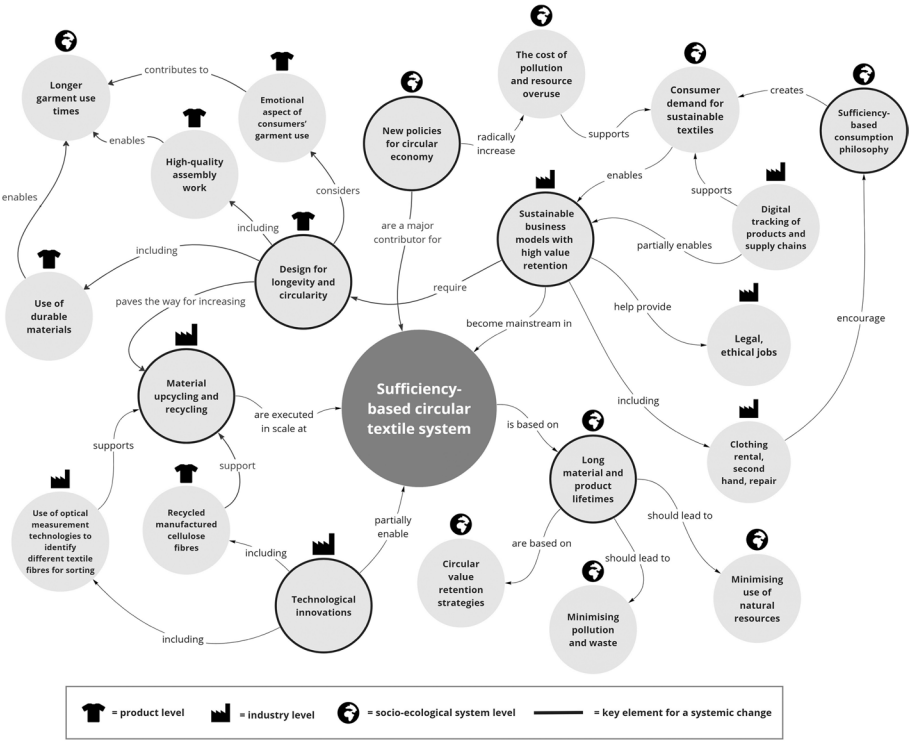


**Fig. 2** A system map showing how the paradigmatic change and co-evolution at different levels could lead to sufficiency-based circular economy with long material and product lifetimes

other hand, without tangible changes to products themselves, attempts to elicit a paradigm shift will be confined to unimplementable ideology.

The challenges of the textile sector are intertwined in the different sub-systems of society: manufacturing systems and economic systems; political, social and cultural systems; and technological and legal systems. Consequently, this new type of textile industry cannot be only an incrementally better version of the current 'growth-at-all-costs' fast-fashion paradigm. It is a system with totally different system targets and structures. New policies? Yes. New kinds of industry practices and business models? Also yes. New types of consumer behaviour? Absolutely. We suggest that for this cross-sectional transformation, the goal of long material and product lifetimes is a fruitful guiding principle for a sufficiency-based circular system that minimises virgin resource intake and waste generation.

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**Author Contribution** All authors contributed to the study conception and design. Sahimaa, Miller and Halme were responsible for organizing and leading the writing process as well as writing the sections concerning socio-ecological system and business models. Niinimäki drafted the section concerning product design. Tanner drafted the sections concerning data management and transparency. Mäkelä, Rissanen and Hummel were responsible for texts concerning material recycling. Härri contributed to the manuscript through her expertise on social sustainability. All authors read, commented and approved the final manuscript.

**Table 1** Key elements driving down material and product lifetimes in the fast-fashion-based textile system, current simplistic solutions, and potential systemic solutions

| | Product level | Industry level | Socio-ecological system level |
|---|---|---|---|
| Key sustainability challenges in the current textile system | Planned obsolescence, low material and product quality and rapid fashion cycles leading to short material and product lifetimes<br>Different fibre blends generate challenges for recycling | Industry cost pressures shifting production to low-labour-cost countries and causing violation of workers' rights and poor visibility of supply chains<br>Linear material use and low value retention leading to deadstock and high amounts of waste<br>Extremely low clothing-to-clothing recycling rate, downcycling clothing into low-value applications and losing value through incineration and landfilling | Pursuing continuous growth in national economies and maximising profits in companies at the cost of environmental and human well-being |
| Examples of simplistic solutions | 'Responsible' collections from alternative, 'less bad' materials causing negative trade-offs and unintended consequences in the system<br>Responsive design: limited batches based on consumer trends | Eco-labels and certifications as the driver for 'greening' the industry | Policies and practices based on ecological modernisation: trusting environmental-economic win-win scenarios to solve wicked problems |
| Examples of systemic solutions | Design for longevity: high-quality materials and assembly work<br>Design for circularity: ensuring product reusability and recyclability<br>Wide application of optical fibre identification technologies to identify different textile fibres and ensure sorting and reprocessing of textiles at scale | Radical changes in business models to support long material lifetimes and value retention through maintenance, reuse, repair, upcycling and recycling<br>Industry-wide collaboration to implement data-assisted circular practices where raw materials, components and end products are systematically tracked in each phase of the product lifecycle | Textile system with long material lifetimes and maximum environmental value retention as the guiding paradigm<br>Sufficiency-based consumption philosophy becoming mainstream |

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## References

1. Niinimäki K et al (2020) The environmental price of fast fashion. Nat Rev Earth Environ 1(4):189–200. https://doi.org/10.1038/s43017-020-0039-9
2. World Bank, AQUASTAT, FAO (2017) Dataset: annual freshwater withdrawals, total. Cited in: Ellen MacArthur Foundation (2018) A new textiles economy: Redesigning fashion's future. http://www.ellenmacarthurfoundation.org/publications. Accessed 15 Aug 2022
3. Kant R (2012) Textile dyeing industry an environmental hazard. Nat Sci 4(1):22–26. https://doi.org/10.4236/ns.2012.41004
4. Volgare M et al (2021) Washing load influences the microplastic release from polyester fabrics by affecting wettability and mechanical stress. Sci Rep 11(1):1–12. https://doi.org/10.1038/s41598-021-98836-6
5. Rodale Institute (2017) Dig deeper: chemical cotton. Cited in: Ellen MacArthur Foundation (2018) A new textiles economy: Redesigning fashion's future. http://www.ellenmacarthurfoundation.org/publications. Accessed 13 Aug 2022
6. Ellen MacArthur Foundation (2017) A new textiles economy: redesigning fashion's future. http://www.ellenmacarthurfoundation.org/publications. Accessed 23 Nov 2022
7. Gardetti MA, Torres AL (eds) (2013) Sustainability in Fashion and Textiles: Values, Design, Production and Consumption. Greenleaf Publishing Limited, pp 1–20
8. Alamgir F, Banerjee SB (2019) Contested compliance regimes in global production networks: insights from the Bangladesh garment industry. Hum Relat 72(2):272–297. https://doi.org/10.1177/0018726718760150
9. Anwary A (2017) Feminised workforce in transnational production: the Bangladesh readymade garment industry. Hist Sociol South Asia 11(2):1–18. https://doi.org/10.1177/2230807516686419
10. Yadlapalli A, Rahman S, Gunasekaran A (2018) Socially responsible governance mechanisms for manufacturing firms in apparel supply chains. Int J Prod Econ 196:135–149. https://doi.org/10.1016/j.ijpe.2017.11.016
11. The Daily Star (2016) Justice Still Eludes Rana Plaza Victims. RSI Lab. http://www.thedailystar.net/business/justice-still-eludes-rana-plaza-victims-cpd-1213720. Accessed 12 June 2022
12. Bhardwaj V, Fairhurst A (2010) Fast fashion: response to changes in the fashion industry. Int Rev Retail Distrib Consum Res 20(1):165–173. https://doi.org/10.1080/09593960903498300
13. Piippo R, Niinimäki K, Aakko M (2022) Fit for the future: garment quality and product lifetimes in a CE context. Sustainability 14(2):726. https://doi.org/10.3390/su14020726

14. Amed I, Berg A, Balchandani A et al (2019) The State of Fashion 2019. McKinsey & Company. https://www.mckinsey.com/~/media/McKinsey/Industries/Retail/Our%20Insights/The%20influence%20of%20woke%20consumers%20on%20fashion/The-State-of-Fashion-2019.ashx. Accessed 15 Mar 2022
15. Buchel S, Hebinck A, Lavanga M, Loorbach D (2022) Disrupting the status quo: a sustainability transitions analysis of the fashion system. Sustainability: Sci, Pract Policy 18(1):231–246. https://doi.org/10.1080/15487733.2022.2040231
16. Valente M (2010) Demystifying the struggles of private sector paradigmatic change: Business as an agent in a complex adaptive system. Bus Soc 49(3):439–476. https://doi.org/10.1177/0007650310369376
17. Aakko M, Niinimäki K (2021) Quality matters: reviewing the connections between perceived quality and clothing use time. J Fash Mark Manag 26(1):107–125. https://doi.org/10.1108/JFMM-09-2020-0192
18. Laitala K, Boks C, Klepp IG (2015) Making clothing last: a design approach for reducing the environmental impacts. Int J Des 9(2):93–107
19. Edbring EG, Lehner M, Mont O (2016) Exploring consumer attitudes to alternative models of consumption: motivations and barriers. J Clean Prod 123:5–15. https://doi.org/10.1016/j.jclepro.2015.10.107
20. Adanacioglu H, Olgun A (2012) Evaluation of the efficiency of organic cotton farmers: a case study from Turkey. Bulg J Agric Sci 18(3):418–428
21. Šaravanja A, Pušić T, Dekanić T (2022) Microplastics in wastewater by washing polyester fabrics. Materials 15(7):2683. https://doi.org/10.3390/ma15072683
22. Niinimäki K, Armstrong C (2013) From pleasure in use to preservation of meaningful memories: a closer look at the sustainability of clothing via longevity and attachment. Int J Fash Des Technol Educ 6(3):190–199. https://doi.org/10.1080/17543266.2013.825737
23. Michud A et al (2016) Ioncell-F: ionic liquid-based cellulosic textile fibres as an alternative to viscose and lyocell. Text Res J 86:543–552. https://doi.org/10.1177/0040517515591774
24. Asaadi S et al (2016) Renewable high-performance fibres from the chemical recycling of cotton waste utilising an ionic liquid. ChemSusChem 9:3250–3258. https://doi.org/10.1002/cssc.201600680
25. Haslinger S et al (2019) Recycling of vat and reactive dyed textile waste to new colored man-made cellulose fibres. Green Chem 21:5598–5610. https://doi.org/10.1039/C9GC02776A
26. Ma Y et al (2016) Upcycling of waste paper and cardboard to textiles. Green Chem 18(3):858–866. https://doi.org/10.1039/C5GC01679G
27. Ma Y, Hummel M, Kontro I, Sixta H (2017) High performance man-made cellulosic fibres from recycled newsprints. Green Chem 20:160–169. https://doi.org/10.1039/C7GC02896B
28. Sederholm H (2022) Closed-loop recycling of Ioncell fibres. Master's thesis,. Aalto University School of Chemical Engineering
29. Twaroch N (2022) Chemical recycling of Ioncell textiles. Bachelor's thesis,. IMC UAS Krems
30. Manley M (2014) Near-infrared spectroscopy and hyperspectral imaging: non-destructive analysis of biological materials. Chem Soc Rev 43(24):8200–8214. https://doi.org/10.1039/C4CS00062E
31. Blanch-Perez-del-Notario C, Saeys W, Lambrechts A (2019) Hyperspectral imaging for textile sorting in the visible-near infrared range. J Spectr Imaging 8:a17. https://doi.org/10.1255/jsi.2019.a17
32. Heikkilä P et al (2019) Telaketju: Towards circularity of textiles. VTT Research report. https://www.cris.vtt.fi/en/publications/telaketju-towards-circularity-of-textiles. Accessed 13 Mar 2022
33. Mäkelä M, Rissanen M, Sixta H (2020) Machine vision estimates the polyester content in recyclable waste textiles. Resour Conserv Recycl 161:105007. https://doi.org/10.1016/j.resconrec.2020.105007
34. Li J, Meng X, Wang W, Xin B (2019) A novel hyperspectral imaging and modeling method for the component identification of woven fabrics. Text Res J 89(18):3752–3767. https://doi.org/10.1177/0040517518821907
35. Cura K, Rintala N, Kamppuri T, Saarimäki E, Heikkilä P (2021) Textile recognition and sorting for recycling at an automated line using near infrared spectroscopy. Recycling 6(1):11. https://doi.org/10.3390/recycling6010011
36. Rashed HS, Mishra P, Nordon A, Palmer DS, Baker MJ (2021) A comparative investigation of two handheld near-ir spectrometers for direct forensic examination of fibres in-situ. Vib Spectrosc 113:103205. https://doi.org/10.1016/j.vibspec.2020.103205
37. Tan C, Chen H, Lin Z, Wu T (2019) Category identification of textile fibres based on near-infrared spectroscopy combined with data description algorithms. Vib Spectrosc 100:71–78. https://doi.org/10.1016/j.vibspec.2018.11.004
38. Arrigo E (2020) Global sourcing in fast fashion retailers: sourcing locations and sustainability considerations. Sustainability 12(2):508. https://doi.org/10.3390/su12020508
39. Mustafa A, Islam MS, Islam S, Khatun M (2016) Impact of RMG sector on livelihood change of women employees of Bangladesh. Soc Econ Geogr 2(1):1–10

40. Mäkelä M, Rissanen M, Sixta H (2021) Identification of cellulose textile fibers. Analyst 146(24):7503–7509. https://doi.org/10.1039/D1AN01794B
41. Khurana K, Ricchetti M (2016) Two decades of sustainable supply chain management in the fashion business, an appraisal. J Fash Mark Manag 20(1):89–104. https://doi.org/10.1108/JFMM-05-2015-0040
42. Terwindt C, Saage-Maass M (2016) Liability of social auditors in the textile industry. Friedrich-Ebert-Stiftung, Global Policy and Development https://media.business-humanrights.org/media/documents/72849f5956d65ca670f850cfa61968f93704900f.pdf
43. Terwindt C, Armstrong A (2019) Oversight and accountability in the social auditing industry: the role of social compliance initiatives. Int Labour Rev 158(2):245–272
44. Huq FA, Chowdhury IN, Klassen RD (2016) Social management capabilities of multinational buying firms and their emerging market suppliers: an exploratory study of the clothing industry. J Oper Manag 46:19–37
45. Evans L et al (2017) Project to support the evaluation of the implementation of the EU ecolabel regulation – Synthesis report. European Commission. https://op.europa.eu/fi/publication-detail/-/publication/67ba4716-5499-11e7-a5ca-01aa75ed71a1. Accessed 12 Feb 2022
46. Arnett G (2019) What the rise of 'ecolabelling' means for retailers. Vogue business. https://www.voguebusiness.com/sustainability/ethical-labelling-selfridges-net-a-porter-kering-allbirds-kering. Accessed 1 Feb 2022
47. Turunen LLM, Halme M (2021) Communicating actionable sustainability information to consumers: The Shades of Green instrument for fashion. J Clean Prod 297:126605. https://doi.org/10.1016/j.jclepro.2021.126605
48. Härri A, Levänen J, Linnanen L (2022) Circular economy: just sectoral transition in the production and consumption of textiles. In: Leal Filho W, Azul AM, Doni F, Salvia AL (eds) Handbook of Sustainability Science in the Future. Springer, Cham
49. Niessen L, Bocken NM (2021) How can businesses drive sufficiency? The business for sufficiency framework. Sustain Prod Consum 28:1090–1103. https://doi.org/10.1016/j.spc.2021.07.030
50. Willersdorf S et al (2020) The Consumers Behind Fashion's Growing Secondhand Market. BCG. https://www.bcg.com/publications/2020/consumer-segments-behind-growing-secondhand-fashion-market. Accessed 14 Sep 2022
51. Berg A et al (2021) Welcome to luxury fashion resale: discerning customers beckon to brands. McKinsey & Company. https://www.mckinsey.com/industries/retail/our-insights/welcome-to-luxury-fashion-resale-discerning-customers-beckon-to-brands. Accessed 1 Feb 2022
52. Palmer A (2021) Online clothing reseller Poshmark closes up more than 140% on first day of trading. CNBC. https://www.cnbc.com/2021/01/14/poshmark-ipo-posh-starts-trading-on-nasdaq.html. Accessed 15 June 2022
53. Bocken NM, Schuit CS, Kraaijenhagen C (2018) Experimenting with a circular business model: lessons from eight cases. Environ Innov Soc Transit 28:79–95. https://doi.org/10.1016/j.eist.2018.02.001
54. Wijnen R et al (2018) MUD JEANS. A Circular Economy Business Model Case. Universidade de Santiago de Compostela. https://minerva.usc.es/xmlui/handle/10347/20259. Accessed 24 Jan 2022
55. Luoma P, Toppinen A, Penttinen E (2021) The role and value of data in circular business models – a systematic literature review. J Bus Mod 9(2):44–71. https://doi.org/10.5278/jbm.v9i2.3448
56. Nayak R, Singh A, Padhye R, Wang L (2015) RFID in textile and clothing manufacturing: technology and challenges. Fash Text 2(1):1–16. https://doi.org/10.1186/s40691-015-0034-9
57. UN (2021) United Nations Economic Commission for Europe - Recommendation n°46: Enhancing traceability and transparency of sustainable value chains in the garment and footwear sector. https://unece.org/trade/publications/recommendation-no46-enhancing-traceability-and-transparency-sustainable-value. Accessed 24 Apr 2022
58. Meadows D (1999) Leverage Points: Places to Intervene in a System. Sustainability Institute. http://drbalcom.pbworks.com/w/file/fetch/35173014/Leverage_Points.pdf. Accessed 14 May 2022
59. Schmelzer M (2015) The growth paradigm: history, hegemony, and the contested making of economic growthmanship. Ecol Econ 118:262–271. https://doi.org/10.1016/j.ecolecon.2015.07.029
60. Bugden D (2022) Technology, decoupling, and ecological crisis: examining ecological modernisation theory through patent data. Environ Sociol 8(2):228–241. https://doi.org/10.1080/23251042.2021.2021604
61. GAIA (2021) High cost of waste incineration. https://www.no-burn.org/wp-content/uploads/The-High-Cost-of-Waste-Incineration-March-30.pdf. Accessed 15 Dec 2022
62. Chevalier M (2021) The potential of mechanical recycling for post-consumer textiles. Master's thesis,. Saxion University of Applied Sciences
63. Dzhengiz T, Miller E, Ovaska J-P, Patala S (2023) Unpacking the circular economy: a problematizing review. Int J Manag Rev 25:270–296. https://doi.org/10.1111/ijmr.12329
64. Spangenberg JH, Lorek S (2019) Sufficiency and consumer behaviour: from theory to policy. Energy Policy 129:1070–1079. https://doi.org/10.1016/j.enpol.2019.03.013

65. Reike D, Vermeulen WJ, Witjes S (2018) The circular economy: new or refurbished as CE 3.0? — Exploring controversies in the conceptualization of the circular economy through a focus on history and resource value retention options. Resour Conserv Recycl 135:246–264. https://doi.org/10.1016/j.resconrec.2017.08.027
66. Siderius T, Poldner K (2021) Reconsidering the circular economy rebound effect: propositions from a case study of the Dutch circular textile valley. J Clean Prod 293:125996. https://doi.org/10.1016/j.jclepro.2021.125996
67. Zink T, Geyer R (2017) Circular economy rebound. J Ind Ecol 21(3):593–602. https://doi.org/10.1111/jiec.12545
68. Salmenperä H (2023) Governing the transition to circularity of textiles – finnish companies ' expectations of interventions for change. Circ Econ Sust. https://doi.org/10.1007/s43615-022-00238-x
69. Le Feber N, Smit MJ (2023) Fashion companies pioneering with eco-innovations in the Swedish fashion industry: motivations, resources, and cooperation. Circ Econ Sust. https://doi.org/10.1007/s43615-022-00246-x

## Authors and Affiliations

**Olli Sahimaa[1] · Elizabeth M. Miller[2] · Minna Halme[1] · Kirsi Niinimäki[3] · Hannu Tanner[4] · Mikko Mäkelä[5] · Marja Rissanen[6] · Anna Härri[7] · Michael Hummel[8]**

✉ Olli Sahimaa
olli.sahimaa@aalto.fi

Elizabeth M. Miller
emiller@ivey.ca

Minna Halme
minna.halme@aalto.fi

Kirsi Niinimäki
kirsi.niinimaki@aalto.fi

Hannu Tanner
hannu.tanner@vtt.fi

Mikko Mäkelä
mikko.makela@vtt.fi

Marja Rissanen
marja.rissanen@tuni.fi

Anna Härri
anna.harri@lut.fi

Michael Hummel
michael.hummel@aalto.fi

1 Aalto University School of Business, Ekonominaukio 1, P.O. Box 21210, 00076 Aalto, Finland

2 Ivey Business School, University of Western Ontario, 1255 Western Rd, London ON N6G 0N1, Canada

3 Aalto University School of Arts, Design and Architecture, PO BOX 31000, 00076 Aalto, Finland

4 VTT Technical Research Centre of Finland Ltd., P.O. Box 1100, 90571 Oulu, Finland

5 VTT Technical Research Centre of Finland, Ltd., PO Box 1000, 02044 VTT Espoo, Finland

6 Tampere University of Applied Sciences, Kuntokatu 3, 33520 Tampere, Finland

7 LUT University, Mukkulankatu 19, 15210 Lahti, Finland

8 Aalto School of Chemical Engineering, Department of Bioproducts and Biosystems, Vuorimiehentie 1, 02150 Espoo, Finland