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ACHIEVING SUSTAINABILITY IN THE CONTEXT OF MASS PERSONALISATION

Ann-Kathrin Briem[1], Thomas Betten[1], Michael Held[2], Daniel Wehner[2], Michael Baumann[2]
[1]Institute for Acoustics and Building Physics (IABP), University of Stuttgart, Stuttgart, Germany
[2]Fraunhofer Institute for Building Physics (IBP), Stuttgart, Germany

Abstract: *Driven by individualisation as a trend and enabled by increasing digitalisation, mass personalisation will go beyond today's mass customisation. However, the sustainability achievements of current manufacturing technology could be compromised by this trend. Small lot sizes are likely to increase per piece manufacturing efforts, and reusability and recyclability might be limited. Nevertheless, personalised products can address user demands much better and hold great sustainability potential. Therefore, sustainability aspects should be considered from the start and a framework for sustainable mass personalisation developed. This paper illustrates these questions and the potentials and risks regarding sustainability through example scenarios.*

Key Words: ***Sustainability, Life Cycle Assessment, Environmental, Mass Personalisation, User, Risks, Potentials, Example Scenarios, Return Logistics, Passenger Transport, Electric Vehicle***

1. INTRODUCTION

The way most products are manufactured changed significantly over time. This change becomes clear when looking at two parameters: the degree of process automation and the degree of product variety. While back in the 1800s custom-tailored products could be found on a broad scale but only afforded by few people (high variety, low automation), Henry Ford's production revolution started the shift to standardised products for the masses in the early 20th century (low variety, high automation). Recent advancements of production technologies have led to mass customisation (MC) combining high automation with high product variety. Furthermore, today's manufacturing landscape is increasingly shaped by regionalisation and globalisation leading to highly complex systems [1].

At the same time, the digital age, making this development possible in the first place, offers new opportunities for producers to utilise data and address user demands. Furthermore, the trend for individualisation has been growing in society for the last decades. Users now desire individual and personalised products to satisfy their needs. Driven by individualisation as a trend and enabled by increasing digitalisation, mass personalisation (MP) will be the next step where user demands are addressed directly and the user can even be integrated into the production process, increasingly becoming a "prosumer" [2].

The challenges arising with this paradigm shift are addressed within the High-Performance Center "Mass Personalization", a cooperation of the four Fraunhofer institutes in Stuttgart, the University of Stuttgart and industry partners [3,4]. The focus of the three initial pilot projects within the High-Performance Center "Mass Personalization" not only lies on developing and improving key enabling technologies for MP, but also on ensuring sustainable development in this context. Within pilot project 2 "Personalized Living Spaces", focused on the personalisation of building and automotive environments, the potential risks and also chances for improvement of the environmental performance of (mass-) personalised products are investigated. For this purpose, the method of Life Cycle Assessment (LCA) is applied in this work. Furthermore, the research focus of the project is put on investigating the socio-economic framework conditions necessary for the MP trend as well as providing users with relevant information for decision making regarding the environmental effects of their choices [4].

This paper shortly introduces the methodology of Life Cycle Assessment according to ISO 14040/44 [5,6]. Furthermore, risks and potentials of MP regarding sustainability are summarized based on existing literature and quantified by two example scenarios using LCA. Finally, the research needs and planned developments within the High-Performance Center "Mass Personalization" are outlined.

2. LIFE CYCLE ASSESSMENT METHODOLOGY

LCA is an established and widespread methodology for evaluating the environmental impacts of a product system (a physical product or a service). The methodology of attributional LCA is internationally standardised in ISO 14040 and 14044 [5,6] and is directly used in product development, but also in planning, policy-making and marketing. The method comprises the following four phases, which are described briefly below in their main objectives [5,6]:

- Goal and scope definition: The goal of the study is defined and according to the goal the functional unit and system boundaries are set. Data requirements are identified and potential limitations are assessed.
- Inventory analysis: The identified data is collected and processed according to the goal and scope of the study.
- Impact assessment: The impact categories (e.g. Global Warming Potential) are selected including the appropriate characterisation models. Afterwards, the results of the inventory analysis are classified and characterised.
- Interpretation: The results are interpreted and prepared for the target audience.

The methodology of LCA is highly iterative and very flexible during its implementation. The complete framework including all phases is shown in Fig. 1. Another important feature of an LCA is the life cycle perspective including all stages from resource extraction to disposal into the assessment, thus no unnoticed burden shifting is possible within the system boundaries.

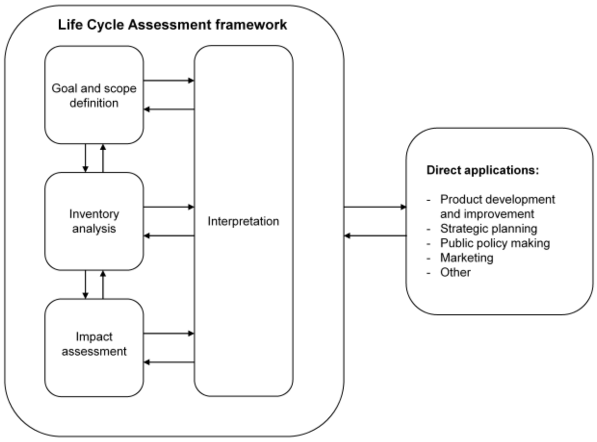

Fig. 1. *Stages of the LCA methodology framework [5,6]*

Attributional LCA traditionally comes from a static and retrospective view on the product life cycle, yet, due to its flexibility and iterative character it is capable of adapting to the requirements of the agile environment of MP. Further information about LCA can be found in [7] and [8].

LCA can only be one tool to assess sustainability within the context of MP, as a flexible and agile framework will be needed to adopt holistic life cycle thinking and include all interrelations, such as the user influence at different stages of the product life cycle. Yet, due to the robustness and maturity of the method, this study focusses on LCA as a tool.

3. RISKS AND POTENTIALS OF MP REGARDING SUSTAINABILITY

MP is a powerful concept enabling the user to influence the environmental impacts of a product or service significantly, whereas conventionally this was mainly the case on the producer side. Due to this shift in power, it will be harder to locate and assess the environmental impacts. Thus, the risks and potentials of MP can only be understood within its socio-economic context, which needs to be examined regarding sustainability. The MP trend is strongly influenced by different stakeholders, including politics, industry, academia and the user as the key stakeholder.

MP in its full extend creates a direct link between user and producer by collecting and transmitting data within the use phase. The use phase mostly plays an important role in the product life cycle, especially from an LCA perspective. Effects of the information from the use phase can create secondary effects on personalisation (e.g. changes in the product development phase). All these interrelations can have positive or negative impacts on the sustainability of a product.

These effects of MP on sustainability have been a research topic in the last decade. While most older studies address one aspect of MC and mainly focus on economic sustainability, recent studies increasingly address environmental sustainability in the context of MC and MP [9,10]. For example, Hora et al. [11] provide a generic framework proposal with several business model patterns for sustainable MC. Trentin et al. [12] empirically investigate how MC and green management are interconnected and conclude that synergies exist between the two paradigms. Fornasiero et al. [13] integrate LCA into the supply chain management of customised products to evaluate the sustainability of different options. Pourabdollahian et al. [10] focus on identifying impact factors of MC on environmental sustainability using a product life cycle approach, propose a research agenda and emphasise the need for quantitative studies in this context.

Based on the authors' research and in accordance with the literature mentioned above, and in particular Pourabdollahian et al. [10], possible risks and potentials for sustainability within MP are listed. Both lists have no claim to comprehensiveness. Possible challenges for the environmental sustainability within MP are:

- Higher energy and resource intensity of personalised compared to conventional production (lot-size 1 production, loss of economy of scale benefits, products with additional features, etc.).
- Limitation of lifetime to one user due to a high degree of personalisation minimising the reusability of the product.
- Potentially high(er) environmental impacts of new production technologies (additive manufacturing, 3D-printing, rapid prototyping, etc.) compared to conventional manufacturing.
- Indirect impacts through digital personalisation and associated computational power and its energy demand.
- Current waste / recycling processes might not be suited for the increased product variety and variance in material composition of personalised products.

Besides these risks, MP also holds great potentials and opportunities for environmental sustainability. Some are listed in the following:

- Resource use minimisation (less features, less materials, optimised material use, due to specific user needs and new production technologies, such as additive manufacturing, 3D-printing, rapid prototyping, etc.).
- Energy efficiency in use phase (smart devices, personalised use pattern, etc.).
- Reduction of negative environmental impacts in general due to secondary effects through changed product use patterns.
- Better understanding of (environmental) impacts through real-time assessments and immediate action to minimise these impacts.

The mentioned theoretical risks and potentials are based on abstract ideas and various different scenarios and single effects can therefore be contradictory to each other. Thus, specific effects need to be evaluated for individual examples. This resulting shift of the current research focus towards the quantification of specific phenomena within the trend of MP is also in accordance with the research agenda proposed in [10].

Within this work, two examples of MP are underlined with quantitative LCA results to develop an understanding for the possible effects and interrelations. The first example examines the overall effect of MP on the return logistics of consumer products and the associated environmental burdens. The second example evaluates an approach to select passenger cars according to the driving behaviour of the respective user taking into account the environmental impacts associated with each option.

4. APPLICATION OF LCA IN THE CONTEXT OF MASS PERSONALISATION

Actions are taken globally to reduce CO_2-emissions and other pollutants. In the EU, one area of focus is the transport sector, as it is the leading source of air pollution in cities and contributes to around 25 % of greenhouse gas emissions in Europe [14]. Measures to reduce these emissions include a higher transport efficiency as well as low-emission and locally emission-free vehicles [14].

The focus of the following examples is put on the influence of (mass) personalisation in the (road) transport sector. Two illustrative example scenarios from this field were selected for this initial investigation. These example scenarios are of theoretical nature and purposely kept simple. They are meant to point out some of the relevant risks and potentials of MP in the context of sustainability.

4.1 EXAMPLE SCENARIO 1: Logistics of personalised consumer products

Consumer products, such as shoes or clothing, are considered in this example scenario. These products are increasingly ordered online through e-commerce platforms and sent in packages to the end user. The return policies usually allow returning the products within a given timeframe without additional costs. The return rate is especially high for clothing items and shoes with values of up to 50 % [15,16]. Due to the high return rate and the product variety offered by online retailers such as Amazon or Zalando, the return logistics are often costly and complex. For personalised products the return rate very likely decreases significantly, because users are more inclined to keep an item that is personalised to their individual wishes and sizing problems are less likely. A return rate of zero (assuming a functional product) is also viable within MP. At the moment the return policies of many companies offering customised products is strict and only allows a return if the product is defective [17]. Therefore, the amount of returns under MP is likely to be significantly reduced. The following examples show the potential of this effect for saving greenhouse gas (GHG) emissions.

According to [15], 250 million packages are returned annually in Germany, generating 123,667 t of CO_2-emissions through transport alone. This number does not include further operations caused by the returned items.

Another example can be found in the annual report 2017 of one of the big European online retailers, which states that the corporate carbon footprint equals 2.54 kg CO_2-equivalent (CO_2-eq.) per order and that 55 % of these GHG emissions can be traced back to outbound logistics including returns [18]. It is not stated how high the return rate is or which specific operations of the return logistics are taken into account. However, it is assumed that the return rate is around 50 % [19,20].

Assuming that a returned order causes twice the amount of emissions due to logistical effort (delivery and return) compared to one that is retained by the user (only delivery), a GHG saving potential can be calculated for this case. 90.5 million orders were handled by the examined online retailer in 2017 in Europe resulting in approximately 126,429 t CO_2-eq.[1] caused by outbound logistics operations. These emissions could be reduced significantly if the return rate is minimised. The following theoretical scenarios are meant to show this potential.

Depending on the return rate, different shares of the total GHG emissions can be traced back to returned and retained orders, respectively. These ratios are shown in Fig. 2. The striped bars indicate the emissions from returned orders and therefore the potential to reduce GHG emissions through lower return rates associated with MP. A high reduction potential is found for the current high return rate of 50 %.

[1] 55 % of the carbon footprint of 90.5 million orders (2.54 kg CO_2-eq. per order) [18]

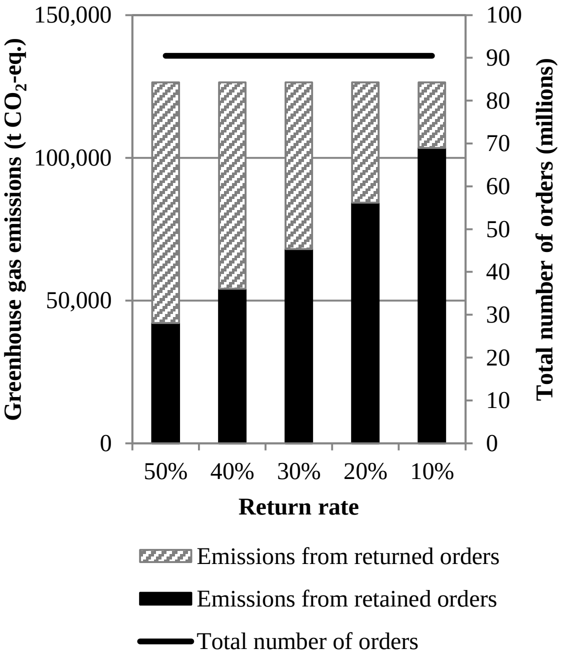

Fig. 2. *Share of emissions caused by outbound logistics of returned and retained orders for different return rates (and constant 90.5 million orders in total)*

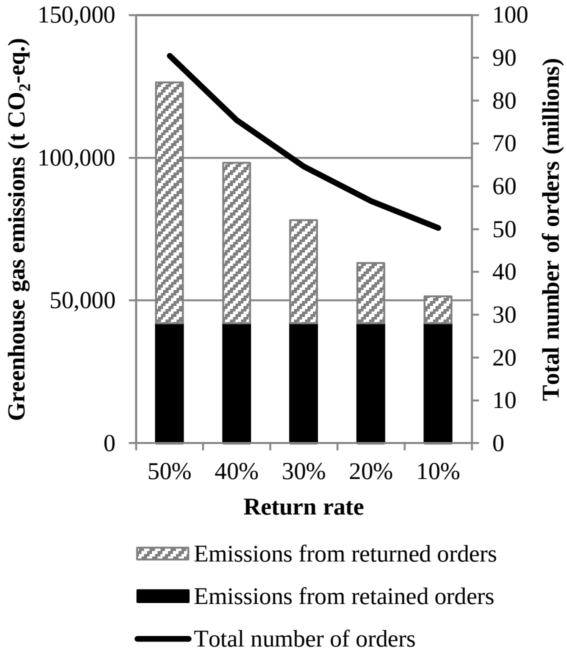

Fig. 3. *Share of emissions caused by outbound logistics of returned and retained orders for different return rates (and constant 45.25 million retained orders)*

Considering that the number of retained orders represents the actual need of the customers, it is assumed that this number stays constant under MP. For this case, the emissions for lower return rates at constant retained orders can be calculated. Assuming that the current return rate is 50 % for 90.5 million total orders, the actual demand would be 45.25 million orders. Based on this constant demand, the emissions for different return rates and the resulting total number of orders are shown in Fig. 3. With a decreasing return rate the GHG emissions of the returns decrease from approximately 85,000 t CO_2-eq. (50 % return rate) to approximately 10,000 t CO_2-eq. (10 % return rate). At the same time the total number of orders decreases from 90.5 million to roughly 50 million.

The results clearly show the high potential that lies in the reduction of the return rate of consumer products through personalisation. Comparing the “status quo” results (50 % return rate) of this example with the results for a return rate of 10 % reveals that, while the carbon footprint of each order can be reduced by approximately 25 %, the GHG emissions of the total number of orders are reduced by almost 60 %. This effect is due to the lower number of total orders. However, these results only include the emissions from outbound logistics. Additional steps resulting in even higher emissions of returned items, such as washing and repackaging, are not taken into account here. Furthermore, a lower number of total orders due to a lower return rate would also influence other areas of a corporation. It can be assumed that these effects would lead to a higher efficiency in at least some of these areas as well, therefore likely further reducing the overall corporate carbon footprint.

4.2 EXAMPLE SCENARIO 2: Vehicle selection based on personal driving behaviour

One alternative for passenger transport to conventional fossil fuelled vehicles are battery electric vehicles (BEVs). These vehicles offer the advantage of being locally emission-free, thus improving urban air quality. How much and under which circumstances these vehicles can contribute to a reduction of GHG emissions depends mainly on the electricity used for charging. This has been verified by various studies, such as [21] and [22].

Personalisation could play a key role in enabling the full potential of electric vehicles. Besides customisation or personalisation regarding design options, the battery system of the BEV could be scaled to the actual demand of its designated user, potentially saving resources required to produce a standardised (possibly oversized) system. Furthermore, by analysing the user behaviour, ideal vehicles or vehicle combinations regarding the user needs and the environmental performance could be selected. Thus, this example scenario aims at personalising the vehicle selection to the user behaviour from an environmental point of view. Therefore, the following example scenario is a more abstract view on MP, as it examines how optimisation regarding the use phase and predicted usage patterns can minimise environmental impacts of personal transport.

First, the statistical driving behaviour of car owners in Germany is investigated in order to classify these users into groups with different demands. Subsequently, an LCA is implemented for different vehicle options and driving profiles. Finally, the most environmentally friendly solution satisfying the needs of each user group is found and evaluated.

4.2.1 Identification of current user behaviour

The average German car owner has an annual mileage of 15.320 km corresponding to a daily mileage of 42 km [23]. Table 1 shows the distribution of the annual mileage over the different mileage classes in Germany for the year 2016 [23] and the classification into three user types defined for this example. Table 2 shows the average annual and daily mileages (based on [23]), and the share of urban, rural and highway driving (based on [24]) for the three classified user types.

Table 1. *Classification of users based on the annual mileage of German car owners [23]*

Annual mileage (km)	**Daily average (km)**	**Share (%)**	**User classification**
< 5,000	< 13.7	5	**A** (24 %)
5,000-9,999	20.5	19	
10,000-12,999	31.5	27	**B** (49 %)
13,000-15,999	39.7	18	
16,000-19,999	49.3	4	
20,000-24,999	61.6	13	**C** (27 %)
25,000-29,999	75.3	5	
> 30,000	> 82.2	9	

The three user types are characterised as follows:

- Type A: This user group is characterised by short routes with an average daily mileage of 19.1 km. It is assumed that most of the travelled routes are urban and that longer distances are avoided or preferably not driven by car, but by other means of transport.
- Type B: This is the most common user type in Germany. It is assumed that this person has a high share of urban driving, but also travels on routes with higher distances occasionally.
- Type C: The longest distances are travelled by users of this group. It is assumed that a high share of routes is rural and highway driving.

Table 2. *Average mileage for each user type (based on [23]) and share of urban, rural and highway traffic (own assumptions based on [24])*

User type	**Mileage (km)**		**Share (%)**		
	1/a	**1/d**	**urban**	**rural**	**highway**
A	7,000	19.1	80	15	5
B	13,100	36.0	50	30	20
C	25,900	71.0	25	35	40

4.2.2 Selection of vehicles

Six generic vehicles are available: two conventional vehicles (petrol and diesel powered) and one BEV in two sizes each (mini and compact class). The main vehicle parameters, such as weight, average consumption (for each user group) and battery capacity for the BEVs are summarised in Table 3.

Table 3. *Vehicle parameters (adapted from [24])*

Vehicle	**Weight (kg)**	**Average consumption**			
		User group			**Unit**
		A	**B**	**C**	
Mini class					
BEV (14 kWh)	960	12.8	15.4	18.2	kWh/ 100 km
CV (petrol)	850	5.7	5.6	5.7	l/100 km
CV (diesel)	870	4.2	3.9	3.7	l/100 km
Compact class					
BEV (40 kWh)	1,540	16.2	18.5	21.2	kWh/ 100 km
CV (petrol)	1,307	6.7	6.6	6.7	l/100 km
CV (diesel)	1,370	5.2	4.9	4.8	l/100 km

BEV *battery electric vehicle*
CV *conventional vehicle*

4.2.3 Implementation into LCA

All generic vehicles are modelled in the “GaBi ts” software and database system [25]. The system boundary is illustrated in Fig. 4. The following points are taken into account:

- Production of vehicles and fuels including the respective background systems
- Combustion of conventional fuels
- Electricity demand of BEVs (the German grid mix and electricity from wind power are evaluated)
- Recycling and disposal efforts without recycling credits

The functional unit is 1 km of passenger transport and a lifetime of 12 years for the vehicles is assumed.

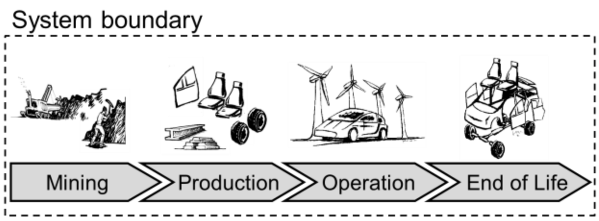

Fig. 4. *System boundary (illustration by [26])*

Due to the screening character of this study, the impact assessment is limited to the Global Warming Potential (GWP_{100}) according to the CML methodology [8]. Relevant emissions are converted to CO_2-equivalents (CO_2-eq.) according to characterisation factors [27] and added up. Table 4 provides an overview over the GWP_{100} of the analysed fuels (including electricity).

Table 4. *GWP_{100} of fuels used in the scenarios [25]*

Fuel	GWP_{100}	Unit and Comment
Petrol	2780	g CO_2-eq./litre production and combustion
Diesel	2918	
Electricity (GER grid mix)	543	g CO_2-eq./kWh average of dynamic grid mix (12 years)
Electricity (from wind power)	9	g CO_2-eq./kWh wind power in Germany

CO_2-eq. *CO_2-equivalents*
GER *German(y)*
GWP_{100} *Global warming potential (100 years)*

4.2.4 LCA results

The results of user group A and C are presented first. User group B is analysed in further depth in the end.

Results for user group A

The results for the GWP_{100} for user group A are shown in Fig. 5. It is assumed that mini-class vehicles are preferred by this user group and thus only the results for the evaluated mini-class vehicles are shown in the figure for a better overview. The results of the compact-class vehicles are higher compared to the respective mini-class vehicles due to higher impacts from production and a higher consumption of the compact-class vehicles. Furthermore, the range of the mini BEVs (approximately 90 km based on the average consumption of user group A and considering a maximum state of discharge of the battery of 80 %)[2] is considered sufficient for this user group due to the average daily mileage of 19.1 km.

The petrol vehicle shows the highest results at the end of a 12 year lifetime with an annual mileage of 7,000 km. The second highest lifetime results can be observed for the diesel vehicle. The BEVs start with a higher burden from the production mainly due to the battery system, but have overall lower impacts at the end of their lifetime compared to the conventional vehicles. Depending on the technology used to generate the electricity, the impacts are between 11 % lower (German grid mix) and 52 % lower (wind power). The break-even point with the diesel vehicle occurs at approximately 56,000 km if the BEV is charged from the German grid or at approximately 23,000 km if electricity from wind power is provided. Both break-even points are likely reached by the typical user of group A within the lifetime of the vehicle.

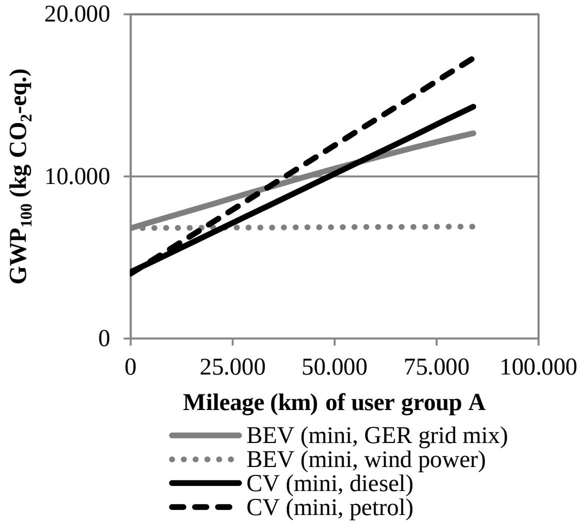

Fig. 5. *Global Warming Potential for user group A with different mini-class vehicles*

Results for user group C

The results for the GWP_{100} for user group C can be found in Fig. 6. It is assumed that this user group prefers compact-class vehicles over mini-class vehicles. Therefore, only the results for the evaluated compact-class vehicles are shown. Furthermore, the range of a mini BEV (approximately 60 km based on the average consumption of user group C) would not be sufficient to satisfy the needs of this group.

The results show that the compact petrol vehicle has the highest GWP_{100} results after a lifetime of 12 years. The BEV has lower results than the petrol vehicle and slightly lower results compared to the diesel vehicle if the electricity is supplied by the German grid mix. However, in this case the break-even point occurs at approximately 300,000 km just before the end of life. Therefore, it cannot be recommended to use the BEV instead of the diesel vehicle due to the late break-even point that might not be reached in some cases. Furthermore, the range of the evaluated compact BEV is approximately 150 km at average consumption. This range is theoretically sufficient for the average daily mileage of 71 km but could be seen as challenging for longer routes that this user will likely drive regularly.

In the case that the BEV could be supplied with electricity from renewable sources and if the range is not seen as challenging, it is worth considering this option instead of the diesel vehicle. The wind powered compact BEV offers GHG emission reductions of over 70 % compared to the compact diesel vehicle with the break-even point at approximately 52,000 km.

[2] All range calculations consider a maximum state of discharge of the battery of 80 %.

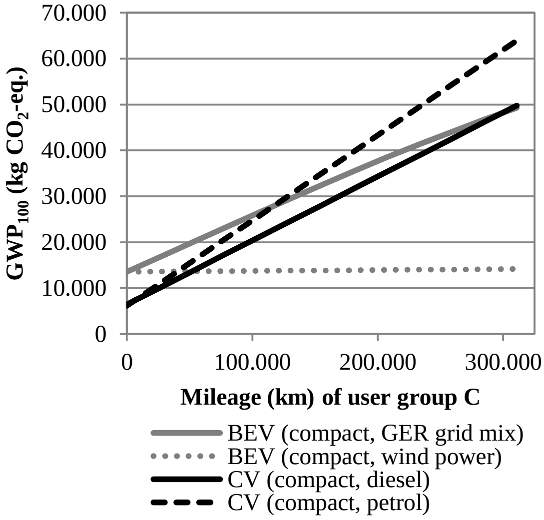

Fig. 6. *Global Warming Potential for user group C with different compact-class vehicles*

Results for user group B

User group B is the largest and most diverse of the three groups (see Table 1). Due to the high uncertainties for this group as a whole, more specific scenarios are required.

Therefore, a concept is assessed, where users own a mini BEV for urban driving and are supplied with a diesel vehicle for routes with longer distances. In this case the latter is part of a car sharing concept, which is not discussed in further depth for this study. It is assumed that the diesel vehicle can be supplied when needed and that user acceptance is high. Table 5 summarises the parameters for the evaluated scenarios for user group B.

Table 5. *Scenarios for user group B*

Scena-rio	Vehicle(s)	Con-sumption	Mileage BEV ($km_{el.}$/a)	Mileage CV (km_{cv}/a)	SF
BA	mini BEV	average B	13,100	0	-
B1	combina-tion of mini BEV and compact diesel CV	BEV: urban CV: average B	10,000	3,100	0.20
B2			7,500	5,600	0.25
B3			6,550	6,550	0.33
B4			5,000	8,100	0.50
B5			2,500	10,600	1
BC	compact diesel CV	average B	0	13,100	-

BEV — *Battery electric vehicle*
CV — *Conventional vehicle*
$km_{el.}$/a — *km driven electrically (BEV) per year*
km_{CV}/a — *km driven diesel powered (CV) per year*
SF — *Sharing factor*

The German grid mix is taken into account for the electricity supply and the total mileage is 13,100 km per year over a lifetime of 12 years in all scenarios. The sharing factor (SF) applies to scenarios B1-B5 and indicates the share of the burdens from the production of the shared diesel vehicle allocated to the user depending on the number of people sharing one vehicle. For example, while five people share the diesel vehicle in scenario B1 resulting in SF = 0.2 (20 % of the burdens from the production are allocated to the user), the diesel vehicle is exclusive to the user in scenario B5 (SF = 1).

Scenario BA relates to users of group B that are close to user group A in their behaviour. A mini BEV with the average consumption and mileage of group B is taken into account, as it is likely that the range of the mini BEV would be sufficient for these users. Similarly, scenario BC relates to users of group B that are close to users of group C and would benefit from the range of a conventional vehicle.

The results for user group B are displayed in Fig. 7. The effect of the sharing concept depends on two independent parameters: the ratio between electric and diesel powered driving and the sharing factor regarding the diesel vehicle. Generally, the overall greenhouse gas emissions decrease if the electrically driven mileage increases. This is due to the low consumption of the BEV under urban conditions. For example, in scenario B4 5,000 km/a are driven with a mini BEV (which is less than the annual mileage of user group A) and the diesel compact vehicle is shared with only one other person (SF = 0,5) leading to lower lifetime emissions compared to scenario BC, where only the diesel vehicle is used. Scenario B5, on the other hand, shows that if the mileage of the BEV is relatively low (2,500 $km_{el.}$/a in this case) and the diesel CV is not shared, the combination is not sufficient to achieve lower emissions. However, if the sharing factor is lower (i.e. more people sharing the vehicle), the results decrease significantly. For the mileage distribution of scenario B5 (2,500 $km_{el.}$/a and 10,600 km_{cv}/a), SF = 0,25 is required to yield lower lifetime emissions compared to scenario BC.

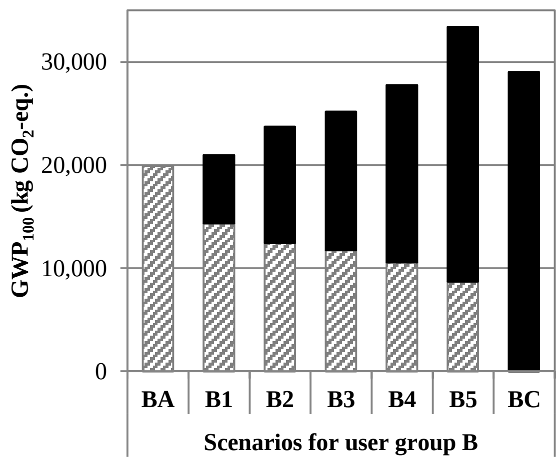

Fig. 7. *Global Warming Potential for different scenarios of user group B*

This example demonstrates that, based on the individual users and their driving patterns, personalised vehicle or vehicle combination can be selected regarding the environmental performance. Depending on the user's values, this might be an important factor to include during the personalisation process.

5. CONCLUSIONS

The concept of MP evolves with and centres on the individual user. Thus, the way we produce and use products and services will change significantly. This development bears potentials and also risks on different levels including impacts on the environment.

This paper focusses on two simple example scenarios about possible developments within MP to demonstrate these potentials and risks. The first example scenario assesses potential effects of MP on the return logistics in the online retail business. A simple back of the envelope calculation examines the environmental impacts (i.e. GHG emissions) in the context of avoided order returns and shows significant mitigation potentials for lower return rates. This could be achieved through tools and techniques of MP (e.g. virtual dressing room or sizing based on user data). Furthermore, this quantitative example underlines the qualitative findings in the literature regarding return logistics, such as mentioned by [10], and therefore contributes to closing the research gap in this regard.

The second example scenario examines how individual transport choices influence the environmental impacts. In the example scenario, users have the choice between conventional and battery electric vehicles (with preselected vehicle options). Based on the behavioural patterns of different user groups, the GWP results can differ significantly, according to their vehicle selection. Within MP, users could be supported (e.g. by software) in their choices based on their personal preferences and behaviour.

The present example only considered the passenger vehicle choice. However, in order to unlock higher emission reduction potentials, other transport options should be considered as well. In a study by Anagnostopoulou et al. [28] users are supported in their transport choices for urban routes by a mobile application for route planning. Different route options and transport modes (car, bike, public transport, walking) are suggested based on the users' personality and "mobility type". The overall aim is to persuade users to choose more environmentally friendly options by informing them about the CO_2-profile of their choices and by displaying persuasive messages, again based on a personalisation algorithm. The authors report successful persuasion, but reveal a bias of their study in the fact that mostly already eco-conscious users took part in it. Assuming that not every user prefers a more environmentally friendly option in any circumstances and at all costs, information about the environmental consciousness and awareness of each individual user needs to be investigated in order to personalise successfully. In this context, Hankammer et al. [29] propose an optimization model for a configurable product based on the customer's sustainability preferences in all three dimensions (economical, environmental, social). Similarly, the authors point out that the limitations of the proposed framework lie within the knowledge of the user regarding the applied sustainability concept, highlighting the necessity to empower the user by providing relevant information to enable informed decision making.

In the present study, both example scenarios demonstrate the significance of MP for environmental sustainability. In the first example scenario the trend creates an indirect effect by avoiding unnecessary order returns and in the second example scenario the user choice could be assisted directly to mitigate environmental impacts. As can be seen in these two simple scenarios, decisions can become complex quite quickly. The complexity increases if a subject, such as sustainability, is the object of the decision-making process, as it is less tangible compared to conventional and common decision-support quantities, such as time or monetary value.

MP is a threat to sustainability, but also an opportunity. Effects and issues similar to the ones discussed in this paper will also arise in other fields and topics related to MP. Thus, the trend needs to be moderated to ensure a favourable impact on sustainability. For this purpose in general, the users require tools to express and evaluate their own environmental consciousness, needs and values.

Yet, the whole socio-economic framework of MP needs to be taken into consideration, when assessing its sustainability. Within this socio-economic framework two directions of personalisation can be seen by the authors:

- Businesses create personalised products or services for the user.
- Users give feedback via articulated choices and demands or via user data and influence the life cycle of the product.

The tools and methods to assess sustainability within MP need the ability to model both of these information streams. Furthermore, MP affects sustainability in two different ways:

- Effects created within society as a whole.
- Effects created by single users, by individual and informed decision making.

When evaluating sustainability both aspects need to be taken into consideration.

6. OUTLOOK AND RESEARCH NEEDS

First of all, sustainability cannot be reduced to impacts on climate change alone. Therefore, environmental assessments with a broader scope than screening need to include other environmental impact categories and dimensions, such as resource consumption and social aspects, as well.

As described above, MP will integrate the user into the product development process and various decisions in the use phase. However, the user needs to be addressed in a simple and comprehensible (possibly even personalised) way, so interfaces addressing the user's needs and enabling interaction between the user and producer will be required.

This study only focused on broad user groups or the whole customer group, yet, already demonstrated potentials to increase environmental sustainability.

Looking at individual users could unlock even greater potential. Simultaneously, user data will become much more diverse (e.g. lot-size 1 or individualised use phase) and to deal with these data, techniques of data science (e.g. artificial intelligence, big data) and psychology (e.g. user and behavioural models) need to be embedded within the available and future tools for environmental assessment.

As mentioned above, one established and robust tool for environmental assessment is LCA. In traditional LCA, the focus is mostly put on the production phase of a product, but with MP a much stronger focus on the use phase will be needed, as significant differences between single users can be expected. This will require more agile approaches within the LCA methodology to address this development.

As a consequence of the user being the key stakeholder in MP, the acquisition and use of user data will be essential as an enabler. Legal and ethical issues around data security will be of interest for all involved parties and need to be ensured in every tool and process.

Some of the described challenges are addressed in the High-Performance Center "Mass Personalization". To address and understand the phenomena of MP holistically all stakeholders need to be involved, including academia, politics, industry and of course the user. In order to achieve this, intensive exchange with politics is needed to ensure beneficial implementation of MP needs into laws and regulations. Industry is needed for joint projects or strategic partnerships to ensure best connectivity of concepts developed with academia to current technologies and easy implementation. And last but not least, it is essential to understand the user and her or his needs. This networking aspect is at the core of the High-Performance Center "Mass Personalization" and will unfold its full potential over the project period and its follow-up projects.

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CORRESPONDENCE

Ann-Kathrin Briem
Institute for Building Physics
University of Stuttgart
Department of Life Cycle Engineering (GaBi)
Wankelstraße 5
70563 Stuttgart, Germany
ann-kathrin.briem@iabp.uni-stuttgart.de

Thomas Betten
Institute for Building Physics
University of Stuttgart
Department of Life Cycle Engineering (GaBi)
Wankelstraße 5
70563 Stuttgart, Germany
thomas.betten@iabp.uni-stuttgart.de