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Limits to Consumption: Sustainable Consumption Considering Planetary Boundaries

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Abstract: Limits to Consumption: Sustainable Consumption Considering Planetary BoundariesLimits to Consumption: Sustainable Consumption Considering Planetary Boundaries

This paper presents the results of the second work package of the project "Limits of Consumption: Sustainable Consumption Considering Planetary Boundaries" conducted on behalf of the German Environment Agency. The focus of the work package was the quantification of consumption boundaries for Germany, illustrated through different consumption patterns.

Within the framework of the project, eleven goods or mixed goods (product basket) were selected that are representative of the consumption areas ofmobility, housing, leisure, clothing and food. The goods considered are milk, passenger car, public transport, (electric) bicycle, air travel, pet, living space, household appliances (white goods), cotton, ICT devices and electricity. For these goods, the environmental impacts relevant within the concept of planetary boundaries, based on the publication by Steffen et al. (2015), were determined. The background system of the GreenSupreme RESCUE scenario1 was used to map the environmental impacts that still exist even after the transformation towards a greenhouse gas-neutral society (Dittrich et al. 2020). For the consumption area food, the Lancet study by Willet et al. (2019) was used complementary. Additionally, variations for three goods (cars, cotton and housing) were examined.

Consumption patterns were elaborated that are compatible with today's patterns. For this purpose, average ranges of today's demand of private households for the above goods or product baskets were researched and typical patterns identified.

Based on the average demand of private households for the goods in the GreenSupreme RESCUE scenario, the typical consumption patterns of today were transferred and the environmental impacts relevant within the planetary boundaries were calculated in a specially designed "consumption calculator". If the environmental impacts exceeded the planetary boundaries, the consumption quantity was changed until the planetary boundaries were met. The identified consumption patterns within the planetary boundaries were thus, presented in the form of six different personas. These personas, or consumption patterns, are largely sustainable and predominantly within the planetary boundaries. This emphasizes that a good life is possible within the planetary boundaries. However, the results also show that the central consumption areas, food, housing and mobility, are of particular environmental relevance. In the future, private consumption must be adapted accordingly in at least one of the central consumption areas. Subsequently, the developed personas in this project can be used for orientation and identification in this regard.

Kurzbeschreibung: Die Grenzen des Konsums: Nachhaltiger Konsum unter der Berücksichtigung von Planetaren Grenzen

In dieser Publikation werden die Ergebnisse des zweiten Arbeitspaketes des Projektes „Grenzen des Konsums: Nachhaltiger Konsum unter der Berücksichtigung von Planetaren Grenzen" vorgestellt, das im Auftrag des Umweltbundesamtes durchgeführt wurde. Im Fokus des Arbeitspakets stand die Quantifizierung von Konsumgrenzen für Deutschland, die anhand verschiedener Konsummuster dargestellt werden.

Im Rahmen des Projekts wurden elf Güter bzw. Mischgüter (Warenkorb) ausgewählt, die repräsentativ für die Konsumbereiche Mobilität, Wohnen, Freizeit, Bekleidung und Ernährung sind. Bei den betrachteten Gütern handelt es sich um Milch, Pkw, öffentliche Verkehrsmittel, (Elektro-)Fahrrad, Flugreisen, Haustiere, Wohnfläche, Haushaltsausstattung (weiße Ware),

[1] UBA (2019): RESCUE scenario GreenSupreme; URL: https://www.umweltbundesamt.de/en/topics/climate-energy/climate-protection-energy-policy-in-germany/a-resource-efficient-greenhouse-gas-neutral-germany/rescue-scenario-greensupreme

Baumwolle, IKT-Geräte und Strom. Für diese Güter wurden die im Rahmen des Konzepts der planetaren Grenzen relevanten Umweltbelastungen in Anlehnung an die Veröffentlichung von Steffen et al. (2015) ermittelt. Hierfür wurde das Hintergrundsystem des Szenarios GreenSupreme genutzt, um die Umweltwirkungen, die auch nach einer Transformation hin zu einer treibhausgasneutralen Gesellschaft bestehen, abzubilden (Dittrich et al. 2020). Für den Konsumbereich Ernährung wurde ergänzend die Lancet-Studie von Willet et al. (2019) genutzt. Zusätzlich wurden Varianten für drei Güter (Pkw, Baumwolle und Wohnen) untersucht.

Zudem wurden Konsummuster recherchiert, die an heutige Muster anschlussfähig sind. Hierzu wurden durchschnittliche Spannweiten der heutigen Nachfrage von privaten Haushalten nach den obigen Gütern bzw. Gütergruppen recherchiert und typische Muster identifiziert.

Ausgehend von der durchschnittlichen Nachfrage der privaten Haushalte nach den Gütern bzw. Mischgütern im GreenSupreme RESCUE-Szenario wurden die typischen Konsummuster von heute übertragen und die im Rahmen der planetarischen Grenzen relevanten Umweltwirkungen in einem eigens dafür entwickelten „Konsumrechner" berechnet. Überschreiten die Umweltbelastungen die planetaren Grenzen, wurde die Nachfragemenge verändert, sodass die planetaren Grenzen eingehalten wurden. Die identifizierten Konsummuster innerhalb der planetaren Grenzen wurden in Form von sechs verschiedenen Personas dargestellt. Diese Personas bzw. Konsummuster sind weitgehend nachhaltig und liegen überwiegend innerhalb der planetaren Grenzen. Dies unterstreicht, dass ein gutes Leben innerhalb der planetaren Grenzen möglich ist. Die Ergebnisse zeigen aber auch, dass die zentralen Konsumbereiche Ernährung, Wohnen und Mobilität von besonderer Umweltrelevanz sind. In Zukunft muss der private Konsum in mindestens einem der zentralen Konsumbereiche entsprechend angepasst werden. Die in diesem Projekt entwickelten Personas können zur Orientierung und Identifikation in dieser Hinsicht genutzt werden.

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BEV	Battery electric vehicle
BMU	Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (*germ. Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz*)
CCS	Carbon Capture and Storage
CH	Switzerland
CH_4	Methane
CO_2	Carbon dioxide
CO_2-eq.	Carbon dioxide equivalent
CPB	Concept of Planetary Boundaries
CSP	Concentrated solar power
DE	Germany
DRI	Direct reduced iron
FAO	Food and Agriculture Organisation of the United Nations
GDP	Gross domestic product
GHG	Greenhouse gases
GLO	Global
ICT	Information and communications technology
IPCC	Intergovernmental Panel on Climate Change
ISIC	International Standard Industrial Classification
IÖR	The Leibniz Institute of Ecological Urban and Regional Development (*germ. Leibniz-Institut für ökologische Raumentwicklung e.V.*)
IVH	German Pet Supplies Industry Association (*germ. Industrieverband Heimtierbedarf*)
kWh	Kilowatt hour
LCA	Life-cycle assessment
LULUCF	Land use and land use change
N	Nitrogen
N_2O	Nitrous oxide
NIR	National emission Inventory Report
P	Phosphor
PHEV	plug-in hybrid vehicle
pkm	Passenger kilometre
PtG	Power-to-Gas
PtL	Power-to-Liquids
PV	Photovoltaics
RER	Rest of Europe, EU-28 without Germany
RoW	Rest of World, World without EU-28

SDG(s)	Sustainable Development Goal(s)
SNG	Synthetic natural gas
SSP	Shared Socioeconomic Pathways
UBA	German Environment Agency (*germ. Umweltbundesamt*)

1 Introduction

1.1 Background and objectives of the project

For decades, the use of natural resources has been increasing with rising prosperity and population. Since 1970, global raw material extraction has more than tripled (WU Vienna 2021), while freshwater abstraction has increased by almost 60 % between 1970 and 2010 (FAO 2021) and forest cover has declined by 178 million ha (net) since 1990 (FAO 2020). This has led to the increase of various environmental pressures, including climate change, acidification and soil degradation, to an extent that there is a risk of overstraining ecological systems and ecosystems reaching their tipping-points. The consequence would be that the Earth would become more inhospitable to humans and life as we know it today.

The limits to the carrying capacity of the Earth's ecosystems are described by the concept of planetary boundaries. The concept was first developed by Rockström et al. (2009) and further developed by Steffen et al. (2015). It describes nine dimensions that are central to the resilience of Earth systems. For the dimensions of climate change, stratospheric ozone depletion, ocean acidification, biogeochemical flows (phosphorus and nitrogen), freshwater use, land-system change and genetic diversity (as part of the dimension of biosphere integrity), global boundaries had already been concretised and control variables defined at the time at which most of the project’s work took place. Meanwhile, proposals for concrete boundaries and control variables for the dimension novel entities have also been made available (Persson et al. 2022). For the dimensions of atmospheric aerosol loading and functional diversity (as the second part of the dimension of biosphere integrity), no exact boundaries have been defined so far.

This concept is the starting point for the research project. The aim is to quantify concrete consumption levels that lie within the planetary boundaries. This is done with a focus on different environmental impacts or dimensions of the concept of planetary boundaries, as well as regarding different goods and services. The project thus aims to identify future consumption patterns that are globally generalisable and lie within the selected planetary boundaries.

1.2 Structure and goals of the work packages

The project is divided into four work packages:

- In work package 1, relevant literature is summarised.
- In work package 2, consumption boundaries are quantified for Germany in the form of different consumption patterns.
- In work package 3, the consumption patterns identified in the previous work package are compared with global growth dynamics.
- In work package 4, the research results are presented and published for different target groups.

1.3 Structure of the report

This report documents the work and results of the second work package.

Chapter 2 explains the procedure and methodology. This includes the selection of the background scenario and the representative goods, the selection of the relevant values for the planetary boundaries, the implementation of the scenario assumptions in LCAs and the derivation of representative consumption patterns.

In chapter 3, the concept of planetary boundaries is operationalised for the research question by deriving the concrete boundaries that will be used in the project.

Chapter 4 presents the interim results for the representative goods. This includes the changes in the environmental impacts of the representative goods that are relevant for the concept of planetary boundaries.

Chapter 5 documents the intermediate results for today's average citizen. Based on the current average consumption of the representative goods, the environmental impacts relevant for the planetary boundaries are calculated and compared to the boundaries.

Chapter 6 documents the interim results for the average citizen of the GreenSupreme scenario. The environmental impacts relevant for the planetary boundaries, caused by the consumption changes assumed in the scenario, are calculated considering the technological changes and are put in relation to the selected planetary boundaries.

In chapter 7, accessible consumption patterns are presented and explained.

Chapter 8 concludes, identifying the limitations of the results and points out the need for further research.

2 Methods

The aim of the work package is to identify six consumption patterns in an already de-fossilised world that do not exceed the planetary boundaries. Further, the consumption patterns should be generalisable for consumption patterns in Germany. To this end, several work steps were carried out, which are described in this chapter.

At the beginning of the project, it was agreed:

- to make use of the concept by Steffen et al. (2015) as far as possible for the concretisation of the planetary boundaries where possible. The concept is a further development of Rockström et al. (2009). In recent years, further research on the concept of planetary boundaries has taken place, in which, among other things, individual dimensions ofthe concept have been concretised or other boundary values have been proposed. However, none of the more recent work is as comprehensive as that of Steffen et al. (2015) and a review of all ongoing discussions was not feasible within the scope of this project. One exception was agreed upon: the Lancet study (Willett et al. 2019) on healthy diets was used as the basis for the consumption area food.

- the GreenSupreme scenario (Dittrich et al. 2020; UBA 2019a) is used as the background narrative for the de-fossilised world (see excursus below). With current production systems and in the face of ongoing climate change, current consumption patterns are not sustainable, so the urgency to transform energy supply, industrial processes, agriculture and many other sectors of the economy is obvious (e.g. IPCC (2021, 2022a; b))[2]. For a sustainable and technically feasible production system in 2050, the Green scenarios provide good and detailed background data that consider all relevant positions of the German Environment Agency (e.g. the exclusion of CCS or the renunciation of an energetic use of primary biomass). Six Green scenarios are available. The GreenSupreme scenario is the most ambitious scenario and comes closest to achieving the goal of keeping the global temperature increase to a maximum of 1.5 °C. Due to the very far-reaching technological changes, it also offers the greatest scope for different consumption patterns.

Excursus: the GreenSupreme scenario[3]

The GreenSupreme scenario (**G**ermany – **re**source **e**fficient and greenhouse gas **n**eutral – Minimizing future greenhouse gas emissions and raw material consumption) describes a very rapid and ambitious transformation path towards a greenhouse gas-neutral and resource-efficient Germany in 2050.

GreenSupreme brings together policy measures, changes in technology and lifestyle changes. In GreenSupreme, energy efficiency potentials are mostly realised and renewable energies are expanded rapidly. For example, the share of renewable energies in electricity supply increases to 86 % by 2030 and to 97 % by 2040. The direct use of electricity, whether via battery-electric vehicles or heat pumps in the private sector and in industrial processes, enables comparatively low-loss use of energy. The use of fossil raw materials is cut back very rapidly, with coal-fired power generation being phased out as early as 2030 and no more utilization of coal in industry by 2040. In the fuel supply sector, innovations are promoted, and technologies are developed early on, so that around 63 TWh of sustainable electricity-based fuels will be imported by 2030. The

[2] Compliance is theoretically only possible under consumption patterns that, in our view, are not accessible to German consumption patterns.

[3] A detailed description can be found in Dittrich et al. (2020) and UBA (2019a).

chemical industry is also increasingly supplied with synthetically produced raw materials. In 2050, fossil raw materials will no longer be used.

Improvements in material efficiency across all technologies and economic sectors, combined with high product quality and long product lifetimes, lead to goods and products that are resource-saving. This includes, for example, resource-efficient construction methods, substitution of emission- or material-intensive raw materials with emission-free or lower-emission and more sustainable raw materials and the significantly increased use of secondary raw materials.

People are also changing their consumption habits. For example, they eat less meat and overall healthier, live in smaller spaces and make greater use of bicycles, public transport and sharing services for their journeys. In addition, they are increasingly demanding sustainable, durable and repairable products, so that the overall demand for goods is decreasing.

The technological changes and the changes in demand lead to changes in the overall economic production. In contrast to other Green scenarios, which assume an annual GDP growth of 0.7%, GreenSupreme assumes a growth exemption in Germany, i.e. zero annual GDP growth, from 2030 onwards.

The above-mentioned changes in technologies and lifestyles towards a transformation to a greenhouse gas-neutral and resource-efficient economy are taking place not only in Germany, but worldwide. As a result, the emission intensity and raw material consumption decreases for imports and upstream chains of raw materials, semifinished products and final goods.

In GreenSupreme, greenhouse gas emissions are reduced by about 97 % by 2050 compared to 1990. Additionally, if natural sinks in agriculture and forestry (LULUCF) are considered, reductions of up to around 104 % are possible. By 2030, a reduction of greenhouse gases (GHG) of 69 % and by 2040 of 88 % compared to 1990 can be achieved (without LULUCF).

In GreenSupreme, the use of primary raw materials can be reduced by 70 % by 2050 compared to 2010. The demand for fossil raw materials drops to zero. The demand for mineral raw materials also decreases significantly, but the demand for specific technology metals required for key technologies such as car batteries, wind power or PV systems increases.

The further work steps consisted of the concretisation of the planetary boundaries, the selection and concretisation of the representative goods, the calculation of life cycle assessments of these goods under the conditions of GreenSupreme 2050, the calculation of environmental impacts relevant for the planetary boundaries and finally the identification of sustainable consumption patterns. The methods are described below.

2.1 Concretisation of the planetary boundaries

The planetary boundaries concept proposes concrete boundary values for Earth for eight out of nine dimensions. Disaggregation to countries can be carried out according to different principles (Dittrich et al. 2021; Keppner et al. 2020):

- The boundary values can be distributed equally among all (living) people according to the principle of equality.
- The boundary values can be distributed according to the principle of historical responsibility. Countries that have used more natural resources in the past or that have

"polluted" the planet more are now entitled to fewer resources or "pollution rights" than countries that have used fewer resources or contributed less to pollution.

- The boundary values can also be distributed among countries according to the principle of the right to development. Here, the level of development of a country is considered: developed countries have a stronger responsibility and higher capabilities than less developed countries.
- The boundary values can also be divided according to the principle of sovereignty. In this case, "grandfathering" is assumed: the current shares of total pollution or use of natural resources are continued.

In this project, a distribution according to the principle of equality was chosen. For this purpose, the population forecast of the scenario Shared Socioeconomic Pathway 1 (SSP 1, see excursus) was used, as this scenario comes closest to the narrative of GreenSupreme. According to this scenario, the global population in 2050 will be 8.479 billion people.

Excursus: the Shared Socioeconomic Pathways[4]

The Shared Socioeconomic Pathways (SSPs) describe framework assumptions for global developments that have been defined for the modelling of greenhouse gas emissions, so that results of different modelling approaches become more comparable.

Key assumptions on the development of population, economic activities and settlement development, assumptions on the level of ambition in mitigating greenhouse gas emissions and assumptions on the response to climate change for different world regions were condensed into five narratives. These were further translated into a set of scenarios, considering uncertainties and variabilities.

SSP 1 describes a sustainable development path. All regions worldwide are pushing for a transformation towards an economy that respects environmental limits. Development is more inclusive, and inequalities within and between countries are gradually reduced. The well-being of all people is central.

SSP 2 describes a middle ground. Historical trends are mostly continued: development and income growth are uneven, some countries are making good progress, others are falling short. International institutions support the SDGs, but progress is slow. Some environmental pressures are worsening, but there are also improvements.

SSP 3 describes a path with strong regional rivalries. National policies are increasingly oriented towards national (or regional) security issues, also at the expense of broader development. As a result, economic development is slow overall, and inequalities persist or worsen. Environmental protection is a low priority internationally, leading to severe degradation of the natural environment in some regions.

SSP 4 describes an unequal development path. Unequal investment in education and the economy is leading to increasing inequalities within and between countries. The gap between an internationally connected society working in knowledge- and capital-intensive sectors and fragmented groups of low-income, poorly educated populations in low-tech sectors is widening.

[4] A detailed description can be found in van Vuuren et al. (2017) and Riahi et al. (2017).

Social cohesion deteriorates, conflicts and unrest increase. Environmental policies focus on local problems in middle- and high-income areas.

SSP 5 describes a fossil development path. The development of competitive markets, innovations, technological progress and a participatory society are central. This happens based on the exploitation of existing fossil raw materials and the spread of energy- and resource-intensive lifestyles all over the world. Local environmental problems such as air pollution are being successfully tackled, and there is confidence in the abilities to manage social and ecological systems effectively, including with geoengineering. (Riahi et al. 2017; van Vuuren et al. 2017)

The per capita boundaries for the relevant environmental impacts can currently be quantified for the dimensions of climate change, freshwater use, land-system change, biochemical flows (phosphorus and nitrogen flows), ocean acidification (impact chain runs indirectly via CO_2 emissions) and for the dimension of stratospheric ozone depletion (see chapter 3). For the other dimensions of the planetary boundaries concept, either no exact boundary is yet defined (e.g. atmospheric aerosol loading), or the boundary cannot be sufficiently clearly related to human activities in the impact chain (biosphere integrity) (Dittrich et al. 2021).

2.2 Selection of representative goods

To concretise the consumption patterns, goods were selected that represent different consumption areas sufficiently well. The consumption areas include food (largely covered by the Lancet study), mobility, leisure, clothing, housing and communication. The goods were chosen in such a way that they could be scaled. The following goods were selected:

1. **In the consumption area of food, milk** was selected to complement the Lancet study. Since most of the environmental impacts in the production of dairy products occur during the production of milk, milk is sufficiently representative of all dairy products.
2. **In the consumption area mobility**, three goods/services were chosen: the **car**, the **(e-) bicycle** and **public transport** (local and long-distance as a mixed service) in the unit of passenger kilometres (pkm). With the three modes of transport, mobility consumption patterns can be scaled and varied sufficiently well.
3. In the **consumption area leisure, air travel** (pkm) and **pets** were selected.
4. The **consumption area of clothing** is represented by **cotton** and **synthetic fabrics**, each as a quantity of fabric, not as a piece of clothing.
5. In the **consumption area of housing**, living space (m^2) derived from an average house based on Deilmann et al. (2017) and a mix of household appliances was chosen.
6. In the **area of communication**, a mix of ICT devices was selected.
7. **Electricity** was chosen as as a cross-sectional good.

For the representative goods, current LCA data sets were selected from the ecoinvent Database[5]. The database contains around 19,000 data sets, in which the most suitable inventories for the representative goods were identified. As far as possible and available, data sets from Germany were selected. The following table 1 shows the selected goods:

[5] https://ecoinvent.org/the-ecoinvent-database/

Table 1: Selected data sets for the representative goods

Consumption area	Representative good	Data set
Food	milk	market for cow milk, GLO, cow milk, kg, 2009–2020
Mobilität	(conventional) car	market for transport, passenger car with internal combustion engine, RER, transport, passenger car with internal combustion engine, km, 2012–2020
	(e-) car	market for transport, passenger car, electric, GLO, transport, passenger car, electric, km, 2000–2020
	e-bicycle	market for transport, passenger, electric bicycle, GLO, transport, passenger, electric bicycle, person*km, 2011–2020
	public transport: long-distance rail transport	transport, passenger train, DE, transport, passenger train, person*km, 2000–2020
	public transport: local rail transport	market for transport, tram, GLO, transport, tram, person*km, 2011–2020
	public transport: bus transport	market for transport, regular bus, GLO, transport, regular bus, person*km, 2011–2020
Leisure	air travel	transport, passenger, aircraft, all distances to generic market for transport, passenger, unspecified, GLO, transport, passenger, aircraft, unspecified, person*km, 2016–2020
	pet	wet dog food, RER, Wet dog food, kg, 2021–2021
Clothing	cotton	market for textile, woven cotton, GLO, textile, woven cotton, kg, 2011–2020
		market for textile, knit cotton, GLO, textile, knit cotton, kg, 2005–2020
	synthetic fabrics	textile production, non-woven polyester, needle punched, RoW, textile, non-woven polyester, kg, 2014–2020
		market for textile, non-woven polypropylene, GLO, textile, non–woven polypropylene, kg, 2013–2020
	other substances (for plausibility check)	market for fibre, viscose, GLO, fibre, viscose, kg, 2011–2020
		market for textile, jute, GLO, textile, jute, kg, 2011–2020
Housing	living space	market group for concrete, medium strength, GLO, concrete, medium strength, m3, 2019–2020
		market for gypsum fibreboard, GLO, gypsum fibreboard, kg, 2011–2020
		market for gypsum plasterboard, GLO, gypsum plasterboard, kg, 2011–2020
		market for stone wool, packed, GLO, stone wool, packed, kg, 2011–2020

Consumption area	Representative good	Data set
		market for ceramic tile, GLO, ceramic tile, kg, 2011–2020
		steel production, electric, low–alloyed, Europe without Switzerland and Austria, steel, low–alloyed, kg, 2013–2023
		market for cable, unspecified, GLO, cable, unspecified, kg, 2005–2020
		structural timber production, RER, structural timber, m3, 2012–2020
		flat glass production, coated, RER, flat glass, coated, kg, 2000–2020
		flat glass production, uncoated, RER, flat glass, uncoated, kg, 1996–2020
		clay brick production, RER, clay brick, kg, 1992–2020
		market for autoclaved aerated concrete block, RoW, autoclaved aerated concrete block, kg, 2011–2020
		roof tile production, RER, roof tile, kg, 1992–2020
		market for polystyrene foam slab for perimeter insulation, GLO, polystyrene foam slab for perimeter insulation, kg, 2009–2020
		sand–lime brick production, DE, sand–lime brick, kg, 1993–2020
		market for glass wool mat, GLO, glass wool mat, kg, 2011–2020
		market for glass wool mat, uncoated, Saint–Gobain ISOVER SA, CH, glass wool mat, uncoated, Saint–Gobain ISOVER SA, kg, 2018–2020
		window frame production, poly vinyl chloride, U=1.6 W/m2K, RER, window frame, poly vinyl chloride, U=1.6 W/m2K, m2, 1996–2020
		market for vinyl chloride, RER, vinyl chloride, kg, 2018–2020
		market for natural stone plate, cut, GLO, natural stone plate, cut, kg, 2011–2020
		market for cement cast plaster floor, GLO, cement cast plaster floor, kg, 2011–2020
		market for cement mortar, RoW, cement mortar, kg, 2011–2020
		market for copper, cathode, GLO, copper, cathode, kg, 2011–2020
		market for aluminium, wrought alloy, GLO, aluminium, wrought alloy, kg, 2011–2020

Consumption area	Representative good	Data set
		market for wood wool, RER, wood wool, kg, 2019–2020
		market for oriented strand board, RER, oriented strand board, m3, 2019–2020
		market for cellulose fibre, RoW, cellulose fibre, kg, 2012–2020
		market for particleboard, uncoated, RER, particleboard, uncoated, m3, 2019–2020
		consumer electronics production, mobile device, smartphone, GLO, consumer electronics, mobile device, smartphone, unit, 2014–2021
	household appliances	market for coffee maker, GLO, coffee maker, unit, 2018–2020
		market for cookstove, GLO, cookstove, unit, 2018–2020
		market for washing machine, GLO, washing machine, unit, 2018–2020
		market for refrigerator, GLO, refrigerator, unit, 2018–2020
		dishwasher production, GLO, dishwasher, unit, 2007–2020
		market for washing, drying and finishing laundry, GLO, washing, drying and finishing laundry, kg, 2013–2020
	furniture (for plausibility check)	market for furniture, GLO, furniture, wooden, kg, 2017–2020
Communication	ICT devices	market for television, GLO, television, unit, 2018–2020
		market for printer, laser, colour, GLO, printer, laser, colour, unit, 2011–2020
		market for router, internet, GLO, router, internet, unit, 2011–2020
		market for computer, laptop, GLO, computer, laptop, unit, 2011–2020
		consumer electronics production, mobile device, tablet, GLO, consumer electronics, mobile device, tablet, unit, 2014–2021
	paper products (for plausibility check)	paper production, newsprint, recycled, CH, paper, newsprint, kg, 2012–2020
Cross-section	electricity	market for electricity, low voltage, DE, electricity, low voltage, kWh, 2014–2020

Source: own compilation based on ecoinvent V3.7.1

Based on the selection above, mixed goods were formed where necessary. Different data sources for the quantities used were consulted for weighting. These are presented together with the environmental impacts in chapter 4.

We estimated the share of greenhouse emissions covered by the representative goods as follows: The average emissions according to the CO_2 calculator (as of December 2023) were used for current emissions. These amount to 10.34 tonnes of CO_2-eq. per person. If we exclude the consumption area of food, the emissions amount to 8.56 tonnes of CO_2-eq. per person. If we calculate the emissions from the representative goods (excluding milk) using data on average consumption quantities, we arrive at emissions of 5.86 tonnes of CO_2. This implies that the representative goods cover around 2/3 of the emissions, although the coverage varies for the individual consumption areas and we only consider the CO_2 emissions and not the other greenhouse gases for the representative goods.

For the year 2050, the consumption-related CO_2 emissions per person from the GreenSupreme-scenario (RESCUE) were used as a comparative value. These amount to 450 kg CO_2-eq. including food. Around 330 kg of these are CO_2-eq. emissions from agriculture (of which 300 kg are methane and nitrous oxide). This results in CO_2 emissions of 120 kg per person (excluding food). The CO_2 emissions from the representative goods of the average person (excluding food and cotton) are 69 kg of CO_2 emissions. This means that the share of representative goods in 2050 is around 58 %.

This value was checked for plausibility by estimating the CO_2 emissions not covered by the representative goods in 2050. As the energy-related emissions are assumed to be 0, these are mainly process-related emissions from industry due to cement, lime and glass, e.g. for the construction and maintenance of public buildings and infrastructure and industry/factories that are not proportionally allocated to one of the representative goods. These emissions are estimated at around 76 kg CO_2. This figure is shown as the base contribution for 'other goods'.

Unfortunately, such an estimate cannot be made for the other environmental impacts due to a lack of scenarios for 2050.

2.3 Method for determining environmental impacts of the representative goods in 2050

The environmental impacts of the goods were calculated based on the ecoinvent life cycle assessment database. For this purpose, database version 3.7.1 (from December 2020) was used in the 'Cut-Off' system model and adapted to the GreenSupreme scenario from RESCUE for 2050. This complex development work was carried out together with the partner ecoinvent association and was realised in the UBA project REFINE (Dittrich et al. 2024a; b). A comprehensive documentation of the methodology is provided in the REFINE report and in the methodological paper (Liebich et al. 2023). The following sections describe the main features and the most important assumptions of the procedure.

The ecoinvent version 3.7.1 life cycle assessment database consists of more than 18,000 individual data sets. The existing data sets usually describe individual technical processes – with their input and output flows between them and the technosphere (above all intermediate products and waste) or the ecosphere (raw materials and emissions). These processes are interlinked, based on assumptions of global production linkages. The database is updated annually, incorporating new data sets.

Technically, the database is constructed as a square matrix of processes. Changes to individual processes in the database and the effect on inputs from upstream process steps in the supply chain can be mapped. For example, the technical conversion of pig iron production to DRI (sponge iron) processes, reduction with hydrogen and subsequent steel production in the electric arc furnace has an impact on the environmental profile of steel production. If steel products are needed for goods of higher processing, the "new" steel is then used.

The adaptation of the ecoinvent database is based on the assumptions for the year 2050 of the GreenSupreme scenario in RESCUE. In the REFINE project, a selection of these assumptions was applied to the ecoinvent dataset (Dittrich et al. 2024a; b; Liebich et al. 2023).The focus in the REFINE project was on the energy sector, so assumptions were changed for key technologies and processes that are particularly relevant for the energy system. This includes the transfer of new and changed technologies that have been added or modified in the database (in total about 300 records, and 70,000 parameters). New processes included are water electrolysis (incl. production of electrolyser) for H_2, direct air capture plant for CO_2, Fischer-Tropsch synthesis PtL (mainly petrol and diesel replacement), methanation PtG (SNG), methanol synthesis (directly from CO_2 and H_2), ammonia from H_2 and N_2, DRI steel production with H_2 as reducing agent and overhead line infrastructure for trucks. The LCAs for wind power plants (onshore/offshore), PV plants (ground-mounted/rooftop), Li-ion battery (in 2050 as Li-S battery), CSP power plants and geothermal power plants were updated.

A very relevant change within the transformation process takes place in the electricity sector. The electricity mixes determined in the GreenSupreme scenario were transferred to the electricity markets in ecoinvent. Extensive model calculations were carried out for Germany in the RESCUE project. The resulting 2050 electricity mix is mainly composed of wind energy (75 %) and photovoltaics (18 %). The electricity mixes of all other countries were also modified in ecoinvent. As a data basis for this, the REFINE project used the publication "Achieving the Paris Climate Agreement Goals" by Dr. Sven Teske (Teske 2019) and the "Pathway for +1.5 °C" scenario described there. The results data were kindly made available to us directly by the publisher. From this, the two regions "Europe without Germany" and "World without Europe" were derived. The electricity mixes in both regions have comparatively lower shares of wind energy in 2050 (42 % and 32 %, respectively) and higher shares of PV (23 % and 31 %, respectively) than Germany. Hydropower is thus 11 % in (rest of) Europe and 7 % in the rest of the world. Biomass also plays a relevant role in Europe with 9 % and in the rest of the world with 5 %. Solar thermal power plants generate about 4 % of the electricity in (rest of-) Europe and as much as 14 % in the rest of the world. The share of geothermal power plants is also important in both regions and is about 5 % in each case. The newly determined electricity mixes were used in the REFINE project in ecoinvent in approx. 170 electricity markets.

According to the GreenSupreme scenario, the electricity and heating demand decreases in all consumption areas. Where technically feasible, heat is provided electrically. The demand for high-temperature heat is still partly covered by the power-to-gas (PtG) products hydrogen and methane. Due to the high effort of transferring the assumptions into the ecoinvent data, the focus of the processing in the REFINE project was placed on processes in industrial sectors that were particularly greenhouse gas intensive and at the same time central to energy technologies. These are the processes of metal production (steel, aluminium, copper), cement and chemicals (processes with ISIC codes 21, 22, 23). Recycling assumptions from GreenSupreme were adopted for the metals zinc and lead, as well as iron/steel, copper and aluminium. For the latter three base metals, the assumptions on the recycling share were updated in the REFINE project and adopted here. The assumption on the improvement of material efficiency (1.2 % per year) was transferred to data sets available in ecoinvent for machinery and packaging. For sectors that have not been stored with specific assumptions in GreenSupreme, the GreenSupreme scenario lists energy savings of 51 % in industrial sectors and 41 % for trade, commerce and services. In ecoinvent, affected processes were filtered out via the ISIC code[6] and modified accordingly.

[6] ISIC: 'International Standard Industrial Classification' = International Standard Classification of Economic Activities

According to the scenario, the non-energetic use of fossil raw materials will also be converted in 2050. For petroleum products and natural gas, which are currently used as feedstock, power-to-liquid (PtL) products from Fischer-Tropsch synthesis or PtG methane will be used.

The selected scenario also envisages strong changes in the transport sector by 2050:

- Passenger cars are completely battery-electric and utilize a lithium-sulphur battery with a high-energy density (350 Wh/kg).
- Light commercial vehicles are also 100 % BEV (battery electric vehicles) in 2050.
- For heavy-duty vehicles up to 32 t, plug-in hybrid (PHEV) vehicles are assumed that use PtL diesel in the combustion engine.
- Lorries and articulated lorries with a permissible gross weight of more than 32 t are most important for freight transport in terms of transport performance. In the GreenSupreme scenario, these vehicles are designed as trolley trucks that mainly drive electrically on motorways. The assumed electric driving share amounts to 65 % on average. PtL-fuel is used as diesel replacement.
- Emissions from combustion engines comply with the EURO 6d emission standard worldwide.
- In aviation and shipping, fossil fuel is also replaced by PtL-fuels.

Among other things, it was not possible to transfer the specific assumptions in the agriculture and forestry sectors, in the glass and lime industry as well as in the textile and paper industry, other recycling assumptions (on technology and precious metals, on building materials, glass, paper and plastics), the extensive changes in building construction and civil engineering as well as assumptions on lightweight construction.

In total, about 70,000 values in data sets were changed or newly created in the database as part of the adaptation of ecoinvent to the GreenSupreme scenario 2050. It should be considered that a change in one dataset, such as electricity production, has a very strong impact on all other datasets, so that the high figures mainly show the extent to which the above-mentioned changes have an impact on other datasets. Ecoinvent has introduced check routines for the technical transfer of the data, which help to avoid systematic errors. In addition, the changes were recorded in the database. After transferring the data to the database, the matrix was recalculated by ecoinvent and the results were transferred to ifeu. Checking the results was a major challenge for everyone involved. Each recalculation generates over 18,000 result data sets, each with about 2,100 elementary flows and 25 indicator results. However, a large number of results is not matched by any reference results from other LCA calculations, so that a direct comparison was not possible. Therefore, a plausibility check of the results was carried out for 60 data sets corresponding to the goods from this project. In the selected scenario, it is known from the RESCUE results that CO_2 emissions from fossil sources are generally reduced by at least 95 % compared to 2020 (with exceptions, e.g. for clinker production, which releases CO_2 from carbonates in the calcination process). In addition, the use of fossil energy sources is excluded globally in the scenario, so that the CED (Cumulative Energy Demand) indicator for fossils must be zero in 2050. Furthermore, the 25 indicators were evaluated for all data sets and compared with the 2020 reference to identify statistical anomalies. A total of 20 iteration loops had to be carried out up to the point where the result for all selected goods appeared predominantly plausible. During the iteration loops, assumptions of the original ecoinvent data set in individual life cycle assessments also had to be changed, as they produced implausible results. For example, every type of mobility in GreenSupreme 2050 led to the growth of forest area. This is obviously nonsensical. The reason is an assumption on the use of closed landfills where road debris is deposited; i.e. the assumption is not necessarily wrong and certainly reasonably justified in the context of the LCA on roads used, but it leads to nonsensical results as the assumption may not be representative of all landfills where road debris is deposited. During the iteration loops the assumption on landfills with road debris was changed. An examination of the influence of all assumptions made in the database, which do not produce obviously implausible results, could not be performed. The median reduction in fossil CO_2 emissions in the results dataset used is 97 % based on the number of LCAs (the reduction in GHG emissions in the GreenSupreme scenario is volume-weighted). The remaining CO_2 emissions mainly come from carbonates, for example in the production of cement.

2.4 Relevant environmental impacts in the context of the planetary boundaries

In the next step, the calculated life cycle inventories of the selected goods were evaluated regarding the flows that are relevant for the planetary boundaries (Dittrich et al. 2021). For this purpose, the following relevant elementary flows are extracted from the life cycle inventories (see table 2). Where necessary, conversions are made, for example the conversion of nitrogen oxide to nitrogen, and positive and negative effects are offset, for example in the conversion of land from or to forest.

At the time of processing, the dimensions of climate change, freshwater use, land-system change and biochemical flows (nitrogen and phosphorus) could be determined.

Table 2: Overview of the elementary flows used from Ecoinvent Life Cycle Inventories

Planetary dimension	Elementary flows
Climate change	Carbon dioxide, fossil, non-urban air or from high stacks Carbon dioxide, fossil, low population density, long-term Carbon dioxide, fossil, unspecified Carbon dioxide, fossil, urban air close to ground Carbon dioxide, fossil, lower stratosphere + upper troposphere
Freshwater use	Water, lake Water, river Water, unspecified natural origin, water Water, unspecified natural origin, ground Water, well, in ground
Land-system change	Transformation from forest, from forest, extensive Transformation from forest, from forest, intensive Transformation from forest, from forest, primary, non-use Transformation from forest, from forest, secondary, non-use Transformation from forest, from forest, unspecified Transformation from forest, from unspecified Transformation from forest, from unspecified, natural, non-use Transformation to forest, to forest, extensive Transformation to forest, to forest, intensive Transformation to forest, to forest, secondary, non-use Transformation to forest, to forest, unspecified Transformation to forest, to unspecified Transformation to forest, to unspecified, natural, non-use

Nitrogen flows	Ammonia, non-urban air or from high stacks Ammonia, unspecified Ammonia, urban air close to ground Ammonia, low population density, long-term Nitric oxide, unspecified Nitrogen oxides, non-urban air or from high stacks Nitrogen oxides, unspecified Nitrogen oxides, lower stratosphere + upper troposphere Nitrogen oxides, low population density, long-term Nitrates, unspecified Nitrates, urban air close to ground Nitrate, non-urban air or from high stacks Nitrate, low population density, long-term
Phosphorus flows	Phosphourus, unspecified Phosphourus, urban air close to ground Phosphourus, low population density, long-term Phosphouric acid, urban air close to ground Phosphorous acid, non-urban air or from high stacks Phosphourus acidtrichloride, urban air close to ground

Source: Dittrich et al. (2021)

2.5 Theoretical and empirical foundations for consumption patterns

Before the consumption patterns were developed, the theoretical basis was laid with a literature research. Search terms such as "consumption patterns", "climate-neutral lifestyles", "household consumption" or similar were used to look for relevant studies. The following studies were examined in more detail:

- Ahlert, G.; Hoffmann, F.; Meyer, M.; Walter, H.; Buhl, J.; Greiff, K.; Lettenmeier, M.; Liedtke, C.; Schipperges, M.; Steger, S.; Teubler, J. (2015): Global nachhaltige materielle Wohlstandsniveaus – Analyse und Veranschaulichung global nachhaltiger materieller Versorgungspfade auf der Ebene von Haushalten. Umweltbundesamt, Dessau-Roßlau. *https://www.umweltbundesamt.de/publikationen/global-nachhaltige-materielle-wohlstandsniveaus* (13.08.2021).

- BMU; UBA (2019): Umweltbewusstsein in Deutschland 2018. Ergebnisse einer repräsentativen Bevölkerungsumfrage. Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit und Umweltbundesamt, Dessau-Roßlau. *https://www.umweltbundesamt.de/publikationen/umweltbewusstsein-in-deutschland-2018* (13.08.2021).

- Froemelt, A.; Dürrenmatt, D. J.; Hellweg, S. (2018): Using Data Mining To Assess Environmental Impacts of Household Consumption Behaviors. In: *Environmental Science & Technology*. American Chemical Society. Vol. 52, No. 15, S. 8467–8478. DOI: *10.1021/acs.est.8b01452*.

- Matasci, C.; Gauch, M.; Böni, H. (2019): Material- und Energieflüsse der schweizerischen Volkswirtschaft. Mit Bewertung der Umweltbelastungen (Projekt MatCH – Synthese). Empa - Materials Science & Technology. *https://www.dora.lib4ri.ch/empa/islandora/object/empa%3A20917/* (13.08.2021).

- Onel, N.; Mukherjee, A.; Kreidler, N. B.; Díaz, E. M.; Furchheim, P.; Gupta, S.; Keech, J.; Murdock, M. R.; Wang, Q. (2018) Tell me your story and I will tell you who you are: Persona perspective in sustainable consumption. In: *Psychology & Marketing*. Vol. 35, No. 10, S. 752–765. DOI: *10.1002/mar.21132*.

- Teubler, J.; Buhl, J.; Lettenmeier, M.; Greiff, K.; Liedtke, C. (2018): A Household's Burden – The Embodied Resource Use of Household Equipment in Germany. In: *Ecological Economics*. Vol. 146, S. 96–105. DOI: *10.1016/j.ecolecon.2017.10.004*.

- UBA (2014a): Klimaneutral leben – Verbraucher starten durch beim Klimaschutz. Ratgeber, Umweltbundesamt, Dessau-Roßlau. S. 28. *https://www.umweltbundesamt.de/publikationen/klimaneutral-leben* (13.08.2021).

The studies were evaluated using the following guiding questions:

1. What is the objective of the publication?
2. Which consumption patterns/household types/personas/milieus are distinguished or identified?
3. Which properties are used to characterise consumption patterns?
4. What methodology is used to develop the consumption patterns?

In addition, statistical data was researched and evaluated, which can be used as a point of reference for developing the consumption patterns. The basis for the consumption patterns is the average person from the GreenSupreme scenario of the RESCUE study, the derivation of which is presented in chapter 6. Statistical data are used to determine the approximate ranges for the individual goods. They can be used to determine by which factor the consumption amounts differ for the individual personas and which values represent realistic minimum and maximum values. It must be considered, however, that in GreenSupreme extensive behavioural changes with an influence on consumption are assumed. In addition, a slightly higher income per capita is assumed in GreenSupreme so that it can be assumed that consumption expenditure will also increase slightly in relation to today.

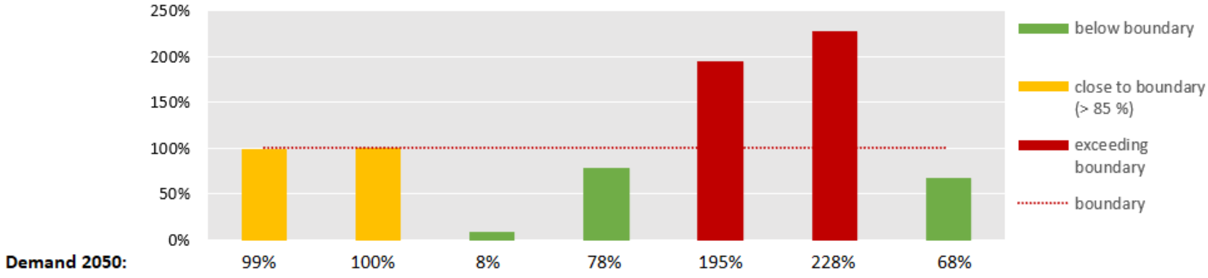
2.6 Development of a consumption calculator

All the data generated was brought together in a calculation tool, the "consumption calculator". The consumption calculator is structured in such a way that the consumed quantities of the representative goods can be varied, and the results are displayed directly. Variants were provided for selected representative goods.

First, results are evaluated regarding their compliance with planetary boundaries (figure 1), then, the percentage share of the demand of different consumption areas in regard to the planetary dimensions is shown (figure 2).

Figure 1: Presentation of results: Compliance with or exceeding of the planetary boundaries by consumption of all representative goods (example)

	Climate change		Land-system change		Biochemical flows		Freshwater use	
	CO_2	CH_4, N_2O	Forest loss	Agricult. area	Phosphorus	Nitrogen	Freshwater	
Unit:	kg CO_2	kg CO_2-eq.	m^2	m^2	gram	gram	m^3	
Boundary per capita:	150	435	10	1533	731	7312	472	
Demand today:					2990	20400		global average
Demand 2050:	148	435	1	1197	1427	16636	322	



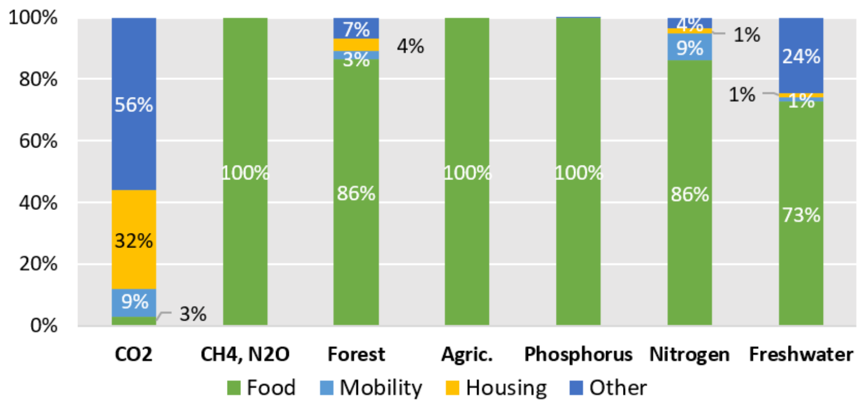
Source: own representation, ifeu

Figure 2: Presentation of results: shares of different consumption areasin relation to the respective planetary boundary (example)

People in household: 2

Selection further unit: per household and year

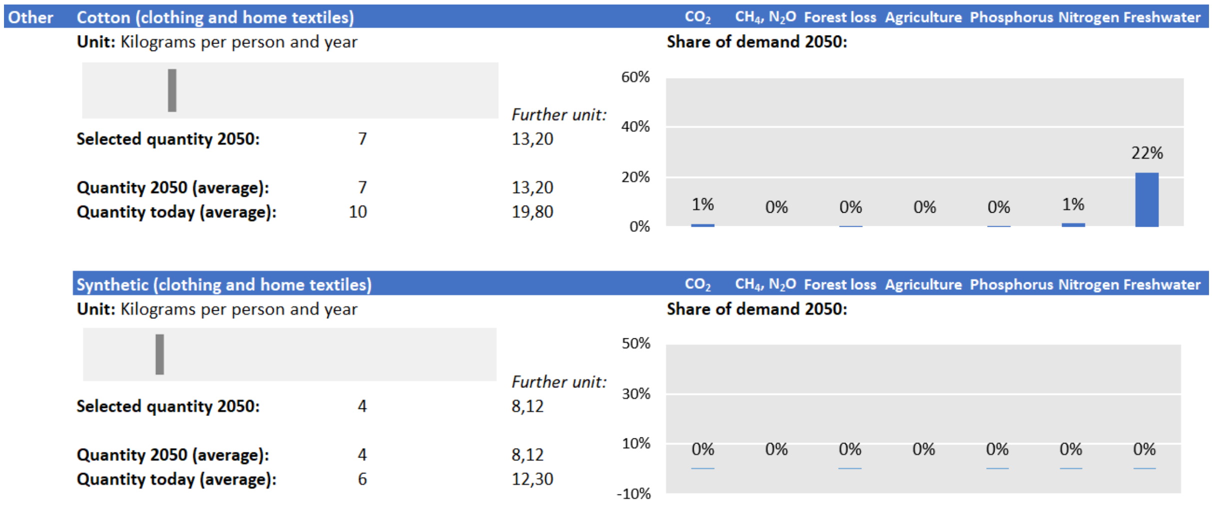
Share of demand 2050:



Source: own representation, ifeu

The quantities consumed can be varied in the consumption calculator for all representative goods. For orientation, the average quantities for "today" and in 2050 (GreenSupreme) are displayed. Furthermore, the shares in different consumption areas, in relation to the respective planetary boundary, are displayed in the consumption calculator. Figure 3 illustrates the structure of the consumption calculator for the consumption sector of clothing. To exclude unrealistic or overly extreme consumption quantities, the sliders were set in such a way that certain plausible quantities could neither be fallen short of nor exceeded (see chapter 7).

Figure 3: Structure of the consumption calculator using the example of the consumption area clothing (example)



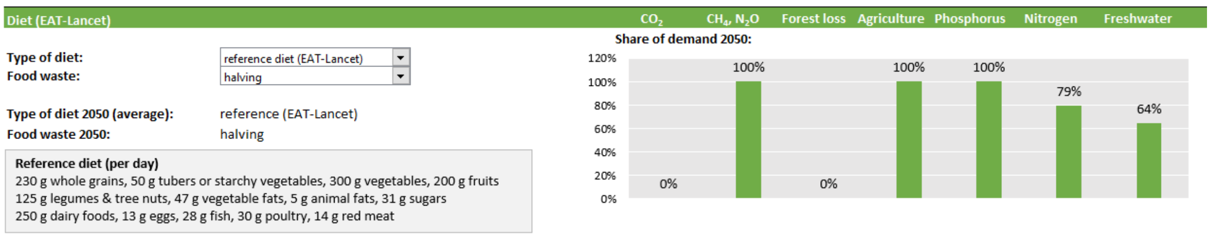
Source: own representation, ifeu

In addition, different variants can be selected for consumer goods:

- in the consumer area of food, various diets according to Willet et al. (2019) (see also figure 51) as well as the amount of food waste can be chosen (as of today or halved);
- in the consumer area of mobility, an electric car and a conventional car (with synthetic fuels) can be selected and air travel can be displayed, only in CO_2 emissions or including additional effects;
- in the consumer area housing, a conventional house and a wooden house are distinguished.

The snapshot of the consumption calculator illustrates the consumption area of food, with variants of diets and food waste in figure 4.

Figure 4: Structure of the consumption calculator by the example of food



Source: own representation, ifeu

This structure makes the consumption calculator very easy and intuitive to use. If "too much" is consumed in one consumption area, it is possible to adjust every other consumption quantity until the planetary boundaries are complied with.

2.7 Elaboration of consumption patterns

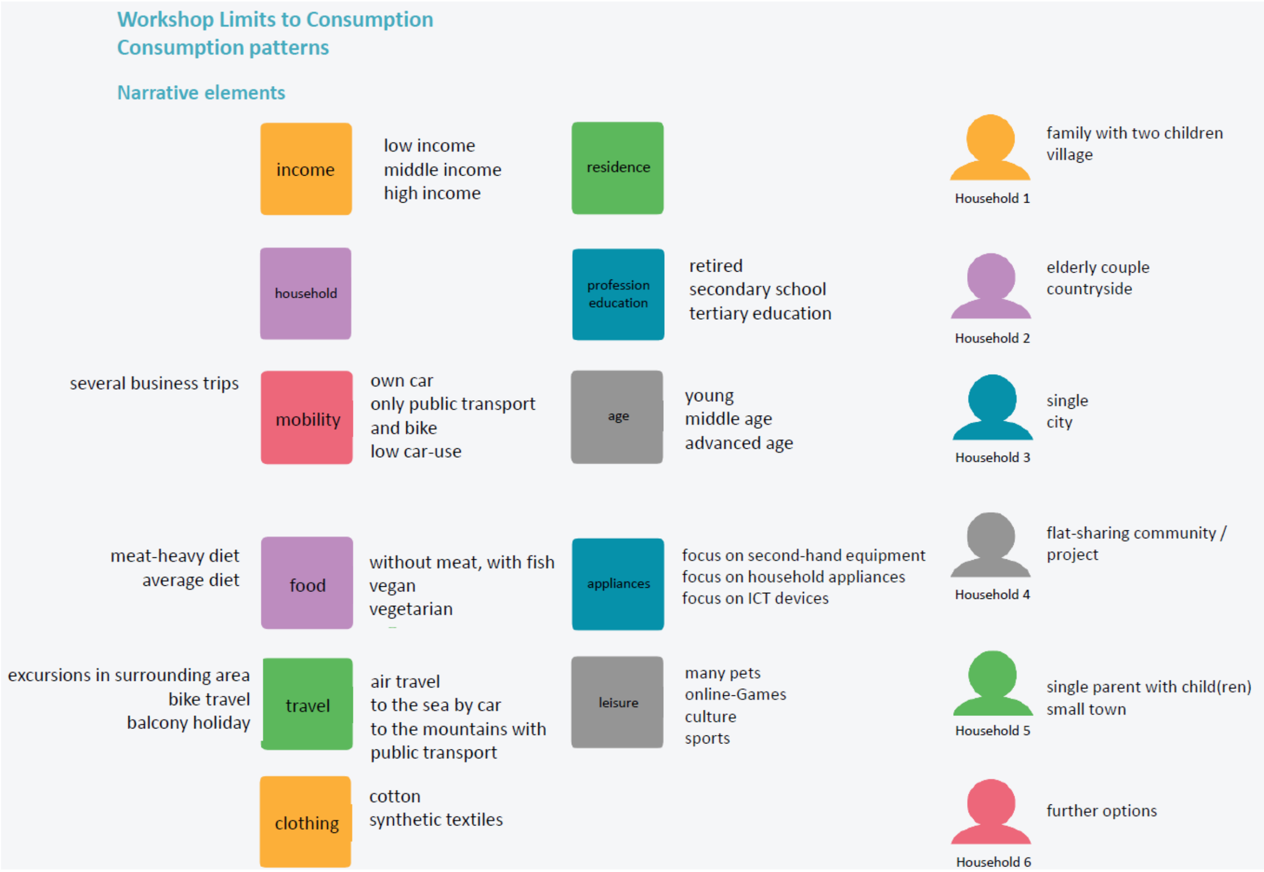
Sustainable consumption patterns were identified at an internal project workshop on the 7th of October 2021. The participants were provided with inputs on the concept of consumption patterns, the method for determining future environmental impacts, the statistical data basis and the results of the RESCUE GreenSupreme average person in several short presentations.

Following this, different household characteristics that should be considered for the different consumption patterns, were established, including:

- Place of residence: big city – small town – countryside
- Household size: single, two-person household, family, large family
- Traditional and new lifestyles: e.g. housing projects.

The overview of narrative elements and the selection of the six different households are shown in figure 5 below.

Figure 5: Preparation and selection of personas



Source: own presentation of interim results from the project workshop, ifeu

In working groups, the selected households were underpinned with further characteristics and suitable personas were developed. The characteristics, for example "frequent driver" or "fashion affine", were quantified in the consumption calculator. Then the consumption of the various goods was calibrated so that the planetary boundaries were not exceeded.

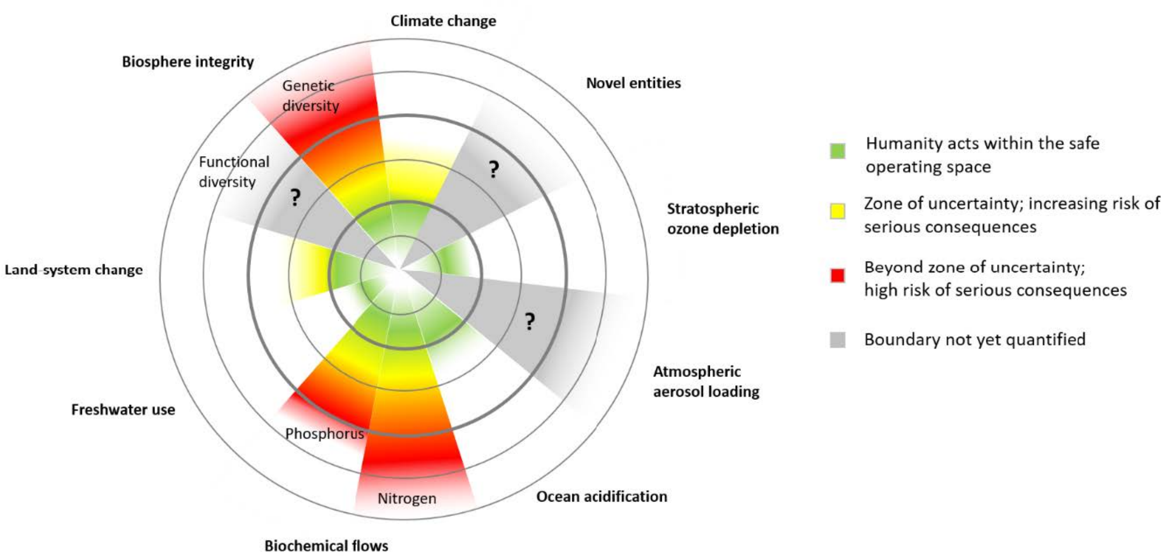
Finally, the results of the working groups were compared. The results showed low variances between consumption patterns for some representative goods. Therefore, consumer goods with a low variance were changed in a final step, so that the sustainable consumption patterns show as much diversity as possible (within the planetary boundaries).

3 Planetary boundaries

3.1 The concept of planetary boundaries

The concept of planetary boundaries identifies nine dimensions or environmental processes that are fundamental to the stability and resilience of the global Earth system. These interact with each other and include climate change, ocean acidification, stratospheric ozone depletion, freshwater use, land-system change, biochemical flows, biosphere integrity, atmospheric aerosol loading, as well as novel entities (figure 6). In their first publication of the concept, Rockström et al. (2009) assume that environmental impacts caused by humans can lead to an abrupt change in environmental conditions to which living organisms, including humans, cannot adapt or cannot adapt quickly enough. The authors quantify so-called planetary boundaries for seven dimensions, within which there is safe room for mankind to act. If this safe room for manoeuvre is exceeded, so-called tipping points can be crossed, which can trigger unpredictable changes in environmental conditions. Steffen et al. (2015) developed the concept of planetary boundaries further; they confirmed the selection of the nine dimensions, but formulated different global boundary values for some dimensions. According to this, two planetary boundaries are currently already exceeded at the global level: genetic diversity as part of the biosphere integrity, and biochemical phosphorus and nitrogen flows (figure 6).

Figure 6: The concept of planetary boundaries



Source: own representation based on Steffen et al. (2015)

This project draws on the concept of planetary boundaries formulated by Steffen et al. (2015). The following table 3 shows the boundaries and uncertainties defined by Steffen et al. (2015).

Table 3: Boundaries and uncertainty ranges in the concept of planetary boundaries according to Steffen et al. (2015)

Dimension	Planetary boundary	Area of uncertainty
Climate change	350 ppm CO_2 in the atmosphere	450 ppm CO_2 in the atmosphere
Land-system change	75 % preservation of original forest area; for temperate forests: 50 %.	54 % preservation of original forest area

Freshwater use	4000 km³ / a	6000 km³ / a
Biochemical flows: a) Phosphorus b) Nitrogen	 a) 11 Tg P / a b) 62 Tg N / a	 a) 22 Tg P / a b) 150 Tg N / a
Biosphere integrity: a) Genetic diversity b) Functional diversity	 a) 10 E/ MSY* b) ≥90 % BII**	 a) 100 E / MSY* b) ≥ 30 % BII**
Stratospheric ozone depletion	< 5 % reduction of pre-industrial O_3 concentration	Crossing only via Antarctica in the Australian Spring
Atmospheric aerosol loading	AOD*** (regional) from 0.25	AOD*** (regional) 0.30
Ocean acidification	≥ 80 % of pre-industrial aragonite saturation	≥ 84 % of pre-industrial aragonite saturation
Novel entities	No variable defined in Steffen et al. (2015)	

Source: own compilation based on Steffen et al. (2015); E / MSY = Extinctions per million species and year; ** BII = Biodiversity Intactness Index; ***AOD = Aerosol Optical Depth

3.2 Derivation of boundary values for the project

In this project, the dimensions of climate change, land-system change, freshwater use and biochemical flows are considered. For the other dimensions, it was either not possible to derive a boundary for Germany or per person, or to relate a derived boundary to life cycle assessment results at the time the project was realized.

For the comparison of the environmental impact of the consumption of an individual person with the planetary boundaries, the selected boundaries are converted into per capita values according to the principle of equality. In the project, consumption is also broken down to an annual perspective. However, the boundaries for the dimensions of climate change and land-system change are not available in Steffen et al. (2015) for an annual perspective and must therefore be derived elsewhere. The concrete threshold values used in the project are described below.

The food sector is shown separately in this project, as the EAT-Lancet study shows additional environmental impacts connected to agricultural land and methane and nitrous oxide emissions, and the assumptions of the scenarios differ somewhat. The boundaries defined here apply to both, food and the other consumption areas. An approximate split between food and the remaining consumption areas is made and explained below.

Boundary value for climate change

The global CO_2 concentration in the atmosphere was 412.5 ppm in 2020 (UBA 2021a). The remaining CO_2 budget as of 01.01.2020 is 400 [700] Gt CO_2, to stay below a mean temperature of 1.5 [1.7] °C with 67 % probability (IPCC 2021).

In the project, the GreenSupreme scenario is used. This is the only Green scenario that – including the accounting of sinks – describes a path that is compatible with the 1.5°C target (UBA 2019a). The calculation considers the remaining greenhouse gas budget of IPCC (2018). The budget has not changed in the current IPCC report; methodological improvements showed that the earlier calculations were too conservative (IPCC 2021). Therefore, it can be assumed that GreenSupreme describes a pathway that remains reasonably consistent with the 1.5 °C target despite all uncertainties[7].

[7] GreenSupreme contains – also in comparison to the IPCC 2021 scenario SSP 1.9 – very ambitious assumptions for the transformation in countries also outside Europe.

Accordingly, the CO_2 emissions per person from GreenSupreme are used as a per capita boundary for the identification of sustainable consumption patterns for 2050. These are 0.29 tonnes of CO_2 per person in the territorial calculation according to NIR and 0.15 tonnes of CO_2 per person in the consumption-based calculation according to the EAA concept, in each case without considering sinks (Dittrich et al. 2020).

A challenge arises from the fact that, in accordance with the agreement, the EAT-Lancet report on healthy diets is to be used for the consumer area of food in the project (Willett et al. 2019). Willet et al. (2019) do not consider CO_2 emissions, but the greenhouse gases methane and nitrous oxide[8]. They estimate a global annual budget of 5 Gt CO_2-eq. for the year 2050, with an uncertainty range of 4.7 to 5.4 Gt CO_2-eq. These greenhouse gases continue to be produced in a de-fossilised world, especially in agriculture. The global population underlying the scenarios is around 9.187 billion people. The boundary corresponds to GHG emissions of 0.54 t CO_2-eq. per person. For comparison: the total GHG emissions per person in GreenSupreme were 0.6 t CO_2-eq. in the territorial calculation and 0.46 t CO_2-eq. in the consumption-based calculation (in each case excluding natural sinks).

Within the framework of the project, neither a recalculation nor a detailed reconciliation of the different boundaries was possible. Therefore, for pragmatic considerations, the following boundaries were used in the consumption calculator for the identification of sustainable consumption patterns that remain within the planetary boundaries:

- Adoption of the values from the Lancet study for the food sector with 0.435 t CO_2-eq. This corresponds to the methane and nitrous oxide emissions of the reference diet with halving of food waste.
- 0.15 t CO_2 per person as the boundary for all other consumption sectors combined. It is relevant here that the changes in forestry assumed in GreenSupreme are considered as a sink (see next chapter on land-system change).

Boundary value for land-system change

According to Steffen et al. (2015), the planetary boundary in the land-system change dimension equals the preservation of 50 % of the original forest area in temperate zones and 54 % for all forests.

The current forest area in Germany is 29.8 %, including woody plants 31 % (UBA 2021b). The forest and wooded area increased by 5,198 km^2 since 2004 (ibid.). About 593,000 ha or 5 % of the forest and woodland area is protected (BMEL 2021). However, only 215,000 ha of the areas are considered wilderness, as they are subject to strict protection requirements or process protection (Zoologische Gesellschaft Frankfurt 2021).

Since the project calculates from the consumer perspective, the global value is assumed. Accordingly, Germany can still convert around 0.06 million km^2 of forest area globally. In the project, this area was divided among the population in 2050 (723 m^2 per person) and over a life span of 75 years to the year 2050. Accordingly, each person could "convert" around 10 m^2 of forest per year through consumption. This approach was chosen to be as methodologically consistent as possible with the other boundaries. It should be noted, however, that a narrower boundary would also be justified to allocate "forest area budgets" to later or currently living people (deceased by 2050) or to be able to guarantee more sinks for CO_2.

[8] CO_2 emissions are covered by the other consumption sector (excl. food).

Willet et al. (2019) defined the maximum agriculturally used area of 13 million km^2 as the boundary for the land-system change dimension for food. Per person, the area (considering the global population in SSP1) is therefore 1,533 m^2.

Since the boundaries do not contradict each other, both approaches were run in parallel in the consumption calculator.

Boundary value for freshwater

According to Steffen et al. (2015), the planetary boundary for freshwater use is 4,000 km^3 per year. This results in a boundary of 472 m^3 per person in 2050. This value was used in the project, the uncertainty range was not considered.

The allocation to the food sector and the remaining consumption areas is based on the estimated demand in the Lancet scenarios. 250 m^3 are allocated to food, the remaining 222 m^3 to the remaining consumption areas.

The Lancet study assumed a different boundary: 1,000 km^3 as the lower boundary and 4,000 km^3 as the upper boundary for food only.

Boundary values for biogeochemical flows

According to Steffen et al. (2015), the planetary boundary for phosphorus is 6.2 Tg/year. The resulting boundary per person is therefore 731 g/year.

According to Steffen et al. (2015), the planetary boundary for nitrogen is 62 Tg/year, and the calculated boundary per person is 7,312 g/year.

These values were used in the project; the uncertainty range was not considered. The allocation is analogous to boundary of the climate change dimension: 75 % was allocated to food and 25 % to the remaining consumption areas. The Lancet study used slightly different boundaries for food production, namely 8.0 Tg phosphorus/year (with an uncertainty range of 6–12 Tg) and 90 Tg nitrogen/year (with an uncertainty range of 65–90 Tg). Assuming that improved management practices are implemented and 50 % of the phosphorus used is recycled, the uncertainty range shifts to 8–16 Tg phosphorus/year and 90–130 Tg nitrogen.

4 Representative goods

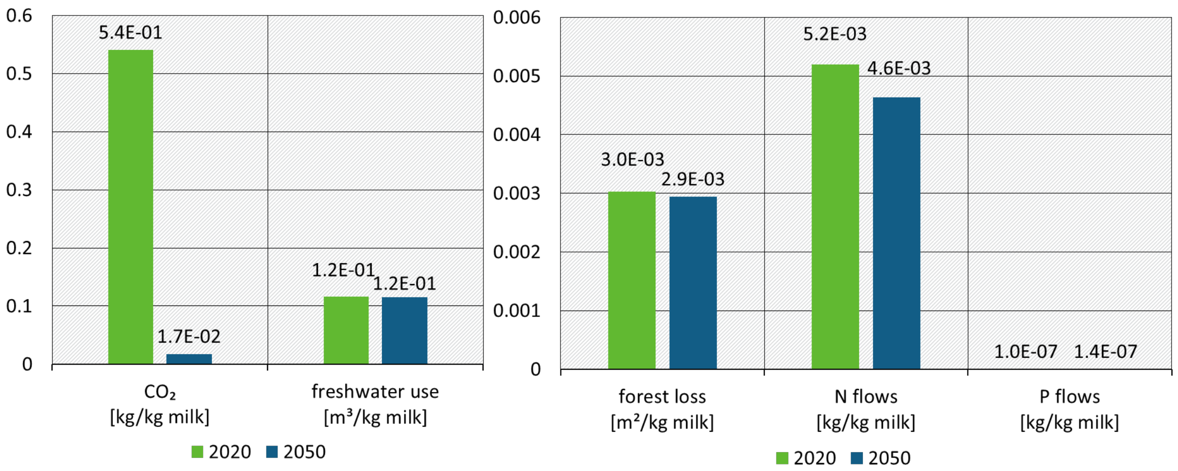
4.1 Representative good 1: milk and results of the EAT-Lancet study

In Germany, approximately 33.3 million tonnes of milk were produced in 2020. Milk is consumed in many forms, e.g. as drinking milk (49.9 kg per person per year), yoghurt (14.8 kg per person per year), cheese (25.4 kg per person per year) or butter (6.3 kg per person per year) (MIV 2021).

In GreenSupreme, eating habits change and fewer animal products are consumed. Dairy products are also replaced by other milk substitutes (such as soy milk). The assumed amount of cow's milk produced is 15.9 million tonnes in 2050 (UBA 2019a).

The environmental impacts that are relevant regarding the concept of planetary boundaries are shown in figure 7. Compared to today, the energy transformation and the further technological changes lead to a strong decrease of the CO_2 emissions[9] per kg of milk (-97 %), forest loss decreases slightly (-3 %) and freshwater use also decreases slightly (-1 %). Phosphorus flows increase rather strongly (+38 %, but at a very low level, while nitrogen flows decrease (-11 %).

Figure 7: Environmental impacts of milk, today and in 2050



Source: own presentation based on own calculations, ifeu and ecoinvent

Milk was chosen as a representative good to complement the Lancet study. It can be selected in addition to the various diets from Willet et al. (2019) within the consumption calculator[10]. Most of the environmental impacts occur during the production of milk, while the environmental impacts during downstream processing are lower (Müller-Lindenlauf et al. 2014). It should be noted that the results are not directly comparable with the results from the Lancet study as a different methodology and different planetary boundary values were used.

As agreed at the kick-off meeting of the project, the assumptions on environmental impacts and consumption patterns from the EAT-Lancet study were adopted for the food sector. In the EAT-Lancet study, a global reference diet was developed that, on the one hand, implements recommendations for healthy nutrition and, on the other hand, stays within the planetary

[9] Methane and nitrous oxide emissions are not shown here. These are covered by the EAT-Lancet study and presented as a separate "food sector".

[10] Note that milk and dairy products are not analysed separately for the personas presented in chapter 7. It is an additional control lever that is only shown in the consumption calculator to adjust milk consumption and to illustrate all selected environmental impacts, mainly CO_2 and forest loss, that are not considered in the LANCET study.

boundaries as far as possible. The reference diet contains the following average amounts per day:

EAT-Lancet reference diet (per day)

Plant-based components:
230 g whole grains, 50 g tubers or starchy vegetables, 300 g vegetables, 200 g fruits, 100 g legumes, 25 g nuts, 47 g vegetable fats, 31 g added sugars

Animal-based components:
5 g animal fats, 250 g dairy foods, 13 g eggs, 28 g fish, 30 g poultry, 14 g red meat

If we compare these quantities with the average quantities consumed in Germany today, it becomes clear that this would imply a drastic change in diet (table 4).

Table 4: Comparison of the average diet in Germany with the EAT-Lancet reference diet

Quantities in kg per person and year	Average 2017 in Germany	Reference diet EAT-Lancet	Difference
Cereals	82.6	84	1 %
Potatoes, Manioc	57.9	18	-69 %
Vegetables	99	109	10 %
Fruit	95	73	-23 %
Legumes, nuts	1.3	46	3400 %
Vegetable fats	18.5	17	-8 %
Animal fats	5.8	2	-69 %
Added sugar	34.8	11	-68 %
Milk	90	91	1 %
Cream and cheese	30		
Eggs	13.8	5	-66 %
Fish	13.5	10	-25 %
Poultry	20.9	11	-48 %
Red meat	66.3	5	-92 %
Total	**629.4**	**481.6**	**-23 %**

Sources: Willett et al. (2019), Destatis (2019)

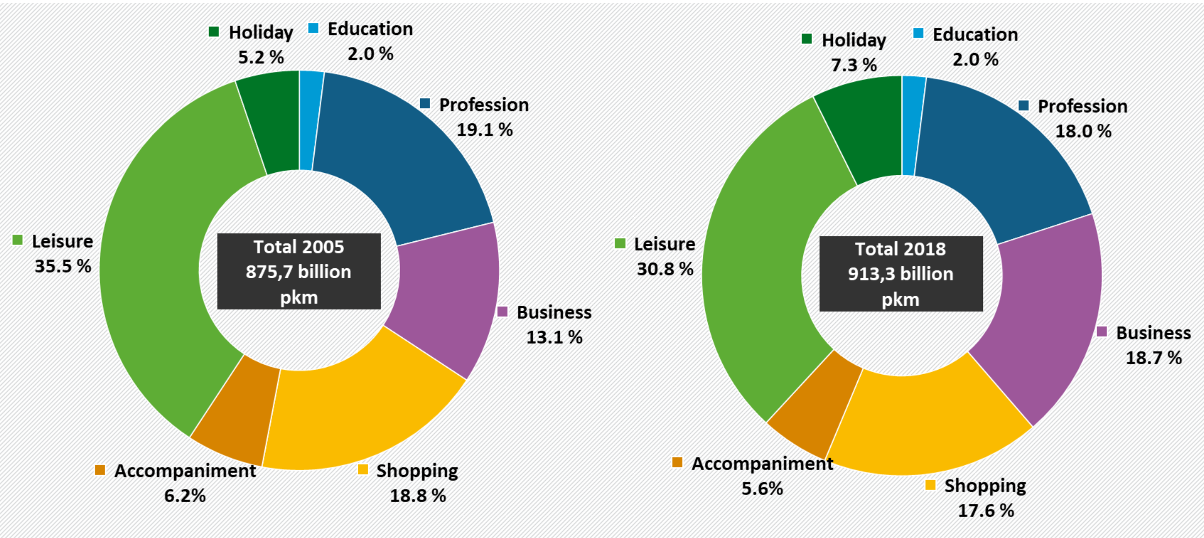
Especially red meat, dairy products, eggs and potatoes need to be reduced by up to 92 %. The consumption of legumes and nuts, on the other hand, should be increased by factor of 34. Another assumption of the reference scenario is a halving of food waste, which is reflected in the total across all foods. This is 23 % lower in the reference diet compared to the current average in Germany.

4.2 Representative good 2: car

In Germany, a total of 48.3 million cars exist at the beginning of 2021, an increase of almost 10 million cars compared to 2000 (Destatis 2021a). Not all vehicles are privately owned; a share belong to companies or the public sector. 77 % of private households owned at least one car in 2021, on average 100 households owned 109 cars (Destatis 2021b).

The number of passenger kilometres travelled by private households rose from 489 billion in 2008 to 563 billion in 2018 (UBA 2023). Most journeys were made for leisure purposes (30.8 %), followed by business and professional purposes (18.7 % and 18.0 % respectively). Compared to previous years, the importance of the car for business purposes and for holidays increased slightly (figure 8).

Figure 8: Purposes for car use, 2005 and 2018 in comparison



Source: own presentation based on UBA (2023)

Cars with combustion engines still dominate. Of the 2.6 million newly registered passenger cars in 2021, around 13.6 % were electric cars and 12.4 % were cars with plug-in hybrid drive systems (KBA 2021). The exact transport performance of electric or hybrid passenger cars is not known.

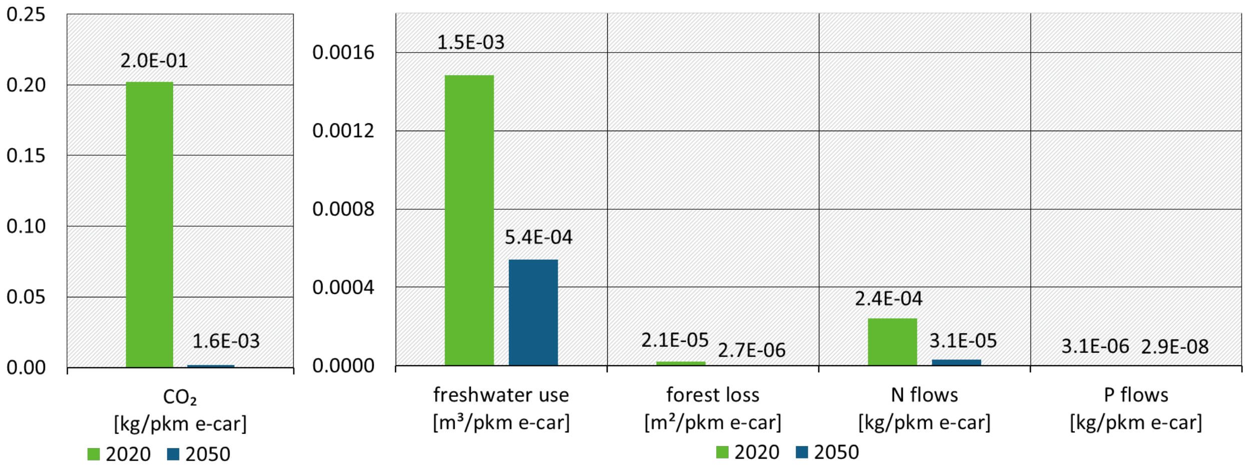
In GreenSupreme, it was assumed that in 2050 only battery-powered cars will be used by private households. At the same time, the amount of car ownership and the modal split change due to increased use of public transport, car sharing and the shift to cycling and walking. The transport performance of all motorised individual transport (including motorbicycles and so forth, including companies and the state) falls from 902 pkm in 2010 to 484 pkm in 2050 (-46 %).

In the project, both the electric car and a car with an internal combustion engine were considered. The latter is operated with synthetic fuels (based on Fischer-Tropsch process) in 2050. The environmental impacts that are relevant for the planetary boundaries are shown for both drives in figure 9 and figure 10.

Compared to today, per passenger kilometre driven with an electric car, CO_2 emissions decrease by 99 %, forest loss by 88 %, nitrogen flows by 87 %, phosphorus flows by 99 % and freshwater use by 64 %. Similarly, for a passenger kilometre driven with an internal combustion engine, CO_2 emissions are reduced by 99 %, forest loss decreases by 97 %, nitrogen flows decrease by 67 %

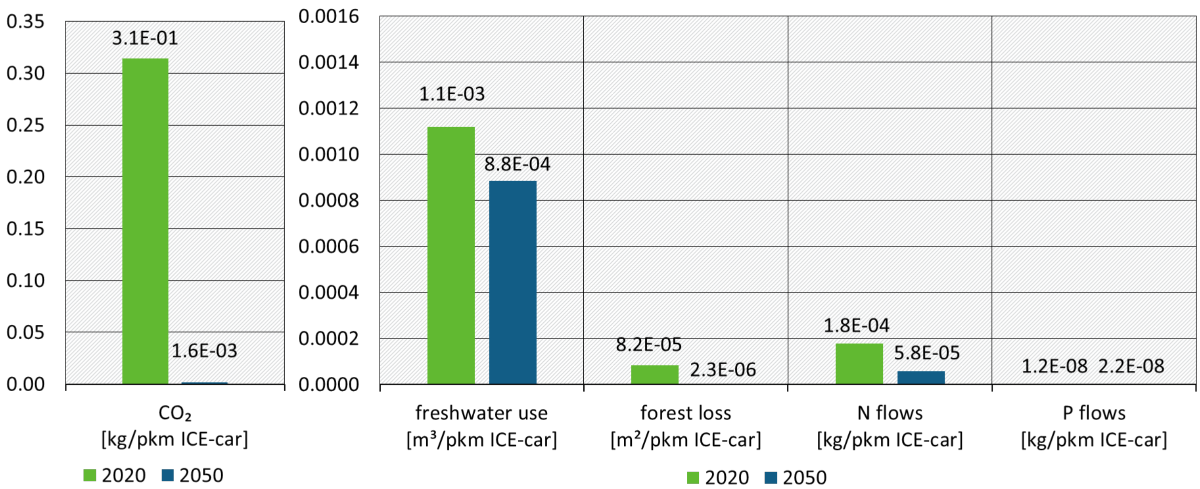
and freshwater use is reduced by 21 %. At the same time, phosphorus flows increase by 88 %, starting from a very low level. The main reasons are the transformations in electricity/fuel production and the composition and performance of the deposited car batteries, as well as the transformations in the metal and plastics industry.

Figure 9: Environmental impacts of an electric car*, 2020 and 2050



Source: own presentation based on own calculations, ifeu and ecoinvent; *with an average electricity mix.

Figure 10: Environmental impacts of a car with combustion engine*, 2020 and 2050



Source: own presentation based on own calculations, ifeu and ecoinvent; *2050 with synthetic fuels, ICE= internal combustion engine.

4.3 Representative good 3: electric bicycle

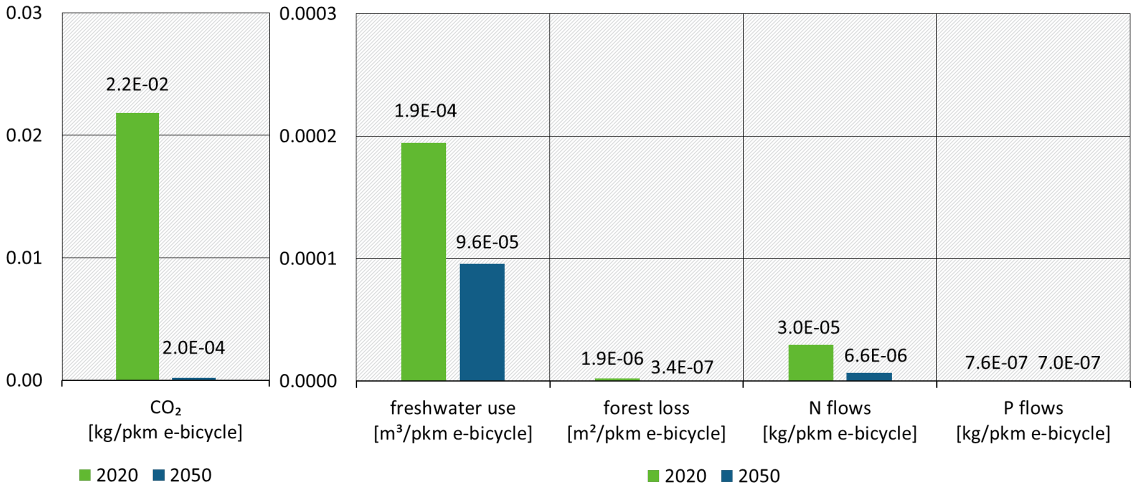
The number of electric bicycles sold in Germany has risen sharply in the past ten years. In 2010, around 200,000 electric bicycles were sold in Germany (BMVI und Difu 2014). In 2021, the number increased to 1.2 million (Destatis 2021c). At the beginning of 2021, 13 % of private households (5.1 million) had at least one electric bicycle (Destatis 2021c). By comparison, there are around 78 million bicycles in Germany in total.

Both the number of journeys and the transport performance covered by bicycle have increased in recent years. Between 2002 and 2017, the number of journeys increased from 25 to 28 million per day and the transport performance rose from 82 to 112 million passenger kilometres per day (Nobis 2019). In 2017, each person in Germany cycled an average of around 495 km. It is not known how many kilometres of this were travelled by electric bicycle; in all age groups, between 4 and 7 km more are travelled daily by pedelec than by a purely muscle-powered bicycle (Nobis 2019).

In the GreenSupreme scenario, the distance travelled by bicycle or on foot increases by 58 % to 118 billion person-kilometres, or 1,641 km per person compared to 2017. An explicit allocation of how much of this is travelled on foot or by bicycle on average, and especially by electric bicycle, was not made.

The environmental impacts relevant in relation to the concept of planetary boundaries are shown in figure 11. CO_2 emissions depend very much on the electricity mix used to charge the batteries, and fall by 99 % as a result of the transformation of the energy systems. Nitrogen and phosphorus flows also decrease by 78 % and 8 % respectively, and freshwater use and forest loss also decrease by 51 % and 82 % respectively (albeit at very low levels throughout).

Figure 11: Environmental impacts of trips with e-bicycle, 2020 and 2050



Source: own presentation based on own calculations, ifeu and ecoinvent

4.4 Representative good 4: public transport

People are increasingly using public transport services to cover their journeys. In 2017, 26 million journeys per day (10 % of all journeys) were made using public transport such as buses and trains. On average, the distance travelled by public transport was 23.1 km. The transport performance of public transport was thus a total of 605 million passenger kilometres per day, or 19 % of the total transport performance. This is a significant increase compared to 2002, when the transport performance was 387 million km per day or 14 % of the total transport performance. (Follmer und Gruschwitz 2019)

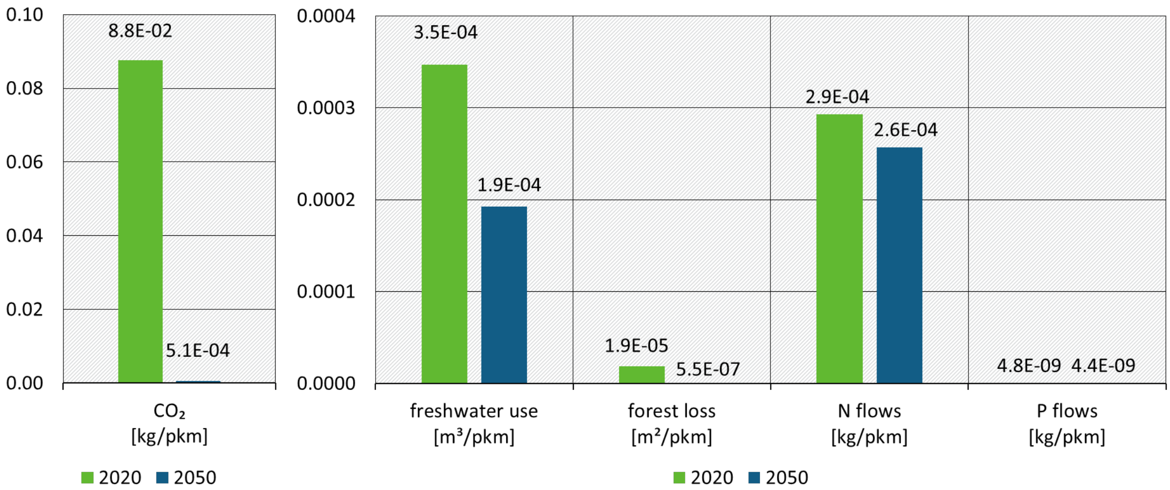
Public transport is divided into local transport (less than 50 km) and long-distance transport (more than 50 km). Around two thirds of the transport performance (108 billion pkm in 2019) is accounted for by local transport, only one third by long-distance transport (51 billion pkm in 2019) (Destatis 2020a).

The routes are mainly covered by buses, trains and taxis. Shipping plays a minor, almost negligible role. Air traffic is not included here, but in chapter 4.5.

In the GreenSupreme scenario, the use of public transport continues to increase at the expense of the previously described motorised private transport (chapter 4.2). A total of 356 billion pkm are travelled by public transport in local (132 billion pkm) and long-distance (224 billion pkm) transport (Destatis 2020a). At the same time, the rail and bus modes of transport, as well as the passenger cars described above, are almost completely electrified.

The average environmental impacts that are relevant in the planetary boundaries concept are shown in figure 12. Compared to today, mainly due to the changes in energy supply and because of changes in metal and plastic production, CO_2 emissions decrease by 99 %, freshwater use by 45 %, forest loss by 97 % and nitrogen flows by 12 % per passenger-kilometre. In addition, phosphorus flows are also decreasing (-10 %), albeit from a very low level.

Figure 12: Environmental impacts from public transport use, 2020 and 2050



Source: own presentation based on own calculations, ifeu and ecoinvent

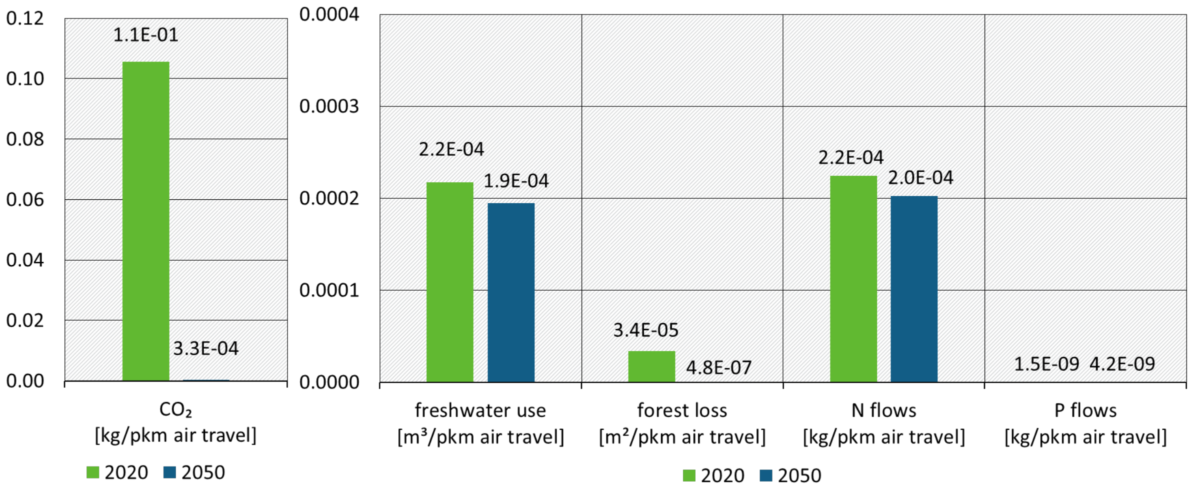
4.5 Representative good 5: aviation

Air travel is also playing an increasingly important role in the mobility behaviour of Germans, as well as in global mobility behaviour. This still holds true although in 2020 – 2022 air travel suffered a sharp decline as a result of the Corona pandemic. In Germany, both the number of people transported and the average distances travelled have increased in recent decades. Transport performance (commercial air transport) totalled around 500 billion pkm in 2019, about 72 billion pkm of which was domestic; in 2020, transport performance was about 124 billion pkm (Destatis 2021d).

In the GreenSupreme scenario, aircrafts are no longer fuelled with fossil fuels, but with synthetically produced fuels. The fuels are produced with CO_2 from the air, as well as other air components and water via electrolysis and Fischer-Tropsch processes. This reduces GHG emissions from aviation. The scenario also breaks the strongly rising demand trend: the sum of all business and private flights by German passengers decrease to 51 and 149 billion pkm respectively in 2050, as compared to 2019.

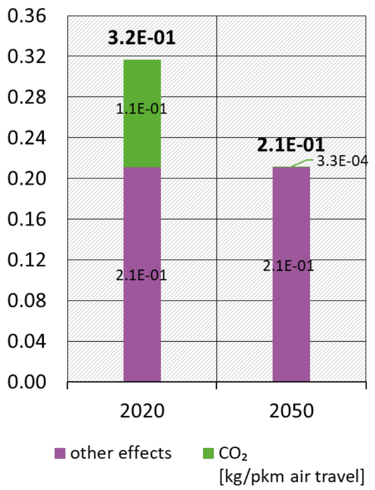
The environmental impacts that are relevant in relation to the concept of planetary boundaries are shown in figure 13. Compared to today, CO_2 emissions decrease by 100 % and forest loss decreases by 99 %. Freshwater use also decreases (-10 %) and nitrogen flows decrease (-10 %). At the same time, phosphorus flows increase (+188%), albeit from a very low level, as a result of the transformation from fossil-based fuels to fuel produced synthetically with the Fischer-Tropsch process.

Figure 13: Environmental impacts of air travel (fuel only), 2020 and 2050



Source: own presentation based on own calculations, ifeu and ecoinvent

Figure 14: Environmental impacts of air travel (incl. other effects), 2020 and 2050



Source: own presentation based on own calculations, ifeu and ecoinvent

Flights cause other effects that have a higher climate impact than CO_2 emissions, partly due to the altitudes at which air travel takes place. Aircraft emit water vapour, nitrogen oxides, sulphate aerosols, soot and unburned hydrocarbons. Together, these are referred to as non-CO_2 climate effects. The Federal Environment Agency (UBA 2021c) assumes that "a total climate impact of global aviation equivalent to three times the CO_2 emitted by aviation alone [...] can, however, be considered a plausible assumption". These non-CO_2 effects, named “other effects”, were included as an additional option in the air travel category in the consumption calculator. It was assumed that the non-CO_2 climate effects in 2050 are the same as in 2020.

4.6 Representative good 6: pets

In Germany, as well as in other European countries, pets play an important role as leisure companions, social partners and family members.

Pets are kept in almost every second household in Germany, with a significant increase in 2020 compared to the previous year. While there were still 34 million pets in Germany in 2019, surveys by the German Pet Supplies Industry Association (*germ. Industrieverband*

Heimtierbedarf, IVH) and the Central Association of Specialist Zoos in Germany (*germ. Zentralverband Zoologischer Fachbetriebe Deutschland*) show an increase of just under one million in 2020. Cats are still the most popular pet (15.7 million), followed by dogs (10.7 million) and finally small animals such as rabbits, guinea pigs, hamsters and mice (5 million). For the most part, pets live in multi-person households, and often several pets are kept at the same time. About 66 % of all families with children own pets, and animal roommates are also increasingly found in single households. In terms of age, the majority of pet owners are in their middle years (IVH 2021).

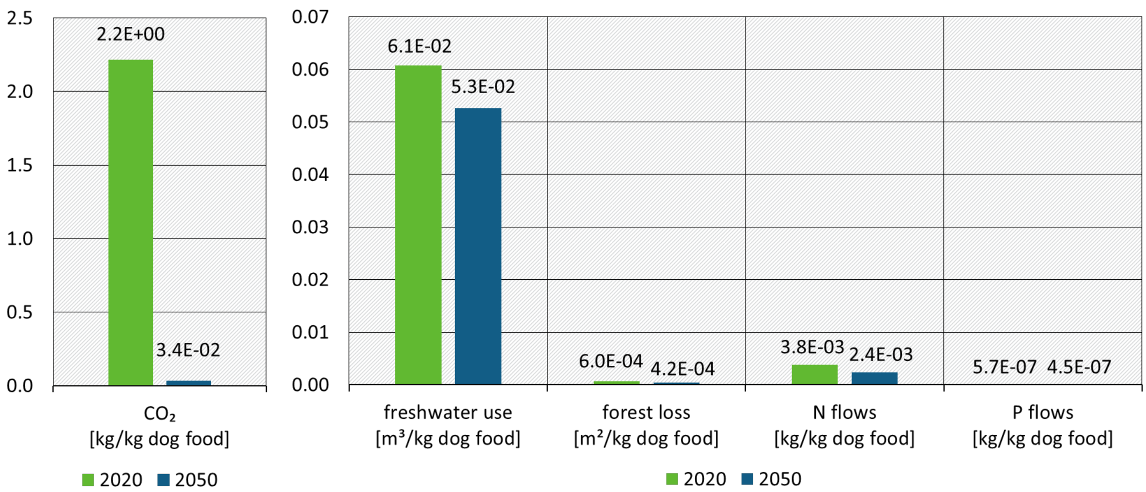
Based on the IVH figures, the average number of pets per person is 0.47 (2020). If the privately owned horses (~ 1.3 million, 2019) are added to the typical domestic pets (FN 2020), the average number of pets and horses per person is 0.49.

On average, a medium-sized dog (here: a Labrador of 29 kg) eats about 2.5 % of its weight daily in terms of wet food, i.e. about 265 kg per year. For comparison: a cat of 4.2 kg on average eats about 6 % of its own weight, per year about 92 kg (Annaheim et al. 2019).

A life cycle inventory for the production of wet dog food was used to calculate the environmental impacts. Thus, other drivers for environmental impacts of pet ownership, including straw or litter use, waste bags, heat loss through cat flaps or the energy used for "walking" trips by car, are not included.

The environmental impacts of pet food are shown in figure 15. As a result of the transformation of energy systems, all energy-related environmental impacts of dog food production (incl. upstream chains) decrease. Compared to today, for the same amount of dog food, CO_2 emissions decrease very strongly (-98 %), as do forest loss (-29 %) and nitrogen flows (-37 %). At the same time, freshwater consumption (-14 %) and phosphorus flows (-22 %) decrease.

Figure 15: Environmental impacts of dog food, 2020 and 2050



Source: own presentation based on own calculations, ifeu and ecoinvent

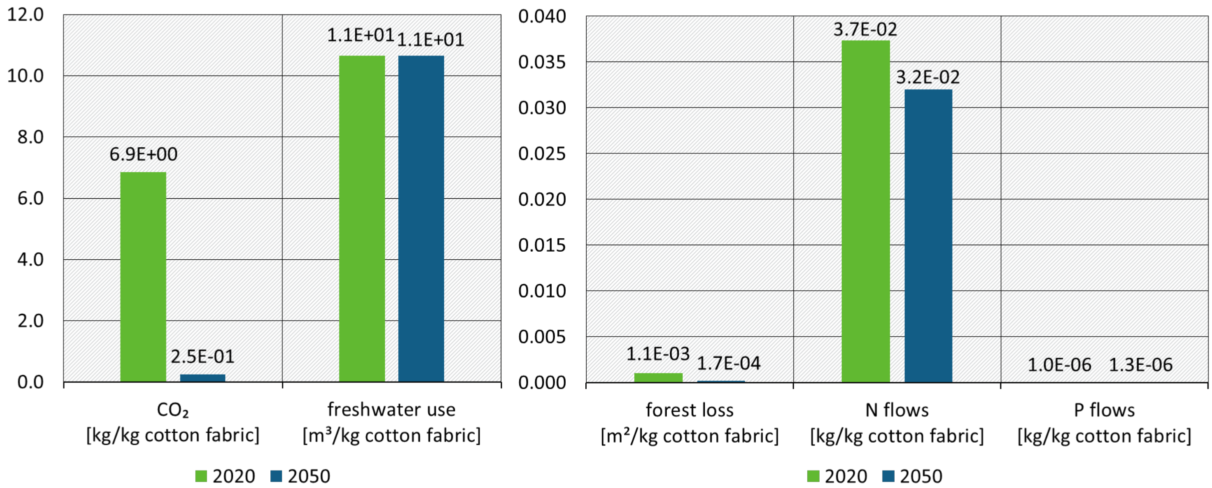
4.7 Representative good 7: cotton

Cotton is one of the most common fibres in the textile industry. This is particularly true for clothing products, where cotton fibres make up the largest share (around 43 % across the EU) (Beton et al. 2014; Gray 2017). In Germany alone, consumers buy an average of sixty items of clothing per year (BMU 2021). Nationwide consumption is over 1 million tonnes of clothing per year (Gray 2017). This puts Germany at the top of EU-wide clothing consumption. This consumption is made up of production and imports minus exports.

Per person, approximately between 10 kg (Ahlert et al. 2015) and 14 kg (Gray 2017) clothing textiles are consumed in Germany within one year. If household textiles are also included, consumption is assumed to be around 17 kg per person (Ahlert et al. 2015). Pure cotton consumption for clothing only is estimated at 7 kg (Ahlert et al. 2015).

The environmental impacts of cotton fabrics are shown in the following figure 16. In the production of cotton fabrics, the use of freshwater for the production and processing of cotton is particularly relevant. Compared to today, CO_2 emissions (-96 %), forest loss (-84 %) and nitrogen flows (-14 %) decrease due to the changes in the energy system. On the other hand, phosphorus flows increase (+24 %, albeit at a low level) and freshwater consumption stagnates (-0.2 %).

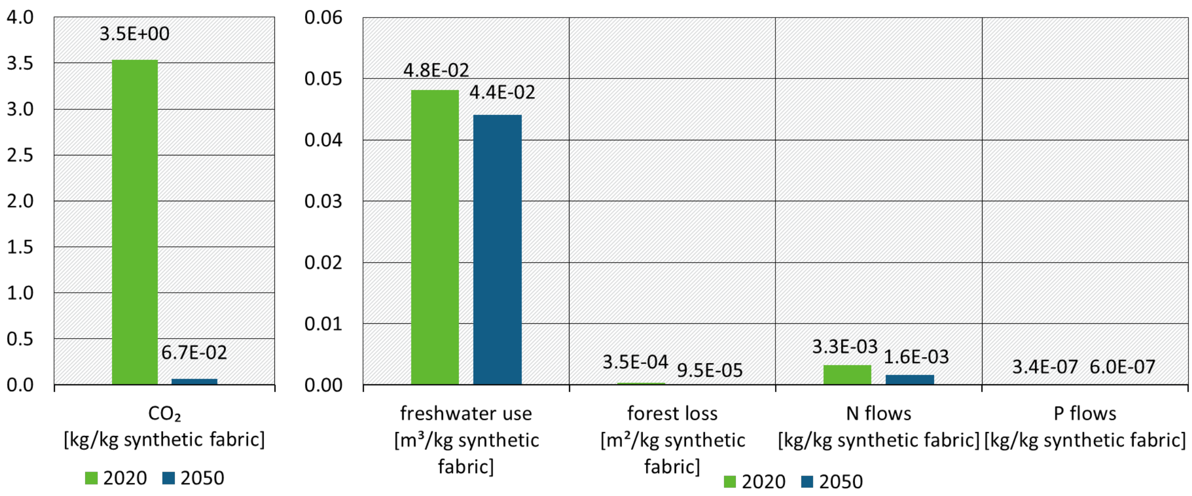
Figure 16: Environmental impacts of cotton fabric, 2020 and 2050



Source: own presentation based on own calculations, ifeu and ecoinvent

In addition to cotton, synthetic fabrics were evaluated and added in the consumption calculator. These are particularly interesting because in 2050 they will no longer be produced from fossil raw materials, but entirely from synthetic raw materials based on CO_2 from the air. The environmental impacts of synthetic fabric that are relevant regarding the concept of planetary boundaries are shown in figure 17. Compared to today, CO_2 emissions (-98 %), freshwater use (-8 %), forest loss (-73 %) and nitrogen flows (-50 %) decrease. At the same time, phosphorus flows increase (+77 %).

Figure 17: Environmental impacts of synthetic fabric, 2020 and 2050



Source: own presentation based on own calculations, ifeu and ecoinvent

4.8 Representative good 8: housing

The current average living space per person is around 47.4 m^2. In the past decades, the average living space has risen continuously. In 2011, for example, the average was 46.1 m^2, and in 1983, each person had only 31.1 m^2 at his or her disposal (Destatis 1985; UBA 2021d). Many factors have contributed to the increase, including the trend towards smaller households and second homes, or the fact that large flats continue to be occupied after children have moved away.

In GreenSupreme, the trend is broken: the average living space per person is around 41 m^2. Modular dwellings that can be enlarged/reduced or converted as needed, communal living and a greater awareness of the impact on land use and other environmental impacts are promoting the trend reversal.

To calculate the factors per m^2 of living space, the survey of the Leibniz-Institut für ökologische Raumentwicklung e.V. (IÖR) was used, namely the material stock in the inventory of residential buildings (Deilmann et al. 2017). This contains different housing types, as well as the materials used in the refurbishment and renovation of the buildings. The building materials were converted to 1 m^2 of living space and the selected life cycle inventories were assigned to the materials in the weighting given in table 5 below. An average service life of 75 years was assumed for the residential buildings.

Table 5: Allocation and weighting of the products to the material groups of IÖR

Material group according to IÖR	Weighting of the selected data sets
Concrete	Market group for concrete, medium strength, GLO
Brick	50 % clay brick production, RER 25 % market for ceramic tile, GLO 25 % roof tile production, RER
Sand-lime brick	Sand-lime brick production, DE
Aerated concrete	Market for autoclaved aerated concrete block, RoW
Other mineral building materials	49.5 % market for cement cast plaster floor, GLO 49.5 % market for cement mortar, RoW

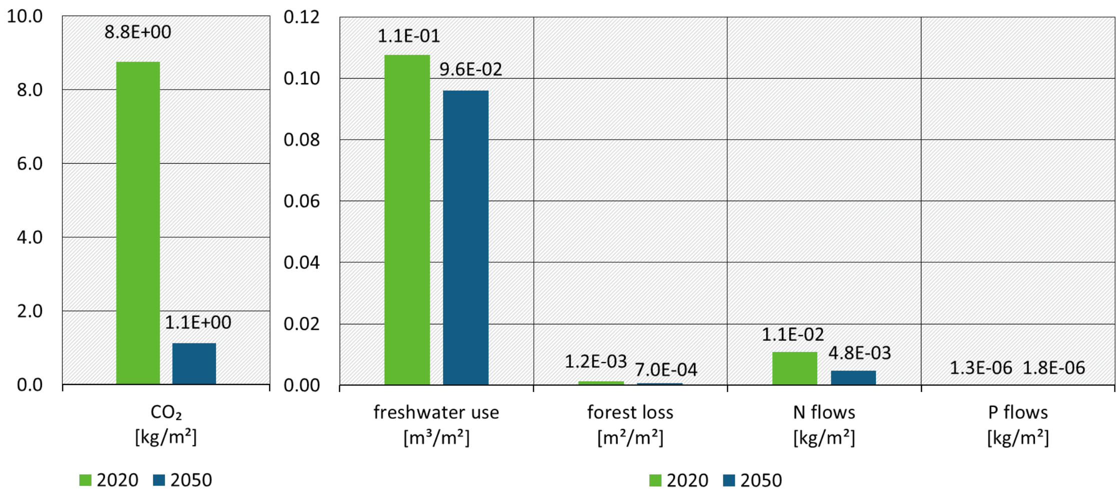
Material group according to IÖR	Weighting of the selected data sets
	1 % market for natural stone plate, cut, GLO
Plasterboard and other gypsum products	50 % market for gypsum fibreboard, GLO 50 % market for gypsum plasterboard, GLO
Building / construction timber	Structural timber production, RER
Other wood	33.33 % market for oriented strand board, RER 33.33 % market for particleboard, uncoated, RER 16.66 % market for wood wool, RER 16.66 % market for cellulose fibre, RoW
Flat glass	50 % Flat glass production, coated, RER 50 % Flat glass production, uncoated, RER
Mineral insulating materials	50 % market for stone wool, packed, GLO 25 % market for glass wool mat, GLO 25 % market for glass wool mat, uncoated, Saint-Gobain ISOVER SA, CH
Plastic insulation materials	Market for polystyrene foam slab for perimeter insulation
Plastic windows	Window frame production, poly vinyl chloride, U=1.6 W/m²K, RER
Other plastics	Market for vinyl chloride, RER
Metals	90 % Steel production, electric, low-alloyed Europe w/o Switzerland 9.75 % market for aluminium, wrought alloy, GLO 0.125% market for cable, unspecified, GLO, cable, 0.125% market for copper, cathode, GLO
Other materials	Not applicable

Source: own compilation, ifeu

In GreenSupreme it was assumed that the demand for housing changes and the trend of increasing living space is reversed. In 2050, the average living space will be 41.2 m^2 per person. At the same time, it was assumed that the dwellings will also change: there will be more demand for timber construction and lightweight construction. Buildings in timber construction or lightweight construction can be very different; a representative wooden and lightweight house is not known. In this project, therefore, the average house was still used, but new technologies were incorporated in the production of the building materials. In addition, a wooden house was added, in which differences from a life cycle assessment comparison between a school building in conventional and in timber construction, based on the representative average house, were transferred (Knappe et al. 2019; Senatsverwaltung für Umwelt, Verkehr und Klimaschutz 2020). This made it possible to expand the variability in the consumption calculator, however, the wooden house is not as statistically reliable as the conventional house.

The changes in environmental impacts that are relevant within the concept of planetary boundaries are shown in figure 18. In addition to the changes in energy production, the conversions in the production of steel, aluminium, copper and plastics are also important influencing factors in the building sector. For a conventional residential building, CO_2 emissions (-87 %), forest loss (-41 %), nitrogen flows (-55 %) and freshwater use (-11 %) decrease. Phosphorus flows, on the other hand, increase by 38 % (at a low level). CO_2 emissions decrease less compared to the other representative goods, because cement production and thus all cement-based building materials (such as concrete, screed, mortar or plaster) are not greenhouse gas neutral even in 2050.

Figure 18: Environmental impacts of a conventional residential building, 2020 and 2050



Source: own presentation based on own calculations, ifeu and ecoinvent

4.9 Representative good 9: household appliances

The equipment of households with household appliances is regularly surveyed and published by Destatis. Accordingly, in 2020, an average household with two persons had 1.25 refrigerators, 0.54 freezers, 0.74 dishwashers, 0.77 microwaves, 0.99 washing machines, 0.43 tumble dryers, 1.14 coffee machines and 0.31 exercise bicycle. The average number of household appliances has increased slightly over the past years. (Destatis 2021b)

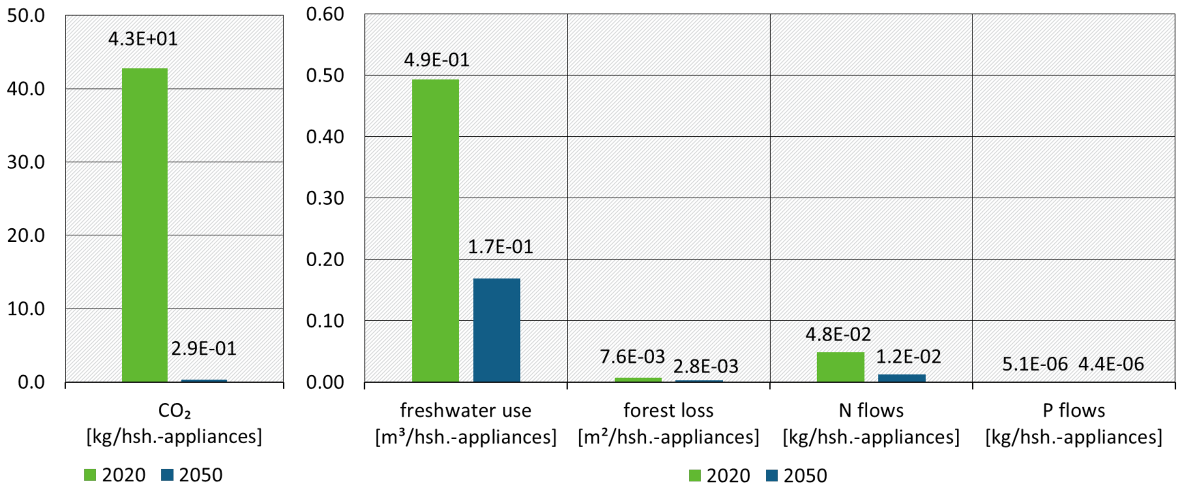
The available LCA data sets were weighted according to the appliances per person and included in an overall mix of household appliances (product basket, *germ. Warenkorb*). The average household appliance basket per person thus contains 0.57 coffee machines, 0.5 cooking stoves, 0.71 washing machines[11], 0.89 refrigerators[12] and 0.37 dishwashers. In the consumption calculator, the same mix was assumed for the year 2050. In the GreenSupreme scenario, it was assumed that the products would be of higher quality and more durable. Therefore, the lifespan of household appliances was increased from 12 years in 2020 to 15 years in 2050.

The environmental impacts of the average household appliances that are relevant to the concept of the planetary boundaries are shown in figure 19. Compared to today, CO_2 emissions decrease by 99 %, forest loss by 63 %, nitrogen flows by 75 % and freshwater use by 66 % as a result of the conversion of energy production and metal and plastic production. Phosphorus flows also decrease by 13 %, starting from an already low level.

[11] The life cycle assessment of the washing machine was also used for tumble dryers.

[12] The life cycle assessment of the refrigerator was also used for freezers and deep freezers.

Figure 19: Environmental impacts of average household appliances, 2020 and 2050



Source: own presentation based on own calculations, ifeu and ecoinvent; hsh. = household

4.10 Representative good 10: ICT devices

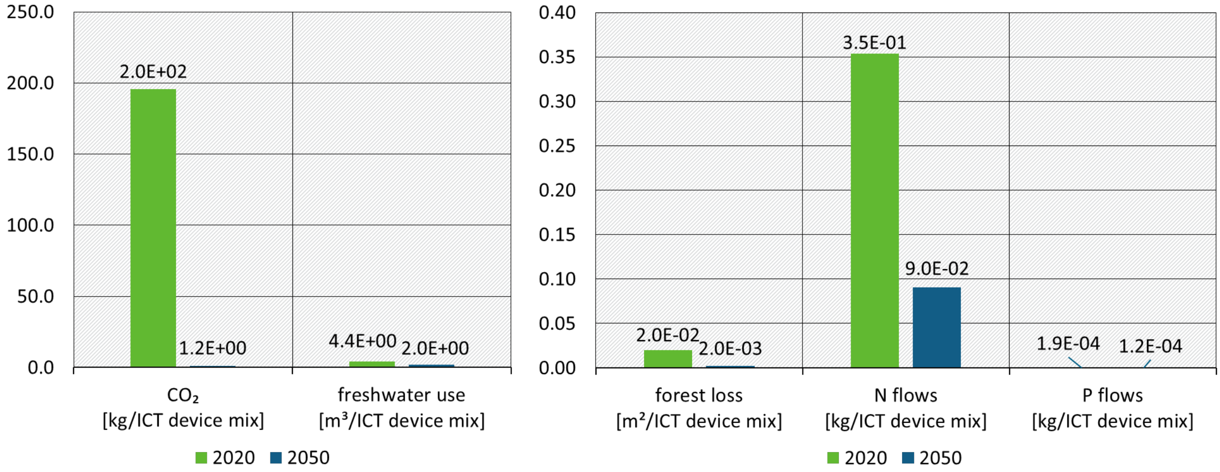
The average ownership of consumer electronics and information and communication devices is regularly surveyed and published by Destatis. According to this survey, each household in 2020 owns, among other things, 1.64 televisions, 0.76 DVD and Blu-ray players, 0.15 video cameras, 1.17 photo cameras as well as 2.28 PCs (including 1.74 mobile devices), 0.86 printers and 2.91 telephones (including 1.56 smartphones). The average ownership has changed differently in the course of the past years in relation to the devices. For example, the number of smartphones and mobile PCs has increased, while the number of cameras or video cameras has decreased. In 2020, 92 % of private households had internet access. (Destatis 2021b)

The available LCA data sets, weighted by equipment in 2020, were compiled and incorporated into a specific ICT product basket. On average, a person owns 0.82 televisions, 0.43 printers, 0.46 routers, 1.14 computers (laptops) and 0.78 mobile devices. The lifespan in 2020 was set at a flat rate of 3 years.

In GreenSupreme, it was assumed that efficiency gains in ICT devices and the trend towards more (mobile) devices would be broken and that on average each person would have about the same amount and types of devices as today. However, it was assumed that consumers would increasingly buy repairable and higher-quality products, so that the average product lifespan would increase. Therefore, the same ICT product basket was assumed in the consumption calculator, but the lifespan was increased to 4 years.

The environmental impacts are shown in figure 20 for the years 2020 and 2050. Due to the transformation of energy production and metal and plastic production, all environmental impacts decrease compared to today, CO_2 emissions by 99 %, forest loss by 90 %, nitrogen flows by 74 %, freshwater use by 54 % and phosphorus flows by 37 %.

Figure 20: Environmental impacts of ICT devices, 2020 and 2050



Source: own presentation based on own calculations, ifeu and ecoinvent

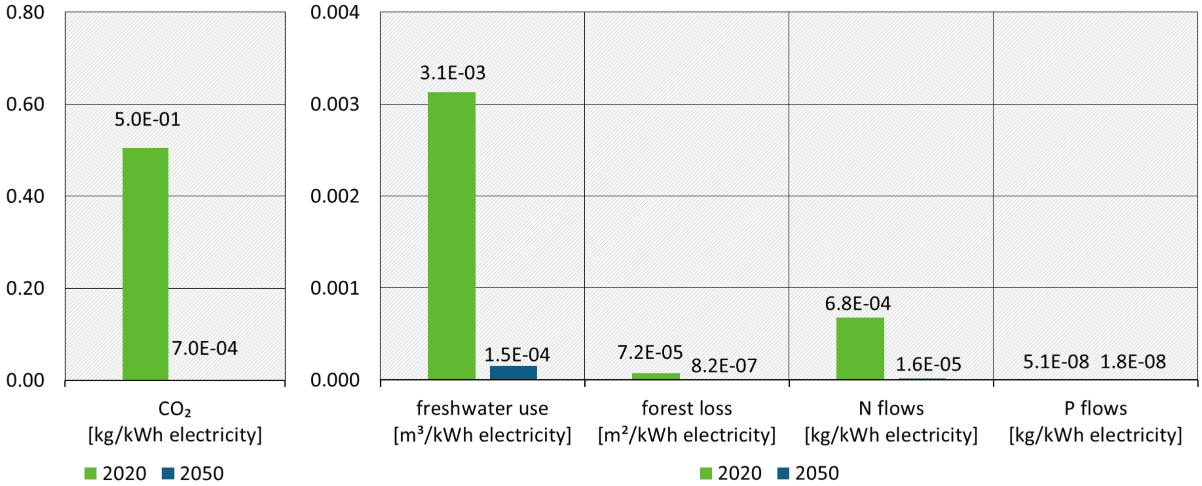
4.11 Representative good 11: electricity

Electricity consumption was included as a cross-sectional good. In 2019, the average electricity consumption of private households was 3,106 kWh, thereof 2,633 kWh were used for electrical appliances (Destatis 2021e).

In GreenSupreme, the energy system changes fundamentally. It is completely transformed from fossil energy sources to renewable energies. In addition to the transformation of electricity generation, renewable energy sources are also made fully or predominantly usable for mobility and heat generation via electricity-based applications such as electric cars or heat pumps. Therefore, the differentiation from other representative goods is important. While heat generation is generally not included in today's electricity consumption because oil, gas or wood are used, heat generation is included in household electricity consumption in GreenSupreme 2050. The mobility sector also switches to electricity as an energy source. In this project, the electricity quantities for mobility are allocated to the use of electric cars and bicycles. The environmental impacts per kWh of electricity are of course the same.

Figure 21 shows the environmental impacts of electricity that are relevant to the concept of planetary boundaries. Compared to today, all environmental impacts are decreasing. For example, CO_2 emissions (-100 %), freshwater use (-95 %), nitrogen flows (-98 %), forest loss (- 99 %) and phosphorus flows (-63 %) decrease.

Figure 21: Environmental impacts of electricity, 2020 and 2050



Source: own presentation based on own calculations, ifeu and ecoinvent

5 Results for today's average citizen: Is a reduction of consumption necessary to stay within the planetary boundaries in 2050?

In chapter 4, the consumption pattern of today's average citizen in Germany was described in detail and the environmental impacts per unit of the respective consumer good were presented.

In this chapter, today's average consumption pattern and the related environmental impacts are summarised:

On average, a German citizen drives 11033 pkm with a fuel-powered car and another 2251 pkm with public transport. Around 80 pkm are covered by e- bicycles. In addition, 1945 pkm are accounted for by private air travel. The average living space today is 47 m^2. In 2020, household appliances per person include 0.57 coffee machines, 0.5 cooking stoves, 0.71 washing machines, 0.89 refrigerators and 0.37 dishwashers. In addition, 287 litres of milk (incl. dairy products) are consumed on average. The average electricity consumption of a person in a private household is 1606 kWh. German consumers prefer cotton clothing and consume on average about 10 kg of cotton plus 6.15 kg of synthetic textiles per year. Furthermore, a person today owns a range of consumer electronics and information and communication devices over a lifespan of 3 years: 0.82 televisions, 0.43 printers, 0.46 routers, 1.14 computers (or laptops) and 0.78 mobile devices. On average, 0.47 pets are kept per person.

The diet is currently characterised by a high consumption of animal products. These take up around 38 % of the annual food quantity per person in Germany (Destatis 2019). In addition, relevant amounts of food waste are produced.

There are several environmental impacts relevant to the planetary boundaries based on the current average consumption pattern. Table 6 shows the environmental impacts that are relevant in the context of food consumption. Table 7 shows the environmental impacts (based on today's consumption quantities of goods without food) without technical changes (current environmental factors are applied) and with technical changes from the GreenSupreme scenario.

Table 6: Relevant environmental impacts of today's average person in the consumption area of food on the planetary boundaries (no change in food waste)

Dimension	Greenhouse gases	Land-system change	Biochemical flows		Freshwater use
Indicator	Methane, nitrous oxide	Agricultural land	Phosphorus	Nitrogen	Freshwater
	Kg CO_2-eq. / a	*m^2 / a*	*g / a*	*g / a*	*m^3 / a*
Environmental impact per person	746	1 808	2 568	18 910	258
Budget per person	**435**	**1533**	**548**	**5484**	**250**

Source: Willett et al. (2019)

Table 7: Relevant environmental impacts per person from the consumption of the representative goods on the planetary boundaries (today, without and with transformations according to GreenSupreme)

Dimension	Greenhouse gases		Land-system change		Biochemical flows				Freshwater use	
Indicator	Carbon dioxide		Forest loss		Phosphorus		Nitrogen		Freshwater	
Unit	*Kg CO_2 / a*		*m^2 / a*		*g / a*		*g / a*		*m^3 / a*	
Transformation	without	with	without	with	without	with	without	with	without	with
Milk and dairy products	155[13]	5.0[13]	0.9	0.8	0.0	0.0	1 491	1 329	33.3	33.0
Fuel car (without) or e-car (with transformation)	3 469	17.9	0.91	0.03	0.13	0.32	1 948	345	12.3	6.0
Public transport	197	1.1	0.04	0.00	0.01	0.01	659	578	0.8	0.4
E-bicycle	1.8	0.0	0.00	0.00	0.06	0.06	2.4	0.5	0.0	0.0
Air travel (without other effects)	206*	0.6**	0.07	0.00	0.00	0.01	437	394	0.4	0.4
Conventional housing	412	52.7	0.06	0.03	0.06	0.08	511	227	5.1	4.5
Electricity	810	1.1	0.12	0.00	0.08	0.03	1 088	26	5.0	0.2
Household appliances	43	0.3	0.01	0.00	0.01	0.00	48	12	0.5	0.2
Cotton	68	2.5	0.01	0.00	0.01	0.01	370	317	105.5	105.4
Synthetics	22	0.4	0.00	0.00	0.00	0.00	20	10	0.3	0.3
ICT devices	196	1.2	0.02	0.00	0.19	0.12	354	90	4.4	2.0
Pets	276	4.2	0.07	0.05	0.07	0.06	473	296	7.6	6.5
Other (base contribution[14])	Not determ.	100	—	—	—	—	—	—	—	—
Total	**5 954.2**	**187.1**	**2.2**	**1.0**	**0.7**	**0.7**	**7 401.2**	**3 626.3**	**175.2**	**158.9**
Budget per person	**150**		**10**		**183**		**1 828**		**222**	

Source: own calculations, ifeu; *If other effects are considered, the flight would account for 616 kg CO_2 or ** 411 kg CO_2 with transformation.

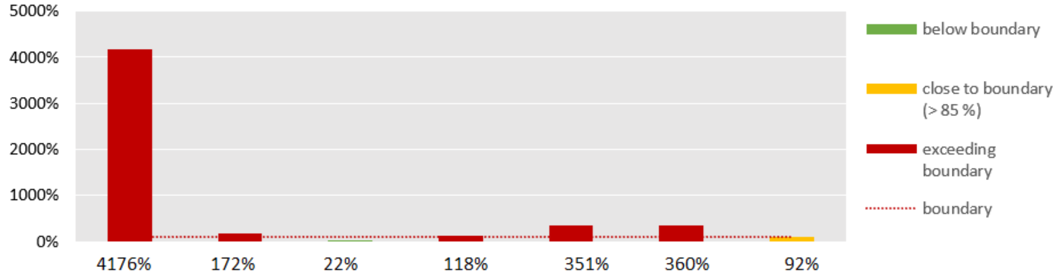
The consumption calculator was fed with the quantities of today's average citizen. The following figure 22 shows the results in relation to the planetary boundaries. For this illustration, the biochemical flows (phosphorus and nitrogen) and the freshwater of the consumption area food and the representative consumer goods without food were added up. These were then set in relation to the respective total budgets.

[13] It should be noted again here that the representative commodity of milk was selected as a supplement to the Lancet study. Methane and nitrous oxide emissions are not shown here; these are included in the greenhouse gases in Table 6 and are covered by the EAT-Lancet study. The "food sector" is always presented separately in the following.

[14] see chapter 2.2

Figure 22: Consumption of today's average citizen (representative goods) compared to the planetary boundaries (incl. other effects during air travel)

	Climate change		Land-system change		Biogeochemical flows		Freshwater use
	CO_2	CH_4, N_2O	Forest loss	Agricultural area	Phosphorus	Nitrogen	Freshwater
Unit:	kg CO_2	kg CO_2-eq.	m^2	m^2	gram	gram	m^3
Boundary per capita:	150	435	10	1 533	731	7 312	472
Demand today:	6 265	746	2	1 808	2 569	26 311	433

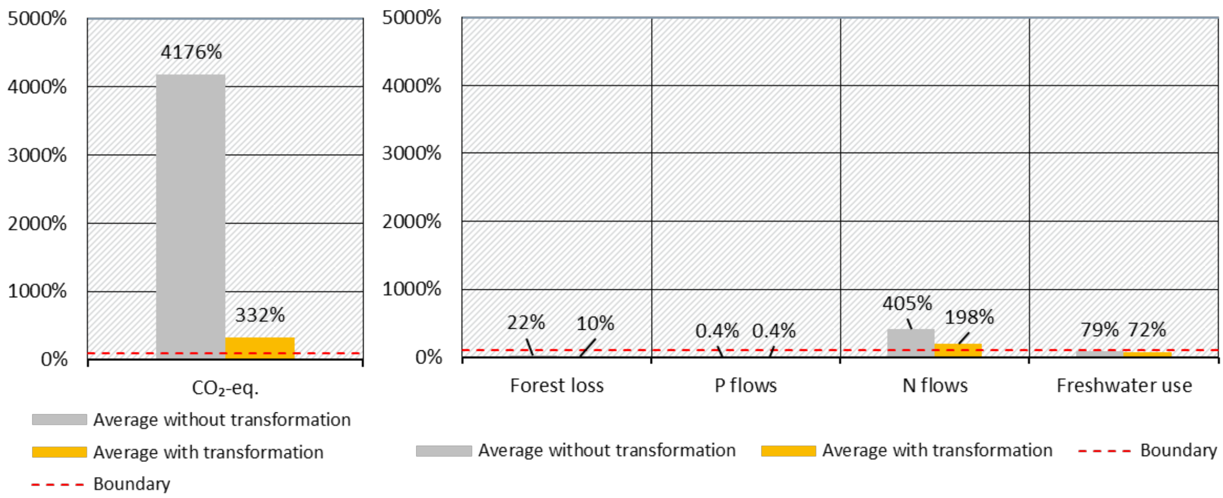


Source: own representation of own results

Table 6, table 7 and figure 22 show that the current consumption of the representative goods clearly exceeds the planetary boundaries for climate change, the annual phosphorus and nitrogen budget (without transformations) as well as the boundary for the agricultural area used. The other boundaries are met. The CO_2 budget is primarily exceeded by the representative goods in the consumption area mobility. In addition, high environmental impacts of methane and nitrous oxide are caused by food consumption and related production systems. The environmental impacts caused by food consumption also exceed the boundaries for biochemical flows.

If ambitious transformations from the GreenSupreme scenario are considered when calculating the environmental impacts – based on today's average consumption levels – a reduction in the use of budgets is possible, as shown in figure 23. Regarding greenhouse gases, transformations would allow for staying within the budget's boundary, but the non-CO_2 effects due to air traffic always lead to the greenhouse gas boundary still being well exceeded.

Figure 23: Environmental impacts of average German consumption (excluding food and base contribution) relative to the planetary boundaries



Source: own calculations ifeu; CO_2-eq. includes climate-impacting effects of flights; methane and nitrous oxide emissions are not included. Environmental impacts of the representative good milk are included.

Technical changes would reduce the current environmental impact in terms of greenhouse gases (CO_2-eq.) by 92 %, but relative to the planetary boundary climate change, there is still an overshoot of 332 % per year. Mobility accounts for the largest share; around 83 % of the greenhouse gases (incl. non-CO_2 climate effects from air travel) produced by the representative goods are caused by flying, despite transformations.

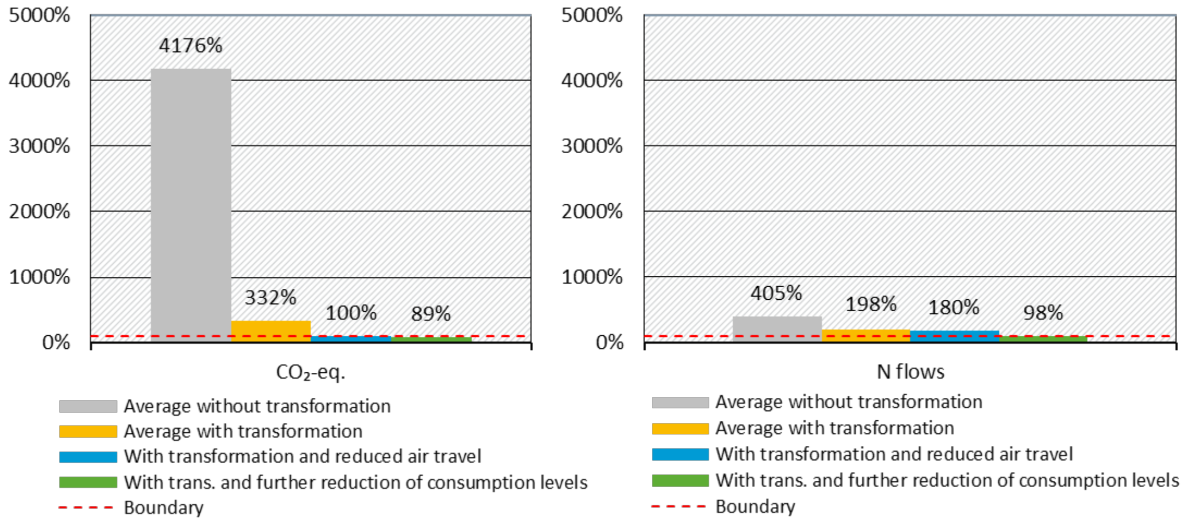
The technical changes could reduce the annual forest loss through the consumption of the representative goods by more than half. For biochemical flows, two opposite developments are possible: while for phosphorus there could be a slight increase (albeit at a low level), a transformation would allow a reduction of the annual nitrogen budget demand by around half, but this still means exceeding the annual nitrogen boundary by 198 % relative to the budget. In terms of current freshwater use, technical changes would also have the potential to reduce overall demand slightly, relative to the boundary this would amount to 72 %.

Consumption of the representative goods within the planetary boundaries is thus less problematic with technical changes, yet the boundaries for climate change and nitrogen remain well exceeded. In view of today's consumption levels, the following figure 23 illustrates the relevance of an ambitious technical transformation, but also shows that an additional contribution to reducing environmental impacts must be made by the consumer to enable sustainable consumption within the planetary boundaries. It should also be noted that a "residual amount" (base contribution), which includes emissions from public buildings, waste, (waste-) water and other communal environmental impacts from the public sector, contributes additionally to exceeding the planetary boundaries. However, this residual has not been determined for today's consumer.[15]

One effective option for action for the consumer would be to reduce the distance flown, while maintaining the same consumption of other goods, to comply with the CO_2 budget. The average flight distance could, for example, be reduced to 300 pkm/year to remain within the boundary for climate change (figure 24; columns in blue). To stay within the boundary for nitrogen, several additional savings would have to be made: it would be possible, for example, to reduce the consumption of milk and dairy products, car journeys and the use of public transport by two thirds each (see figure 24; columns in green).

[15] For comparison: The CO_2 calculator of the Federal Environment Agency (https://uba.co2-rechner.de/en_GB/) includes an amount of 1.15 t CO_2 eq. per person for public emissions. The approaches in the CO_2 calculator and in this project are not identical, but the larger contributions such as GHG emissions from wastewater or public buildings are included in both calculations.

Figure 24: Environmental impacts of average German consumption (excluding food and base contribution) relative to CO_2 and nitrogen budgets without and with transformation as well as with reduced consumption levels



Source: own calculations ifeu; CO2 also considers the climate-impacting effects of flights.

In the GreenSupreme scenario, inhabitants change their consumption habits: They eat less meat and healthier, live in smaller living spaces and make greater use of bicycles, public transport and sharing services for their journeys. In addition, they increasingly demand sustainable, durable and repairable products, so that the demand for goods decreases overall. Therefore, the consumption quantities in 2050 will also change (see chapter 6).

Different changes in personal lifestyles can be illustrated by vivid narratives. Possible consumption patterns in 2050 within planetary boundaries are described in chapter 7.

6 Results for the GreenSupreme average citizen

The starting point for identifying sustainable consumption patterns is the average consumption in GreenSupreme in 2050.

In the consumption area of food, the average consumption in GreenSupreme roughly corresponds to the reference diet from the Lancet study. Furthermore, in GreenSupreme, significantly fewer animal products are eaten than in the present. In addition, GreenSupreme, like the Lancet study, assumes a significant reduction in food waste and technological changes in agriculture.

According to the GreenSupreme scenario, the average citizen travels 6731 km by electric car in 2050 and 3296 km by public transport. Regarding the distance travelled by bicycle or on foot, an assumption was made in GreenSupreme. It was assumed that 50 % of these distances are travelled by e-bicycle. With regard to aviation, 2072 km are flown privately by plane.

The average living space is 41 m^2. In the consumption calculator, a conventional average house was assumed, which is slightly higher in CO_2 consumption than a wooden house. The equipment with household appliances is comparable to today's. However, in GreenSupreme it was assumed that the consumption decisions fall on products that are of higher quality and repairable and thus have a longer lifespan (+33 % on average). The average electricity consumption of private households is 1,714 kWh in 2050 (incl. heating). Not included is the electricity consumption of mobility, which is calculated directly in the consumption area of mobility, and the electricity or energy consumption of industry and tertiary sector, which is largely included in the upstream chain of goods.

Average German consumers prefer clothing that is of higher quality and repairable and can therefore be used for a longer time (+33 %). The longer lifespan also applies to ICT devices. In the GreenSupreme scenario, the trend of buying more and more ICT devices per person is broken. Instead, the average number of devices remains constant, but they are used longer due to the longer lifespan. In the GreenSupreme scenario, no explicit assumptions were made about pets. Therefore, the average ownership of pets is maintained.

The resulting environmental impacts relevant to the planetary boundaries are shown in table 8 and table 9.

Table 8: Environmental impacts per person in the consumption area of food, in 2050

Dimension	Greenhouse gases	Land-system change	Biochemical flows		Freshwater use
Indicator	Methane, nitrous oxide	Agricultural land	Phosphorus	Nitrogen	Freshwater
	Kg CO_2-eq. / a	*m^2 / a*	*g / a*	*g / a*	*m^3 / a*
Environmental impact per person	435	1 197	1 426	13 203	207
Budget per person	435	1 533	548	5 484	250

Source: Willett et al. (2019)

Table 9: Environmental impacts per person through consumption of the representative goods (excl. food) in 2050

Dimension	Greenhouse gases	Land-system change	Biochemical flows		Freshwater use
Indicator	Carbon dioxide	Forest loss	Phosphorus	Nitrogen	Freshwater
	Kg CO_2 / a	*m² / a*	*g / a*	*g / a*	*m³ / a*
Milk and dairy products	4.1	0.70	0.03	1 106.7	27.5
E-car	10.9	0.02	0.20	210.6	3.6
Public transport	1.7	0.00	0.01	846.3	0.6
E-bicycle	0.2	0.00	0.58	5.4	0.1
Air travel (CO_2 only)	0.7*	0.00	0.01	420.0	0.4
Conventional housing	46.0	0.03	0.07	198.4	3.9
Electricity	1.2	0.00	0.03	28.0	0.3
Household appliances	0.3	0.00	0.00	12.2	0.2
Cotton	1.8	0.00	0.01	224.1	74.5
Synthetics	0.3	0.00	0.00	6.6	0.2
ICT devices	1.2	0.00	0.12	90.4	2.0
Pets	4.2	0.05	0.06	296.2	6.5
Other (base contribution)[16]	76.0	n.a.	n.a.	n.a.	n.a.
Total	**148.5**	**0.81**	**1.13**	**3 445.0**	**119.8**
Budget per person (without diet)	**150**	**10**	**183**	**1 828**	**222**

Source: own calculations, ifeu; *Air travel (incl. other effects) would be 437 kg CO_2/a

The planetary boundaries in the dimension of climate change were defined by the GreenSupreme scenario (table 9) or by the reference diet (table 8) (Willett et al. 2019). Therefore, it is logical that the average citizen complies with the boundaries. The planetary boundary land-system change is also respected in the framework as defined for this project (chapter 3). The planetary boundary for freshwater consumption and the boundary for phosphorus flows are also not exceeded. The boundary for nitrogen flows, however, is not met. One important reason for exceeding the nitrogen boundary is that the annual per capita budget is already well exhausted by the consumption of milk and dairy products. In addition, the new technologies for generating energy have high phosphorus and nitrogen flows.

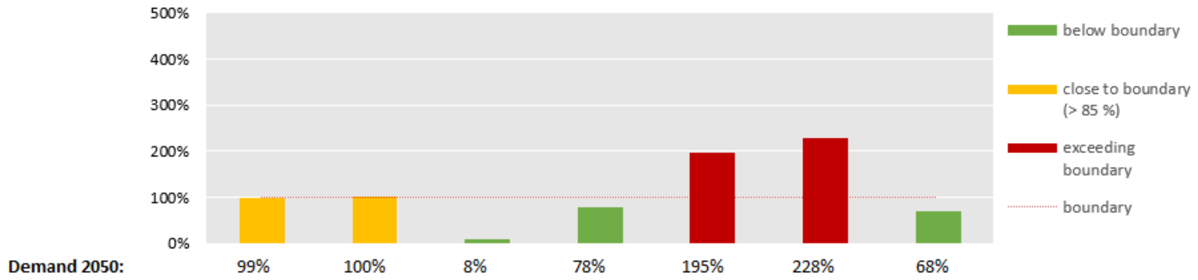
The consumption calculator was fed with the average consumption level of the GreenSupreme citizen. Figure 25 and figure 26 show the results in relation to the planetary boundaries. For this

[16] see chapter 2.2

illustration, the biochemical flows (phosphorus and nitrogen) and the freshwater of the consumption area food (table 8) and the representative consumer goods without food (table 9) were added up. These were then set in relation to the respective total budgets.

Figure 25: The consumption level of the GreenSupreme average citizen compared to the planetary boundaries (incl. only CO_2 from air travel)

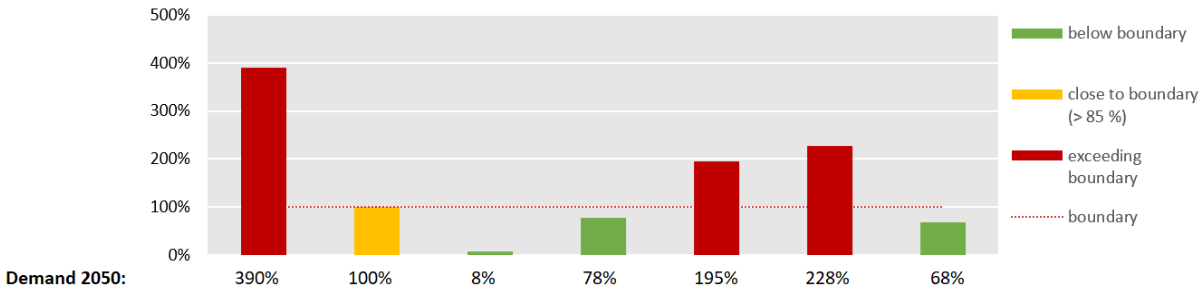
	Climate change		Land-system change		Biochemical flows		Freshwater use
	CO_2	CH_4, N_2O	Forest loss	Agricult. area	Phosphorus	Nitrogen	Freshwater
Unit:	kg CO_2	kg CO_2-eq.	m²	m²	gram	gram	m³
Boundary per capita:	150	435	10	1533	731	7312	472
Demand 2050:	148	435	1	1197	1427	16636	322



Source: own representation of own results, ifeu

Figure 26: The consumption level of the GreenSupreme average citizen compared to the planetary boundaries (incl. other effects during air travel)

	Climate change		Land-system change		Biochemical flows		Freshwater use
	CO_2	CH_4, N_2O	Forest loss	Agricult. area	Phosphorus	Nitrogen	Freshwater
Unit:	kg CO_2-eq.	kg CO_2-eq.	m²	m²	gram	gram	m³
Boundary per capita:	150	435	10	1533	731	7312	472
Demand 2050:	586	435	1	1197	1427	16636	322



Source: own representation of own results, ifeu

By adding up the respective "sub-budgets" (consumption with and without food), it becomes clear that the boundaries for the phosphorus and nitrogen flows are exceeded (see figure 25). Furthermore, if non-CO_2 effects from air travel are considered, the boundary for climate change (CO_2-eq.) is also exceeded (see figure 26).

7 Generalisable consumption patterns

7.1 Literature review on consumption patterns

In the following, the studies on different patterns of consumption are presented in profiles. The analysis questions described in chapter 2 are used here.

UBA (2015): Klimaneutral leben (*transl. Climate-Neutral Living*) & BMU and UBA (2019) Umweltbewusstsein in Deutschland (*transl. Environmental Awareness in Germany*).

Objective: The German Environment Ministry (BMU) and the German Environment Agency (UBA) commission a representative survey on environmental awareness every two years. Based on the survey and the concept of "social milieus", environmental behaviour and attitudes to ecological issues of the population of Germany were analysed. The brochure "Klimaneutral leben" (engl. *Climate Neutral Living*) published by UBA offers insights into possible climate neutral lifestyles in the form of five different environmental types (personas). These are intended to illustrate the effects of lifestyles on the CO_2 footprint and give readers the opportunity to identify different lifestyle options.

Methodology: The personas can be assigned to the identified milieus of the environmental awareness study that are receptive to environmental issues (environmentally oriented (22 %), sustainability oriented (14 %) and orientation seekers (20 %)). The CO_2 emissions of the individual personas are calculated with the CO_2 calculator.

Personas (selection): Sabine T. is a gourmet and represents the LOHAs (Lifestyle of Health and Sustainability). She lives in an apartment building, does not own a car, uses green electricity and buys organic products. Renouncement is a foreign word for her.

For Peter B., quality goes before quantity. He lives in a spacious passive house with a solar system and pays attention to low fuel consumption when buying a car.

For Katharina C., less is more. She lives in a small flat and works part-time to consciously have more time. In return, she does without her own car and cycles a lot.

Linus L.'s career means a lot to him. He is always busy and is on the road a lot. To compensate for his considerable CO_2 emissions, he donates to offset projects that meet the Gold Standard.

Characteristics: including name, living space, place of residence and characteristics of buildings (insulation, type of house, distance to work), mobility behaviour (car sharing, own car, BahnCard, long-distance travel), purchase of heat and electricity (green electricity, own solar system), diet (organic, vegetarian), energy efficiency of household appliances, support of environmental associations and projects, consideration of environmental labels, financial investment (purchase of CO_2 certificates, investments in wind energy or sustainability funds).

Teubler et al. (2018): A Household's Burden & Ahlert et al. (2015): Nachhaltige materielle Wohlstandsniveaus (*transl. Levels of sustainable material wellbeing*).

Objective: Calculation of the resource footprint of different household types.

Methodology: First, average household types were identified using a cluster analysis of micro-household statistics from 2008. These data were then linked with LCA data to calculate household commodity demand for selected goods (Ahlert et al. 2015) or total household commodity demand (Teubler et al. 2018) respectively. As the studies build on each other, they are presented jointly.

Household types: 7 different clusters were identified in Ahlert et al. (2015):

Commoners (27 %): middle to older age groups, predominantly 2-person households ('empty nesters'), 80–140 m² living space, one third pensioners, average electricity consumption, slightly below average fuel consumption, new purchases rare, material possessions and financial security important, overrepresented in small towns (< 100,000).

Young (13 %): younger to middle-aged, 2–4-person households, 60–140 m² living space, overrepresented in large cities (> 500,000), slightly below-average electricity consumption, average fuel consumption, many new purchases in planning, striving for professional establishment.

Established (14 %): younger to middle-aged, upper professional qualifications, living in the surrounding area, overrepresented in small communities (< 20,000), mostly homeowners, 100–160 m² living space, pronounced mobility, 2–5+ persons, average electricity consumption, above-average fuel consumption, high standard of living, above-average amenities.

Large families in rural areas (6 %): middle to older age groups, overrepresented in small communities (< 20,000), high proportion of homeowners, 3 and more person households, a lot of living space, very high electricity consumption, average fuel consumption, rather low mobility, very high amenities, large and multi-generational families with a lot of living space.

Disadvantaged (33 %): higher and younger age groups slightly overrepresented, predominantly non-working people, overrepresented in cities (> 100,000), usually renters, small living space (two-thirds under 80 m²), 1–2 person households, usually no car, low mobility, heterogeneous socio-cultural profile, low electricity consumption, very low fuel consumption.

Elitist (2 %): predominantly male main income earner, middle-high age groups, very high proportion of academics, large flats, several cars, very high level of equipment and lifestyle, large flats of 100 m² or more, mostly 3- and multi-person households, high-income level, high electricity consumption, extremely high fuel consumption, wealthy, well-off families, appreciation of the special and exclusive.

Performer (5 %): middle age groups, high proportion of academics, highly committed to their profession, significantly above-average mobility, many long-distance trips, large flats, average electricity consumption, high fuel consumption, significantly above-average mobility.

Characteristics: including socio-cultural profile, equipment level for 14 products, standard of living, educational attainment, typical occupations, equipment level, income level, dwelling size, electricity and fuel consumption, average age, education level, residence size, household size.

Results: Relatively small differences in household appliances were observed between the clusters (e.g. the average number of televisions in the household ranged from 1.8 to 2.14; for used cars from 0.33 to 1.46). There were larger differences between clusters in electricity and fuel consumption (electricity between €521 and €2,300 per year, fuel between €238 and €5,675 per year). The consumption data results in resource footprints between 6 and 17 tonnes per year. The cluster of the disadvantaged represents a downward outlier with 6 tonnes. The next cluster up is already at 11 tonnes.

Onel et al. (2018): Tell me your story and I will tell you who you are: Persona perspective in sustainable consumption, in: Psychology and Marketing.

Objective: In the study, personas are designed with the aim of understanding motivations and incentives for sustainable consumption behaviour.

Methodology: The methodology is explorative. 14 in-depth, qualitative interviews on consumer behaviour were conducted.

Personas: Personas are defined as "abstractions of groups of real consumers with similar characteristics and needs". The following personas are identified: the holistic sustainable type, the transitionally sustainable type and the limited sustainable type.

Evan (holistic sustainable): 35, scientist, vegan diet, environmental justice and equality as motivation, striving for social and ecological transformation, public transport use, small living space, proximity to nature important, second-hand clothes.

Marcus (transitional sustainable): 37, general contractor, view of sustainability limited to the individual, no linkage between the different dimensions of sustainability, importance of social norms, organic food, focus on waste prevention, reliability and durability as significant purchasing criteria e.g. when buying a car.

Theresa (limited sustainability): 41, paediatrician, local shopping, focus on health, awareness of only isolated aspects of sustainability, focus on one area of action (e.g. organic food or renewable energy).

Characteristics: lifestyle, motivation, commitment to sustainability, behaviour in the areas of need mobility, clothing and nutrition.

Froemelt et al. (2018): Environmental Impacts of Household Consumption Behaviors' & Matasci et al. (2019): Material- und Energieflüsse der schweizerischen Volkswirtschaft (transl. Material and energy flows in the Swiss economy)

Objective: In the study, material flows and CO_2 emissions are determined for different behavioural archetypes.

Methodology: Based on data on 9734 households from Switzerland for the period from 2009 to 2011, a cluster analysis was conducted. Monetary expenditures were combined with Ecoinvent[17] coefficients to determine the environmental impacts.

Household types: First, Froemelt et al. (2018) identified 28 clusters with similar consumption behaviour and household characteristics. A clear correlation between income and greenhouse gas emissions was found. Matasci et al. (2019) then grouped the clusters into five groups, each with a 20 % share of the population, ranked by the average environmental impact of the clusters.

The first quintile consists of families only, e.g. a cluster of very young adults with small babies, and mainly tenants. In other quintiles, the household types are more mixed. For example, in the top quintile there are families and 1–2-person households with medium and high incomes.

Findings: The lowest quintile causes 16 % less greenhouse gases, the top quintile 17 % more greenhouse gases than the average. The increase is steady from quintile to quintile across all

[17] https://ecoinvent.org/the-ecoinvent-database/

consumption sectors, i.e. higher environmental impacts are observed in each of the consumption sectors construction, mobility and consumption (Matasci et al. 2019).

Characteristics: consumption expenditure (monetary) by 365 consumption categories, quantities purchased for 92 categories, household endowment with twenty durable goods, household size, income by 8 categories, age, marital status, national origin.

Two other studies that deal with consumption patterns or personas, at least marginally, are also worth mentioning:

- Grünewald et al. (2021): Narrative einer erfolgreichen Transformation zu einem ressourcenschonenden und treibhausgasneutralen Deutschland, Erster Zwischenbericht (*transl. Narratives for a successful transformation to a resourceefficient and climate neutral Germany, First interim report*), UBA Texte 26/2021.
- Schipperges et al. (2018): Erfolgsbedingungen für Systemsprünge und Leitbilder einer ressourcenleichten Gesellschaft, Band 4 (*transl. Success conditions for system leaps and concepts for a resource-efficient society, Vol. 4*), UBA Texte 87/2018.

The former is also about future consumption patterns. Personas are to be developed based on the RESCUE scenarios. Thus, the task is similar to the one in this project. However, the corresponding next report has not yet been published, so the results cannot yet be included here.

Schipperges et al. (2018) derived guiding principles for sustainability using a scenario technique and then investigated the attitudes of different social milieus towards these guiding principles.

What conclusions can be drawn from the literature? Two methods for developing consumption patterns can be distinguished: The consumption patterns are either statistically derived with the help of a cluster analysis and comprehensive household statistics, or based on types determined through interviews or surveys, they are designed as fictional personas with narrative elements.

A common feature of the literature considered is that it deals exclusively with current consumption patterns. Since future consumption patterns are to be developed in this project, they cannot be derived directly from statistics. Moreover, the detailed consumption statistics at the level of individual households are not freely available.

Another observation is that the differences in consumption and the associated environmental impacts between the various statistically determined clusters are relatively small. Of course, this is also a consequence of the fact that mean values are determined for numerous households in each cluster. The actual variance at the level of individual households is certainly significantly higher. However, it is interesting to note that even when many relatively small clusters are grouped by environmental impact, as in Matasci et al. (2019), deviations of only -17 % to +16 % from the average can be observed. This observation suggests that the consumption patterns developed should not represent too extreme variants to be accessible.

7.2 Statistical data basis

This chapter presents the statistical data that can be used as a point of reference for developing consumption patterns.

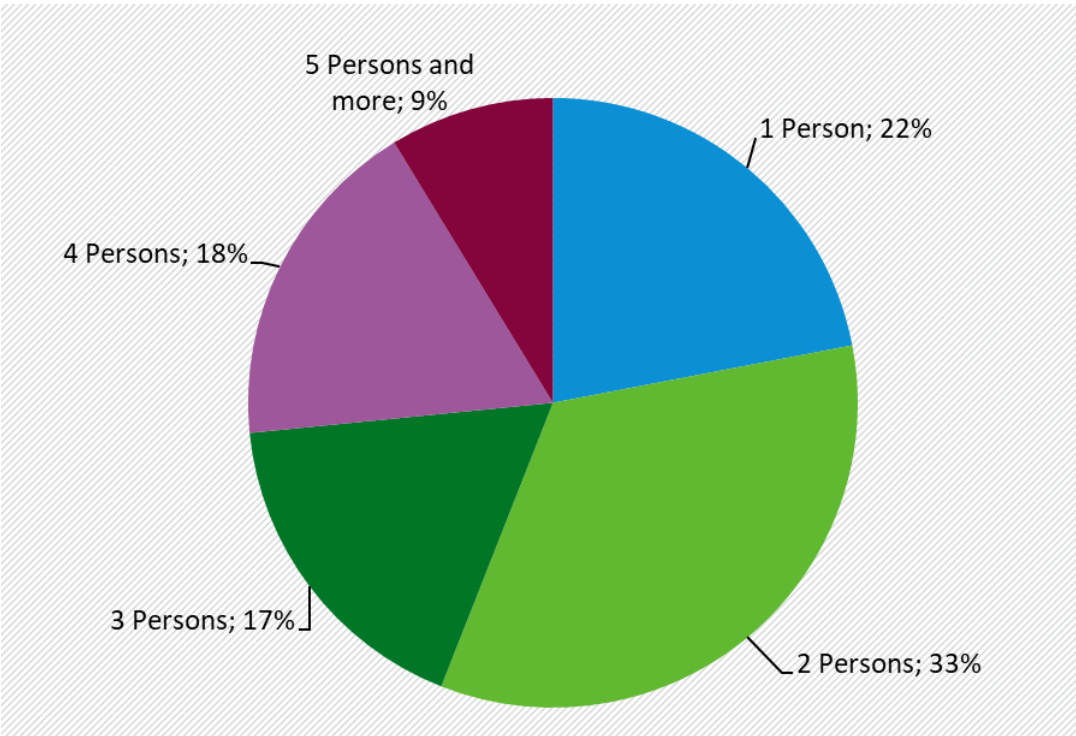
In addition to Destatis (German Statistical Office), data sources include a UBA study with a representative survey of per capita energy consumption for various population groups

(Kleinhückelkotten et al. 2016), as well as an unpublished, internal data evaluation on profiles of the UBA CO_2 calculator.

Destatis prepares data on private household consumption in various publications. The data are differentiated according to household size, net income, household type, occupation, age and gender of the main income earner and housing situation (rented or owned). The data are predominantly monetary and broken down by areas of need/categories of consumption. For food and energy, there is also physical data on the quantities purchased or consumed.

The data from Destatis are predominantly reported at the household level, i.e. per household and not per person. For our evaluations, we have converted the data using the average number of individuals per household. One third of the people in Germany covered by the household statistics[18] live in 2-person households. Single households follow in second place with 22 %. The lowest proportion with 9 % is people living in households with 5 or more persons.

Figure 27: Proportion of people in households by household size in 2018



Source: Destatis (2021f)

Table 10 provides an overview of the consumption expenditure of private households by monthly household net income and areas of need in 2018. The table shows that as household income rises, the share of expenditure on transport, leisure, entertainment and culture, as well as on other items, increases. The share for housing and food, on the other hand, decreases with increasing household income.

[18] Households with a monthly household net income > € 18,000, subtenants, house and company staff, persons in collective accommodation and institutions and homeless persons are not included in the household statistics (Destatis 2021f).

Table 10: Household consumption expenditure 2018

Monthly net household income	< €1 300	€1 300 — €2 600	€2 600 — €3 600	€3 600 — €5 000	> €5 000
Private consumer spending	€1 059	€1 761	€2 551	€3 253	€4 657
... of which in % for:					
Housing, energy, maintenance	44.5	38.5	35.4	33	29.1
Food, beverages, tobacco products	17.4	15.1	13.9	13.3	11.6
Traffic	8.2	11	13.2	14.6	16.4
Leisure, entertainment, culture	8.2	10.5	11.2	11.4	12
Clothing, shoes	3.5	4.2	4.3	4.5	4.9
Other	18.2	20.8	22.1	23	26

Source: Destatis (2021g)

The strongest differences in average consumption expenditure per person are typically found in the differentiation of households by household size and by household net income. Unfortunately, there is no simultaneous differentiation according to two characteristics. The following list shows the range of consumption expenditure per person according to areas of need and household types:

Table 11: Bandwidths for private consumer spending in 2019

	Average	Minimum	Minimum value	Maximum	Maximum value
Housing, energy, maintenance	€445	5-person household	€228	Woman living alone	€678
Food, beverages, tobacco products	€178	5-person household	€126	Man living alone	€220
Transport	€176	Income < €1 300	€59	Income > €5 000	€257
Leisure, entertainment, culture	€142	Income < €1 300	€74	Income > €5 000	€185
Clothing, shoes	€53	Income < €1 300	€31	Income > €5 000	€74
Interior decoration and household appliances	€71	Income < €1 300	€37	Income > €5 000	€96

Source: Destatis (2020b)

Overall, only relatively small variances can be observed here as well; as a rule, the variance is a factor of 2 to 3. It can be assumed that the variance in physical quantities is even lower since different amounts of money can be spent on the same products. The greatest variance is found in transport (factor 4.36) and the smallest in food (factor 1.74).

Physical data can be found on housing and electricity consumption by Destatis and on energy consumption of mobility by Kleinhückelkotten et al. (2016):

- Housing: living space ranges from 28 m^2 (4-person household in apartment) to 120 m^2 (1 person in family home) (Destatis 2021f).
- Electricity consumption: 1300 kWh to 2200 kWh per person and year (Destatis 2022)
- Energy consumption for everyday mobility: 956 kWh to 7900 kWh per person per year. (Kleinhückelkotten et al. 2016)

Kleinhückelkotten et al. (2016) summarise their results as follows: "Total personal energy consumption [increases] strongly with income level and formal education level [...]. It increases with age, is greater for men than for women and tends to decrease with household size."

7.3 Description of the individual consumption patterns

The objective of developing consumption patterns in this project is to make consumption in 2050 imaginable and to illustrate possible changes in personal lifestyles to stay within the planetary boundaries. In other words, the consumption patterns should present vivid narratives of what consumption in 2050 could look like within planetary boundaries. What changes compared to today? What are the consumption options if planetary boundaries are to be respected?

By consumption patterns we mean typical and generalisable consumption quantities (of goods and services and in terms of energy consumption and mobility patterns) for different population groups. Environmental impacts associated with consumption are estimated using representative goods.

As these are future consumption patterns, they cannot be derived directly from data, unlike some studies described in the literature. Therefore, in this project we use personas, which are described with the help of various narrative elements. For this purpose, the clusters with common characteristics found in the literature serve as a stimulus for the selection of household types, since it can be assumed that the clusters found in the literature with their typical characteristics will also hold in 2050.

Since the consumption patterns should be accessible, care was taken not to develop narratives that were too extreme. Nevertheless, some personas were assigned above-average consumption in certain areas, which means that there can be large differences between the individual patterns. However, an orientation towards the statistically determined bandwidths was considered useful.

7.3.1 Yılmaz family

The Yılmaz family lives in ‚a small town in Germany with 10,000 inhabitants. The family of four lives with their four dogs in a spacious detached house with a garden. The trips to the daughter's football matches, the way into town to work or the short holiday on the Dutch coast – the family covers many distances with their two electric cars. The great luxury of the family is the sauna in the basement, which is used especially by 14-year-old Mara and whose electricity consumption is always a cause for discussion at the family table.

The consumption pattern of the family is shown in table 12. Public transport use is below average, and car use is also slightly below average. The house has 140 m^2 of living space (35 m^2 each), which is slightly below the average living space in 2050. ICT equipment and electricity consumption, due to the sauna, are clearly above average. In terms of food, the family follows the reference diet.

Table 12: Consumption pattern of the Yılmaz family compared to the average in 2050

Consumption area	Representative goods	Consumption per person and year	
		Average	Yılmaz family
Mobility	E-car [pkm]	6 731	6 000
	Fuel-powered car [pkm]	0	0
	Public transport [pkm]	3 296	1 550
	E-bicycle [pkm]	821	0
	Air travel [pkm]	2 072	0
Housing	Conventional housing [m^2]	41	35
	Wooden house [m^2]	0	0
	Electricity [KWh]	1 714	4 000
	Household appliances [Index]	100	100
Other	Cotton [kg]	7	7
	Synthetics [kg]	4	4
	ICT devices [Index]	100	150
	Pets [Index]	0.47	1
	Other [Index residual CO_2]	100	100
Food	Diet	Reference	Reference
	Food waste	Halving	Halving

Source: own elaboration ifeu

The consumption of the representative goods results in environmental impacts that are below average in terms of CO_2 and biochemical flows ofphosphorus and nitrogen, but slightly above average in terms of forest loss and freshwater use (see table 13).

Table 13: Yılmaz family – environmental impacts of consumption per person (excluding food) in 2050

Environmental impact	Yılmaz family	Average	Budget
CO_2 [kg]	141.7	144*	150
Forest loss [m²]	0.16	0.11	10
Phosphorus [g]	0.64	1.09	183
Nitrogen [g]	1 829	2 338	1 828
Freshwater [m³]	99	92	222

Source: ifeu's own calculations; *Only CO_2 effects were considered for aviation.

Table 14 shows the environmental impacts in detail according to goods.

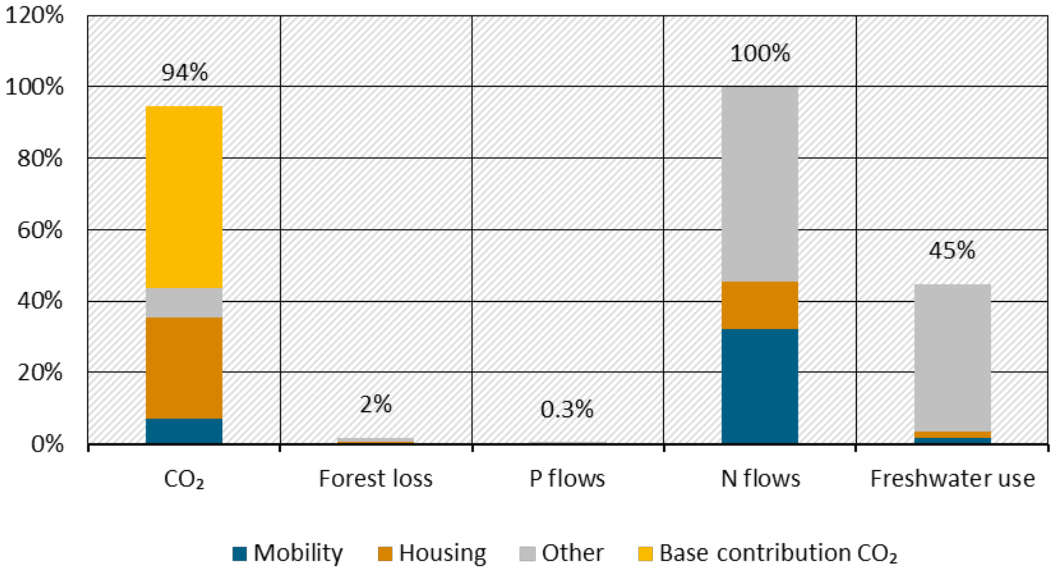
Table 14: Yılmaz family – environmental impacts of consumption by goods (excluding food) in 2050

Consumption area	Representative goods	CO_2 [kg]	Forest loss [m²]	Phosphorus [g]	Nitrogen [g]	Freshwater [m³]
Mobility	E-car	9.7	0.0	0.2	187.7	3.2
	Fuel-powered car	0.0	0.0	0.0	0.0	0.0
	Public transport	0.8	0.0	0.0	398.0	0.3
	E-bicycle	0.0	0.0	0.0	0.0	0.0
	Air travel (incl. other effects)	0.0	0.0	0.0	0.0	0.0
Housing	Conventional housing	39.3	0.02	0.06	169.4	3.4
	Wooden house	0.0	0.0	0.0	0.0	0.0
	Electricity	2.8	0.0	0.1	65.4	0.6
	Household appliances	0.3	0.0	0.0	12.2	0.2
Other	Cotton	1.8	0.0	0.0	224.1	74.5
	Synthetics	0.3	0.0	0.0	6.5	0.2
	ICT devices	1.9	0.0	0.2	135.7	3.0
	Pets	8.9	0.1	0.1	630.3	13.9
	Base contribution CO_2-eq.	76.0	N.A.	N.A.	N.A.	N.A.
Total		141.7	0.2	0.6	1 829.2	99.3
Budget		**150**	**10**	**183**	**1 828**	**222**

Source: own calculations ifeu

Unlike for the average consumer, all boundaries are respected.

Figure 28: Yılmaz family – environmental impacts of consumption per person (excluding food) relative to planetary boundaries



Source: own calculations ifeu

The family follows the reference diet and thus has an average environmental impact for food.

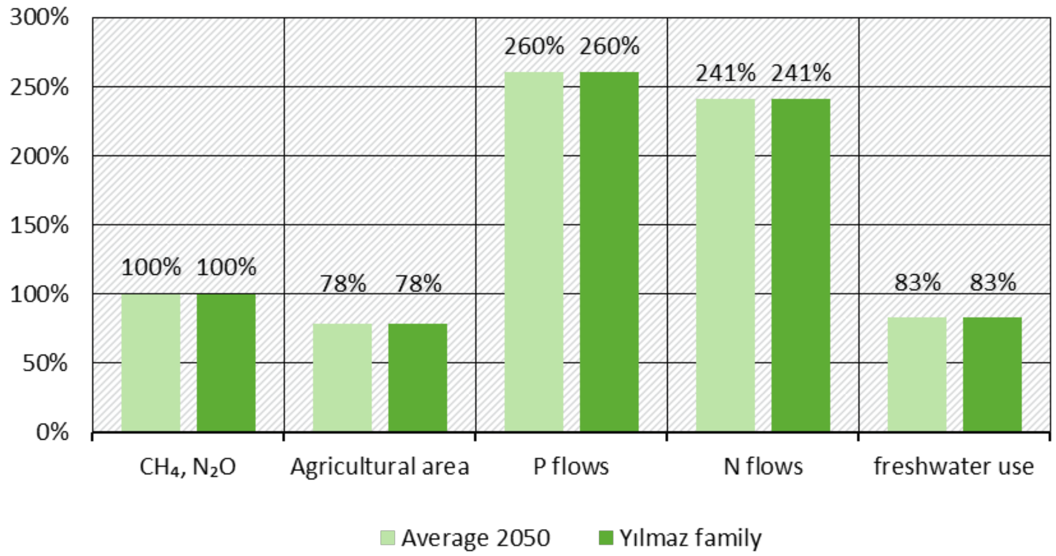
Table 15: Yılmaz family – environmental impacts per person in the food requirement field in 2050

Planetary boundary	Environmental impact	Average	Yılmaz family	Budget
Climate change	CH_4, N_2O [kg CO_2-eq.]	435	435	435
Land-system change	Agricultural area used [m²]	1 197	1 197	1 533
Biochemical flows	Phosphorus [g]	1 426	1 426	548
	Nitrogen [g]	13 203	13 203	5 484
Freshwater	Freshwater use [m³]	207	207	250

Source: own calculations based on Willett et al. (2019)

Relative to the planetary boundaries, the boundaries for phosphorus and nitrogen are exceeded while the other boundaries are kept.

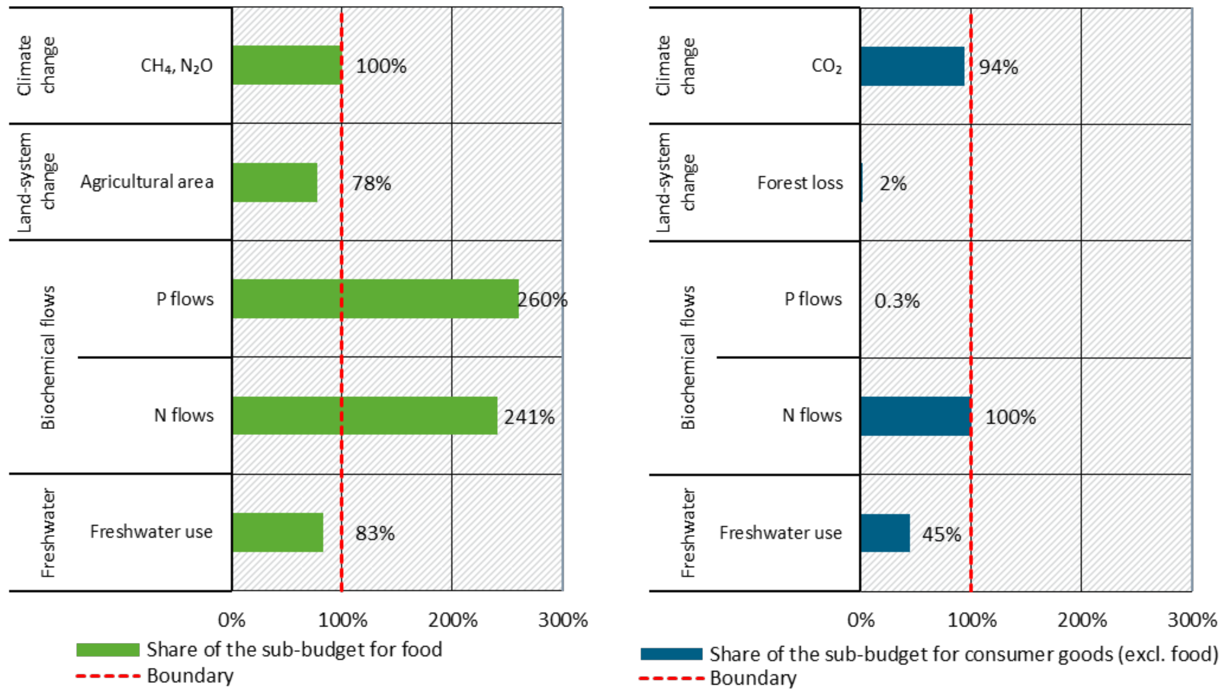
Figure 29: Yılmaz family – environmental impacts of food per person relative to planetary boundaries compared to the average in 2050



Source: own calculations based on Willett et al. (2019)

Figure 30 shows the environmental impacts of the Yılmaz family for both separate budgets (consumption of representative goods without food and food only) in 2050.

Figure 30: Yılmaz family – environmental impacts of consumption: food (left) and non-food (right) relative to planetary boundaries/budget in 2050



Source: own calculations, the environmental impacts of food are based on results from Willett et al. (2019). Note: The figures show shares of separate budgets for the respective planetary boundaries/environmental impacts due to the different methodological approaches (see chapter 3.2) which refer to the "food sector" (according to Willet et al. (2019)) and the "non-food consumption".

7.3.2 Mr. and Mrs. Schmitt

Hilda and Tarik Schmitt are proud to celebrate their golden wedding anniversary this year. Since retiring, they finally have time for regular trips to the nearby mountains by car, where they go for long walks with their two dogs. They live together in the wooden house where they also raised their two, now grown-up, children. Their household is therefore very well-equipped. To keep in touch with their children and grandchildren, they both have notebooks and smartphones. There are also two televisions in the household so that there are no arguments about the choice of programmes.

The consumption pattern of the Schmitt couple is shown in table 16. Although they take frequent trips to the mountains, they travel less than the average. They drive an e-car, which they received from their children for their golden wedding anniversary. The distances they cover with their comfortable e-bicycle for everyday errands are about the same as the average in the year 2050. Although both rarely fly, they resort to travelling by plane to make longer and now somewhat more arduous long-distance journeys possible. They usually use the train to get there and the plane for the return journey. About 10 years ago, they flew back to Berlin from their holiday on the island of Gotland in Sweden. This year, they plan to make a similar trip to celebrate their wedding anniversary.

The shared wooden house has a living space of 150 m^2 (á 75 m^2 per person) and is thus significantly above the average of 41 m^2 per person for conventional living spaces. Due to its size, the home has a relatively high heat demand, which is covered by electricity. In addition, the regular use of the many household and ICT devices also leads to a 46 % higher electricity consumption compared to the average. For health reasons, the couple has been following a vegetarian diet for several years, but their pets (two dogs and two cats) are fed a diet with a high meat content.

Table 16: Consumption pattern of the Schmitt couple compared to the average in 2050

Consumption area	Representative goods	Consumption per person and year	
		Average	Mr. and Mrs. Schmitt
Mobility	E-car [pkm]	6 731	5 000
	Fuel-powered car [pkm]	0	0
	Public transport [pkm]	3 296	400
	E-bicycle [pkm]	821	800
	Air travel [pkm]	2 072	65
Housing	Conventional housing [m^2]	41	0
	Wooden house [m^2]	0	75
	Electricity [KWh]	1 714	2 500
	Household appliances [Index]	100	120
Other	Cotton [kg]	7	5
	Synthetics [kg]	4	6

Consumption area	Representative goods	Consumption per person and year	
		Average	Mr. and Mrs. Schmitt
	ICT devices [Index]	100	150
	Pets [Index]	0.47	1.1
	Other [Index residual CO_2]	100	100
Food	Diet	Reference	Vegetarian
	Food waste	Halving	Halving

Source: own elaboration ifeu

The consumption of the couple's representative goods results in environmental impacts that are above the average in 2050 for forest loss and phosphorus. For CO_2, the couple is below average (see table 17).

Table 17: Mr. and Mrs. Schmitt – environmental impacts of consumption per person (excluding food) in 2050

Environmental impact	Mr. and Mrs. Schmitt	Average	Budget
CO_2 [kg]	134.5**	144*	150
Forest loss [m²]	0.21	0.11	10
Phosphorus [g]	1.3	1.09	183
Nitrogen [g]	1 627	2 338	1 828
Freshwater [m³]	79	92	222

Source: own calculations ifeu; *For the flight, only CO_2 effects were considered; ** If non-CO_2 effects are considered, the environmental impact is 148 kg CO_2

Table 18 shows the environmental impacts in detail by goods.

Table 18: Mr. and Mrs. Schmitt – environmental impacts of consumption by goods (excluding food) in 2050

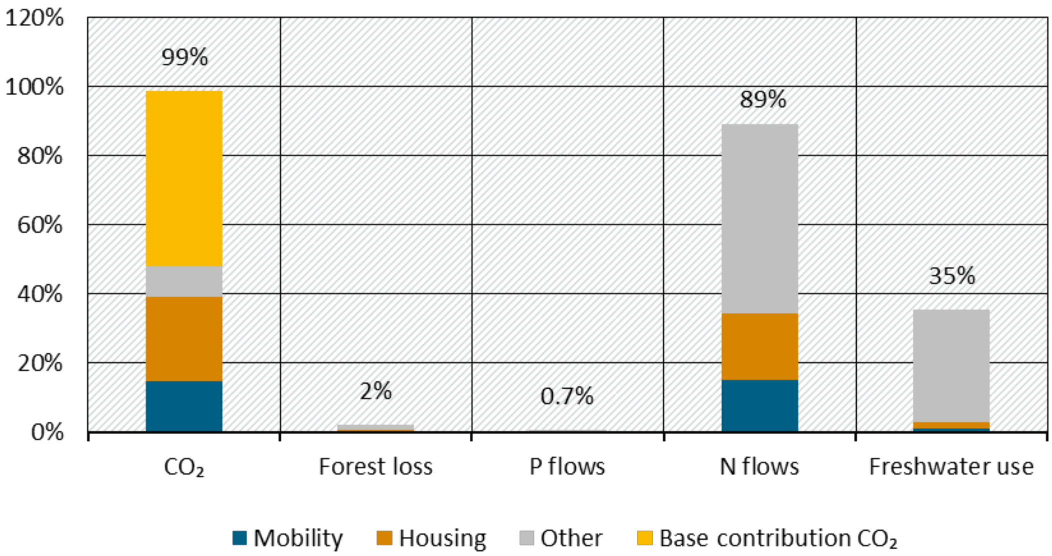
Consumption area	Representative goods	CO_2 [kg]	Forest loss [m²]	Phosphorus [g]	Nitrogen [g]	Freshwater [m³]
Mobility	E-car	8.1	0.0	0.1	156.4	2.7
	Fuel-powered car	0.0	0.0	0.0	0.0	0.0
	Public transport	0.2	0.0	0.0	102.7	0.1
	E-bicycle	0.2	0.0	0.6	5.3	0.1
	Air travel (incl. other effects)	13.7	0.0	0.0	0.0	0.0

Consumption area	Representative goods	CO_2 [kg]	Forest loss [m²]	Phosphorus [g]	Nitrogen [g]	Freshwater [m³]
Housing	Conventional housing	0.0	0.0	0.0	0.0	0.0
	Wooden house	34.5	0.1	0.2	295.1	3.4
	Electricity	1.7	0.0	0.0	40.9	0.4
	Household appliances	0.4	0.0	0.0	14.6	0.2
Other	Cotton	1.3	0.0	0.0	160.0	53.2
	Synthetics	0.4	0.0	0.0	9.8	0.3
	ICT devices	1.9	0.0	0.2	135.7	3.0
	Pets	9.8	0.1	0.1	693.3	15.3
	Base contribution CO_2-eq.	76	N.A.	N.A.	N.A.	N.A.
Total		148.2	0.2	1.3	1 627	79
Budget		**150**	**10**	**183**	**1 828**	**222**

Source: own calculations ifeu

By consuming the couple's goods, all boundaries are respected.

Figure 31: Mr. and Mrs. Schmitt – environmental impacts of consumption per person (excluding food) relative to planetary boundaries



Source: own calculations ifeu; In the consumer area mobility, the non-CO_2 effects of air travel were considered.

The diet of the Schmitt couple leads to average to slightly below-average environmental impacts. For phosphorus, these are 3.8 % and for nitrogen 3 % below the average in 2050.

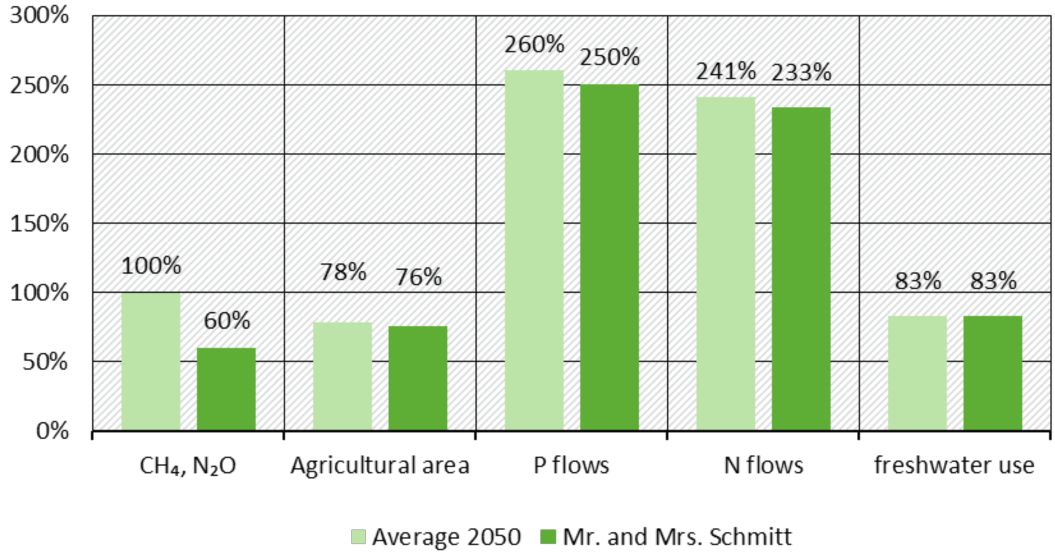
Table 19: Mr. and Mrs. Schmitt – environmental impacts per person in the food requirement field in 2050

Planetary boundary	Environmental impact	Average	Mr. and Mrs. Schmitt	Budget
Climate change	CH_4, N_2O [kg CO_2-eq.]	435	261	435
Land-system change	Agricultural area used [m²]	1 197	1 165	1 533
Biochemical flows	Phosphorus [g]	1 426	1 372	548
	Nitrogen [g]	13 203	12 801	5 484
Freshwater	Freshwater use [m³]	207	207	250

Source: own calculations based on Willett et al. (2019)

Relative to the planetary boundaries, the phosphorus and nitrogen boundaries are exceeded. Due to the couple's vegetarian diet, the boundary for climate change is clearly undercut. For the land-system change and freshwater boundaries, the couple's environmental impacts are about average.

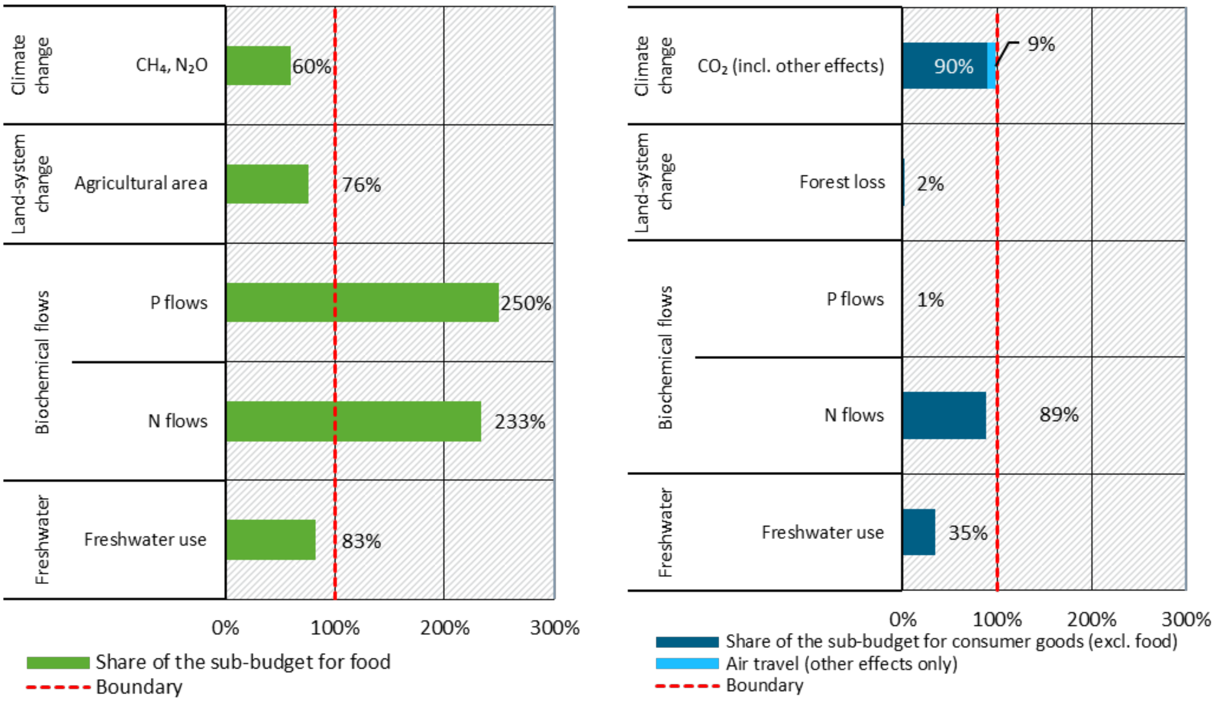
Figure 32: Mr. and Mrs. Schmitt – environmental impacts of food per person relative to planetary boundaries compared to the average in 2050



Source: own calculations based on Willett et al. (2019)

Figure 33 shows the environmental impacts of the Schmitt couple for both separate budgets (consumption of representative goods without food and food only) in 2050.

Figure 33 : Mr. and Mrs. Schmitt – environmental impacts of consumption: food (left) and non-food (right) relative to planetary boundaries/budget in 2050



Source: own calculations; environmental impacts of nutrition based on Willett et al. (2019). Note: The figures show shares of separate budgets for the respective planetary boundaries/environmental impacts due to the different methodological approach (see chapter 3.2.) which refer to the "food sector" (according to Willett et al. (2019)) and the "non-food consumption".

7.3.3 Chris Bassey

Chris Bassey lives in Munich in a spacious single flat. His electricity consumption is low because he travels a lot for work in his car, which runs on renewable fuel. As a politician, he spends a lot of time in committee meetings and at receptions. He is very happy that vegan options are now offered at the buffets as a matter of course, as he eats exclusively vegan. However, he is also aware that large amounts of food continue to be thrown away in catering, causing an above-average amount of food waste. Elegant clothing is important to him. When buying, he pays attention to high quality and follows the trends from current fashion magazines.

Chris Bassey uses his car less than the average citizen in 2050. He mostly prefers the train, which he uses as a mobile office. This means that his trips by public transport are above average. As shown in table 20, Chris Bassey's consumption pattern is also characterised by the purchase and ownership of many items of clothing and portable technical devices. In one year, his clothing purchases amount to 1 kg more cotton and 2.5 times more synthetic fabrics than the average in 2050. In terms of electricity consumption, Chris Bassey is below average, especially since he is rarely at home.

Table 20: Chris Bassey's consumption pattern compared to the 2050 average

Consumption area	Representative goods	Consumption per person and year	
		Average	Chris Bassey
Mobility	E-car [pkm]	6 731	0

Consumption area	Representative goods	Consumption per person and year	
		Average	Chris Bassey
	Fuel-powered car [pkm]	0	3 300
	Public transport [pkm]	3 296	3 550
	E-bicycle [pkm]	821	0
	Air travel [pkm]	2 072	0
Housing	Conventional housing [m^2]	41	50
	Wooden house [m^2]	0	0
	Electricity [KWh]	1 714	1 100
	Household appliances [Index]	100	80
Other	Cotton [kg]	7	8
	Synthetics [kg]	4	10
	ICT devices [Index]	100	200
	Pets [Index]	0.47	0
	Other [Index residual CO_2]	100	100
Food	Diet	Reference	Vegan
	Food waste	Halving	no change

Source: own elaboration ifeu

Bassey's consumption pattern results in environmental impacts that are above the average in 2050 for CO_2 and for freshwater (see table 21).

Table 21: Chris Bassey – environmental impacts of consumption per person (excluding food) in 2050

Environmental impact	Chris Bassey	Average	Budget
CO_2 [kg]	145	144*	150
Forest loss [m^2]	0.05	0.11	10
Phosphorus [g]	0.5	1.09	183
Nitrogen [g]	1 825	2 338	1 828
Freshwater [m^3]	98	92	222

Source: ifeu's own development; *Only CO_2 effects were considered for the flight.

Table 22 shows the environmental impacts in detail by goods.

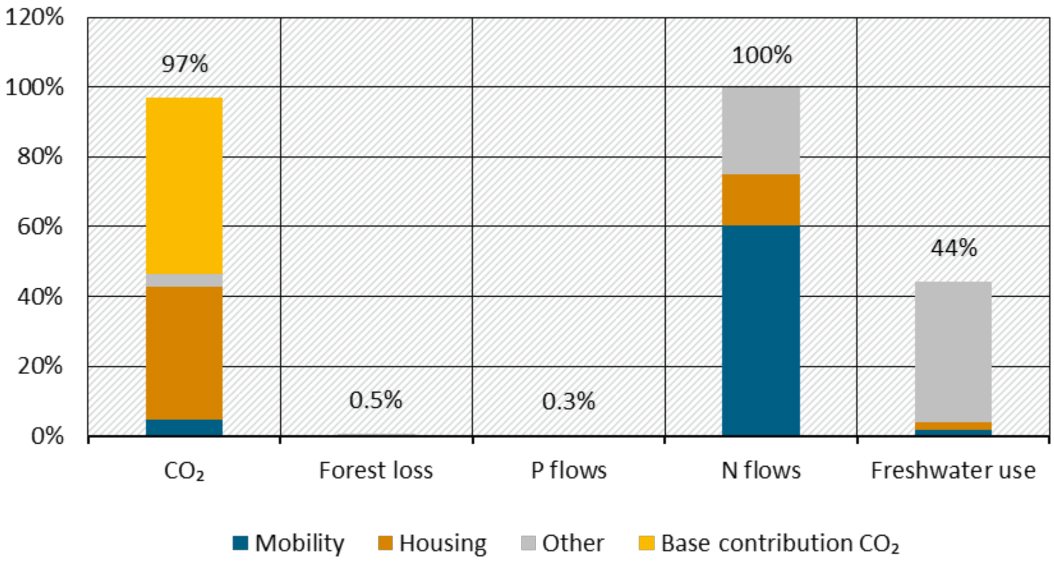
Table 22: Chris Bassey – environmental impacts of consumption by goods (excluding food) in 2050

Consumption area	Representative goods	CO_2 [kg]	Forest loss [m²]	Phosphorus [g]	Nitrogen [g]	Freshwater [m³]
Mobility	E-car	0.0	0.0	0.0	0.0	0.0
	Fuel-powered car	5.4	0.0	0.1	190.5	2.9
	Public transport	1.8	0.0	0.0	911.5	0.7
	E-bicycle	0.0	0.0	0.0	0.0	0.0
	Air travel (incl. other effects)	0.0	0.0	0.0	0.0	0.0
Housing	Conventional housing	56.1	0.0	0.1	242.0	4.8
	Wooden house	0.0	0.0	0.0	0.0	0.0
	Electricity	0.8	0.0	0.0	18.0	0.2
	Household appliances	0.2	0.0	0.0	9.7	0.1
Other	Cotton	2.0	0.0	0.0	256.1	85.1
	Synthetics	0.7	0.0	0.0	16.3	0.4
	ICT devices	2.5	0.0	0.2	180.9	4.0
	Pets	0.0	0.0	0.0	0.0	0.0
	Base contribution CO_2-eq.	76.0	N.A.	N.A.	N.A.	N.A.
Total		145.5	0.05	0.5	1 825	98.3
Budget		**150**	**10**	**183**	**1 828**	**222**

Source: own elaboration ifeu

Although Chris Bassey has a relatively large living area, is moderately mobile and owns twice as many ICT devices as the average, the planetary boundaries are respected.

Figure 34: **Chris Bassey – environmental impacts of consumption per person (excluding food) relative to planetary boundaries**



Source: own calculations ifeu

In the consumption area of food, there are slightly above-average environmental impacts. Keeping food waste at today's level is sufficient to exceed the boundaries for phosphorus and nitrogen more significantly than the average. For land-system change, phosphorus and nitrogen, the increase is 11.8 %, 9.9 % and 10 % respectively compared to the average. Regarding freshwater, the increase is of around 21 % compared to the average consumption in 2050. The resulting environmental impacts of today's food waste are emphasized. For greenhouse gases, the environmental impacts are below average.

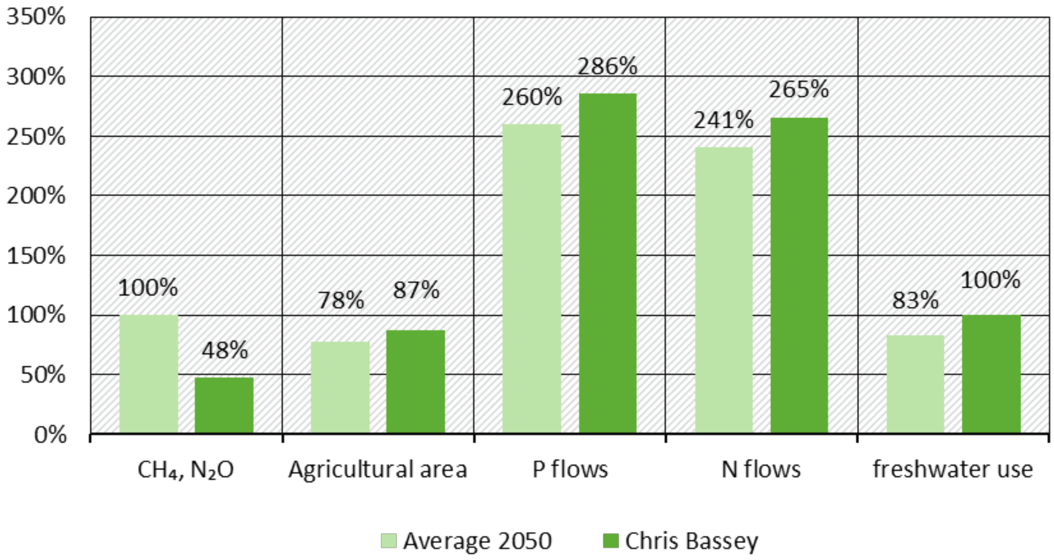
Table 23: **Chris Bassey – environmental impacts per person in the food requirement field in 2050**

Planetary boundary	Environmental impact	Average	Chris Bassey	Budget
Climate change	CH_4, N_2O [kg CO_2 -eq.]	435	207	435
Land-system change	Agricultural area used [m²]	1 197	1 339	1 533
Biochemical flows	Phosphorus [g]	1 426	1 567	548
	Nitrogen [g]	13 203	14 531	5 484
Freshwater	Freshwater use [m³]	207	250	250

Source: own elaboration ifeu

Relative to the planetary boundaries, there is a significant overshoot of the phosphorus and nitrogen boundaries (see figure 35). These exceedances are also significantly above average. For freshwater, the boundary is respected, but there is an excess demand that can be attributed to higher food waste. The high nitrogen and phosphorus flows are also related to the high food waste, such as that generated by buffets. Biochemical flows occur as part of agricultural harvesting, which is often transported long distances (indirect loading); nitrogen and phosphorus also cause direct nutrient loading due to food waste, (untreated) faecal matter or, in some cases, downstream pollution following municipal wastewater treatment (Willett et al. 2019).

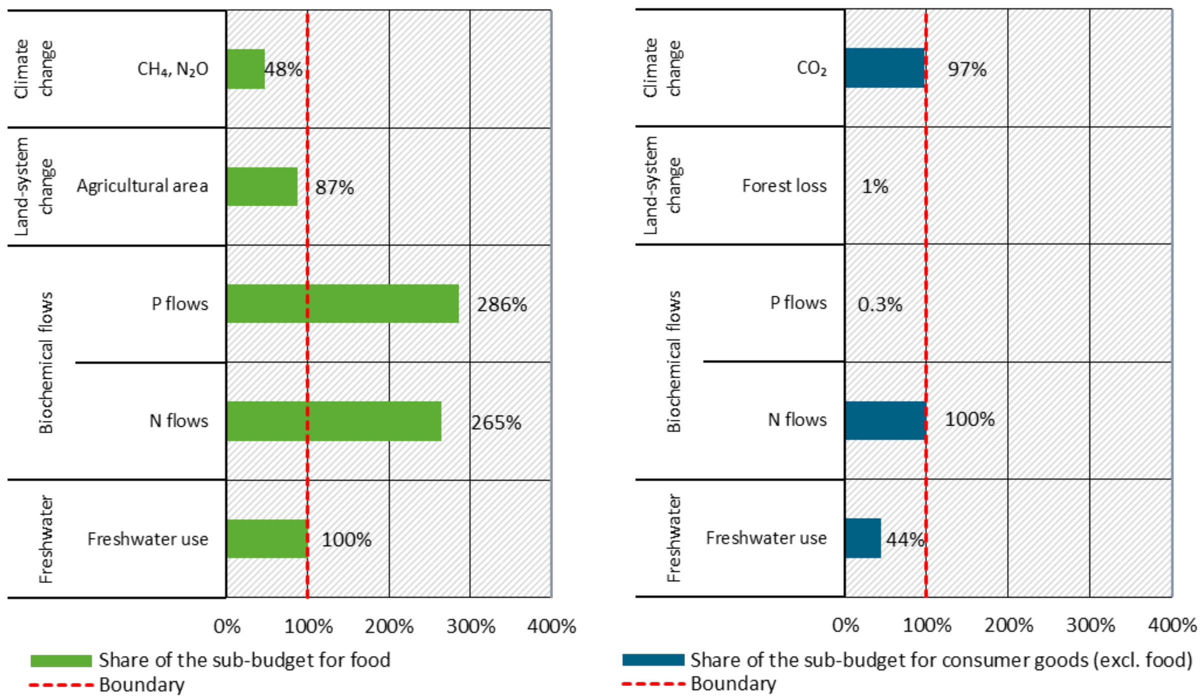
Figure 35: Chris Bassey – environmental impacts of food per person relative to planetary boundaries compared to the average in 2050



Source: own calculations based on Willett et al. (2019)

Figure 36 shows once again Chris Bassey's environmental impacts for both separate budgets (consumption of representative goods without food and food only) in 2050.

Figure 36: Chris Bassey – environmental impacts of consumption: food (left) and non-food (right) relative to planetary boundaries/budget in 2050



Source: own calculations; environmental impacts of nutrition based on Willett et al. (2019). Note: The figures show shares of separate budgets for the respective planetary boundaries/environmental impacts due to the different methodological approach (see chapter 3.2.) which refer to the "food sector" (according to Willett et al. (2019)) and the "non-food consumption".

7.3.4 Kaulatz family

For the Kaulatz family, everyday life with four children is quite hectic. Fortunately, the 180-square-metre flat is very well laid out, so that each family member has his or her own space. The routes to the nursery school and school are covered by bicycle. There is also a very large e-bicycle, which can accommodate three of the four children. To go on holiday, the family uses the train – luckily the luggage can be sent to the holiday destination in advance. The three cats are a concession to the two eldest daughters Polina and Rebecca. When it comes to clothing, the family makes nor compromises – it is important to them that the clothes correspond to fashion trends.

The Kaulatz family is very mobile and uses the well-developed public transport network and long-distance trains for their annual holiday in Italy. As a result, more kilometres are travelled per person and year than the average citizen travels in 2050. The family of six shares the living space, effectively providing 30 m^2 per person, which is well below the average of 41 m^2. The equipment with household appliances and the electricity consumption are also below average. The consumption of cotton and synthetic fabrics is slightly above average. In terms of nutrition, the family follows the reference diet.

Table 24: Consumption pattern of the Kaulatz family compared to the average in 2050

Consumption area	Representative goods	Consumption per person and year	
		Average	Kaulatz family
Mobility	E-car [pkm]	6 731	0
	Fuel-powered car [pkm]	0	0
	Public transport [pkm]	3 296	6 000
	E-bicycle [pkm]	821	1 200
	Air travel [pkm]	2 072	0
Housing	Conventional housing [m^2]	41	30
	Wooden house [m^2]	0	0
	Electricity [KWh]	1 714	2 300
	Household appliances [Index]	100	110
Other	Cotton [kg]	7	10
	Synthetics [kg]	4	8
	ICT devices [Index]	100	120
	Pets [Index]	0.47	0.05
	Other [Index residual CO_2]	100	100
Food	Diet	Reference	Reference
	Food waste	Halving	Halving

Source: own elaboration ifeu

The consumption of the family's representative goods results in environmental impacts that are above average for freshwater. All other environmental impacts are below average (see table 25).

Table 25: Kaulatz family – environmental impacts of consumption per person (excluding food) in 2050

Environmental impact	Kaulatz family	Average	Budget
CO_2 [kg]	120	144*	150
Forest loss [m²]	0.04	0.11	10
Phosphorus [g]	1.1	1.09	183
Nitrogen [g]	2 218	2 338	1 828
Freshwater [m³]	115	92	222

Source: ifeu's own calculations; *Only CO_2 effects were considered for the flight.

Table 26 shows the environmental impacts in detail by goods.

Table 26: Kaulatz family – environmental impacts of consumption by goods (excluding food) in 2050

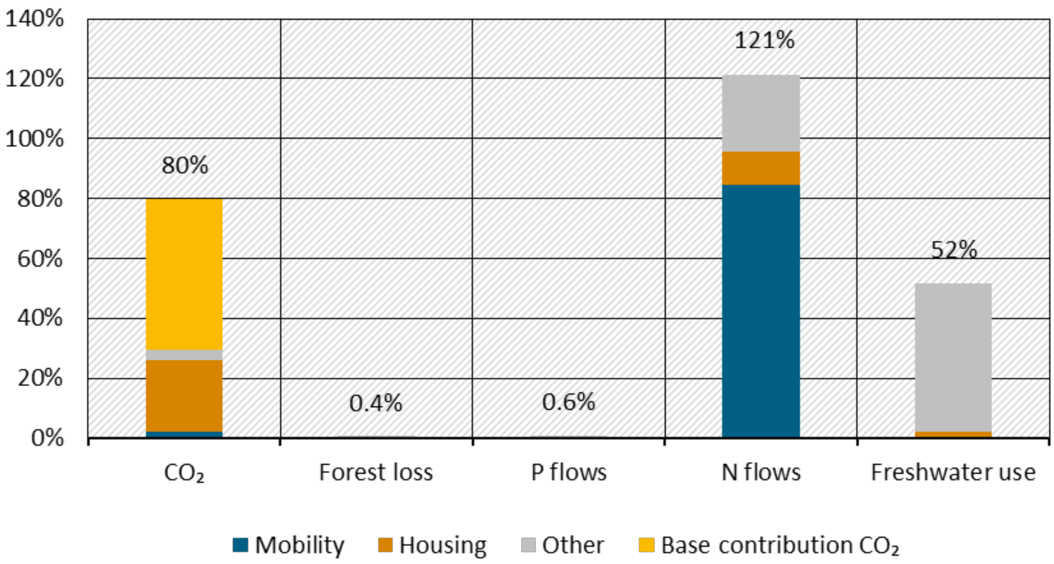
Consumption area	Representative goods	CO_2 [kg]	Forest loss [m²]	Phosphorus [g]	Nitrogen [g]	Freshwater [m³]
Mobility	E-car	0.0	0.0	0.0	0.0	0.0
	Fuel-powered car	0.0	0.0	0.0	0.0	0.0
	Public transport	3.1	0.0	0.0	1 540.6	1.2
	E-bicycle	0.2	0.0	0.8	7.9	0.1
	Air travel (incl. other effects)	0.0	0.0	0.0	0.0	0.0
Housing	Conventional housing	33.7	0.0	0.1	145.2	2.9
	Wooden house	0.0	0.0	0.0	0.0	0.0
	Electricity	1.6	0.0	0.0	37.6	0.3
	Household appliances	0.3	0.0	0.0	13.4	0.2
Other	Cotton	2.5	0.0	0.0	320.1	106.4
	Synthetics	0.5	0.0	0.0	13.1	0.4
	ICT devices	1.5	0.0	0.1	108.5	2.4
	Pets	0.4	0.0	0.0	31.5	0.7

Consumption area	Representative goods	CO_2 [kg]	Forest loss [m²]	Phosphorus [g]	Nitrogen [g]	Freshwater [m³]
	Base contribution CO_2-eq.	76.0	N.A.	N.A.	N.A.	N.A.
Total		119.9	0.0	1.1	2 217.8	114.5
Budget		**150**	**10**	**183**	**1 828**	**222**

Source: own calculations ifeu

As with the average consumer, the boundary for nitrogen is clearly exceeded. The other boundaries are complied with.

Figure 37: Kaulatz family – environmental impacts of consumption per person (excluding food) relative to planetary boundaries



Source: own calculations ifeu

In the consumption area of food, the environmental impacts of the family are in line with those of the average consumer in 2050. The environmental impacts of the family are therefore within the budget, with the exception of the biochemical flows.

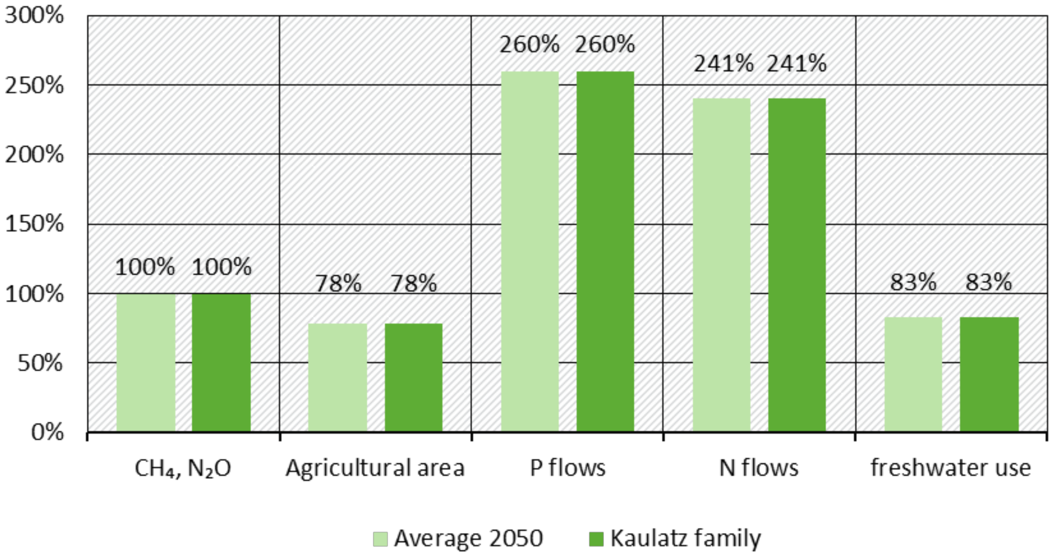
Table 27: Kaulatz family – environmental impacts per person in the food requirement field in 2050

Planetary boundary	Environmental impact	Average	Kaulatz family	Budget
Climate change	CH_4, N_2O [kg CO_2-eq.]	435	435	435
Land-system change	Agricultural area used [m²]	1 197	1 197	1 533
Biochemical flows	Phosphorus [g]	1 426	1 426	548
	Nitrogen [g]	13 203	13 203	5 484
Freshwater	Freshwater use [m³]	207	207	250

Source: own calculations based on Willett et al. (2019)

Relative to the planetary boundaries, in the consumption area of food, the phosphorus and nitrogen boundaries are exceeded in analogy to the average citizen. The other boundaries are respected.

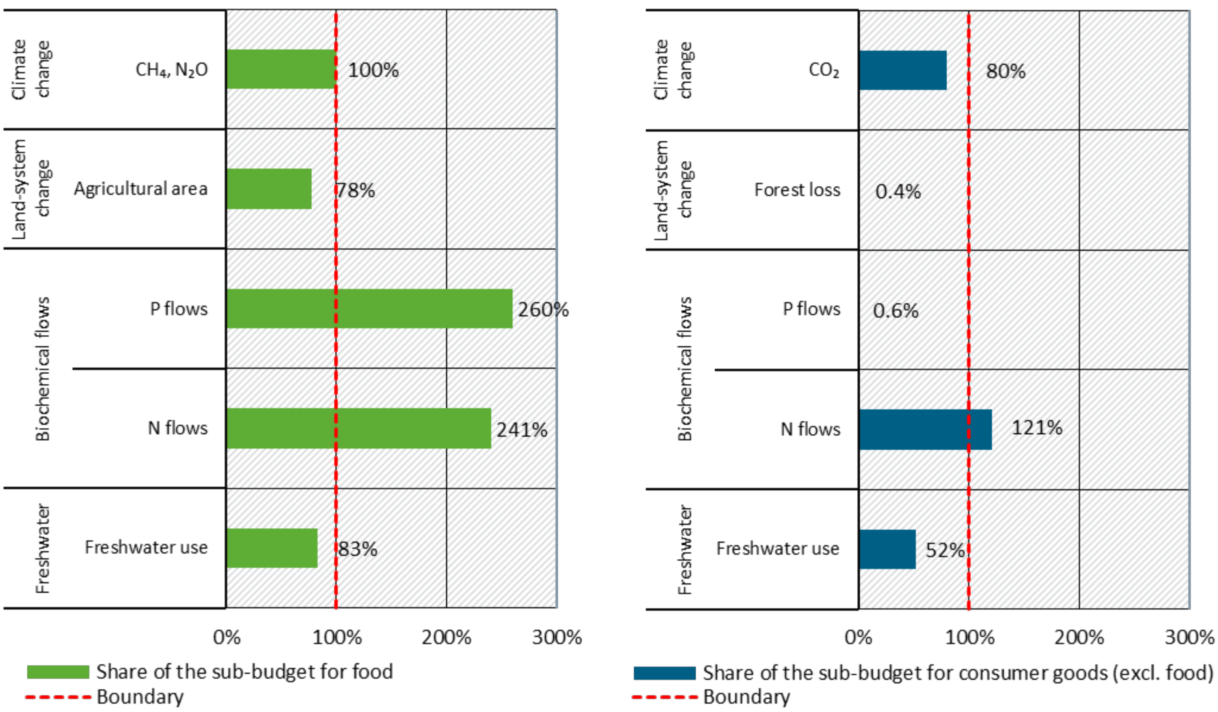
Figure 38: Kaulatz family – environmental impacts of food per person relative to planetary boundaries compared to the average in 2050



Source: own calculations based on Willett et al. (2019)

Figure 39 shows the environmental impacts of the Kaulatz family for both budgets separately (consumption of representative goods without food and food only) in 2050.

Figure 39: Kaulatz family – environmental impacts of consumption: food (left) and non-food (right) relative to planetary boundaries/budget in 2050



Source: own calculations; environmental impacts of nutrition based on Willett et al. (2019). Note: The figures show shares of separate budgets for the respective planetary boundaries/environmental impacts due to the different methodological approach (see chapter 3.2.) which refer to the "food sector" (according to Willett et al. (2019)) and the "non-food consumption".

7.3.5 Nowak family

Claire Nowak and her 7-year-old son Adrien live in a house together with six other parties near Hamburg. The house community sticks together – clothes and toys are passed on, so that Adrien is well-equipped even without buying anything new. A large part of their modest income goes towards the upkeep of the car, which Claire depends on because of her shift work. Every 10 years, both of them fly to Corsica for an extended holiday. The route is difficult to manage by train and ferry due to Claire's tight holiday schedule.

Clair's commute is reflected in the car kilometres, which are still significantly lower than the average, but public transport is used more than average. The infrequent flight is reflected in the annual person-kilometres and is a consumer good that has a significant impact on GHG emissions due to the non-CO_2-related effects. When it comes to food, the family makes a point of leaving as little as possible or throwing it away. Claire often cooks ahead or prepares packed lunches for herself and her son, because food waste is very high in the canteen or in large kitchens at school and work (UBA 2014b). In the other areas of need, the small family is below average.

Table 28: Consumption pattern of the Nowak family compared to the average in 2050

Consumption area	Representative goods	Consumption per person and year	
		Average	Nowak family
Mobility	E-car [pkm]	6 731	2 500
	Fuel-powered car [pkm]	0	0
	Public transport [pkm]	3 296	3 500
	E-bicycle [pkm]	821	0
	Air travel [pkm]	2 072	240
Housing	Conventional housing [m^2]	41	0
	Wooden house [m^2]	0	30
	Electricity [KWh]	1 714	2 500
	Household appliances [Index]	100	90
Other	Cotton [kg]	7	3
	Synthetics [kg]	4	2
	ICT devices [Index]	100	80
	Pets [Index]	0.47	0
	Other [Index residual CO_2]	100	100

Consumption area	Representative goods	Consumption per person and year	
		Average	Nowak family
Food	Diet	Reference	Vegetarian
	Food waste	Halving	Halving

Source: own elaboration ifeu

The consumption of the representative goods results in significantly lower environmental impacts compared to the average (see table 29).

Table 29: Nowak family – environmental impacts of consumption per person (excluding food) in 2050

Environmental impact	Nowak family	Average	Budget
CO_2 [kg]	100**	144*	150
Forest loss [m²]	0.04	0.11	10
Phosphorus [g]	0.3	1.09	183
Nitrogen [g]	1 367	2 338	1 828
Freshwater [m³]	38	92	222

Source: ifeu calculations; *only CO_2 effects were considered for the flight; **if non-CO_2 effects are considered, the environmental impact is 150 kg CO_2

Table 30 shows the environmental impacts in detail by goods.

Table 30: Nowak Family – environmental impacts of consumption by goods (excluding food) in 2050

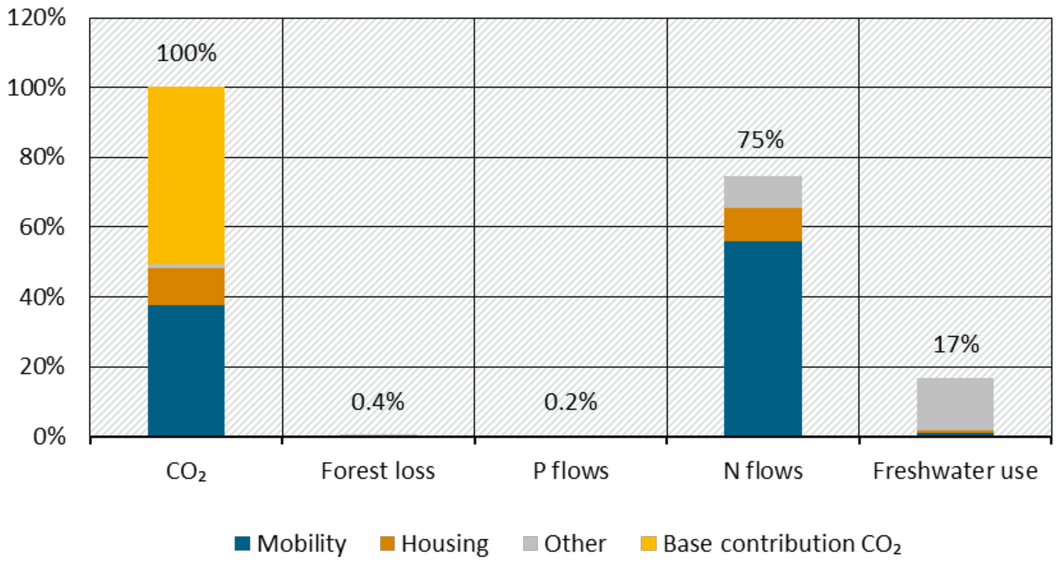
Consumption area	Representative goods	CO_2 [kg]	Forest loss [m²]	Phosphorus [g]	Nitrogen [g]	Freshwater [m³]
Mobility	E-car	4.1	0.0	0.1	78.2	1.4
	Fuel-powered car	0.0	0.0	0.0	0.0	0.0
	Public transport	1.8	0.0	0.0	898.7	0.7
	E-bicycle	0.0	0.0	0.0	0.0	0.0
	Air travel (incl. other effects)	50.7	0.0	0.0	48.6	0.0
Housing	Conventional housing	0.0	0.0	0.0	0.0	0.0
	Wooden house	13.8	0.0	0.1	118.0	1.4
	Electricity	1.7	0.0	0.0	40.9	0.4
	Household appliances	0.3	0.0	0.0	10.9	0.2

Consumption area	Representative goods	CO_2 [kg]	Forest loss [m²]	Phosphorus [g]	Nitrogen [g]	Freshwater [m³]
Other	Cotton	0.8	0.0	0.0	96.0	31.9
	Synthetics	0.1	0.0	0.0	3.3	0.1
	ICT devices	1.0	0.0	0.1	72.4	1.6
	Pets	0.0	0.0	0.0	0.0	0.0
	Base contribution CO_2-eq.	76.0	N.A.	N.A.	N.A.	N.A.
Total		150	0.04	0.3	1 367.0	37.6
Budget		**150**	**10**	**183**	**1 828**	**222**

Source: own calculations ifeu

The small family is within the budgets for all environmental impacts. In terms of greenhouse gases, air travel contributes to a large part of the environmental impacts. Even with overall low consumption levels (small living space, little new clothing, no pets, etc.), the margin for flying is very small. Every 10 years, a family member can only fly 240 km to meet the per capita climate change boundary. This shows that flying, even with greenhouse gas neutral fuel, is a huge problem even in 2050 and is only possible to a very small extent within planetary boundaries, mainly due to the climate-change effects at high altitudes.

Figure 40: Nowak family – environmental impacts of consumption per person (excluding food) relative to planetary boundaries



Source: own calculations ifeu; In the consumer area mobility, the non-CO_2 effects of air travel were considered.

The Nowak family's diet and halving of food waste leads to below-average environmental impacts and, with regard to freshwater, to average impacts. For land-system change, these are 40 % below the 2050 average, for nitrogen and phosphorus 3 % and around 4 % respectively, and for greenhouse gases 40 % below the 2050 average.

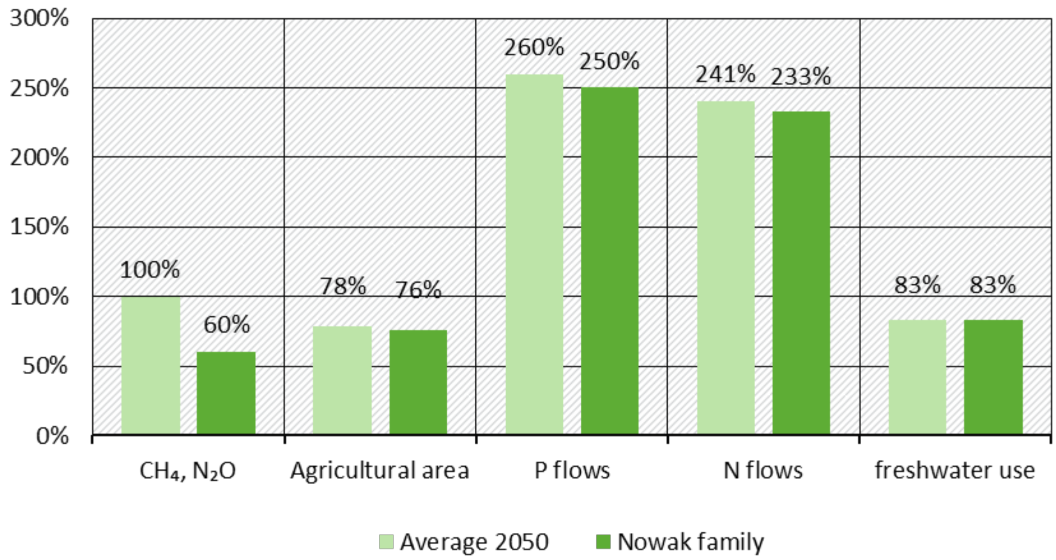
Table 31: Nowak family – environmental impacts per person in the food requirement field in 2050

Planetary boundary	Environmental impact	Average	Nowak family	Budget
Climate change	CH_4, N_2O [kg CO_2-eq.]	435	261	435
Land-system change	Agricultural area used [m²]	1 197	1 165	1 533
Biochemical flows	Phosphorus [g]	1 426	1 372	548
	Nitrogen [g]	13 203	12 801	5 484
Freshwater	Freshwater use [m³]	207	207	250

Source: own calculations based on Willett et al. (2019)

An overshoot, relative to the planetary boundaries, occurs for phosphorus and nitrogen in the consumption area of food (see figure 41).

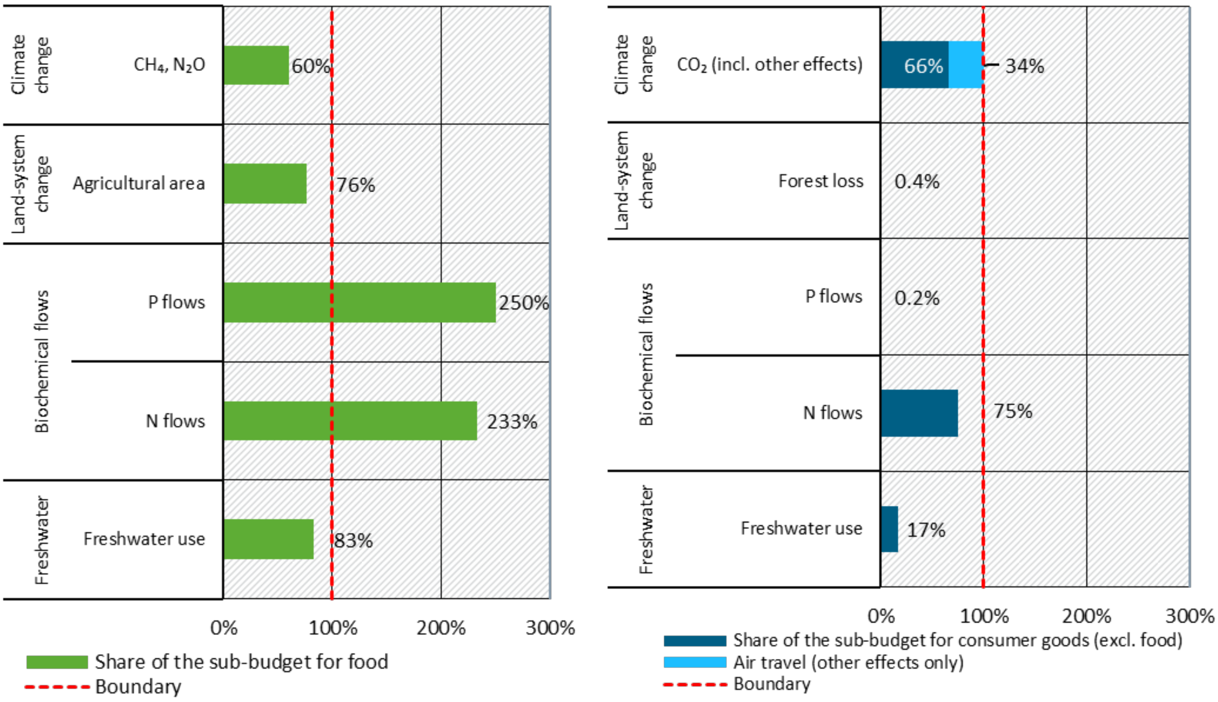
Figure 41: Nowak family – environmental impacts of food per person relative to planetary boundaries compared to the average in 2050



Source: own calculations based on Willett et al. (2019)

Figure 42 shows once again the environmental impacts of the Nowak family for both budgets separately (consumption of representative goods without food and food only) in 2050.

Figure 42: Nowak family – environmental impacts of consumption: food (left) and non-food (right) relative to planetary boundaries/budget in 2050



Source: own calculations; environmental impacts of nutrition based on Willett et al. (2019). Note: The figures show shares of separate budgets for the respective planetary boundaries/environmental impacts due to the different methodological approach (see chapter 3.2.) which refer to the "food sector" (according to Willett et al. (2019)) and the "non-food consumption".

7.3.6 Villa Villekulla

Villa Villekulla is home to six people of all ages for whom community and ecology are very important. That is why they also live in a flat in a wooden apartment building. They shop together, usually vegan. The six of them travel a lot, mostly by public transport, because no one wants to miss out on travelling far away. Around three times a year, long journeys are made by public transport and most of the flat-sharing community use the well-developed rail network to regularly visit relatives and friends in Berlin, Hamburg and on Lake Constance. The shared electric VW bus has also made it all the way to China via the Silk Road. Greece, Bulgaria and Corsica are also popular destinations for the group. In everyday life, the VW bus is usually parked in the garage and the flat-sharing group uses local transport and e-bicycles for their daily commute. Of course, everyone in the household has a laptop and a smartphone. The washing machine and kitchen equipment are shared.

The high mobility of the community is reflected in the person-kilometres: trips by car and public transport are more than twice the average, trips by e-bicycle are almost five times the average. The living space of 25 m^2 per person is relatively small. The economical use of electricity and the household appliances available in relation to the number of persons also result in a below-average consumption pattern (see table 32).

Table 32: Consumption pattern of Villa Villekulla compared to the average in 2050

Consumption area	Representative goods	Consumption per person and year	
		Average	Villa Villekulla
Mobility	E-car [pkm]	6 731	15 000
	Fuel-powered car [pkm]	0	0
	Public transport [pkm]	3 296	7 000
	E-bicycle [pkm]	821	4 000
	Air travel [pkm]	2 072	0
Housing	Conventional housing [m^2]	41	0
	Wooden house [m^2]	0	25
	Electricity [KWh]	1 714	1 000
	Household appliances [Index]	100	30
Other	Cotton [kg]	7	5
	Synthetics [kg]	4	2
	ICT devices [Index]	100	200
	Pets [Index]	0.47	0
	Other [Index residual CO_2]	100	100
Food	Diet	Reference	Vegan
	Food waste	Halving	Halving

Source: own elaboration ifeu

The consumption of the representative goods results in environmental impacts that are below average for three planetary boundaries, but phosphorus and nitrogen are above average in 2050 (see table 33).

Table 33: Villa Villekulla – environmental impacts of consumption per person (excluding food) in 2050

Environmental impact	Villa Villekulla	Average	Budget
CO_2 [kg]	121	144*	150
Forest loss [m^2]	0.07	0.11	10
Phosphorus [g]	3.6	1.09	183
Nitrogen [g]	2 756	2 338	1 828
Freshwater [m^3]	68	92	222

Source: ifeu calculations; *Only CO_2 effects were considered for the flight.

Table 34 shows the environmental impacts in detail by goods.

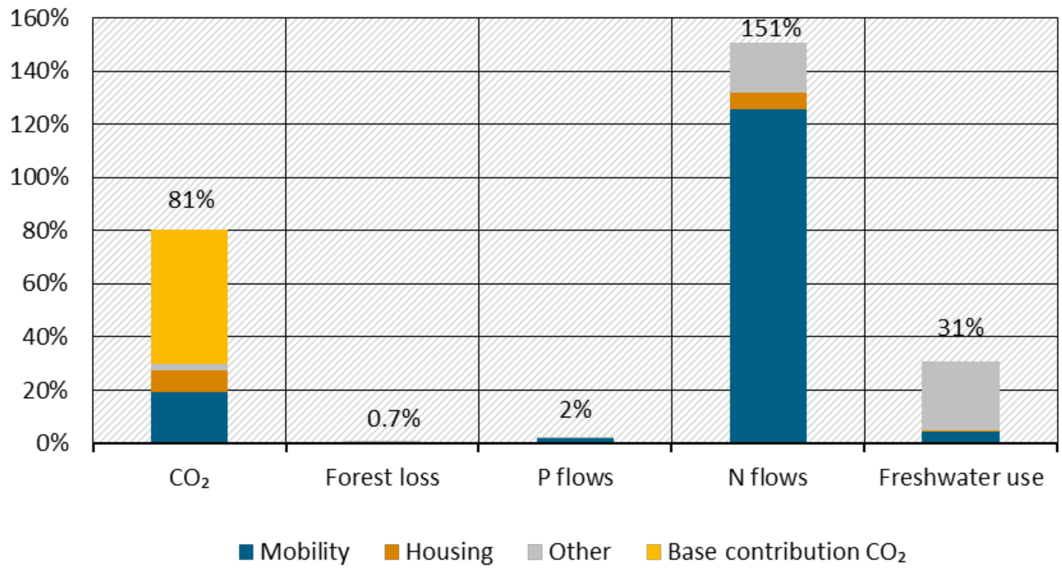
Table 34: Villa Villekulla – environmental impacts of consumption by goods (excluding food) in 2050

Consumption area	Representative goods	CO_2 [kg]	forest loss [m²]	Phosphorus [g]	Nitrogen [g]	Freshwater [m³]
Mobility	E-car	24.3	0.04	0.4	469.3	8.1
	Fuel-powered car	0.0	0.00	0.0	0.0	0.0
	Public transport	3.6	0.00	0.0	1 797.3	1.3
	E-bicycle	0.8	0.00	2.8	26.3	0.4
	Air travel (incl. other effects)	0.0	0.00	0.0	0.0	0.0
Housing	Conventional housing	0.0	0.00	0.0	0.0	0.0
	Wooden house	11.5	0.02	0.1	98.4	1.1
	Electricity	0.7	0.00	0.0	16.3	0.2
	Household appliances	0.1	0.00	0.0	3.6	0.1
Other	Cotton	1.3	0.00	0.0	160.0	53.2
	Synthetics	0.1	0.00	0.0	3.3	0.1
	ICT devices	2.5	0.00	0.2	180.9	4.0
	Pets	0.0	0.00	0.0	0.0	0.0
	Base contribution CO_2 -eq.	76.0	N.A.	N.A.	N.A.	N.A.
Total		120.9	0.1	3.6	2 755.5	68.4
Budget		**150**	**10**	**183**	**1 828**	**222**

Source: own calculations ifeu

The boundary for nitrogen is clearly exceeded by the consumption of goods by one person at Villa Villekulla, which is primarily due to the high mobility by public transport.

Figure 43: Villa Villekulla – environmental impacts of consumption per person (excluding food) relative to planetary boundaries



Source: own calculations ifeu

The vegan diet of the Villa Villekulla community leads to slightly below-average environmental impacts; for greenhouse gases, these are even 62.5 % below average. For fresh water, there is an increase of about 5 % compared to the average.

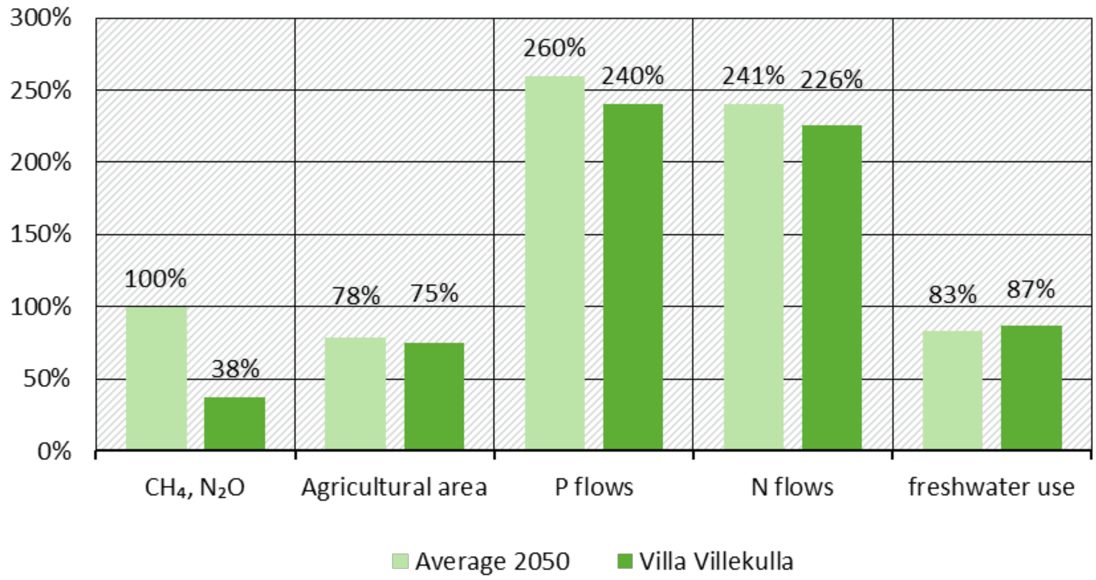
Table 35: Villa Villekulla – environmental impacts per person in the food requirement field in 2050

Planetary boundary	Environmental impact	Average	Villa Villekulla	Budget
Climate change	CH_4, N_2O [kg CO_2-eq.]	435	163	435
Land-system change	Agricultural area used [m²]	1 197	1 143	1 533
Biochemical flows	Phosphorus [g]	1 426	1 317	548
	Nitrogen [g]	13 203	12 398	5 484
Freshwater	Freshwater use [m³]	207	218	250

Source: own calculations based on Willett et al. (2019)

Relative to the planetary boundaries, the phosphorus and nitrogen boundaries are exceeded. The vegan diet falls well below the boundary for climate change. For the land-system change and freshwater boundaries, the environmental impacts of Villa Villekulla roughly correspond to the average in 2050.

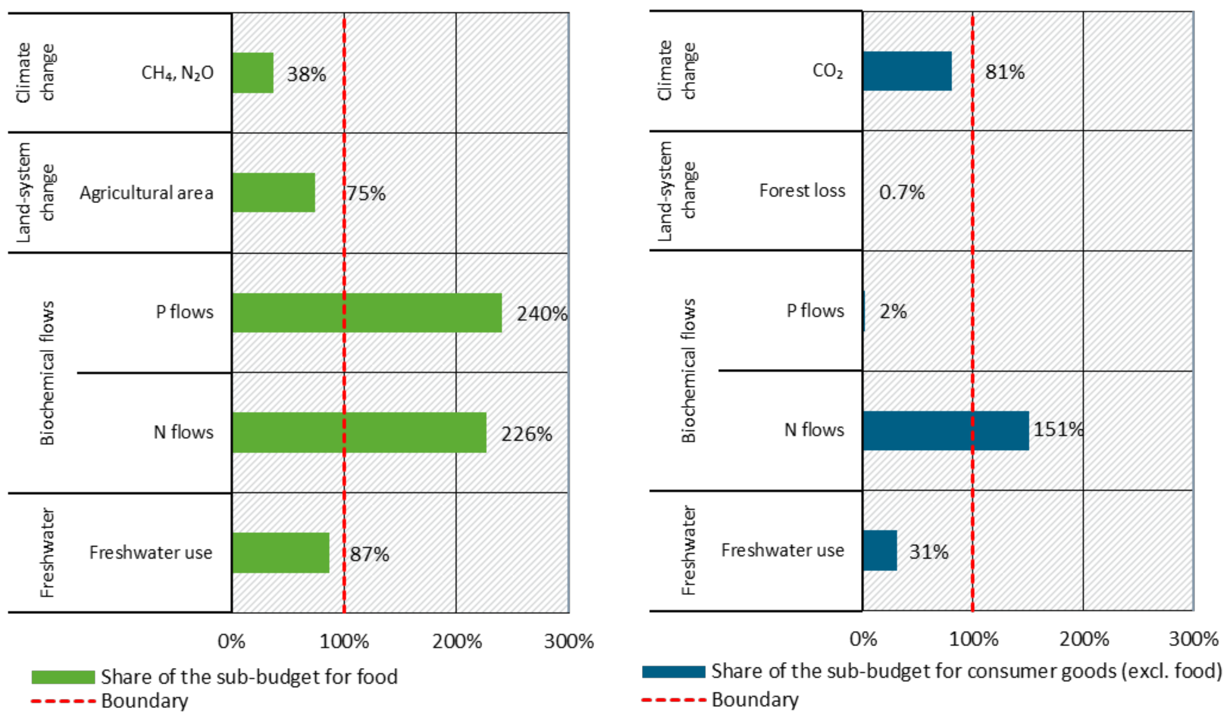
Figure 44: Villa Villekulla – environmental impacts of food per person relative to planetary boundaries compared to the average in 2050



Source: own calculations based on Willett et al. (2019)

Figure 45 shows once again the environmental impacts of Villa Villekulla for both budgets separately (consumption of representative goods without food and food only) in 2050.

Figure 45: Villa Villekulla – environmental impacts of consumption: food (left) and non-food (right) relative to planetary boundaries/budget in 2050



Source: own calculations; environmental impacts of nutrition based on Willett et al. (2019). Note: The figures show shares of separate budgets for the respective planetary boundaries/environmental impacts due to the different methodological approach (see chapter 3.2.) which refer to the "food sector" (according to Willett et al. (2019)) and the "non-food consumption".

8 Conclusion

8.1 Summary and comparison of consumption patterns

The following comparison summarises the similarities and differences between the various consumption patterns at a glance. The figures for the average in 2050 refer to the average consumer according to the derivation in chapter 6.

The figures for today are based on today's average consumption of the representative goods (see chapters 4 and 5). The environmental impacts are calculated based on the coefficients for the environmental impact per unit of the representative good for 2050, i.e. the environmental impacts are described to which today's average consumption of the representative goods would lead in a climate neutral world in 2050.

Table 36: Consumption of the representative goods in comparison (values per person)

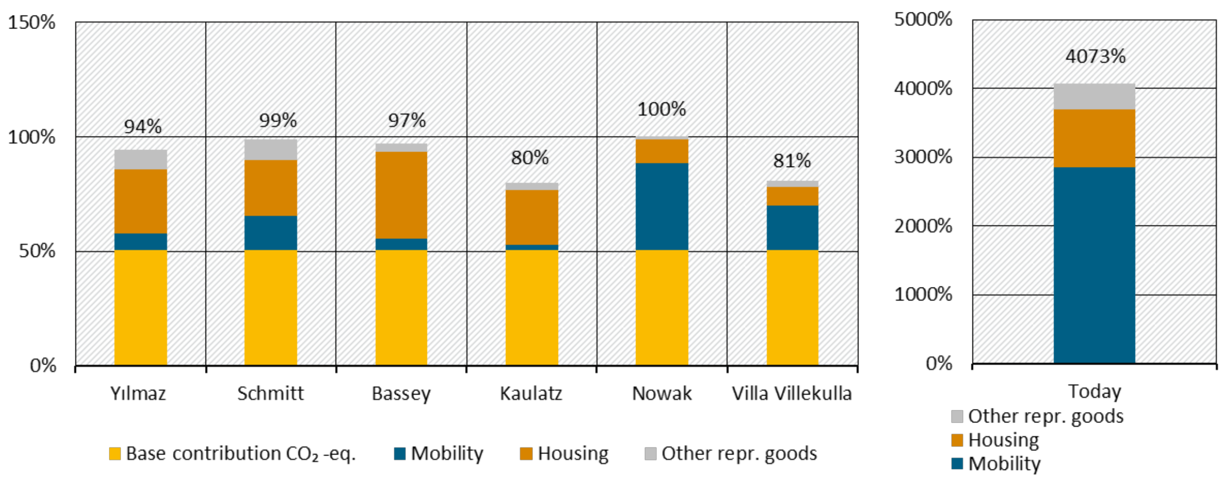
Representative goods	Yılmaz	Schmitt	Bassey	Kaulatz	Nowak	Ville-kulla	Average 2050	Today
E-car [pkm]	6 000	5 000	0.0	0.0	2 500	15 000	6 731	0.0
Fuel-powered car [pkm]	0.0	0.0	3 300	0.0	0.0	0.0	0.0	11 033
Public transport [pkm]	1 550	400.0	3 550	6 000	3 500	7 000	3 296	2 251
E-bicycle [pkm]	0.0	800.0	0.0	1 200	0.0	4 000	820.6	82.0
Air travel [pkm]	0.0	65.0	0.0	0.0	240.0	0.0	2 072	1 945
Conventional housing [m^2]	35.0	0.0	50.0	30.0	0.0	0.0	41.0	47.0
Wooden house [m^2]	0.0	75.0	0.0	0.0	30.0	25.0	0.0	0.0
Electricity [KWh]	4 000	2 500	1 100	2 300	2 500	1 000	1 714*	1 606*
Household appliances [Index]	100	120.0	80.0	110.0	90.0	30.0	100.0	100.0
Cotton [kg]	7.0	5.0	8.0	10.0	3.0	5.0	7.0	9.9
Synthetics [kg]	4.0	6.0	10.0	8.0	2.0	2.0	4.1	6.2
ICT devices [Index]	150.0	150.0	200.0	120.0	80.0	200.0	100.0	100.0
Pets [Index]	1.00	1.10	0.00	0.05	0.00	0.00	0.47	0.47
Base contribution [Index]	100.0	100.0	100.0	100.0	100.0	100.0	100.0	k.A.
Diet	refe-rence	vege-tarian	vegan	refe-rence	vege-tarian	vegan	reference	today's average (world)

Representative goods	Yılmaz	Schmitt	Bassey	Kaulatz	Nowak	Ville-kulla	Average 2050	Today
Food waste	halving	halving	no chang e	halving	halving	halving	halving	no change

Source: ifeu's own development, * The values for 2050 include the electricity demand for heating (heat pump). The values for today do not include the heat demand for heating. This amounts to additionally around 6,000 kWh (Destatis 2022).

The Kaulatz family and Villa Villekulla perform best in terms of CO_2 emissions (incl. other climate-impacting effects from flights) (figure 46). For the Kaulatz family, the lack of a car is responsible for this. In Villa Villekulla, the decisive difference is the significantly smaller living space. The emissions of today's average consumption would clearly exceed the share of the budget by 4,073 %. This is due to the climate-impacting effects of the almost 2,000 kilometres of the annual air travel per person. Furthermore, the higher average living space of 47 m^2 also plays a role.

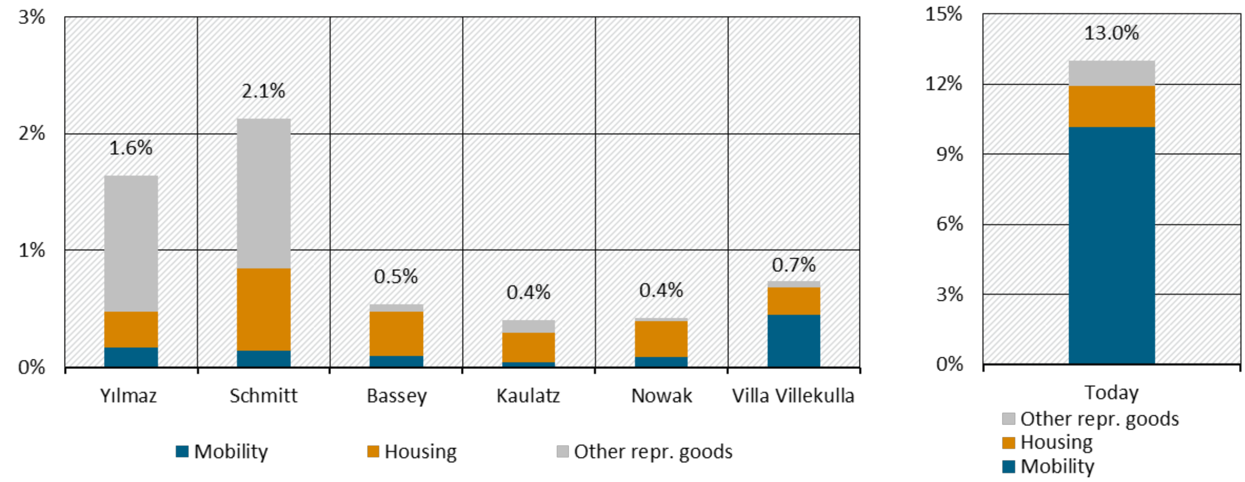
Figure 46: GHG emissions from consumption of representative goods (excluding food) in 2050 and today relative to planetary boundaries in comparison



Source: own calculations ifeu; mobility: for flights, non-CO_2 effects are also considered.

The forest loss environmental impact (figure 47) is not critical for any of the consumption patterns. However, the representative goods do not fully cover this indicator, as wood-based goods such as paper/books were not examined.

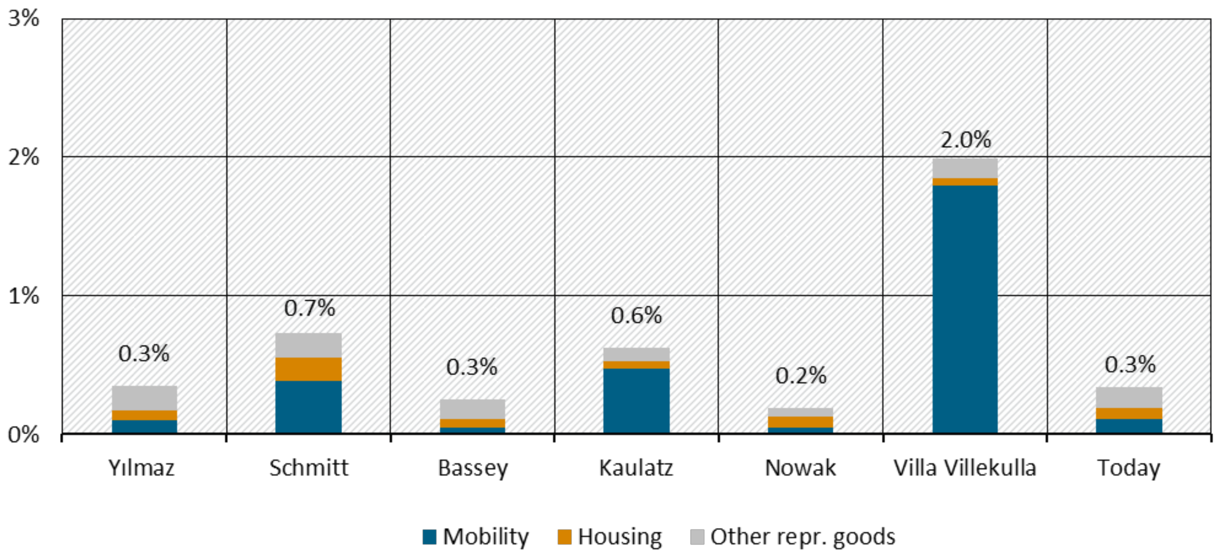
Figure 47: Forest loss due to consumption of representative goods (excluding food) in 2050 and today relative to planetary boundaries in comparison



Source: own calculations ifeu

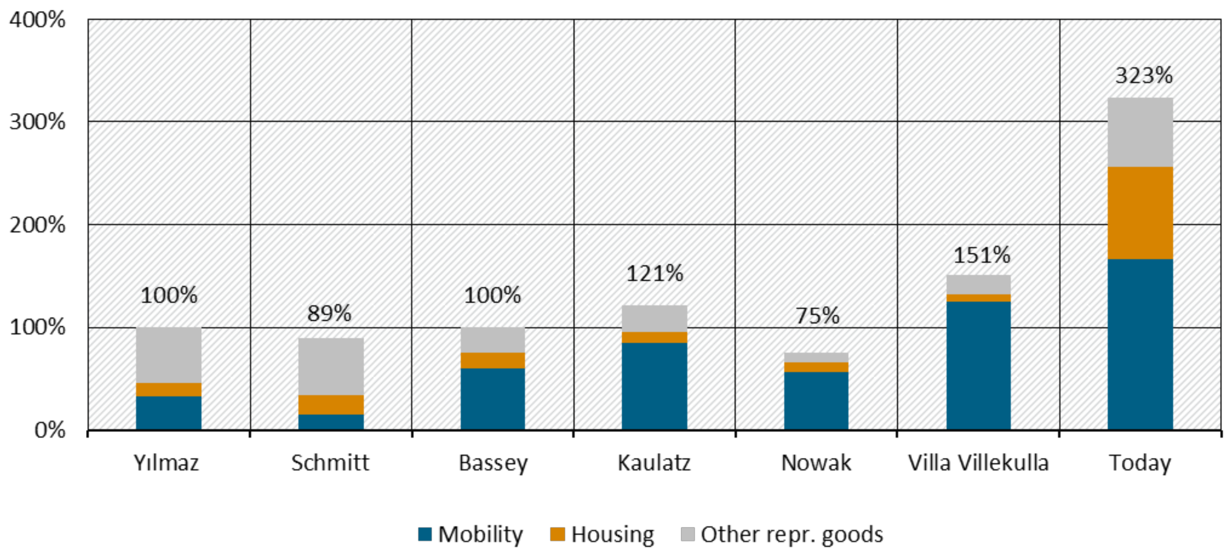
While phosphorus is also uncritical outside the food sector (figure 48), the planetary boundary for nitrogen is exceeded by two of the consumption patterns (figure 49). The Nowak family's nitrogen demand is 75 % of the budget, due to the family's low mobility (apart from one flight every 10 years). It is thus the lowest compared to the other consumption patterns. The degree of overspending in the other consumption patterns differs slightly. Villa Villekulla has the highest demand due to many kilometres travelled by public transport.

Figure 48: Phosphorus by consumption of representative goods (excluding food) in 2050 and today relative to planetary boundaries in comparison



Source: own calculations ifeu

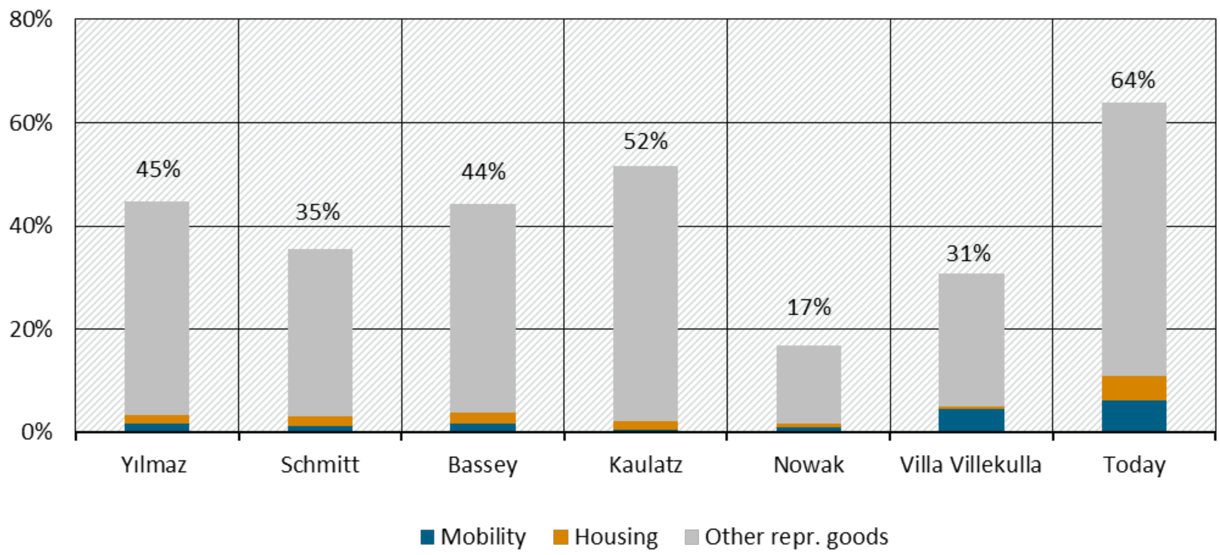
Figure 49: Nitrogen from consumption of representative goods (excluding food) in 2050 and today relative to planetary boundaries in comparison



Source: own calculations ifeu

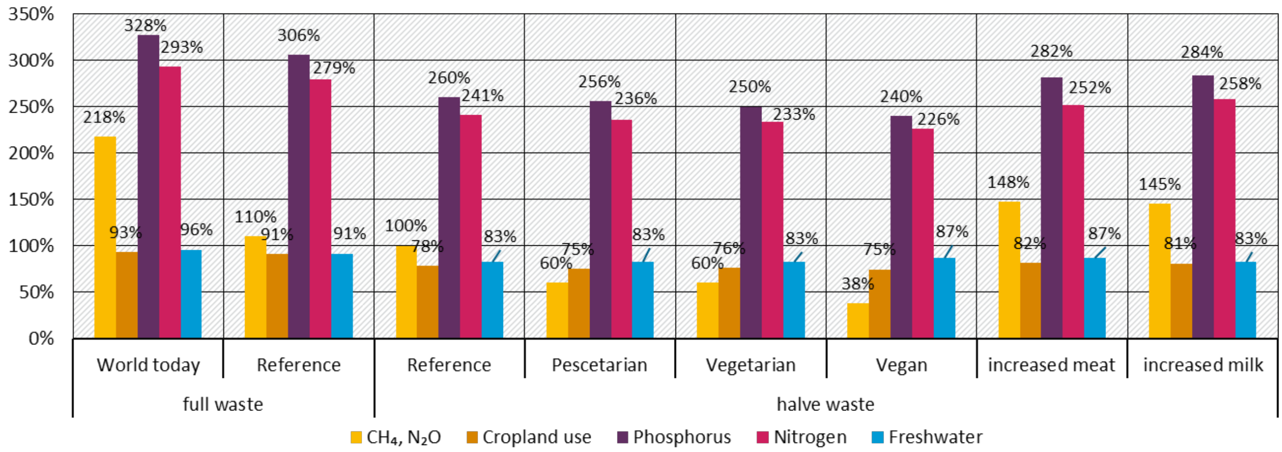
Figure 50 shows that the planetary boundary for freshwater demand is not exceeded by any of the consumption patterns. The freshwater demand arises outside of food (or animal feed) mainly from cotton cultivation and the use of wood. The Kaulatz family has the highest demand (52 % of the budget), as they have an above-average cotton consumption.

Figure 50: Freshwater demand from consumption of representative goods (excluding food) in 2050 and today relative to planetary boundaries in comparison



Source: own calculations ifeu

Figure 51: Environmental impacts of diet for the different dietary patterns in comparison



Source: own calculations based on Willett et al. (2019)

For the comparison in the consumption area of food, we consider the different scenarios according to Willett et al. (2019) (figure 51). All the diets exceed the boundaries for nitrogen and phosphorus. The boundary for methane and nitrous oxide is also exceeded by many dietary patterns. The boundaries for diets within the planetary boundaries are thus very narrow. Especially regarding the consumption of animal products, the margin is very small. Compared to today, a drastic reduction is necessary (see chapter 4.1), as Germany is clearly above the average of the world today.

8.2 Uncertainties

The results raise different questions regarding the accuracy of the results and the remaining uncertainties:

- Is the concept of planetary boundaries (CPB) the right concept to identify sustainable lifestyles? The CPB is certainly well suited and it has been explicitly designed for comparable questions. However, there are two issues to think about:

  a) On the one hand, we have not yet been able to consider all dimensions in the project. Possibly the inclusion of further dimensions will narrow down the possible sustainable lifestyles further.

  b) On the other hand, the concept does not explicitly address challenges such as the use of raw materials. The identified lifestyles require raw materials for which it is unclear whether they will be available – globally generalised – from an economic and ecological point of view. Here we see a need for research into the raw material requirements of globally generalisable sustainable consumption styles. From the analyses of the GreenSupreme scenario in the RESCUE project, for example, it is known that there could be shortages of the raw materials lithium, cobalt or raw materials of the platinum group.

- The assumed boundaries were derived and explained in chapter 3. They were based on the boundaries formulated for the present; these were transferred to the future. This is a pragmatic approach, but it is not necessarily correct. The boundaries for greenhouse gas emissions and for forest areas, for example, could also be drawn more narrowly than our boundaries in this project, with good reason. Given the impact of climate change on current forests, it could also be argued more strictly, e.g. that net forest areas should not be converted at all. Forest would thus be protected as a carbon sink but would no longer be usable as a substitute for other (more greenhouse gas-intensive) raw materials. With the same production technology, this implies that the construction of wooden houses or the use of wooden components in conventional buildings would no longer be possible within planetary boundaries. Similarly, regarding greenhouse gas emissions, it could be argued that in 2050 fewer or no more CO_2 emissions would be permissible because the CO_2 budget has been used up by 2050. This would mean that all products containing cement, glass or quicklime can only be consumed in smaller amounts (or not at all) within the planetary boundaries.

- While many technological changes were assumed, even more production technologies were assumed to remain constant. This applies to the technologies for the extraction of abiotic and biotic raw materials as well as the production of many other products and the provision of services. The impacts of climate change are already showing that technological changes are becoming more relevant. For example, agriculture in Germany currently requires little irrigation (UBA 2019b). This means that the amounts of freshwater used for food and for biotic raw materials in all other products are small. If droughts increase, the amount of irrigation will inevitably increase, and with it, the amounts of freshwater used to produce the representative goods. Similar examples can be found in other areas: for example, the amount of energy used for transporting goods on rivers is likely to increase further as a result of low water levels, or for extracting raw materials as mines are depleted.
- The environmental impacts of other goods (base contribution) could only be calculated in relation to greenhouse gas emissions, but not for other environmental impacts. It can thus be assumed that the conversion of forest areas, the use of freshwater and the release of nitrogen and phosphorus are greater. For example: In Germany, the chemical industry is currently the largest consumer of freshwater in the manufacturing sector (Destatis 2023). Freshwater consumption itself, however, does not decrease by simply changing the raw material base (from fossil to synthetic raw materials). Freshwater consumption is thus still used for products such as plastics, paints or varnishes and is consequently very likely not adequately represented by the selected representative goods.
- The representative goods were provided with LCA data that were closest or most similar to the representative good. Logically, LCA data that were available were used for this. It was assumed that the existing (most similar) data set for the product is actually representative for this product group, without this being able to be checked in detail within the framework of the project. However, household appliances or ICT devices, for example, can be very different, ranging from large to small, made of different materials or equipped with different technical features. The representative washing machine used in the project, for example, is very light at around 30 kg. The results are thus based on a concrete selection of goods that were originally selected for LCA for other reasons, but it remains untested to what extent these selections are sufficiently suitable for our project purposes. The preparation of LCAs also inevitably involves the use of simplifications and many assumptions that are incorporated into the results. The results suggest an accuracy that is not necessarily achieved.

8.3 Closing remarks

Our analysis shows that today's hotspots of consumption will remain hotspots in the future. Today, private households produce most greenhouse gases in the consumption areas of food, housing and mobility. In a de-fossilised world, these three will continue to be the most relevant consumption areas with respect to the planetary boundaries. The majority of nitrogen and phosphorus flows, methane and nitrous oxide emissions, and freshwater consumption come from food production. This applies to the reference diet as well as to reduced-meat and meat-free diets. Despite major improvements, the diet adopted by Willett et al. (2019), remains challenging in terms of compliance with planetary boundaries. Mobility will still require energy for cars, public transport and aeroplanes. Relevant quantities of CO_2 emissions are produced in the production of the vehicles and for energy generation, forest area is converted, and nitrogen is released. If the further effects of flights are included, flights are by far responsible for the most greenhouse gases and are almost impossible within planetary boundaries. The production of building materials used for housing leads to relevant amounts of CO_2 emissions as well as nitrogen; also, forest area is converted and fresh water is consumed. This means that even in a world in which energy is no longer supplied by fossil fuels but by renewable energy sources, food, housing and mobility remain the most environmentally critical areas of consumption.

The consumption area of clothing is only relevant in relation to the dimension of freshwater if cotton fibres are used. ICT devices or household appliances, as well as the amount of electricity used, are almost irrelevant in terms of compliance with the planetary boundaries. Only pets have a slightly larger effect on the dimensions of nitrogen and freshwater.

The generalisable consumption patterns considered cover a relatively broad spectrum of different consumption areas. Given the uncertainties, elaborated in the chapter before, it can be assumed that the identified consumption patterns represent an "optimistic selection". However, flights are not justifiable in any consumption pattern when the non-CO_2 effects are considered, unless a person "saves up" greenhouse gas emissions over many years and reduces other consumer goods. Furthermore, a very large living space cannot go hand in hand with intense mobility by car or public transport and a meat-based diet (reference) within planetary boundaries. If consumption is significantly above average in one of the three central consumption areas, one or both of the other consumption areas must inevitably be reduced.

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