The Environmental Impact of Green Consumption and Sufficiency Lifestyles Scenarios in Europe: *Connecting local sustainability visions to global consequences*

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The sustainability transformation calls for policies that consider the global consequences of local lifestyles. We used stakeholders' visions of sustainable lifestyles across Europe to build 19 scenarios of sufficiency (net reductions) and 17 of green consumption (shift in consumption patterns). We applied Environmentally Extended Multi-Regional Input-Output analysis to model scenarios by assuming widespread adoption of the proposed lifestyles changes. Finally, we estimate the domestic and foreign implications for land, water, carbon and human toxicity potential. We distinguish the options with most potential from those that are seemingly fruitless or present backfire risks. While our method allows for testing a large number scenarios under a consistent framework, further work is needed to add robustness to the scenarios. However, we do find a range of indicative results that have strong potential to contribute to mitigation efforts. Services: We find that a local and sharing service economy has a maximum reduction potential of 18% of the European carbon footprint (CF). Clothing & Appliances: Sharing and extending lifetimes of clothes and devices could diminish CF by approximately 3%. Transport: Reducing motorized transport by remote work and active travel could mitigate between 9-26% of CF. Food: Vegan diets could spare 4% of the land and reduce up to 14% of CF. Bio-economy: Switching to biomaterials and bioenergy tend to reduce carbon and toxic emissions at the risk of increasing water and land use. Housing: Passive housing and decentralized renewable energy reduces carbon emissions up to 5 and 14%, respectively. We characterize the sensitivity of our results by modelling income rebound effects and confirm the importance of deterring expenditure in resource intensive goods.

1) Introduction

Sustainable lifestyles can be broadly defined as "living well within earth's limits"(Jackson 2011; O'Neill et al. 2018). Encouraging sustainable lifestyles is a central strategy towards the 12th UN's Sustainable Development Goal of "Responsible Consumption and Production"(Akenji and Bengtsson 2014). This goal stems from recognizing that the global environmental crisis is ultimately driven by resource-intensive lifestyles, needs and wants (Vita et al. 2019; Vásquez et al. 2018a).

Europeans live some of the worlds' most unsustainable lifestyles (Ivanova et al. 2016, 2017). Driven by the level of consumption and living standards, European households emit up to 20 t CO_2 per capita/yr (Ivanova et al. 2017). Only 20% of those emissions are related to household fuels, while most emissions are embodied in consumer products and services (Ivanova et al. 2016, 2017). Further, Europe is a net importer of resources and carbon emissions with about half of its footprint occurring abroad (Tukker et al. 2016). Thus, alternative consumption and lifestyle changes are indispensable to reach environmental goals, especially in wealthy nations (Bjørn et al. 2018a; Rogelj et al. 2018).

Informing the transition to sustainable lifestyles was the main goal of the EU FP7 funded project GLAMURS (Green Lifestyles, Alternative Models and Upscaling Regional Sustainability). From 2014-2017, GLAMURS applied theoretically-based and empirically-grounded frameworks to research the main obstacles and prospects for sustainable lifestyles in Europe (Dumitru et al. 2017) (see glamurs.eu). Empirically, the project compared the lifestyles of average citizens with the lifestyles of members of local grassroots sustainability initiatives (Vita et al. 2018), conducted action research with those local initiatives, and organized backcasting workshops where multiple stakeholders developed visions and pathways towards sustainable lifestyles.

The purpose of this paper is to present a novel approach and analysis related to the environmental impact of sustainable lifestyle options, which was done as part of the GLAMURS project. The overarching objective of this article is to assess the environmental consequences of lifestyle scenarios obtained from a range of backcasting visions. Our hypothesis is that footprint reductions can be achieved through widespread adoption of sustainable lifestyle options proposed by stakeholders. In the paper, we approve or disprove our hypothesis for each envisioned lifestyle option and discuss the environmental potentials/pitfalls of lifestyles changes.

We start out from the visions produced during backcasting workshops across several European countries. We identified consumption-related elements from the visions and modeled them as scenarios of changed or reduced household demand. We evaluated the environmental outcomes by running a simulation through the EXIOBASE Environmentally-Extended Multiregional Input-Output Model (EE-MRIO) (Moran et al. 2018; Wood et al. 2017).

Linking qualitative methods to global models of consumption and resources allows us to compare stakeholder views with the environmental and social consequences implied in social change. Naturally, such a modelling effort is subject to at least two considerations. First, there is no standardized methodology to translate from narratives to quantitative modelling (Kemp-Benedict 2004; O'Brien et al. 2014). Although backcasting is common in scenario analysis (O'Neill et al. 2017; Schanes et al. 2019), it is not commonly linked to life-cycle oriented modelling due to the complexity of both, the demand of current lifestyles and the global supply chains serving this demand. Whilst EE-MRIO databases are becoming increasingly detailed and capable of providing product-specific results, such analyses are generally indicative rather than very precise.

Second, economy-wide scenario modelling are typically meant either to predict or characterize counterfactual developments (Distelkamp and Meyer 2019; Bjørn et al. 2018b; Rogelj et al. 2018). This is not the case of backcasting scenarios, where stakeholders normatively describe their visions of sustainability -regardless of expert judgments about "feasibility". Thus, backcasting scenario evaluation is meant to characterize the broad implications of a vision. Here, the results should be regarded as a first iteration that provides a sense of direction and magnitude of environmental consequences of lifestyles options.

Our modelling decisions follow recent parametrization approaches of scenario simulation with EE-MRIO (Moran et al. 2018; Wood et al. 2017), whilst giving more weight to the stakeholder visions. To strengthen our quantitative evaluation, our scenarios do not model changes in single goods, but rather reflect a bundle of goods associated to a particular lifestyle choice.

This paper seeks to inform the transition to sustainable lifestyles by combining participatory modelling with Multiregional Input-Output Analysis to evaluate a range of scenarios that : 1) Reflect the lifestyles envisioned by different stakeholders 2) Characterizes sufficiency and green consumption alternatives assuming widespread adoption of sustainable lifestyles, and 3) Discuss the implications for environmental footprints and quality of life of different scenarios.

1.1 Overview of sustainable lifestyles, green consumption and sufficiency

Recent efforts explore demand-side options for reducing consumption (**sufficiency**) or consuming less polluting goods (**green consumption**) (Schanes et al. 2016; Girod et al. 2014; Wynes and Nicholas 2017; Dietz et al. 2009; Gardner and Stern 2008; Bjørn et al. 2018a). Most studies point to plant-based diets, conserving energy, curtailing travel and living car-free as the most promising actions to reduce impact while enhancing human well-being (Schanes et al. 2016; Girod et al. 2014; Wynes and Nicholas 2017; Dietz et al. 2009; Gardner and Stern 2008; Ivanova et al. 2018; Ahmad et al. 2017; Westhoek et al. 2014).

Sufficiency scenarios represent lifestyles that seek to reduce material consumption and aspire to a higher quality of life (Jackson 2005). Sufficiency assumes that once basic needs are satisfied, well-being relies more on health, social relationships, time affluence, and other factors (O'Neill et al. 2018; Vita et al. 2019). Sufficiency lifestyles are supported by the proposal of voluntary simplicity (Jackson 2005) and align with alternative economic models such as de-growth or steady state (D'Alisa et al. 2015; Steinberger and Roberts 2010; Brand-Correa and Steinberger 2017). Sufficiency or "de-growth" assumes the satisfaction of human needs through material and non-material needs in a steady state economy (Vita et al. 2019). While a sufficiency paradigm lowers the risk of rebound effect of monetary savings, it also implies employment challenges such as shorter working hours and the necessary adjustments to protect livelihoods.

By contrast, **green consumption** stands here for consumption that relates to "green growth" economic models (Lorek and Spangenberg 2014). The main assumption is that economic growth may be compatible with sustainability, due to increasing eco-efficiency via technological improvement, servicing and shifting to a circular economy (Akenji 2014). Green consumption options rely on clean technologies (e.g., renewable energies, biotechnology) and reducing waste by closing material cycles as much as possible through extending lifetimes, re-use, retrofit, remanufacturing, and recycling (Steen-Olsen and Hertwich 2015). Under this paradigm, people aspire to a sustainable use of resources without needing to change current lifestyles and economic practices in a fundamental way (Akenji 2014).

Demand-side policies aim to incentivize sustainable lifestyles through behavioral ‘nudges’ and infrastructures that encourage sufficiency or green consumption (Creutzig et al. 2018; Ürge-Vorsatz et al. 2018). However, the whole spectrum, scale and effectiveness of demand-side solutions remains understudied (Creutzig et al. 2018). A broader perspective would include radical lifestyles changes, typically founded on needs-centered views on well-being (Vita et al. 2019), new social norms (Nyborg et al. 2016a), grassroots innovations (Vita et al. 2018), shared economies (PWC 2015) and others (see (Creutzig et al. 2018; Jackson 2005; Baumann and Vita 2015; Akenji 2014; Wiedenhofer et al. 2018)).

Unlike top-down deployment of low-carbon technologies or economic instruments (Wiebe 2016; European Commision 2014), policies for lifestyle changes require of citizens’ engagement and approval in order to succeed (O’Brien 2015; Nyborg et al. 2016b). Even benevolent top-down policies that do not resonate with the target group are bound to generate resistance, be costly or even create social distress (Sekulova et al. 2017). Further, non-participative public planning restricts the communities’ role in launching initiatives to tackle social and environmental challenges (O’Brien 2015; Sekulova et al. 2017).

1.2 Participatory visioning and economy-wide modelling for scenario assessment

Backcasting can be used as a participatory process suitable to embed stakeholder and citizens’ views into decision making (Vergragt and Quist 2011; Quist et al. 2016b). It literally means “looking back from the future” and when done in a participatory way consists of collectively envisioning a desirable future and paths forward to get there (Robinson 1990). Planning through backcasting can smoothen tensions between top-down policies and the actual needs of citizens and stakeholders (Vergragt and Quist 2011; Quist and Vergragt 2006).

Participatory modelling has gained popularity, with the long-overdue recognition that involving stakeholders is key in addressing socio-ecological issues (Brand-Correa et al. 2018; Jordan et al. 2018; Carlsson-Kanyama et al. 2008). The challenge is to find a balanced tool that is supportive of, and supported by, stakeholders while providing comprehensive and transparent insights of the implications of different pathways (Jordan et al. 2018).

Studies on demand-side options often vary in scope and methods, hindering comparisons or meta-studies (Hertwich 2005b; Hertwich and Katzmayr 2004; Schanes et al. 2016). Assessing options through a consistent economy-wide model allows for: 1) Considering global supply-chains and trade, 2) Aggregate effects at the European level while isolating household potential 3) Product granularity to build specific scenarios 4) Comparison between scenarios and with respect to status-quo baseline 5) Multi-criteria assessment of trade-offs and synergies by comparing multiple resource and emission footprints.

Understanding the global impacts of the sustainable lifestyle scenarios is not a trivial task in todays' globalized economy. Could upscaling the envisioned changes lead to footprint reductions? We use EXIOBASE (Wood et al. 2015), a state of the art EE-MRIO, to evaluate the scenarios' potential to mitigate footprints of land, water, carbon and human toxicity. We employ a multi-indicator dashboard to discuss potentials and pitfalls of scientifically assessed and stakeholder-inspired, visions of sustainable lifestyles.

2) Method: Environmental Assessment of alternative consumption scenarios

In this paper, we expand the spectrum of options for sustainable lifestyles while involving stakeholders' views. We selected visions of sustainable lifestyles produced by European citizens, sustainability frontrunners, public managers, and other stakeholders compiled in the GLAMURS project (Quist et al. 2016b, 2016a). We then translated the qualitative scenarios into an EE-MRIO framework, which made it possible to systematically quantify and compare the environmental implications of a range of sufficiency and green consumption scenarios.

Figure 1 summarizes the procedure and methods used in this research. We conducted backcasting workshops where stakeholders described visions of sustainable lifestyles. We then identified the visions that imply alternative consumption scenarios and the goods that would need to change or reduce in each scenario. We use the backcasting information to parameterize our model in terms of whether the changes occur only in household consumption, or also in production recipes and which is their adoption rate. We then simulate the scenario as a "shock" with economy-wide effects (Wood et al. 2017). Finally, we calculated the environmental consequences and compared them to current European impact in order to determine the potential of realizing such scenario.

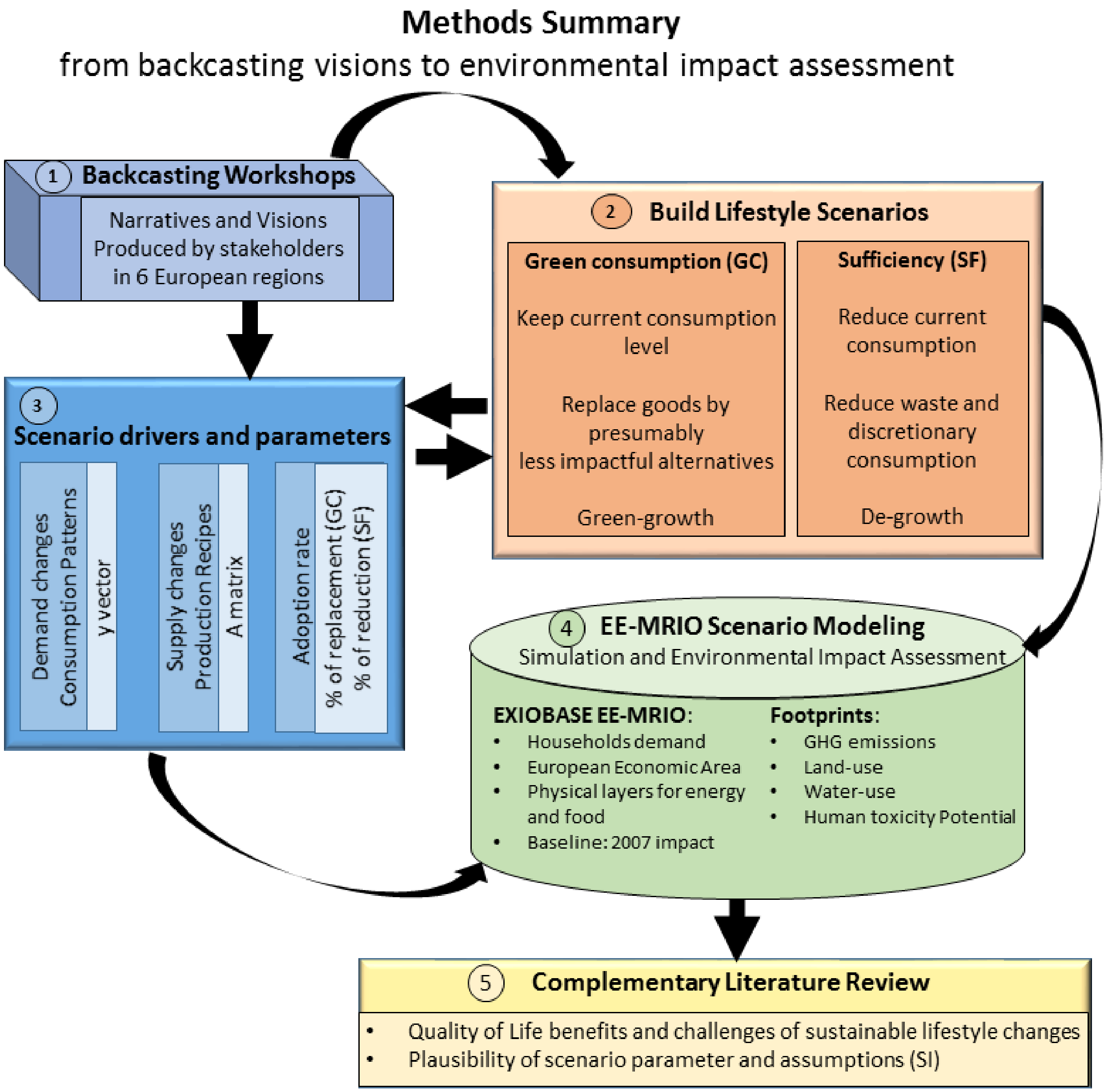


Figure 1 Schematic illustration of steps and framework to model the environmental impact of envisioned consumption scenarios from backcasting workshops. More detail on the steps to translate from qualitative backcasting to quantitative scenarios available in the Supplementary Information (SI).

From backcasting visions to lifestyle scenarios

The data to build consumption scenarios derives from the project GLAMURS, an interdisciplinary research project on sustainable lifestyles (Dumitru et al. 2017). Two backcasting workshops with typically 30-40 participants were conducted in each study region (Table 1): Banat Timis, Romania; Halle, Germany; Danube-Bohemian Forest, Austria; Galicia, Spain; Lazio and

Rome, Italy; and the Rotterdam-Delft-The Hague metropolitan region, the Netherlands (Quist et al. 2016b).

During two series of visioning and backcasting workshops, stakeholders from different societal spheres, including civil society, policy, knowledge and business developed and discussed visions for sustainable lifestyles in the future, including lifestyles changes. More details about the backcasting workshops and their participants can be found in reports of the GLAMURS project (Quist et al. 2016a, 2016b; Dumitru et al. 2017).

Table 1 List of backcasting workshop participants by country and type of participant. The table summarizes two workshops that produced reports (Quist et al. 2016a, 2016b; Dumitru et al. 2017) which constitute the basis of our analysis. NB: Romania had less participants due to weather events.

Total	Austria	Germany	Italy	NL	Romania	Spain
Nr. of participants	**32**	**35**	**31**	**37**	**15**	**41**
Business	10	10	0	0	3	0
Civil society	5	15	16	18	2	18
Government	14	4	3	4	2	11
Knowledge	3	5	12	14	9	12
Other	0	1	0	1	0	0

For the work reported in this paper the backcasting vision reports were scanned for statements proposing lifestyles options that involve consumption changes. We then classified according to their consumption category (e.g., food, transport, etc.). We interpreted the visions statements as literally as possible to set up consumption scenarios that are explicit about the goods and services that would decrease, increase or substitute each other. For example, to model scenarios based on statements such as "clothes will be produced locally and with low transport," we reduced transportation requirements of the clothing sectors ("*Local Clothing*") and quantified the environmental consequences. Another example is a scenario where all food would be vegan or vegetarian, meaning full replacement of animal products. This modelling decision implies that our analysis does not show a "feasible" reduction but rather the "maximum potential" of mainstreaming such a lifestyle.

Despite a great amount of sustainable lifestyle options proposed by stakeholders, we could only model those that can be translated into "alternative consumption options". Text excerpts from the backcasting reports that were used to build scenarios are provided in Supplementary Information (SI).

We further identified whether the vision corresponds to a sufficiency scenario – implying net reductions in consumption– or green consumption –implying consuming more eco-efficient alternatives. We end up with 19 sufficiency scenarios, 17 green consumption. Additionally, the researchers introduced 5 sensitivity scenarios, to provide a contrast to some of the sustainable lifestyle scenarios.

2.1 Footprints and Database

We use an environmentally-extended input-output framework to calculate the current environmental pressures of European consumption as a baseline (year 2007), and then compare it with the resulting footprints from the modelled scenarios. Environmental footprint, **fp**, represents the total consumption impacts from European households. We calculate **fp** as a function of household demand, $\boldsymbol{y}$, as follows:

$$\mathbf{fp} = \mathbf{s}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} + \boldsymbol{dhe} \qquad (1)$$

where $\boldsymbol{s}$ is the intensity coefficient vector resulting from dividing the total resource or emission required for the production of a given good by its economic output (e.g. CO_2/EUR), **I** is the identity matrix and **A** is the technical coefficient matrix, representing the inter-industry requirements. The $\boldsymbol{dhe}$ vector represents direct household emissions from the combustion of fuels for transport, cooking and heating.

Our modelling is based on EXIOBASE2, an Environmentally Extended Multiregional Input-Output (Wood et al. 2015) database. EXIOBASE2 represents the production and consumption of 200 economic goods for 43 countries and 5 rest-of-world regions for the year 2007. Satellite accounts for resources and emissions are available for each sector and country. For each footprint, we consider the resources and pollutants in **Table 2**. Our unit of analysis is the final demand of households of the European Economic Area, hereafter referred as Europe. See SI for details on countries included and EXIOBASE2 coverage.

Table 2 Environmental footprints, including factors of productions and chemicals covered.

Footprint	Coverage	Unit
Carbon Footprint	Global Warming Potential of CO_2, CH_4, N_20 (combustion and non-combustion) and SF_6. Includes direct household emissions (GWP 100, IPCC 2007).	Mt CO_2 equivalent
Human Toxicity Potential	NOx, NH_3, dioxins (PCDD_F),HCB, PM10, As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn and SO_x (combustion and non-combustion). Non baseline characterization factors (CML, 2001)(CML-Leiden University).	Mt 1,4-dichlorobenzene-equivalent
Land Footprint	Total land use: forests, pastures and arable land	M km^2
Water Footprint	Total blue water consumption. Includes direct household water consumption.	Km^3

2.2Modelling consumption changes with EE-MRIO

The global EE-MRIO described above accounts for different production recipes, trade supply chains and household consumption patterns across nations. The parameters that ultimately drive the scenarios are changes in consumption, production recipes and uptake rates (Figure 1). The basis of the model to simulate backcasting scenarios is to perturb the EE-MRIO by modifying the consumption patterns in the **y** vector or production recipes in the **A** industry matrix (Wood et al. 2017). The magnitude of the perturbations follow the uptake rates stated in Table 3. The full mathematical model to simulate changes in consumption using an EE-MRIO has been adopted from Wood et al. (Wood et al. 2017).

Here we model visions of alternative consumption patterns in households (**y** vector of final demand per product), and/or changes in industrial recipes (**A** matrix of technical coefficients). We assume a regular functioning of welfare institutions (health, education, pensions etc.) by holding all services provided by governments and social institutions (NPISH) constant.

We model three types of scenarios (Wood et al. 2017):

1. Change in households' demand (Change in **y**): Either a reduction in consumption or consuming different goods. In both cases, the scenario modelling consists of simulating a demand change in the relevant goods.
2. Change in industries' demand (Change in **A**): When the envisioned scenario depends on changes in inter-industries production recipes and inputs. For example, to produce *Natural Fibres* implies reducing the inputs of synthetic textiles to the apparel sectors.
3. Change at both households' and industries' demand (Change in **A** and **y**): Some scenarios entail simultaneous changes in household demand and industrial practices.

> For example, adopting vegetarian diets would imply that households reduce their purchase of meat directly (**y**) but also that restaurants have less demand for meat products (**A**).

While sufficiency scenarios imply a net reduction in the consumption of specific goods, green consumption scenarios imply that the reduced consumption of one product (i) is substituted by increasing the demand of another product (g). As substitute, products may differ in price or energy content per functional unit, the extent of replacement is affected by the relative differences (p) between the products, with no differences having a unitary value.

Expenditure was kept as the monetary functional unit for most services and aggregated product categories, as no physical layer could be derived. The original model allowed for price differences in product substitutes but did not explicitly consider the physical utility delivered by goods (e.g., energy use, calories provided) (Wood et al. 2017). In this research, we enhanced the model by introducing a physical layer to balance food and energy goods to ensure food and energy sufficiency in our scenarios.

For food and energy, which make up nearly half of the EXIOBASE 2 goods, prices underlying the EXIOBASE 2 model (Wood et al. 2015) were used to convert to mass or volume. Further, data on energy content was applied in order to convert to physical functional units i.e. kcal or TJ by weight in kilograms (or by volume in m^3), as explained in the SI and data file. Deriving physical functional units allows us to introduce the current living standards as a constraint by keeping the same level of nutrition (kcal) or energy use (kWh) while shifting the means of provision, as proposed by green consumption scenarios. This allows us to model reductions in food and shelter without falling in a situation of food scarcity or energy poverty.

The differences in prices or energy content per kilogram of fuels and food that modulate product substitution are modelled as follows:

$$p_{ig} = \frac{p_g}{p_i} \qquad (2)$$

Where p_{ig} determines the proportion of expenditure shifted in a given scenario. For example, a value of 0.5 would mean 50% of the expenditure of reduced products, i is shifted to increased products, g. This would be the case if a substitute energy carrier delivered twice as dense as the current i.e. double energy per weight. For monetary layers, an example would be buying textiles for do-it-yourself clothes is five times cheaper than in-store apparel i.e. $p \approx 0.2$. Differences in price and energy densities modulate the substitution share in products demanded by households and industries alike (Wood et al. 2017).

While differences in energy densities are modelled for all food and energy, price differences between substitute goods modelled in monetary terms were rarely assumed, reported in the "price deflator" row in the Supplementary Data modelling parameters. Differentiating price and quality between comparable goods is limited by the product aggregation in EE-MRIO analysis (Girod and de Haan 2010)

Table 3 is a full account of the envisioned consumption scenarios modelled in this paper. The "visions" column describes the actions to achieve sustainable lifestyles articulated by the backcasting workshops participants. Since our goal is to understand the possible environmental outcomes of scaling up the envisioned lifestyles, we assumed aggressive uptake rates to reflect a maximum potential. However, we consider technical or physical limitations when relevant (i.e., food waste cannot be totally eliminated, minimum daily caloric intake (Vásquez et al. 2018b), etc.). Assumptions are detailed in the SI. When pertinent, we model "sensitivity scenarios" to provide an opposite case for comparison. For example, we model *Industrial Materials* as a contrast to a scenario of building with *Natural Materials*. Sensitivity scenarios, however, do not represent stakeholders' visions.

It should be noted that scenarios of either reduced consumption or reduced inputs to production are applied directly and thus imply a reduction in the GDP of the economy, given that all other variables remain constant (see discussion and limitations). In the discussion we consider economic challenges and quality of life benefits associated with the scenarios. In the SI, we characterize the sensitivity of considering an economic rebound effect for the scenarios that represent monetary savings.

Table 3 Scenarios built from backcasting visions. The values for **y** and **–** parameters indicate the assumed adoption level in household demand or inter-industry demand, respectively, where the value indicates the degree of substitution in the case of green consumption e.g. 1 is full substitution of products. For sufficiency, the value indicates the level of reduction, where 1 represents a total ban of a bundle of goods. (See SI for details on assumptions). Visions marked with * are modelled through physical balances (kcal or kWh) and baseline energy are introduced as a constraint to be kept constant. E.g. Interpretation Key: Animal free clothing proposes a vegan fashion industry, which imply replacing animal textiles with plant-based textiles. This is classified as green consumption (GC) because it keeps clothing consumption constant but with different, presumably more sustainable, materials. The adoption rate is full (y = 1, A=1) because it implies a total ban of animal textiles both in household consumption and in industrial recipes.

	Visions	Description	Modelled changes in consumption	SF/GC	y	A
Clothing	Animal Free	No clothing of animal origin (vegan clothing).	Substitute wool, furs, leather, and replace with textiles/plant-based fibers.	GC	1	1
	Durable Fashion	Reduces textile consumption e.g., clothes swap, second hand use, repairs	Reduces clothes and wearing apparel by 80%. Shift 20% of spending by textile materials (fibers and wool) and leather.	SF	0.8	0
	Natural Fibres	No petroleum-based clothes. Only natural fibres, e.g., wool, fur, cotton	Replace plastic/rubber inputs to clothing sectors with natural fibres by 90%.	GC	0	0.9
	Local Clothing	Only local clothing clothes and fibers.	Reduce by 50% the transport inputs to sectors of clothing and apparel.	SF	0	0.5
Construction	Minimum Construction work	Minimal construction due to large scale co-habitation and downsizing. Only minimal repairs and renovation takes place.	Reduce all construction work and materials by 90%	SF	0.9	0.9
	Repair Renovate	Intensive refurbishment and renovation of existing residential buildings.	Shift 5% of all overall expenditure (except for food) to increase construction work and building materials.	GC	0.5	0.9
	Natural Materials	Building with natural construction materials: wood, clay, stone and sand.	90% decrease in cement, bitumen, metals and foundry work. Increase in wood, clay, sand, stone and non-metallic mineral products.	GC	0.9	0.9
	Industrial Materials	Building and renovation with industrial materials: concrete and metals	Reduce wood, clay, sand, stone and non-metallic mineral products. 90%. Increase in concrete and metals.	SS	0.9	0.9
Food - Diet	Processed Food*	Shift towards more processed food and ready to eat food products.	Reduce all raw and plant-based foods, as well as live animals, by 80%. Replace with processed food products.	SS	0.8	0
	Food Sufficiency*	Limits food consumption to 2586 kcal/day. Reduces food surplus.	Reduce all food product spending by 27%, corresponding to the average surplus calories in Europe (Hiç et al. 2016; Vásquez et al. 2018a).	SF	0.27	0
	Mediterranean Diet*	High consumption of plant-based food, fish, dairy, and wine. Less meat.	Decrease non-fish meat products by 80%, increase all others foodstuff. Hotels and restaurants (H/R) change their inputs.	GC	0.8	0.8
	Vegetarian*	Vegetarian food with dairy and eggs but no meat.	Reduce meat and fish to 100%. Replace with plant-based food, diary, and processed food. Hotels and restaurants change their inputs.	GC	1	1
	Vegan*	Vegan food (no red/white meat, eggs, or dairy products).	Eliminates all food animal products. Increase all other food. Hotels and restaurants change their inputs.	GC	1	1
	Healthy Vegan*	Vegan food and eliminates processed foods, sugars and beverages.	Eliminates all food animal products, processed food, sugar and beverages. Hotels and restaurants change their inputs.	GC	1	1
Food SC	Local Food	Shift towards locally sourced food, including hotel/restaurant sector.	Reduce transport needs of food industries by 50%.	SF	0	0.5
	Organic Food	Food and animals are produced without agrochemicals.	Reduce fertilizers, chemicals and medicines as inputs to food and H/R products by 100%.	SF	0	1
	Seasonal Food	Less vegetables grown in greenhouses through seasonal consumption	Reduce inputs of fuels and electricity to vegetable sector by 30%.	SF	0	0.3
	Less Waste	Reduce food waste at the household level.	Reduce all food product spending by 12% (Vanham et al. 2015) (corresponding to estimated calories that currently go to waste).	SF	0.12	0
Man. products	Share & Repair	Collaborative ownership of appliances and tools. Second-hand buying/renting, tool library and repair cafés. Shift to services.	Reduced consumption of machinery and electronic apparatus and their retail/trade by 50%. 10% of expenditure shifts go to renting apparatus.	GC	0.5	0
	Offline Minimalist	Less media, Internet, telecommunication equipment etc.	80% reduction of media, machinery, electric apparatus, telecommunication devices and services related.	SF	0.8	0
	Durable appliances	Extended appliance lifetime, increased reparability lowers consumption	80% reduction of general appliances, office equipment devices and precision instruments.	SF	0.8	0
	No Chemicals &Plastics	Reduces use of chemicals and plastic, e.g., bottled beverages, plastic bags	90% reduction of chemicals, fertilizers, cleaning agents, plastics and rubbers at the household.	SF	0.9	0
Mobility	Frequent Flyer	Flies frequently.	Reallocate 2% of all product spending, except on food, towards air transport.	SS	0.02	0
	Cycling & Flying	Cycling increases, reducing land transport but people fly with the savings.	50% reduction of products related to local land mobility, shifting expenditure to air mobility.	GC	0.5	0
	No Flying	Stops flying.	Eliminates all air transport services.	GC	1	0
	Renewable Fuels	Public transport and private vehicles use mostly liquid biofuels.	Substitute 90% of all fossil transport fuels by bio gasoline, biodiesel, ethanol fuels and others. Including direct household mobility. Inputs to land transport services and motor fuel retail industry shift towards biofuels.	GC	0.9	0.9
	Less Cars (50%)	Expanded public transport, car co-ownership and ride share are deployed.	Substitutes 50% of income spent on private vehicles and fuels with land public transportation (bus, train, metro, etc.).	GC	0.5	0
	Less Transport (50%)	Overall decreased mobility, e.g., through digital lifestyles and efficient cities	50% reduction of all products related to mobility.	SF	0.5	0
	Work from Home (50%)	Reduces need for mobility by working from home, telecommute, living close to work, etc.	Reduces spending on mobility by land by 50%.	SF	0.5	0
	Work from Home (50%) ER	Same as "Work from Home" but ER assumes that more time spent at the home could increase electricity and heating needs.	Reduces spending on mobility by land by 50%, increase electricity and heating fuel spending by 20%.	SF	0.5	0
	Bike Walk Full	Bikes/walks everywhere for land commute. Other mobility constant.	100% reduction of vehicles, fuels and services related to mobility by land.	SF	1	0
Services	Leisure Services	Increased travel agencies, restaurant food, spa, entertainment, etc. Focus on hedonism and disregards insurances and financial security.	80% reduction expenditure in health, education and financial services and instead spends on entertainment, tourism, hotels and restaurant and shopping.	SS	0.8	0
	Non-Market Services	Large-scale collaborative economy and inter-community exchanges, voluntary work, time banks and community services.	80% lower use of all services.	SF	0.8	0
	Community Services	Engaged in recreational, sport and cultural organizations, high communication	Decrease leisure services and tourism by 80%, substitutes with recreational and membership organization services.	GC	0.8	0
	Local Services	Local and decentralized service supply. Local economy favors servicing.	Reduce direct household spending on local mobility by 20% (Wiedenhofer et al. 2018). Reduce transport inputs into all services by 30%.	SF	0.2	0.3
Shelter	100 % Fossil Fuels*	Replaces household renewable fuels and electricity with fossil fuels	Full replacement of current renewable electricity and energy with fossil sources.	SS	1	0
	Renewable Electricity*	Renewable electricity by wind, photovoltaic, solar, geothermal and tidal.	Reduce fossil electricity by 100%, replace with renewable electricity.	GC	1	0
	Passive housing	Passive house standard and energy-efficient dwellings.	Reduce energy spending by 43% (Mosenthal and Socks 2015) (i.e. 40% lower energy need). Shifts 20% of consumption to construction work and insulation.	GC	0.43	0
	No energy Ecovillage	Models a pre-industrial energy use while keeping all else constant.	Decrease spending on energy carriers and grid services by 100%. Models the impacts of current electricity and fuel consumption.	SF	1	0
	High-tech Ecovillage	Decentralized, local, small-scale renewable energy production distributed through micro grids.	Decrease spending on fossil based electricity and overall transmission grid services. Substitute with local generation of renewable electricity: solar, hydro, wind, geothermal. All other fossil fuels for heating remain the same.	GC	1	0
	Water Off-Grid	No conventional water distribution. Water use from natural sources.	100% reduced expenditure on collected and purified water, distribution services of water.	SF	1	0

SF= sufficiency (net reduction), GC= Green consumption (shift in consumption), SS= Sensitivity Scenario, ER = Energy Rebound,

3) Results

3.1 Current status of European impact

Table 4 shows the impact intensity per euro spent for detailed consumption categories. Food is the most water and land intensive category, while mobility and shelter are the most carbon intensive(Ivanova et al. 2016). Transport emits the most human toxins per euro, while services have a relatively impacts per EUR. Table 2 serves as a baseline to interpret the scenario modelling results.

Table 4 Average intensities in impact per euro for consumption categories. Calculated as footprint of each product category divided by the total consumption of that category aggregated for Europe. DCB: dichlorobenzene. Own calculation based on EXIOBASE(Wood et al. 2015). Calculations of energy per kilo for food and fuels can be found in the SD.

European environmental intensity of consumption

	Carbon (kg CO_2 eq/EUR)	Human Toxicity Potential (kg 1,4-DCB eq/EUR)	Land (m^2/EUR)	Land (m^2/kg)	Water (liter/EUR)	Water (liter/kg)
Clothing and apparel	0.79	0.70	1.70		31.79	
Construction materials and work	0.75	0.49	3.29		8.27	
Food: Processed	1.11	0.62	3.61	10	118.92	333
Food: Dairy	1.45	0.62	4.70	13	80.49	222
Food: Meat and fish	1.44	0.65	3.63	76	94.67	1972
Food: Plant-based	1.35	0.44	7.81	19	292.80	712
Manufactured products: Appliances, machinery and electronics	0.70	0.71	0.51		8.44	
Manufactured products: Media and communication apparatus	0.55	0.57	0.88		9.15	
Manufactured products: Plastic, paper	3.44	4.19	1.38		41.85	
Transport: By air	2.01	0.77	0.38		6.98	
Transport: By land	2.04	0.94	0.49		8.72	
Transport: By water	3.09	122.28	0.48		9.05	
Services: Information technology	0.37	0.30	0.35		5.07	
Services: Business and financial	0.19	0.16	0.17		2.78	
Services: Health, education and research	0.28	0.23	0.47		8.84	
Services: Renting services and real estate	0.18	0.16	0.19		2.30	
Services: Recreation and tourism	0.50	0.58	0.97		25.30	
Services: Trade and retail	0.39	0.54	0.48		8.90	
Housing: Electricity and fuels	4.46	0.66	1.89		12.18	
Housing: Household commodities	1.06	0.70	2.23		16.76	
Housing: Recycling	1.09	1.10	0.48		7.28	
Housing: Waste treatment	1.16	0.40	0.39		6.67	

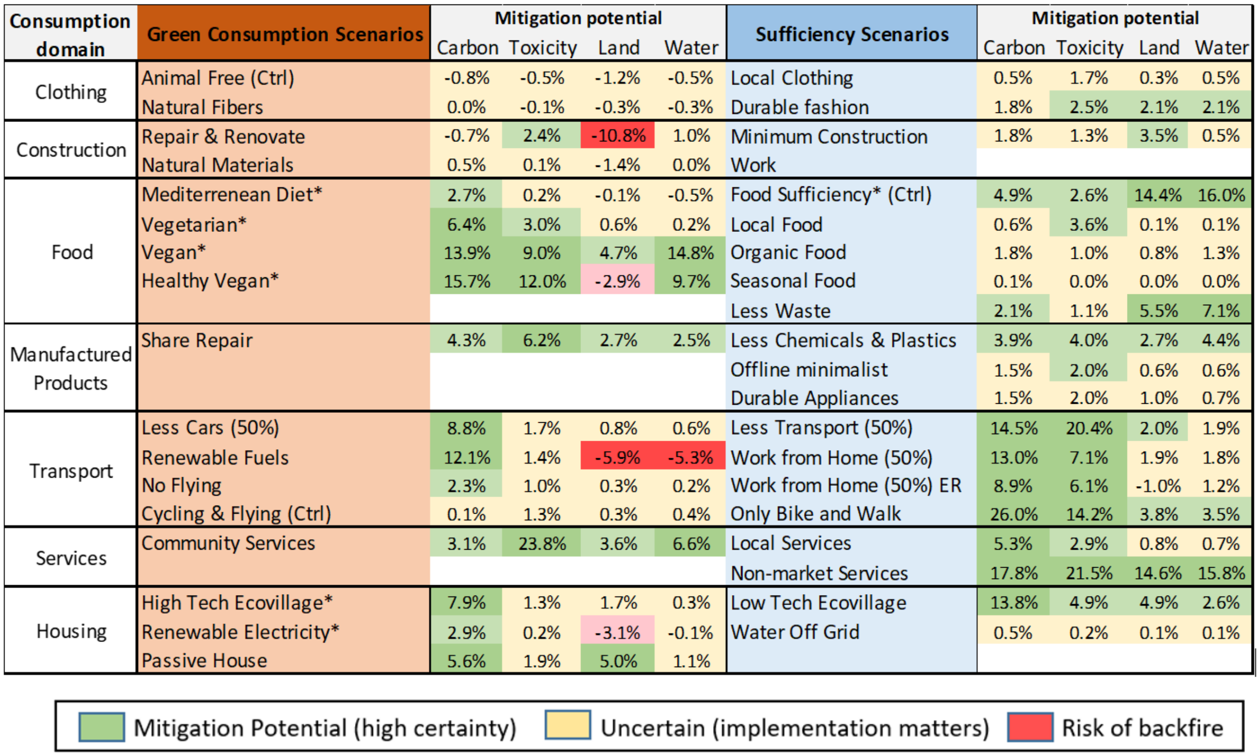
3.2 Environmental impact assessments of green consumption and sufficiency scenarios

Table 5 summarizes the impact assessments for the envisioned scenarios of green consumption and sufficiency. **Sufficiency** options have higher mitigation potential in the domains of transport, services and clothing, while **green consumption** options show more reductions in the domains of food and manufactured products. We find that large-scale shifts towards plant-based diets, reductions in motorized transport and energy-efficient housing offer the most potential to curb European environmental impacts (Wynes and Nicholas 2017). Reducing manufactured products and clothing hold considerable potential, above 2% across footprints.

While here we contrast green consumption and sufficiency, in practice some of these actions might be complementary. For example, adopting plant-based diets does not exclude preventing food waste or eating organic. For green consumption options, however, the environmental impact of the alternative goods and the volume of consumption, would largely determine the environmental outcome, e.g., the foods chosen to replace meat in diets(Rao et al. 2018).

We mark footprint changes below 2% in yellow to signal outcome where the observed change is relatively small and the practical implementation of such scenario could tip the balance towards reduction or increase. Energy and food scenarios were modelled through a physical energy layers (marked with * in Figure 2 and Table 3) in order to maintain current energy demand (kcal or kWh) and model the isolated effect of shifting food and energy carriers (such as in *Renewable Electricity* or *Vegetarian.)*. See SI for modelling of physical layers.

Table 5: Environmental synergies and trade-offs of green consumption and sufficiency scenarios. Mitigation potential (green and positive) or backfire (red and negative) expressed as a percent difference (Δ) with respect to the baseline. Color-coding as follows: yellow: Δ ±2%; light red: Δ < -2%; dark red: Δ <-5%; light green: Δ >2%; dark green: Δ >5%. Yellow color represents small and thus uncertain results. The outcome of these actions would depend on their practical implementation. The values summarize the percentages reported in Figure 2.



Consumption domain	Green Consumption Scenarios	Mitigation potential				Sufficiency Scenarios	Mitigation potential			
		Carbon	Toxicity	Land	Water		Carbon	Toxicity	Land	Water
Clothing	Animal Free (Ctrl)	-0.8%	-0.5%	-1.2%	-0.5%	Local Clothing	0.5%	1.7%	0.3%	0.5%
	Natural Fibers	0.0%	-0.1%	-0.3%	-0.3%	Durable fashion	1.8%	2.5%	2.1%	2.1%
Construction	Repair & Renovate	-0.7%	2.4%	-10.8%	1.0%	Minimum Construction Work	1.8%	1.3%	3.5%	0.5%
	Natural Materials	0.5%	0.1%	-1.4%	0.0%					
Food	Mediterrenean Diet*	2.7%	0.2%	-0.1%	-0.5%	Food Sufficiency* (Ctrl)	4.9%	2.6%	14.4%	16.0%
	Vegetarian*	6.4%	3.0%	0.6%	0.2%	Local Food	0.6%	3.6%	0.1%	0.1%
	Vegan*	13.9%	9.0%	4.7%	14.8%	Organic Food	1.8%	1.0%	0.8%	1.3%
	Healthy Vegan*	15.7%	12.0%	-2.9%	9.7%	Seasonal Food	0.1%	0.0%	0.0%	0.0%
						Less Waste	2.1%	1.1%	5.5%	7.1%
Manufactured Products	Share Repair	4.3%	6.2%	2.7%	2.5%	Less Chemicals & Plastics	3.9%	4.0%	2.7%	4.4%
						Offline minimalist	1.5%	2.0%	0.6%	0.6%
						Durable Appliances	1.5%	2.0%	1.0%	0.7%
Transport	Less Cars (50%)	8.8%	1.7%	0.8%	0.6%	Less Transport (50%)	14.5%	20.4%	2.0%	1.9%
	Renewable Fuels	12.1%	1.4%	-5.9%	-5.3%	Work from Home (50%)	13.0%	7.1%	1.9%	1.8%
	No Flying	2.3%	1.0%	0.3%	0.2%	Work from Home (50%) ER	8.9%	6.1%	-1.0%	1.2%
	Cycling & Flying (Ctrl)	0.1%	1.3%	0.3%	0.4%	Only Bike and Walk	26.0%	14.2%	3.8%	3.5%
Services	Community Services	3.1%	23.8%	3.6%	6.6%	Local Services	5.3%	2.9%	0.8%	0.7%
						Non-market Services	17.8%	21.5%	14.6%	15.8%
Housing	High Tech Ecovillage*	7.9%	1.3%	1.7%	0.3%	Low Tech Ecovillage	13.8%	4.9%	4.9%	2.6%
	Renewable Electricity*	2.9%	0.2%	-3.1%	-0.1%	Water Off Grid	0.5%	0.2%	0.1%	0.1%
	Passive House	5.6%	1.9%	5.0%	1.1%					

🟩 Mitigation Potential (high certainty) 🟨 Uncertain (implementation matters) 🟥 Risk of backfire

Overall, we find encouraging environmental outcomes from the envisioned consumption scenarios. Switching towards locally sourced, peer-to-peer and community services could mitigate 3-23 % of European environmental impacts. Reducing transport needs, working from home and switching to cycling and walking are options that do not present trade-offs and could mitigate 9-26% of carbon and 2-4% of land and water impacts. Switching to plant based diets has the potential to mitigate between 4-15% across impacts, while reducing food waste and surplus could reduce 2-5% of carbon and save up to 16% of water.

Switching the fibers used in clothing has negligible effects, but making clothes last longer (e.g., through swapping and repairing) could lead to 2% reduction in European impacts. Similarly, sharing and repairing household appliances and devices could yield a 2.5-6% reduction across impacts. Finally, the outcome of alternative housing would depend on the chosen energy carriers. If forestry products are to supply the current heating and cooking needs, carbon emissions could be reduced by 8%, but at the cost of doubling land requirements. Adopting *passive house* standards or to live at the margins of centralized energy systems show no-trade offs and could reduce 5-14% of European impacts.

The magnitude of our results are in line with previous analyses. Previous assessments associate housing, transport and services to 70% of carbon emissions, while food alone takes up half of the water and land embodied in European consumption(Ivanova et al. 2017, 2016). Clothing, construction, and durable goods together account for about twenty percent of resource use and emissions(Ivanova et al. 2017, 2016). The following section describes results for each consumption category in detail.

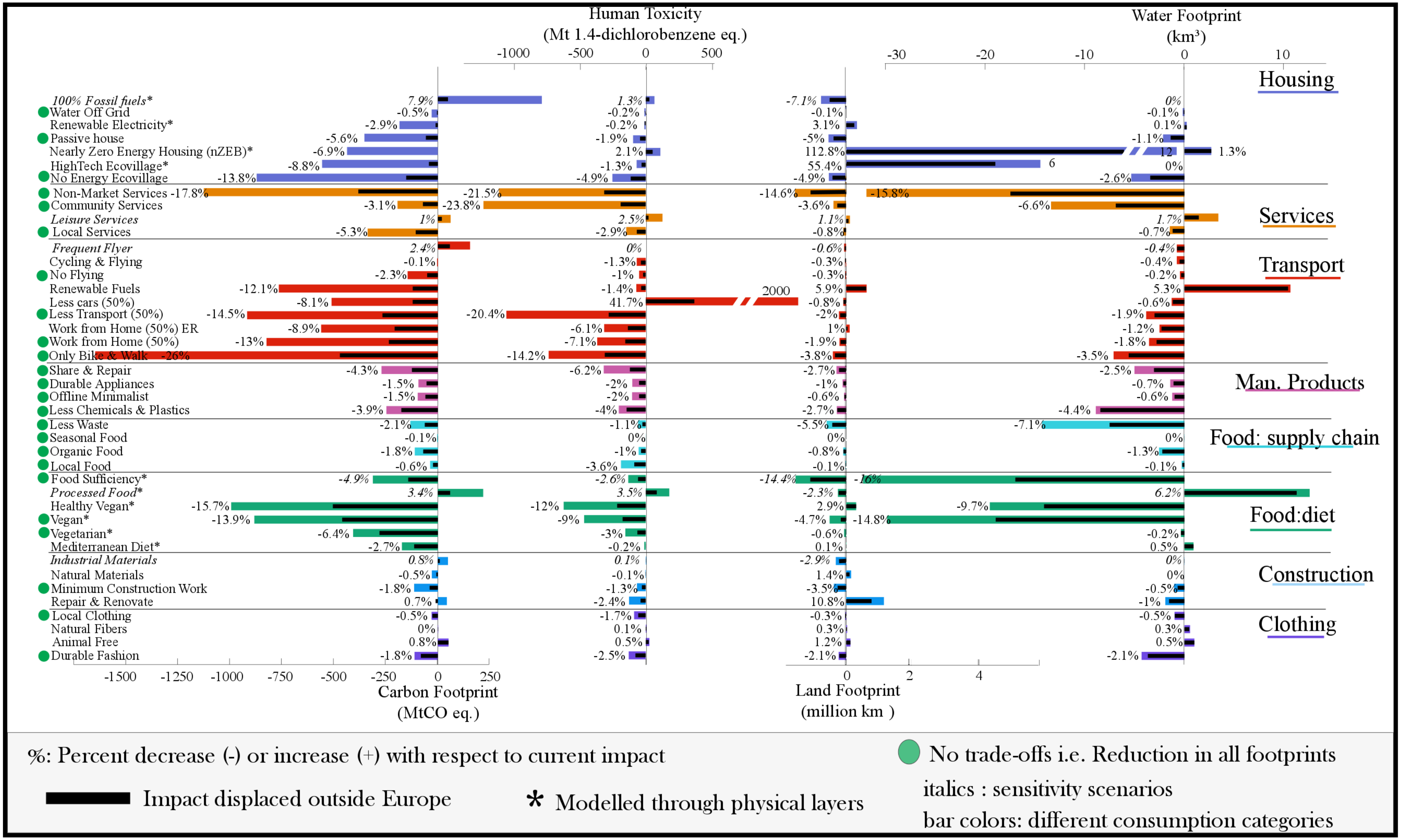


Figure 2 Relative and absolute footprint changes with respect to lifestyle change scenarios. Percent values indicate deviation with respect to baseline: total European household footprints of 2007. Black bars show the impact share that occurs outside the European Economic Area. A green dot indicates the consumption changes that present a positive reduction and no trade-offs across footprints to indicate the "safe options." Asterisk * indicates lifestyles modelled through physical energy balances of kcal or kWh. ER=energy rebound (see Table 3). To contrast the sustainability visions, we included some worse case scenarios to show the range (indicated by *italics).*

Clothing

While net reductions in the consumption of clothing and construction may curb impacts, simply shifting materials offers modest reductions with possible trade-offs, as shown in Figure 2. Durable Fashion could halve current impact of clothing, reducing the environmental of Europeans by 1.8-2.5% by extending clothes' lifetimes and increasing secondhand re-use. Lowering clothes miles by preferring Local Clothing reduces human toxicity by 1.7% due to the high toxicity of transportation fuels (Table 4). with marginal reductions in other footprints (Figure 2). Replacing all synthetic fibers with *Natural Fibers* has a negligible mitigation potential across footprints. Phasing out animal fibers for plant-based and synthetic fibers would require 1.2% more land and 0.5% more water as shown by the *Animal free* clothing scenario. Choosing natural over synthetic clothing materials present negligible carbon reduction potentials with potential increases in other footprints. In sum, only sufficiency scenarios of net reductions in clothing offer mitigation potential.

Construction

Co-habitation and downsizing of living spaces could Minimize Construction Work, reducing land and carbon footprints by 3.5 and 1.8%, respectively. Intensive Repair & Renovation could increase land use about 11% and slightly reduce other footprints, due to the lower intensity of construction goods with respect to other categories (Table 4).

Using more *Natural Materials* in construction results in a carbon reduction of 0.5% but a land increase of 1.4%. *Natural Materials* such as wood, stone, sand and clay require more land but emit less carbon since they require less processing and energy compared to concrete and metals. We model the opposite case in *Industrial Materials* by building with concrete, steel and aluminum. This would decrease land by 3% while increasing carbon footprint by 0.8%. Although construction is not typically associated with lifestyles, 70% of Europeans households own their dwelling(Eurostat 2018) and thus can influence the energy efficiency and materials in their houses. Renovation for thermal performance could decrease energy use per area but expansion of current living spaces would have the opposite effect (Vásquez et al. 2016).

As with clothing, the choice of natural over synthetic materials in construction shows a negligible potential reduction in carbon, toxicity and water accompanied by potential increase in land. Again, only sufficiency scenarios in construction offer considerable mitigation potential. Noteworthy, wood materials are rather intensive in "forest land", while natural fibers rely mainly on croplands (e.g., cotton) (Table 4,**Table 2**).

Food: Diets

All low-meat diets provide significant environmental footprint reductions (Figure 2). A *Mediterranean Diet* would lower non-fish meat and increase legumes, oils, vegetables, cereals, fish and dairy, and could reduce carbon emissions by 2.7% at the cost of a slight increase of land and water. A full *Vegetarian* diet would reduce carbon and toxicity by 6.4 and 3.0%, respectively. Removing dairy products and eggs (*Vegan* lifestyle) yields a reduction potential of carbon (14%) and of toxicity and water footprints of 9 and 15%, respectively. With a *Healthy Vegan* diet (reduced sugar, beverages and other processed food products), the carbon and toxicity footprints would be decreased by 16 and 12%, respectively. The slight land footprint increase for *Healthy Vegan* lies in the low price but relatively high calorie of unhealthy vegan foods such as sugar and beverages. Supplying calories with sugar requires less total land than supplying the same calories with oils and nuts, for example. This result is not conclusive, and in practice the outcome would depend on the food products that constitute a *Healthy Vegan* diet(Rao et al. 2018).

We model the sensitivity scenario of *Food Sufficiency* by limiting the calorific intake to a sufficient amount for European standards of 2586 kcal/day(O'Neill et al. 2018) and find that such measure may reduce the total carbon footprint by 4%, twice the potential found by a prior study of France(Vieux et al. 2012). *Food Sufficiency* yields a decrease in total agricultural land needed; the water and land footprints may decrease by 16% and 14%, respectively. Our results agree with previous findings that show 20% of European food is supplied in a surplus, which in turn largely drives waste and overeating (Hiç et al. 2016). The *Processed Food* simulates a higher intake of processed food and lower intake of plant-based and staple foods. This would increase all footprints except land, for a similar reason as discussed above with respect to the *Healthy Vegan*, but also because supplying current caloric needs exclusively through *Processed Food* would come at a greater cost, and thus prevent expenditure in other products (see "physical layers" in SI).

Food: Supply chain

Organic Food could reduce carbon (1.8%), land (0.8%) and water (1.3%) while *Local Food* reduce toxicity footprint (3.6%) due to lower transport needs. The scenario of more *Seasonal Food*, where energy inputs to agriculture reduce by 30% (Girod et al. 2014), has no significant mitigation potential. Europe consumes a large share of imported food, and agriculture requires relatively low energy inputs. However, in a scenario where a larger share of food is produced within Europe, the effects of seasonal food might be more significant.

We confirm previous findings of *Organic Food* having lower impact than consuming *Local Food* which reduces food miles (Avetisyan et al. 2014). However, when we add human toxins to this debate, we find that *Local food* is preferable for reducing toxicity in Europe. Policies to favor synergies between *Organic*, *Seasonal* and *Local* agriculture could lead to dynamic effects that yield potential beyond our estimates (Westhoek et al. 2014). *Less Waste* would imply reduction of food consumption by 12% (Vanham et al. 2015) (1.2% of total household expenditure). Our results agree with previous estimates of at least 2% of European carbon to be food waste (Hoolohan et al. 2013) and are within the 2-7% range reported by Usubiaga et al, based on EXIOBASE (Usubiaga et al. 2018). Indeed, we find reducing food waste can reduce by 5.5 and 7% the use of land and water, half of it outside Europe.

Combining sustainable diets and supply chains could yield further reductions. A *Vegan* diet with *Less Waste* and *Organic Food* could potentially reduce footprints of up to 18, 11 and 24%, for carbon, land, and water, respectively. Our general findings agree with previous research that reports low-meat diets (Tukker et al. 2010; Rao et al. 2018; Wynes and Nicholas 2017; Schanes et al. 2016) and organic food (Reganold and Wachter 2016; Hoolohan et al. 2013) have lower environmental impact than conventional diets. In sum, we find most reduction potential by shifting to non-meat diets, while reducing food waste and miles yield lower, yet considerable, reduction potentials.

Manufactured products

Share & Repair reduces carbon by 4.3% and toxicity by 6%; assuming increased sharing, reparability, re-use and product-service systems. The scenario of *Durable Appliances* and *Offline Minimalist* show comparable reduction potentials. *Durable Appliances* extends useful lives of appliances while *Offline Minimalist* reduces personal electronic devices and media consumption to offer a reduction of 1.5 and 2% for carbon and toxicity, respectively. A scenario of *Less Chemicals & Plastics* entails lowering household chemicals and plastics, with a 4% reduction potential in carbon. Reducing chemicals reduces the pressures of foreign land and water, while *Share & Repair* has a significant reduction of carbon and toxicity within Europe.

Mobility

Replacing all local land transport with biking and walking (*Only Bike Walk)* can potentially reduce carbon by 26% and toxicity by 14%. *Work from Home* implies mainstreaming flexible and remote work, thereby halving current commutes and reducing carbon and toxicity by 13% and 7%. If *Work from Home* becomes widespread, there is a risk of increased use of fuel and electricity at home. We estimate such possibility in *Work from Home ER* at mitigation potentials of only 9% carbon and 6% toxicity. Such rebound could be counteracted by energy efficient housing or decentralized working spaces that workers can reach without motorized transport.

Similar to others, we find that shifting to public transport is efficient in reducing carbon(Duarte et al. 2016; Wynes and Nicholas 2017). *Less Transport* implies 50% reduction in all motorized transport, thereby reducing toxicity (20%) and carbon (14%). The *Less Cars* scenario models a large adoption of car-free lifestyles, implying a 50% expenditure shift from private vehicles towards collective transport and shared vehicles. This could reduce carbon up to 8.8% and toxicity by 1.7%. By modelling transport through a top-down MRIO, we do not consider the demand of passenger-kilometers directly. Since 80% of current European commute is done with passenger-cars(Eurostat 2014), shifting monetary demand from private to public transport could lead to a surplus of passenger-kilometers, e.g., more buses, trains and ferries. Thus, bottom-up, country-specific data on fleet inventory and passenger-kilometers by transport mode would increase the accuracy of the model.

Adopting *Renewable Fuels* for mobility potentially decreases carbon (12%) and toxicity (1.4%), with the risk of increasing pressures on foreign land and water by 5.8 and 5.3%. This result stresses the importance of considering consequences abroad in policies such as the EU 2020 energy strategy(European Commision 2014). *No Flying* could reduce carbon by 2.3% while the sensitivity scenario of *Frequent Flyer* shows that carbon could increase by 2.5%. Shifting demand from other goods towards flying frequently would actually reduce the land and water footprint, due to relative low water and land intensity, and high price of air travel, compared to other goods (Table 4).

Cycling and flying portrays a scenario of commuting by walking, cycling and public transport but flying with the savings. We find that the carbon reductions of active transport would be offset by the rebound effect of flying, with the risk of increasing toxic emissions by 3%. This result suggests that air transport should be discouraged as active transport is encouraged, to prevent a rebound effect.

Services

The *Local Services* scenario portrays a lifestyle that mostly takes place within the neighborhood. It entails a moderate reduction of short distance mobility coupled with preference for locally sourced services that require less transport logistics. Favoring *Local Services* could reduce carbon (5.3%) and toxicity (3%) footprints. The lifestyle of *Community Services* portrays reduced tourism and leisure to be more engaged in recreational, sport and cultural organizations. Citizens would be active in community organization and communications, leading to a reduction of toxicity (24%) and water (6.7%) due to a combined effect of reduced transport needs and shifting toward services with lower impact intensity, such as organizations and club membership.

Non-market Services envisions communities where citizens largely supply each other with services through collaborative economies, voluntary work, time banks and community services, reducing all impacts by 15-20%. Even if services are less impactful per euro compared to physical goods (Table 4) their consumption volume makes them relevant for impact mitigation, as shown by *Community Services.*

Scenario of non-market economy models possibilities of nearly zero marginal cost to produce goods and services supported by global collaborative commons and internet of things (Rifkin 2015; Grubler et al. 2018). The premise of such a self-provision scenario relies on regional exchange networks organized towards satisfying most needs of their members and even use their own alternative currencies (Sekulova et al. 2017). This is the premise of the gift economy and conviviality tools (Sekulova et al. 2017; Dumitru et al. 2016; Illich 1971). However, this result should be interpreted cautiously because switching to *Non Market Services* would imply economic de-growth and possibly lower incomes, which are macroeconomic effects beyond our scope.

Leisure services is a sensitivity scenario to contrast *community services*. We find that increasing *Leisure Services* would slightly increase current footprints by shifting expenditure in health and education towards entertainment, tourism, restaurants and shopping. The results suggests market-based leisure and entertainment are more impactful than health, education, pension services, etc. While the latter arguably contribute more to the common good and quality of life (Stiglitz et al. 2010). Modern economies rely on stimulating the demand for market leisure and entertainment due to their profitability (Debord 1994; Druckman and Jackson 2010). Nevertheless, leisure could potentially be more satisfied through non-market, low-carbon, options (Vita et al. 2019; Druckman and Jackson 2010).

Shelter

Renewable electricity shows that shifting remaining fossil fuels to renewable electricity would lead to increased land and water while decreasing carbon footprint by 3%. We interpret this result with caution, as the scenario assumes the European renewable energy mix for 2007, where hydropower held a major share, but the outcome might be different with larger contributions from solar and wind. Previous findings confirm that large scale hydro-power and biofuels are land and water intensive

Consequently, switching to *100% Fossil Fuel* would decrease land but increase carbon, reflecting the freeing up of land currently used to supply hydropower and biofuels.

Passive Housing could potentially save 6% carbon and 5% land by reducing space heating by 40% through renovating for energy efficient dwellings. The efficiency potential was estimated by comparing current statistics on European space heating needs(European Energy Agency 2010) to the passive house standard (15 kWh/(m^2yr) passive), according to previous approaches (Mosenthal and Socks 2015) (see SI).

A *HighTech Ecovillage* simulates self-sufficient and decentralized renewable electricity generation. This scenario leads to a reduction of 7.9% of carbon and modest reductions, between 0.3-1.7%, in other footprints. A *HighTech Ecovillage* fits the idea of an urban ecovillage, which reduces the share of fossil fuels and the impact of grid services and transmission. *No energy Ecovillage* portrays off-grid settlements with radical net reductions that eliminate all need for market energy. This could reduce carbon by 14% and land by 5%, which corresponds to the baseline impact of household energy. This scenario simulates pre-industrial lifestyles with respect to energy while keeping other consumption constant. The proponents of this vision mentioned zero energy constructions (e.g., bio-constructions, solar heaters, biogas digester, etc.) in order to maintain decent living standards (SI data) (Omann et al. 2016).

Supplying *Water off-Grid* through natural sources offers slight impact reduction. This is due to the large role of government subsidy in water infrastructure and supply. Even if eliminating centralized water supply might be unrealistic today, recent studies signal the opportunity of replacing engineered grey infrastructure by natural infrastructures to enhance water capture, availability and quality (Palmer et al. 2015).

4) Discussion

The construction of scenarios is a key activity in sustainability studies and related policy development (Huppmann et al. 2018; van Vuuren et al. 2017a; Grubler et al. 2018). While most resource-assessment scenarios deal with hypothetical trajectories of development (O'Neill et al. 2017; Riahi et al. 2017), only few focus on the potential of demand-side solutions (Grubler et al. 2018; Creutzig et al. 2018; Schanes et al. 2016) and even fewer build on the views of non-academic stakeholders (Jordan et al. 2018; Carlsson-Kanyama et al. 2008). Paradoxically, the sustainability scenarios that meet a 1.5°C climate target rely heavily on mainstreaming sustainable lifestyles (Grubler et al. 2018; van Vuuren et al. 2017b; Riahi et al. 2017). Hence, identifying and supporting lifestyles that are environmentally sound and socially accepted is key for current mitigation and adaptation challenges (Ürge-Vorsatz et al. 2018; Riahi et al. 2017).

In this study, we built scenarios based on stakeholders' visions of sustainable lifestyles to distinguish the options with most potential from those that are seemingly fruitless or present backfire risks. By simulating scenarios in an economy-wide model, we identified that the most promising sufficiency scenarios (net consumption reductions) are curtailing motorized transport, reducing market services via the shared economy, conserving energy, reducing food waste or surplus and increasing durability of clothes and devices. Green consumption (consumption changes) show most potential in shifting towards plant-based diets, sharing and repairing appliances, retro-fitting insulation for passive housing and replacing market leisure and entertainment for community-oriented, cultural and sports services.

4.1 Strengths and Limitation

Modelling through an EE-MRIO enables a high-throughput evaluation of different scenarios under a harmonized framework, through a global life-cycle perspective, and considering multiple environmental criteria. The drawback is that our results are only indicative and further scenario development as well as refining modelling options within each consumption domain could yield results that are more precise.

In most MRIOs single products or goods entail higher uncertainty, specially those with relatively small values (Moran and Wood 2014). In this article we mostly model consumption goods bundles (e.g. food products) and in few cases large single products (flying). EXIOBASE is one of the MRIOs with higher product-resolution and its advantages have been previously discussed (Wood et al. 2015). The uncertainty inherent to MRIOs is well characterized and tackling this shortcoming is an effort of the wide IO community as these databases mature (Moran and Wood 2014; Min and Rao 2017; Rodrigues et al. 2018).

In our paper, the “modelling choices” derive from stakeholder interaction. As such, we do not aim to “improve” their visions but to evaluate their environmental performance. The advantage of striving to a faithful representation is that scenarios are traceable to the visions reported in the backcasting reports. Further, assessing all visions as a whole provides a comprehensive and transparent first indication of the spectrum of sustainable lifestyles and the relevant options. Future applications that focus on exploring policy feasibility could refine and add complexity to specific scenarios.

4.2 Further Work

One challenge of coupling qualitative assessments from backcasting to an MRIO framework is that some envisioned lifestyles lie beyond the scope of Input-Output modelling. For example, non-technical visions that encourage sharing economies, including downsizing of living space and shared ownership might have significant potentials, but are better assessed through specific surveys of household consumption or building types (Vásquez et al. 2016; Ivanova et al. 2018; Vita et al. 2018; Daly 2017).

Future research on MRIO scenarios could be validated at finer geographical scales by better representing the local context. In this paper, for example, we introduce physical data to model energy and food to enhance the realism of EE-MRIO scenario modelling. Depending on the research question, coupling to bottom-up physical data such as urban infrastructure, transport fleet or household characteristics could be an asset (Ivanova et al. 2017, 2018).

A common limitation of economy-wide modelling in Industrial Ecology, whether Input-Output or Material Stock Dynamics, is the lack of explicit consideration of in-use capital stocks, with some remarkable efforts in this direction (Södersten et al. 2018; Wiedenhofer et al. 2019). Construction scenarios could be enhanced by modelling in-use stocks. However, due to the long lifetimes of buildings, construction materials typically represent a small share of the footprint compared to yearly energy flows (Vásquez et al. 2016).

For household consumption, some "capital" goods are implicitly represented in MRIOs –e.g., housing is included in household demand through imputed rent. Similar, construction services, office rental, machineries and other stock-like inputs are modelled as production inputs to other industries, including service sectors.

Our EE-MRIO model represents a snapshot of the economy and disregards feedback dynamics (Wood et al. 2017). In reality, we expect that scaling up alternative consumption patterns would have non-linear effects due to social tipping points and learning curves (Nyborg et al. 2016a). The advantage of the linear and static nature of our EE-MRIO model is that it eases the interpretation of simulation results.

Although we focus on Europe, we expect the general direction of our results to be applicable to other continents, with differences in the magnitudes and shares of foreign impacts. Still, repeating the analysis for other regions and emerging economies is a topic for further research.

4.3 Adequacy of scenario parameters

The purpose of our assessments is not to forecast reductions but to characterize the ranges of potentials and risks of materializing visions. To do so, we assume widespread adoption of particular lifestyles. Nevertheless, in the SI we discuss the potential challenges of mainstreaming sustainable lifestyles and compare the scenario parameters proposed by the stakeholders with previous scientific literature

The peer-to-peer or sharing economy has been identified as a key feature of sustainable societies. A recent study estimates above 70% reduction in energy intensities and yields economy-wide energy reduction of 40%, due to sharing and collaborative economies as well as decentralization of energy services by 2050 (Grubler et al. 2018). Here we assume that widespread sharing economies, modelled in the *Non-Market Service*s scenario, could reduce household demand of market services by 80%. Such a reduction might seem ambitious given status-quo. However, a large portion of European services represent non-basic needs, meaning that household consumption of services is largely discretionary and their reduction would not drastically impact quality of life (Jackson and Marks 1999; Druckman and Jackson 2010). Noteworthy that we do not affect the demand of governments and non-profits serving households, which provide the largest share of welfare services in Europe.

Most of the visions in this paper presume disruptive socio-technical changes. (Geels et al. 2017). Historically, we have failed to predict the major technological and social breakthroughs of the last 15 years (Rifkin 2015). However, a large share of renewables, the shared economy (transport and housing), cryptocurrencies, repair cafés, cooperatives and even widespread adoption of vegetarianism are increasingly enabling options for sustainable lifestyles. It is up to the wider community, civil societies, firms and governments to decide and develop strategies to enhance ambitious lifestyles changes.

4.4 Characterizing Uncertainty: The income rebound effect

Reducing or changing consumption can lead to savings, which consumers may spend on other impactful goods, thus triggering a rebound effect which might undermine the environmental benefits of lifestyles changes (Hertwich 2005a). In the SI, we repeat the scenario analysis considering the potential income rebound effect by modelling savings as increased consumption, according to current expenditure patterns (Wood et al. 2017). We report the rebound effect as a uncertainty measure but acknowledge that voluntary lifestyle changes driven by environmental values (and not economic incentives) are less subject to rebound (Hurst et al. 2013; Thøgersen 2013; Jackson 2005).

We find the largest potential rebounds for sufficiency scenarios since they entail the largest savings. However, sufficiency is in line with a de-growth paradigm and which implies a steady or downsized GDP , thus lowering the risk of rebound (Sekulova et al. 2017). Noteworthy, a full analysis of the rebound effect would not only consider savings, but also changes in prices and corresponding rules of purchasing behaviors.

From this uncertainty test, we conclude that policies to manage potential rebound effects are recommendable. A traditional measure is to increase the prices or role out taxes to hold energy-service prices constant (Grubler et al. 2018). Such measures are more acceptable if the tax addresses redistribution, social justice or a more fair access to resources , with the perk that equality discourages positional consumption (Sekulova et al. 2017). More progressive measures include planning saturation of service demand e.g., peak passenger-km travel, peak per capita energy consumption or declining the number of emitted driver licenses (Grubler et al. 2018).

4.5 The challenges of green consumption

Although **sufficiency** options are generally more efficient and less risky, they are not as popular as **green consumption** because of their conflict with prevailing economic growth paradigms (Lorek and Spangenberg 2014; Akenji 2014; Vita 2016).

As expected, all sufficiency scenarios show unanimous reductions across footprints. On the other hand, green consumption scenarios shift expenditure towards the goods that stakeholders perceived as more "environmentally-friendly", generally based on their lower-carbon emissions. Nevertheless, while some green consumption scenarios yield reductions in carbon and toxicity, these typically come at the potential risk of increasing land and water requirements. This occurs specially when replacing carbon-intensive goods with land and water intensive renewable fuels, materials and crops.

4.6 Lifestyle changes in the Shared Socioeconomic Pathways

The sufficiency and green consumption scenarios that we model here are compatible with the most desirable scenario of the Shared Socioeconomic Pathways (SSP), the SSP1 "Sustainability – Taking the Green Road", which in turn is most compatible with mitigation and adaptation (Riahi et al. 2017; O'Neill et al. 2017; Grubler et al. 2018). Its central feature is high environmental awareness and moving towards less resource-intensive lifestyles, starting by high-income countries (O'Neill et al. 2017). However, detailed lifestyles changes are not easily represented in the SSP research because the demand sectors of Integrated Assessments Models (IAMs) are often highly aggregated i.e., industry, energy and transportation (Riahi et al. 2017). We foresee research opportunities in liking EE-MRIO with IAM-SSP research by adding heterogeneity and allowing for more stylized scenarios (Rao et al. 2017; Pauliuk et al. 2017).

4.7 Displaced impacts and intra-generational solidarity

Greenhouse emissions contribute to global climate change regardless of their source location. On the other hand, the negative health effects of toxicity emissions depend on the local context (climate, pollution levels) and exposure to people (Johansson et al. 2017). Similarly, the consequences of land-use and water are highly dependent on the local biodiversity, vegetation, water availability and resource management practices (Haberl et al. 2007).

In terms of global justice, helping the world's poor meet their needs is an attitudinal pre-requisite for sustainable lifestyles in wealthy countries (Schäpke and Rauschmayer 2014). At least half of food and clothing impacts embodied in European consumption have consequences abroad (black bars on Figure 2). Changes in European diets and fashion would relieve land and water resources in producing countries, which are typically more climate vulnerable (Tukker et al. 2014). However, reducing meat and clothing also benefits Europeans by reducing domestic carbon and toxicity due to less processing, packaging and shipping. Sustainable housing mainly benefits European impacts due to territorial electricity generation and local sourcing of fuels. Appliances and electronics are largely produced outside Europe and thus reducing manufactured products yields more benefits in foreign lands. International cooperation for sustainability could prioritize the lifestyle changes that yield most bi-lateral benefits (Haberl et al. 2007; Keohane and Victor 2016).

4.8 Co-benefits and challenges of sustainable lifestyles

Beyond footprint trade-offs, there are potential social trade-offs implied in the visions, discussed at length in the SI. Sufficiency measures could hinder economic growth and employment under the current work-growth paradigm (D'Alisa et al. 2015). To prevent negative social effects, labor and welfare institutions would require different practices to decouple wellbeing from paid employment. Examples of new welfare practices include work-sharing or basic income schemes (D'Alisa et al. 2015; Sekulova et al. 2017). Indeed, many of the backcasting visions went beyond environmental concerns to include wellbeing aspects, such as working less, social connections, being healthier or having more free time (Quist et al. 2016a, 2016b). Such aspects go beyond our modelling scope but could be interesting leverage points for policymaking.

To complement the environmental analysis, in the SI we include a literature review of the individual and societal benefits and challenges for quality of life associated with the modelled lifestyle changes. For example, current European diets are characterized by an intake of animal products above dietary recommendations for saturated fat and red meat (Westhoek et al. 2014). Substitution of high saturated-fat, high-calorie meats, and processed foods with fibre rich foods, fruits and vegetables has been linked to reduced risk of coronary heart disease (Dora et al. 2015). Individuals with frequent walking or cycling habits show better mental and physical health than their sedentary counterparts (Haines et al. 2009). At societal scale, lower environmental pollution from renewable energy has proven benefits for public health (Gibon et al. 2017). Relying less on market services and more on shared economy correlates with social empowerment and sense of community (Frenken and Schor 2017).

5) Conclusion

The sustainability transformation requires not only innovative technologies but also innovative lifestyles and engaged, well informed, citizens. In this study, we connect backcasting visions to EE-MRIO to systematically assess scenarios of sustainable lifestyles and provide a scoreboard of the options across consumption domains (GLAMURS et al. 2016; Quist et al. 2016a). We confirm that some lifestyle changes envisioned by European citizens are promising options, with the additional benefit that citizens demand such changes and that they are compatible with increased quality of life. We also identify those options that are arguably fruitless or even risk backfire by increasing other resources.

Except for switching to plant-based diets, the lifestyles with most potential generally imply curbing consumption towards sufficiency levels. While we contrast sufficiency and green consumption to show the independent contribution of each scenario, some scenarios are not mutually exclusive and may be implemented synergistically to yield greater benefits. By studying multiple environmental indicators we detect fewer trade-off risks and larger impact reduction across footprints for sufficiency lifestyles, compared to green consumerism. Because European lifestyles drive significant impact abroad, it is key to take responsibility by cooperating with trading partners to deploy sustainable resource management, fair-trade and greener supply chains.

This study provides an overview of the options for change and their consequences for the purpose of comparison. Hence, our results are indicative of potential but not policy conclusive. In practice, the outcome of the scenarios would largely depend on the implementation pathways. We rather present a framework to integrate citizens' perspectives and imaginative alternatives into sustainability scenarios to broaden the range of demand-side solutions.

Participatory modelling for sustainability can be seen as building human capital via social learning or knowledge co-production (Bandura 2006). Its practice enriches scientific research, the participants and, if taken to its ultimate consequences, the general public, by leading to policies that truly consider the visions and needs of citizens. Understanding the global consequences of local visions and actions is a pre-requisite to focus on the most promising options, and stir governments, industries and communities towards them.

Supplementary Information

The Supplementary Information includes methodological details and data to model food and energy scenarios through a physical layer. We discuss the relevant assumptions regarding the adoption rates of scenarios. We present an uncertainty analysis assuming an income-rebound for the scenarios that yield savings. We conduct a literature review on the co-benefits and challenges for quality of life associated to the scenarios as well as critically discuss the adequacy of our scalability parameters. The supplementary data file includes all the results on the environmental assessments for each scenario. We include the full inventory of literal text extracts from the backcasting workshops that were used to build scenarios, including the consumption implications and modelling decisions.

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